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Analysis of the relative technical efficiency of Brazilian electricity distribution companies: a DEA approach

Análise da eficiência técnica relativa de empresas brasileiras distribuidoras de energia elétrica: uma abordagem DEA

Análisis de la eficiencia técnica relativa de empresas brasileñas distribuidoras de energía eléctrica: un enfoque DEA

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Abstract
This article analyzes the relative technical efficiency of Brazilian electricity distribution companies. The search for efficiency has been steady in many sectors and the industry now represents a significant source of economic development for the country. The electricity distribution companies have undergone major transformations due to the transference of share control to private initiatives. The primary research technique used was a quantitative approach known as the descriptive and data envelopment analysis (DEA) based on data from 2012. It was identified that just 1 out of 17 Brazilian electricity distributors of the census is classified as efficient. It is worth noting that COSERN and RGE are the best benchmarks for inefficient firms and hold various awards for quality and industry management. Of all the variables evaluated, Power installed most affected efficiency scores. Among the variables that are necessary to improve were Global Performance Continuity and Average Response Time.
Keywords: Technical efficiency; Electricity Sector; Power Distribution; Data Envelopment Analysis

Resumo
Este artigo analisa a eficiência técnica relativa das empresas brasileiras distribuidoras de energia elétrica. A busca por eficiência tem sido constante em muitos setores e a indústria representa uma importante fonte de desenvolvimento econômico para o país. As distribuidoras de energia elétrica passaram por maiores transformações devido a transferência de controle acionário para empresas privadas. A pesquisa possui característica descritiva e abordagem quantitativa, utilizando como técnica de pesquisa a Análise Envoltória de Dados (DEA) realizada com base em dados de 2012. Identificou-se que apenas 1 em 17 distribuidoras de energia elétrica foram consideradas tecnicamente eficientes. As empresas COSERN e a RGE são os melhores benchmarks para as empresas ineficientes e são detentoras de diferentes prêmios de qualidade e gestão do setor. A variável que mais contribuiu para os escores de eficiência das empresas foi a variável Potência Instalada e as variáveis que necessitam de melhorias são o Desempenho Global de Continuidade e Tempo Médio de Atendimento.
Palavras-chave*: Eficiência técnica; Setor Elétrico; Distribuidoras de energia elétrica; Análise Envoltória de Dados*

Resumen
Este artículo analiza la eficiencia técnica relativa de las empresas brasileñas distribuidoras de energía eléctrica. La búsqueda por eficiencia ha sido constante en muchos sectores y la industria ahora representa una importante fuente de desarrollo económico para el país. Las distribuidoras de energía eléctrica han pasado por mayores transformaciones debido al cambio de control accionario para empresas privadas. La investigación tiene características descriptivas y abordaje cuantitativo, utilizando como técnica de investigación el Análisis Envolvente de Datos (DEA), fue realizada con base en datos de 2012. Se identificó que sólo 1 de 17 distribuidoras de energía eléctrica fueron consideradas técnicamente eficientes. Las empresas COSERN y RGE son las mejores benchmarks para las empresas ineficientes y son poseedores de diferentes premios de calidad y gestión del sector. La variable que más contribuyó a la tasa de eficiencia de las empresas fue la variable Potencia Instalada. Las variables que necesitan de mejoras son el Desempeño Global de Continuidad y el Tiempo Medio de Atención.
Palabras clave: *Eficiencia técnica; Sector Eléctrico; Distribuidoras de energía eléctrica; Análisis Envolvente de Datos*

1 Introduction

Over the past three decades, infrastructure sectors worldwide have shifted their focus toward increasing their capacity and use. According to Faria and Gomes (2009), the globalization of markets through economic openness to international trade reflected in several Brazilian infrastructure sectors, including the electricity sector. Vaninsky (2006) concluded that the production of electrical energy is an extensive process, involving large amounts of capital resources, labor and technology.

From 2009 onward, the Brazilian government privatized part of the electric system with the intention of improving the quality of services, freeing competition, reducing cost, reinvesting in the country's generating capacity, etc. Moreover, the once state monopolized sector, became partly operated by private companies under concession. The Brazilian electrical system was overhauled which has created opportunities and expanded businesses (FARIA; GOMES, 2009).

The electrical sector is regulated by the National Electric Energy Agency (ANEEL), which pre-establishes the energy tariffs placed on consumers. In 2012, the Federal Government proposed a reduction of the tariff which would benefit several sectors of society, especially industry, which accounts for half of national energy consumption. Distributors must continuously seek efficiency, aiming to maximize their resources (MARTINS ET AL, 2017, no prelo).

Until recently there was little interest in reducing consumption or increasing the efficiency of energy production processes. However, because of the amendments in the politics of the electric sector, the number of programs and projects are growing, creating population awareness, and embracing practical steps for the efficient use of electricity (BALTAR; KAEHLER; PEREIRA, 2005). In this regard, the Data Envelopment Analysis (DEA) has increased in popularity and strengthened as an alternative tool to evaluate the relative efficiency of enterprises.

According to Miranda, Gramani and Andrade (2012), DEA is a methodology used to measure and assess the relative efficiency of Decision Making Units (DMUs), using multiple inputs to produce multiple outputs. Zhou, Pou and Ang (2008) note that DEA was accepted as the primary technique to measure efficiency of power companies worldwide. For Macedo, Nova and Almeida (2009) the assessments measuring the efficiency of the company in relation to others generate consistent results. Status reports of the companies are created using benchmarks, ranking competing entities. Pessanha et al. (2010) mentioned that this technique has gained widespread use among regulators of the electrical sector, especially in the regulation of electricity transmission and distribution services.

This study analyzes the relative technical efficiency of Brazilian electricity distribution companies. In addition, it aims to identify the determinants of the technical relative efficiency, the benchmark units and the percentage of improvements for the inefficient companies.

The study has been adopted due to the impact of the electricity sector on the economic and social environment as well as the infrastructure projects of Brazil. It is also justified, since the activity of distribution of electric energy has undergone major transformations regarding the transfer of share control to private initiatives. In light of these changes, namely a new structure for the sector, study of efficiency acquires relevance.

This paper is organized into five sections. The first section is the introduction. Section two reviews the literature and the main theoretical issues that support the research concerning efficiency and the electricity sector. Section three describes the methodology employed for the research development, stressing the classification, companies, model and variables used.

Section four shows the results and analysis of data related to efficiency, determinants, benchmarks and their potential for improvement. Conclusions are then presented in section five, followed by the references used in the research.

2 Literature Review

2.1 The production function and the concept of efficiency

Production involves the transformation process of an input condition to an output condition, the act of producing a certain level of output requires a set of inputs - called input or factor of production (CLARK, 1996). To Besanko and Braeutigam (2004) the production function is comprised of comprised of the following factors: Capital (K), Labor (L) and Technology (T), represented by the equation (1).

$$Q= f(L, K, T) \quad (1)$$

Where: Q is the amount produced; f the function; L labor employed; K capital invested; T the level of technology used. According to Ferreira (2012, p. 40):

> "capital and labor are the factors which cause variations along the production function, while technology can shift the function, causing the company to produce more from the same combination of inputs, using fewer inputs for a given output level".

To Sowlati (2005), efficiency is the ability to reach the outputs with minimum inputs, therefore efficiency is related to productivity. Sales (2011), compares efficiency of what was produced to what could have been produced, keeping the number of inputs constant. The inverse relationship is also true, for a specific amount of inputs used production is maximized.

Farrell (1957) says that efficiency can be divided into two categories: technical and allocative. Technical efficiency can be considered the conversion of physical inputs into relative outputs and ultimately best practices. In other words, using the current technology generates no input waste in production of a given amount of output. Allocative (or economic) efficiency is related to the fact that inputs correlate to a given level of output, influencing companies to select number of entry prices in order to minimize production costs. Similarly, with the same cost, a higher level of production is obtained, assuming that the enterprise is already considered technically efficient (BHAGAVATH, 2011).

2.2 The Brazilian Electrical Power Sector

It is noted that from 1993 until recently, several changes have been made to the regulations in the Brazilian power sector. The Law No. 8631 of 1993 is considered to be a milestone in the electric sector model to extinguish the tariff equalization and establish a new environment for power supply. One of the most significant changes took place in the economic regulation of the distribution of electricity companies, ultimately encourage increased business efficiency (DORIA; LAKOSKI; SOUZA, 2011).

According to Faria and Gomes (2009), a major milestone took place in 1995 when all the concessions related to public services, including the power industry, became the object of competitive bidding. In 1996, ANEEL (National Electric Energy Agency), the regulatory agency that oversees the supervision of private companies responsible for the electricity systems was established. It was necessary to adjust to the new market, thus changes took place from the participating companies in order to manage and control their resources (FARIA; GOMES, 2009).

According to Doria, Lakoski and Souza (2011), the report *Restructuring Project of the Brazilian Electrical Sector* was published in 1997. The purpose of the reform was to enable the administration to concentrate on policy and regulatory duties and transfer the roles of operation and investments to the private sector. At that time, generation, trade, transmission and distribution were divided into separate segments. The transmission and distribution, characterized as natural monopolies, required a more complex set of rules. Competition was introduced in the generation and commercialization sectors, and the transmission and distribution sectors introduced “price control” to replace “profit control” to provide incentives for efficiency.

According to Jamasb and Pollitt (2000), from 1990 on, many countries established reforms in infrastructure, especially in the electrical sector, in order to promote competition. This study shows that several countries adopted a regulation incentive in the transmission and distribution segments, to maximize efficiency. This process involves comparing actual performance against benchmark performance. Miranda et al. (2009) says that over the past twenty years, the infrastructure sectors worldwide have experienced a significant transformation. From this perspective, policy emerged shifting power to the private sector in order to increase operational efficiency and reduce prices thereby, increasing satisfaction as a whole.

Even though the processes of restructuring presents local difficulties, the US and most western European countries, advocates for the restructuring of the electrical sector, have eased the quest for efficiency. China and Eastern Europe have stressed decentralization. Latin American countries, including Brazil, seek increased efficiency (via competition), but need to prioritize means to attract private investments, thus reducing the need for public funds. A major outcome of the sector reform is fixing the tariff structure. Which became a responsibility of the regulatory agent ANEEL. ANEEL’s objectives intend to reconcile the interests of consumers and regulate utility, namely, the incentives for efficiency, maintenance of the financial and economic balance of concession, as well as suitable quality of the product and service (SOLLERO; LINS, 2004).

Particularly in Brazil, the regulatory agency (ANEEL) verifies the results of the quality of services and stimulates behavior that leads to efficiency, i.e. efficient operational costs. Efficient operational costs are defined in the Enterprise Reference Model, which are based on economic analysis and engineering. Practices associated with efficient operational costs must adherence to geographical indicators as well as market and technical provisions within the concession area that are specific to the environment of the dealer activity, ensuring the provision of services at the required quality levels. This methodology uses cost drivers of activities and resources, in addition to market benchmarks (DORIA; LAKOSKI; SOUZA, 2011).

In the publication of the Technical Note nº 265/2010, ANEEL indicated its intention to use benchmarking models based on the parameterization of each activity developed by a power distribution company to establish limits of operational costs and decrease the complexity of enterprise reference models. Using benchmarking models allows thousands of parameters to be overwritten by a few. For example, the number of consumption units, the size of the distribution network and market covered, and some environmental variables that characterize the concession areas (DORIA; LAKOSKI; SOUZA, 2011).

The next section presents the procedures adopted for selection of studies associated with the electric sector which used DEA to measure efficiency.

2.3 Studies related to Efficiency in the Electricity

In this study, the criteria used for selection of national studies used the database from CAPES as the primary source, and the following criteria were regarded as open query: “DEA” and “electric”. The international studies had EBSCO database as their primary source, and the following criteria considered the words “DEA” and electricity as free consultation. In both cases, we searched the reference in other studies.

Furthermore, this research contains 19 studies: 3 national, 14 international and 2 national dissertations. The main variables of inputs and products identified were: Installed Power (kVA); Network extension (Km); Number of employees; Equivalent Length of Continuity (DEC); Equivalent Frequency of Continuity (FEC); the whole area (Sqkm); Consumed electricity (Mwah) and Number of consumers (Fig. 1).

Figure 1 - Studies related to Efficiency in the Electricity

Author	Title	Inputs	Outputs
Tschaffon and Meza (2014)	Assessing the Efficiency of the Electric Energy Distribution using Data Envelopment Analysis with undesirable outputs	Running costs; DEC; FEC	Energy consumption; Number of consumers; Aneel Consumer Satisfaction Index
Pinheiro (2012)	Regulação por incentivo à qualidade: comparação de eficiência entre distribuidoras de energia elétrica no Brasil	operacional costs; total costs, DEC; FEC	Number consumer units; Energia total distribuída; Network extension (Km)
Yuzhi and Zhangna (2012)	Study of the input-output overall performance evaluation of electricity distribution based on DEA method	Network extension (Km) under 110KV; Substation equipment capacity below 110KV.	Number of consumers; Amount of electricity sold; Line Loss per Unit.
Shu, Zhong and Zhang (2011)	Electricity consumption efficiency and influencing factor analysis based on DEA method	Energy consumption; Number of employees; Social Capital.	Gross Domestic Product (PIB)
Pessanha et al. (2010)	Avaliação dos custos operacionais eficientes das empresas de transmissão do setor elétrico brasileiro: uma proposta de adaptação do modelo DEA adotado pela Aneel	operational costs;	Processing capacity; Network extension (Km) Number of transformers; Number of modules.
Von Geymueller (2009)	Static versus dynamic DEA in electricity regulation: the case of US transmission system operators	Transmission of materials and supplies: Transmission of wages and salaries; Length of transmission line; Total installed capacity of transformers responsible for transport.	Transmission of electricity.
Santana (2008)	Responsabilidade socioambiental e valor da empresa: uma análise por envoltória de dados em empresas distribuidoras de energia elétrica	Cost of services; Investment in machinery and equipment; Deferred assets; Investment in socio-environmental responsibility;	Company value
Meza *et al.* (2007)	Seleção de variáveis em DEA aplicada a uma análise do mercado de energia eléctrica.	energy consumption	PIB; Index of Consumer Potential; Human development Index

Cont.

Figure 1 - Studies related to Efficiency in the Electricity

Author	Title	Inputs	Outputs
Santana, Périco and Rebelatto (2006)	Investimento em responsabilidade sócio-ambiental de empresas distribuidoras de energia elétrica: uma análise por envoltória de dados	Total assets; Socio-environmental investment.	Revenues
Vaninsky (2006)	Efficiency of electric power generation in the United States: analysis and forecast based on data envelopment analysis	Operational expenses; Loss of energy.	Capacity utilization.
Pombo and Taborda (2006)	Performance and efficiency in colombia's power distribution system: effects of the 1994 reform	Number of employees; Number of transformers and substations; Network extension (Km) PIB Capacity installed;	Total sales (GWh); Total customers; Urban area served.
Abbott (2006)	The productivity and efficiency of the australian electricity supply industry.	Social capital; Number of employees; Fuel; Other materials and services.	Electricity supplied (GWh)
Jamasb, Nillesen and Pollitt (2004)	Strategic behaviour under regulatory benchmarking	Controllable operating expenses.	Electricity units delivered; Number of consumers Network extension (Km)
Cherchye e Post (2003)	Methodological advances in DEA - a survey and an aplication for the dutch electricity sector	Controllable operating costs.	Number of consumers;Peak demand> 110V; Peak demand <110V; Network extension (Km); Number of transformers
Pacudan and Guzman (2002)	Impact of energy efficiency policy to productive efficiency of electricity distribution industry in the philippines	Number of employees; Network extension (Km) Losses of networks (GWh)	Number of consumers; Service area (Km²); Sales of electricity (GWh)
Førsund and Kittelsen (1998)	Productivity development of norwegian electricity distribution utilities	Work (h); Loss of energy (MWh); Materials (1000 NOK); Capital (1000 NOK)	Distance index; Number of consumers; Total energy delivered (MWh)
Yunos and Hawdon (1997)	The efficiency of the national electricity board in Malaysia: an intercountry comparison using DEA	Installed capacity (MW); Job; Total system losses (%); Public generation capacity factor (%)	Gross electricity produced (GWh)
Bagdadioglu, Price and Weyman-Jones (1996)	Efficiency and ownership in electricity distribution: a nonparametric model of the turkish experience	Labor; Capacity of Processing (MVA); Network extension (Km) General costs; Losses in the network (MWh)	Number of consumers; Electricity supplied (MWh); Maximum Demand (MW); Service area (Km²)
Weyman-Jones (1991)	Productive efficiency in a regulated industry: the area electricity boards of England and wales	Number of employees; Network extension (Km).	Sales for domestic, commercial and industrial consumers (KWh);

Surce: authors.

Based on Figure 1, we identified the variables most used in studies about technical efficiency in electricity companies and select them. Jamash and Pollitt (2001) reviewed 20 studies about electricity distribution efficiency and established the variables most use as inputs: number of employees, network length and transformer capacity and as outputs measures energy delivered and number of customers.

3 Methodological Procedures

3.1 General Research Classification

The research has a descriptive character in terms of objectives and is a survey according to the procedures. According to Beuren (2006), the descriptive research reports the phenomena studied, in this instance, describes the reality of companies selected based on their relative technical efficiency. In this case, the objects of study are the Brazilian electricity distribution companies. Data were obtained from the statistical yearbooks of the National Electricity Regulatory Agency (ANEEL) and from financial reports available on the BM&FBOVESPA website. The research study has a quantitative approach with the purpose of reducing the phenomena to numerical values by using an instrument based on the mathematical analysis of the problem (Richardson, 1999). The analysis method used was data envelopment analysis. For the DEA scores we used the Frontier Analyst 4.0 software. For inverted frontier analysis, we used SIAD software (MEZA ET AL., 2005A, 2005B).

3.2 Population

We selected the companies listed on the BM&FBOVESPA (2012) to be assessed in this study, and they were sorted in electricity segment, totaling an initial population of 64 companies. However, to achieve the objectives proposed, the companies were divided based on similar DMUs in their productive processes, activities, inputs and outputs. In this case, companies whose main activity is participating in other corporations e.g. holdings, generating companies, transmission or trade of electric power have been excluded from the sample. Given these exclusions, the actual population is restricted to the electricity distribution companies, resulting in a census of 18 companies, according to Figure 2.

Figure 2 - Brazilian companies distributors of electric energy

Abbreviation	State	Abbreviation	State	Abbreviation	State	Abbreviation	State
AES SUL	RS	COELBA	BA	CPFL-PA	SP	ESCELSA	ES
AMPLA	RJ	COELCE	CE	CPFL-PI	SP	LIGHT	RJ
BANDEIRANTE	SP	CEMAR	MA	ELEKTRO	SP	RGE	RS
CELPA	PA	COSERN	RN	ELETROPAULO	SP		
CEMAT	MT	CEEE-D	RS	ENERSUL	MS		

Source: Authors based on BM&FBOVESPA.

The choice of the electrical sector is intentional (BEUREN, 2006) because the activities are compatible with the purpose of this study to determine the relative technical efficiency of the Brazilian electricity distributors. The activity of electric energy distribution underwent major changes regarding the transfer of share control to private initiatives. In light of these changes, a new structure of the sector emerged, and, the study of the metric of efficiency became relevant. In addition, this study was made possible through access to quality, reliable information available via ANEEL and at BM&FBOVESPA.

3.3 Collection, Processing and Analysis of Evidence

The variables of inputs and outputs used to analyze the efficiency of the selected units were restricted to the year 2012, since the study is not longitudinal. Additionally, the year was chosen largely due to the relevance and availability of information obtained from the statistical yearbooks of the National Electricity Regulatory Agency (ANEEL) and the financial reports available on the BM&FBOVESPA website.

In the definition of inputs and outputs it is necessary to consolidate the variables of the Joint Area (km²) and Number of Consumers in the variable Demographic Density (Units / km²), in order to make companies comparable. If each variable were considered separately, a company could change their efficiency score simply because of a large distribution area. Generally, this is the case of companies operating mainly in regions where the concession area corresponds to state geographic boundaries. Therefore, a company's score might be impacted if its concession area is smaller than a state, which happens mainly in the Southeast.

Other variables that are favorable for consolidation are the DEC and FEC in DGC (Global Performance Continuity), both of the latter include continuity indicators of the distribution companies. Furthermore, the DGC incorporates the indicator for the limits/goals of levels of continuity set for each area.

Comparatively, the variable ART (Average Response Time) was included in the model, where it is considered to be an operational indicator of the quality of services of the electrical sector. The list of selected variables is shown in Figure 3 along with their inputs and outputs, technical efficiencies and respective descriptions.

Figure 3 - Variables of selected products and inputs

Variables		Description
Input	Power installed (kVA)	Potential power distribution. Corresponds to an installed capacity of distribution power transformers in kilovolt-ampere (kVA).
	Network extension (Km)	Network size. Corresponds to the network length in kilometers (Km) that cater to urban, rural area, their own networks and private networks.
	Number of employees	Number of employees. Corresponds to the total manpower employed and outsourced at the end of the year.
Product	DGC	Overall performance indicator of continuity of a distribution company. Corresponds to the level of continuity of the distribution (DEC and FEC) concerning limits established for their concession area.
	ART (minutes)	Average service time in minutes for emergency situations. Corresponds to the sum of the Average Time of Preparation (APT), Mean Time Displacement (MSD) and Average Execution Time (TME) in emergency situations.
	Consumed electricity (Mwah)	Total electricity consumed. Corresponds to electricity supplied during the year in megawatt-hours (Mwah) in industrial, commercial, rural residential or another sphere.
	Demographic density (units/km²)	Number of customers served compared to the total serviced area. Corresponds to the total home consumer units, industrial, commercial, rural or other classes divided by service area in square kilometers (km²).

Source: Authors based on related studies.

Initially, the collinearity between the variables was verified (Table 1). However, it was necessary to exclude the variables Consumed electricity and Demographic density due to the high collinearity between them. The company CELPA was also excluded because it was outlier.

The orientation of the model was chosen, based on the minimization of inputs, otherwise known as maximization of outputs. The focus is on the maximization of the outputs, which outputs seeks to maximize the products used while keeping the level of inputs consistent. It was

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preferable to target outputs because this orientation is defined based on the configuration problem, since the goal is to maximize outcome while maintaining the same amount of inputs, as per the work research of Almeida, Mariano and Rebelatto (2006).

Table 1 – Correlation between inputs and outputs

	Power installed	Network extension	Nº of employees	DGC	ART	Consumed electricity	Demographic density
Power installed (I)	1						
Network extension (I)	-0,16	1					
Number of employees (I)	0.58	0.22	1				
DCG (O)	0.10	0.04	0.20	1			
ART (O)	-0,02	0.03	0.32	0.60	1		
Consumed electricity (O)	**0.96**	-0,23	0.57	0.00	-0,12	1	
Demographic density (O)	**0.74**	-0,39	0.54	-0,01	-0,06	0,85	1

Source: Authors based on related studies.

After DEA model is used, if constant returns (CRS) or variable scale (VRS), are obtained from the evaluation of the correlations between inputs and outputs considering the variables of inputs: Installed Capacity, Extended Network and Number of Employees and the products: DCG and ART, there is an increase in the amounts of inputs and it generates a proportionately greater or less variation in output, indicating the use of constant returns to scale (CCR).

Figure 4 – CCR model

$$\text{Max Eff}_0 \sum_{r=1}^{s} u_j y_{j0}$$

subject to

$$\sum_{i=1}^{m} v_i x_{i0}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leqslant 0, j = 1 ; \dots ; n$$

$$u_{rj} ; v_i \geqslant 0 \; \forall r, i$$

Source: Chaves, Mello & Meza (2016).

In this model, v_i and u_r, respectively, are input values i , i =1, … , m , and output r, r =1, … , s, multipliers; x_{ij} and y_{rj} are DMU j, j =1, … , n inputs i and outputs r; x_{io} and y_{ro} are DMU 0 inputs i and outputs r. Frontier Analyst 4.0 is the software that was used to determine the relative technical efficiency of distribution companies in the Brazilian electrical power system.

3.4 Data Envelopment Analysis

The term Data Envelopment Analysis (DEA) was introduced by Charnes, Cooper and Rhodes (1978) and the first model is known by CCR, in reference to the initials of their names. However, it is also referred to as Constant Returns to Scale (CRS) which evaluates the total efficiency by identifying efficient and inefficient DMUs using multiple inputs and outputs with the construction of a single virtual input and a single virtual product. The second model is known as BCC, an acronym for Banker, Charnes and Cooper (1984). The model is also called

VRS, Variables Returns to Scale, which evaluates the technical efficiency and may present increasing or decreasing variable returns to scale.

The Data Envelopment Analysis enables the efficiency of each DMU to be calculated in order to make comparisons between the units of the group analyzed, highlighting the best (SANTIN, 2014; NEVES JUNIOR et al, 2012). An efficient organization in a group cannot occur in another group and vice versa. According to Koopmans (1951), a DMU is completely efficient if, and only if, it is not possible to improve any input or output without worsening some other input or output. According to Alirezaee and Afsharian (2010), an efficient DMU in the CRS model is also efficient in the VRS model; however, the reciprocal may not be true.

Both models can maximize the efficiency in two ways: product-oriented and input-oriented. According to Chudasama and Pandya (2008), the input-oriented model is used to evaluate how much the inputs can be reduced while maintaining the same level of outputs. The product-oriented model is utilized to calculate how much outputs can be increased while keeping the input level constant.

The BCC models differ from the CCR models due to the insertion of the variables *u and *v, applied in input and output orientations. These variables represent scale factors, indicating decreasing returns to scale when positive, or increasing returns to scale when negative. If null, values are determined by constant returns to scale (COOPER, SEIFORD, ZHU, 2004).

According to Ferrier, Rosko and Valdmanis (2006), the DEA does not have a provision for “noise.” In other words, additional estimates for the presence of unknown parameters are not made. As a result, all deviations from the frontier are typically attributed to inefficient performance, which is disadvantageous. Asmild et al. (2006) state that the DEA is advantageous because it is unnecessary to establish weights for the variables. It is desirable to assign values to weights to not distort the results, as a single variable is often responsible for the efficiency scores.

Andrade et al (2014) argue that DEA approach without weight restriction may lead to a low quantity of discriminatory results, which can lead to false scores. Authors based on Sollero and Lins (2004) suggest the use of inverted frontier.

The classic DEA frontier is an optimistic evaluation, while the inverted frontier is pessimistic. On the other hand, inverted frontier has the best DMUs. The normalized composed efficiency index is calculated dividing each DMU composed efficiency index by the major one along all DMUs, as shown in (2): (MEZA, 2005A).

Composed efficiency index = (Classic efficiency - Inverted efficiency + 1) / 2 (2)

4 Analysis of Results

4.1 Analysis of Technical Efficiency of Electricity Distributors

Efficiency scores for each unit were generated using the Frontier Analyst 4.0 software to calculate the maximization of the production function. The CRS model was considered the most appropriate method to achieve purpose of the study. See Table 2 for results. The scores are organized on an ordinal scale of efficiency, considering units with scores of 100 % efficient and those with scores lower than 100% inefficient. The scores range from 100% to 56.40%, and 9 in 17 (52.94%) Brazilian power distribution companies reached a score of 100%, 41.17% were in the range of less than 100%. The average score was 65.21%.

Technical aspects regarding the quality of services offered to consumers in the electricity supply were analyzed. ANEEL (2012) highlights the continuity indicators DEC (Equivalent Duration Continuity) and FEC (Equivalent Frequency Continuity). The DEC records the number of hours on average per year the consumer had no electrical power, and the FEC measures the average number of power outages. To compare the performance of energy suppliers, ANEEL has recently created the DCG indicator (Global Performance Continuity), as the parameters and measurements of DEC and FEC are overseen by municipalities. ANEEL's website (2012) offered an indicator to assess the level of continuity of the distribution (calculated values of duration and frequency of interruptions) regarding the limits established for the concession area (limits established by the Authorizing resolutions of ANEEL).

Table 2 - Scores of the electrical power distributors

DMUs	SCORES	DEC	FEC	DGC	RANK.	ART
AMPLA	100%	16.93	9.04	0.98	1 º	669,29
BANDEIRANTE	100%	9.42	6.03	0.85	2 º	176,22
CEEE-D	100%	19.36	12.96	1.06	3 º	314,03
CEMAR	100%	21.64	10.91	0.63	4 º	660,23
COSERN	100%	14.49	7.91	0.73	5 º	151,22
CPFL-PI	100%	5.64	4.23	0.66	6 º	98,81
ESCELSA	100%	9.88	6.37	0.83	7 º	362,72
LIGHT	100%	18.15	8.39	1.53	8 º	750,53
RGE	100%	14.33	8.75	0.81	9 º	206,17
ENERSUL	97,5%	12.73	8.08	0.78	10 º	229,73
AESSUL	96,2%	14.11	8.41	0.83	11 º	333,43
CEMAT	77,5%	33.75	24.22	1.07	12 º	253,38
ELEKTRO	73,1%	9.82	5.33	0.84	13 º	402,45
ELETROPAULO	61,3%	8.35	4.65	0.82	14 º	234,8
CPFL-PA	44,4%	7.48	5.37	0.81	15 º	118,32
COELCE	38,1%	8.06	4.62	0.46	16 º	220,29
COELBA	33,6%	19.98	8.87	0.88	17 º	222,28
Correlation with efficiency		-21,04%	-20,70%	-44,16%	-36,07%	-11,59%

Source: Authors, based on data collected.

According to information available on the ANNEL website (2012), there is another indicator of the electricity sector: Average Response Time (ART), which evaluates emergency instances via sets of indicators linked to consumption units. This indicator, expressed in minutes, is calculated monthly by distribution companies for every set of consumption units. It is composed of the sum of the following indicators: Average Preparation Time, Mean Time Displacement and Average Execution Time. Table 2 shows the efficiency of each company, indicators of continuity of services and the ART.

Table 3 – Efficiency scores using inverted

DMUs	SCORES	AWARDS	DMUs	SCORES	AWARDS
COSERN	100,00%	2	ENERSUL	81,30%	4
CEEE-D	97,30%	0	CEMAR	61,30%	1
BANDEIRANTE	95,20%	0	ELEKTRO	59,40%	11
RGE	94,10%	7	CPFL-PA	57,60%	3
AMPLA	92,90%	0	CEMAT	44,60%	0
CPFL-PI	92,10%	2	ELETROPAULO	35,30%	2
ESCELSA	91,20%	0	COELCE	21,90%	13
AESSUL	90,80%	2	COELBA	19,30%	0
LIGHT	90,30%	0			

Source: Authors.

In Table 2, there is a correlation between the ranking of continuity of services and the scores of technical relative efficiency of the selected companies. It had no significant influence on the results of the scores for technical efficiency, since the correlation between the ranking of continuity of services and scores of relative technical efficiency remained at –36.07%.

Using the inverted frontier approach, scores were obtained for normalized composited efficiency presented in Table 3. Data shows only COSERN was considered efficient. Again, it is not possible to affirm that best efficiency companies have won the most awards.

4.2 Analysis of the Determinants of Technical Efficiency

Table 4 shows the percentages that each input and output contributed to the scores of the technical relative efficiency of each efficient DMU. The percentage of high standard deviations indicate that the values change considerably in both variables. Therefore, efficiency is not only determined by one input or output, but by their combination. That is, a variable does not explain the industry, but explains a company. Disregarding the variable Network Extension that has not contributed to the efficiency scores of any of the efficient DMUs in at least one of the variables of every DMU, we find that there is some input or output that did not contribute to the efficiency score, representing 0%.

Table 4 - Percentage of contribution of inputs and outputs

DMU's	*Inputs*			*Outputs*	
	Installed Power	Network Extension	Number of Employees	DGC	ART
AMPLA	36,6	63,3			99,9
BANDEIRANTE	60,1	25,1	14,7	81,9	18
CEEE-D	24,8	24,7	50,4	43,3	56,6
CEMAR	99,9				99,9
COSERN	60,6		39,3	99,9	
CPFL-PI			99,9	70	29,9
ESCELSA	5,5		70,1	10	89,9
LIGHT		99,9		99,9	
RGE	34,9	37,2	27,2	99,9	
ENERSUL	72,4		27,5	71,8	28,1
AESSUL	5,5	22,3	72,1	10,8	89,1
CEMAT	71,7		28,2	99,9	
ELEKTRO		21,7	78,2		99,9
ELETROPAULO		99,9		99,9	
CPFL-PA			99,9	99,9	
COELCE	57,7	42,2		46,6	53,3
COELBA	99,9			92,9	7

Source: authors.

According to Table 4, the outputs of the DGC is the variable that has contributed most to the efficiency scores of the Brazilian electricity distributors. The DGC variable contributed specially for the efficiency to reach their maximum level since the inefficient companies did not contribute at the same level.

Moreover, the inputs of the installed power excel at an average of 46.05% for the efficient firms and 61.44% for the inefficient companies and are also a determining factor in assessing their efficiency. This variable is the determinant of the technical efficiency of the Brazilian electricity distributors, that is, the largest contributor to the efficiency scores. The topic 4.3 will address and expand the approach on the issue of percentage improvements for the different variables, as well as the analysis of benchmark units.

4.3 Analysis of Benchmark Units and Percentages of Improvement

The DEA methodology enables you to find solutions of efficiency for less efficient DMUs, the benchmarks. The electricity distribution companies where the efficiency score has proved superior can be used as benchmarks for other companies and to themselves. According to Cavalcante and Faria (2009, p. 49) "these benchmarks suggest what needs to be modified in the inputs or outputs and how to improve them to transform inefficient units in efficient."

Figure 5 - Benchmarking for inefficient units

	AMPLA	CEMAR	COSERN	CPFL-PI	ESCELSA	LIGHT	RGE
AESSUL	X			X	X		X
CEMAT			X				X
COELBA		X	X				
COELCE	X	X	X				
CPFL-PA				X			
ELEKTRO					X		X
ELETROPAULO						X	
ENERSUL		X	X				X

Source: Authors.

Figure 5 shows the classification of efficient companies to a number of inefficient companies to which they are benchmark. RGE and COSERN stands as benchmarking for the highest number of inefficient units (four), followed by CEMAR (three) and ESCELSA, CPFL-PI. Comparatively, AMPLA (two), LIGHT (one), BANDEIRANTE are not the best examples for the selected DMUs, but are still considered efficient electricity distribution companies from the list of efficient companies.

Furthermore, it is relevant to the benchmark companies the awards received. Table 5 shows the distribution companies of electricity who received the award ABRADEE in the last three years. ABRADEE (2013) defines the award: "It's the most visible aspect of the Benchmarking Programme." This program was created to increase competitiveness, enhance management and strive for excellence in service to the population. It also seeks to identify performance benchmarks and best practices to spread them among all distribution utilities, providing a sustained and rapid process of quality improvement (ABRADEE 2013).

Table 5 - Winners of the award ABRADEE

DMUs	SCORES	AWARDS	DMUs	SCORES	AWARDS
AMPLA	100%	0	ENERSUL	97,5%	4
BANDEIRANTE	100%	0	AESSUL	96,2%	2
CEEE-D	100%	0	CEMAT	77,5%	0
CEMAR	100%	1	ELEKTRO	73,1%	11
COSERN	100%	2	ELETROPAULO	61,3%	2
CPFL-PI	100%	2	CPFL-PA	44,4%	3
ESCELSA	100%	0	COELCE	38,1%	13
LIGHT	100%	0	COELBA	33,6%	0
RGE	100%	7			

Source: Authors, based on data collected.

In contrast, the benchmark companies were not awarded the most compared to other leading companies. RGE was the only company benchmarking that was awarded more between benchmarking companies. In 2012, according to administration reports, RGE was awarded in two categories: Quality Management and Best Distributor of Energy in the Southern Region. COELCE, while not considered the core enterprise of benchmark for the study, exceled as a result of consecutive ABRADEE awards, ranking as the Best Distributor of Energy in Brazil (4th consecutive year) and also Best in Client Review (4th consecutive year). It has also been awarded for Best Distributor in the Northeast (7th consecutive year), 1st place in Brazil Social Responsibility (2nd consecutive year), and 1st in Quality Management in 2012.

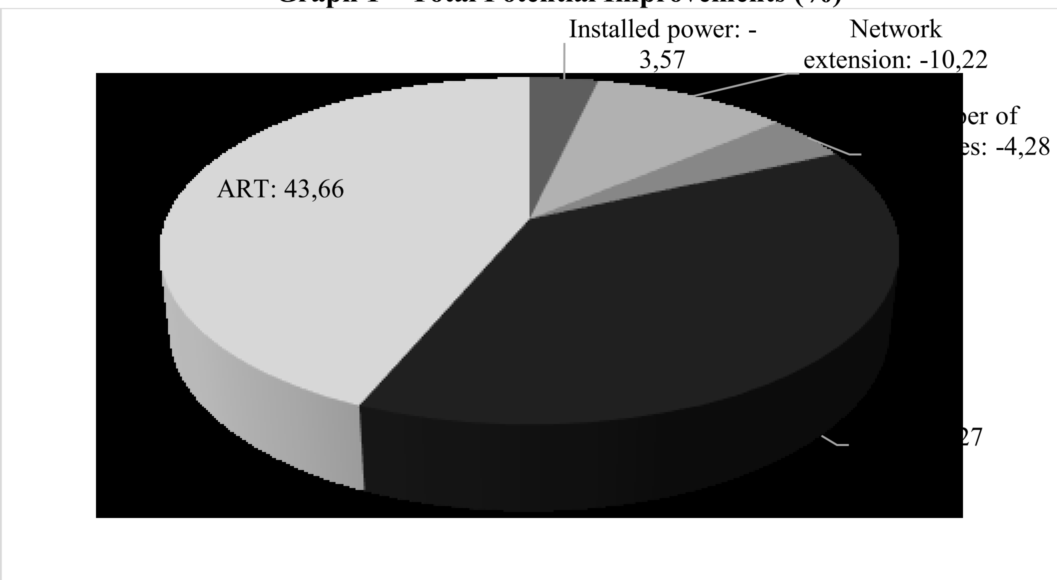
In addition to receiving the trade associations of ABRADEE, COELCE was recognized by the National Quality Award (PNQ[1]) 2011 edition, for the quality of their management. The prize is valid for two consecutive years for the winning company, recognized as a world-class company. In addition, the company received one of the highest recognitions in international management, the Iberoamerican Quality Award 2012. The company achieved Gold level, which is the highest title awarded by the Fundación Iberoamericana para la Gestión de la Calidad (Fundibeq), responsible for assessing practices in administration of companies in Latin America, Portugal and Spain. Only those awarded in the LOI are accredited to participate in the Iberoamerican.

The concessionaires ENERSUL and ELEKTRO are considered inefficient firms, and received consecutive awards from ABRADEE. ENERSUL ranks among the efficient companies at 97.975% efficiency, justifying the four awards received in the last three years. ELEKTRO was the only company in the sample that faced reduction in the provision/consumption of electricity, as compared to the same period last year, affecting their electricity performance (73.1%) in 2012.

Improvement percentages enable projections to be made of inefficient units on the efficiency frontier, suggesting optimal production values and input. This allows for current performance levels to be assessed and feasible goals to be established. Moreover, it enables the manager to implement goals, but the company needs to consider whether the percentages are likely to be achieved.

The results of the input and output variables for the total selected DMUs suggest that the Average Response Time (43.66%) is key to total potential performance, according to Graph 1.

Graph 1 – Total Potential Improvements (%)



Source: Authors, based on data collected.

[1] This prize is similar to Malcom Baldrige Award in USA and/or Deming Prize in Japan.

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Table 6 shows the percentages that each variable can improve with respect to efficient companies. The companies must collaborate to reduce the use of their installed power (on average 31.15%), optimize network extension (on average 42.97%) and best utilize the number of employees (on average 50.95%). All have standard deviations comparable to the average, which is very close among the variables (10.54%, 18.13% and 19.39%, respectively). In this case, input variables pose potential equivalent improvements, seemingly balancing the variables.

The DGC indicator (represented by DEC and FEC), which measures the time and the frequency of power outages to consumers, can impact providers' services through possible system loss. These losses, partially related to clandestine connections, occur frequently in peripheral regions of the capitals. The ART could be connected to the "Light for All" program, which was established in mid-2003 to connect 10 million people to the power grid, directly impacting in the number of consumers. In addition to affecting the Average Response Time, it can affect the extension of the networks. The main focus of the program is to reach underserved areas, often remote, rural areas where network distribution does not reach. "Light for All" utilizes resources from the power sector to fund shared investments between government and private electricity distribution companies. The project was designed to expand and seek innovative solutions to meet the country's energy demands. The technological environment may impact businesses, including the installed power (MME 2013).

Table 6 - Potential improvements (%) for inefficient DMUs

DMU's	*Inputs*			*Outputs*	
	Installed Power	Network Extension	Number of Employees	DGC	ART
ENERSUL	0	-39	0	2,6	2,6
AESSUL	0	0	0	4	4
CEMAT	0	-48,1	0	29,1	29,5
ELEKTRO	-7,9	0	0	67,4	36,8
ELETROPAULO	-44,1	0	-29,5	63	179,2
CPFL-PA	-8,7	-62,4	0	125,4	131
COELCE	0	0	-1,4	162,3	162,3
COELBA	0	-24,5	-42	197,6	197,6
MEAN	**-7,6**	**-21,8**	**-9,1**	**81,4**	**92,9**
MAXIMUM	**0,0**	**0,0**	**0,0**	**197,6**	**197,6**
MINIMUM	**-44,1**	**-62,4**	**-42,0**	**2,6**	**2,6**
STAND.DEVIATION	**9,5**	**21,8**	**13,3**	**60,3**	**74,7**

Source: Authors, based on data collected.

Singularly, another issue which may affect the ART is the ground mesh in the regions served by electricity distributors. Part of the line system crosses hills, mountains and patches of towers, landscapes characterized by difficult access. This can cause significant increases in the Average Response Time by the maintenance teams.

The results identify the efficiency scores, determinant variables that forge the efficiency frontier, and the Installed Capacity variable that stand out in promoting efficiency. The Extended Network, Number of Employees and Average Response Time variables deserve attention and potential improvement. It is recommended to follow the guidelines for inefficient units. It was also possible to identify those benchmark units for the inefficient companies.

In Tschaffon and Meza (2014) study, in which 20 Brazilian electricity distributors were analyzed in 2008, COELBA was the only company considered efficient and we identified COELBA as the company with the lowest efficiency score. Pinheiro (2012), when conducting an evaluation of Aneel's ranking (DGC-based ranking) for electricity distributors, found that efficient distributors generally present better performance in cost or quality.

5 Final Considerations

In this study, we examined the technical efficiency of Brazilian electricity distribution companies. To determine the efficiency of DMUs, we used the methodology of output-oriented Data Envelopment Analysis (DEA), seeking to maximize the outputs while maintaining the level of the production. The variables used as inputs and products were selected based on studies related to the electrical sector which adopted the same methodology.

Furthermore, the Constant Returns to Scale (CCR) model was the most appropriate for the study. The DEA reports that 1 1in 17 selected companies are on the efficiency frontier, COSERN. Among the inefficient firms (below 70%) seven are highlighted for their efficiency, namely: CEMAR, ELEKTROELEKTROELEKTRO, CPFL-PA, CEMAT, ELETROPAULO, COELCE and COELBA.

After the analysis of efficiency scores on the technical indicators of continuity (DGC), it was identified that companies located on the border of efficiency were not among the best in the ranking of these indicators in 2012. In other words, it was not possible to identify a relationship between the indicators of continuity and efficiency scores.

The technical efficiency of the Brazilian electricity distribution companies has a determining element: Installed Power. The input Network Extension, a variable that contributed minimally to efficiency scores, relates to a possible inefficiency. The longer the distribution networks, the higher the system losses. Moreover, several variables in this model were not explicitly regarded, although they may be embedded in the ratings. For instance, the level of loss or theft can vary greatly between different concessionaires, helping to explain higher or lower efficiency. In the case of benchmark units, we identified the company COSERN and RGE as benchmark, standing out in relation to the other companies in respect to awards it has received, with the exception of COELCE, due to consecutive awards earned in recent years. These awards of recognition in the electricity sector, taking into consideration issues related to excellence in management and quality in services, to the best industry practices.

In addition, the results show that for inefficient companies to reach the maximum efficiency score, the Global Performance Continuity and Average Response Time stand out among the variables that require potential improvement.

Ultimately, this study contributed in determining the technical efficiency using different variables from the ones used in the national studies identified, adding to the ART model and changing the reading on the DEC, FEC, Number of Consumers and the Joint Area. Moreover, the efficiency scores found in the study can be seen as indicators to assist in assessing the performance of companies. This study can serve as a complement to or comparison for the efficiency indicators systems already used by the National Electric Energy Agency - ANEEL.

The Data Envelopment Analysis enabled inputs, that is, a comparison between all units in the analysis which were part of study. Therefore, the results cannot be considered absolute or comparable with other companies and industries directly. We conclude that the applied model contributes to a reassessment on consumption of inputs, analysis of results and identification of benchmark among the units analyzed.

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