International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2017, 7(3), 14-23.

Performance Assessment of Brazilian Power Transmission and Distribution Segments using Data Envelopment Analysis

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ABSTRACT

In this study, we conducted efficiency analyzes of both power transmission and distribution segments in Brazilian electricity sector. In order to accomplish these analyzes, data envelopment analysis-variable returns to scale models, cost analysis and window analysis approaches were carried out. The results showed that overall efficiency and stability in the distribution sector are higher than in transmission sector, which suggest that distribution companies are better managed regarding their operational costs compared to those within transmission segment. Moreover, it was accounted that approximately R$ 21 billion could have been saved if decision making units (within distribution and transmission systems) analyzed had operated with maximum level of efficiency from 2008 to 2014. Consequently, energy tariff prices paid by each consumer could have also been lower.

Keywords: Data Envelopment Analysis, Window Analysis, Power Transmission and Distribution Segments
JEL Classifications: C14, C38, O13

1. INTRODUCTION

In the recent decades, important regulatory reforms have been implemented in the electricity markets in many countries, aiming to increase the electricity sector efficiency (Çelen, 2013; Erdogdu, 2011; Nepal and Jamasb, 2015; Tovar et al., 2011). According to Erdogdu (2011), Nepal and Jamasb (2015) and Tovar et al. (2011), the reform programs include vertical separation (unbundling) of energy industry, privatization of the electricity industry and establishment of regulatory authorities. Although, reform programs differ from one country to another and they have been accomplished without paying much attention to the institutional environment in which they occur (Erdogdu, 2013).

In Brazil, reforms in the electricity sector have begun through the National Privatization Program created through the Law 8,301 in 1990 (Melo et al., 2011). As a result of these reforms, the Brazilian electricity sector was divided into: Generation, transport (transmission and distribution), and marketing; and the National Agency of Electric Energy (ANEEL), the agent responsible for the regulation and supervision of the electricity sector, was created.

Regarding the electricity sector in Brazil, there are 3,152 generating projects, 64 distribution companies, 77 transmission utilities and 100 marketing agents (ABRADEE, 2015). In this context, the efficiency levels which the operating activities occur impact on the tariff price (related to electricity consumption) charged to consumers, since operating costs of companies are taken in account to establish the prices. Thus, it becomes relevant to assess the performance of companies within power industry. It might be accomplished through data envelopment analysis (DEA). It is a nonparametric technique used to evaluate relative efficiency of a homogeneous set of decision making units (DMUs) through linear programming (Zanella et al., 2015). Based on input and output values, the efficient frontier is formed by the DMUs of the efficiency reference set (ERS), which are the ones with maximum level of efficiency. Thus, according to Amado et al. (2013), this technique is very effective in determining best practices and it has been extensively used for benchmarking studies.

Many applications of DEA in the electricity sector can be found in a wide variety of countries. In the generation segment, some works can be mentioned as Jha and Shrestha (2006) in Nepal;

Fallahi et al. (2011) in Iran; Chien et al. (2007) in Taiwan; Sarica and Or (2007), Sözen et al. (2012) in Turkey; Barros (2008) in Portugal; Dedoussis et al. (2010) in Greece; Lins et al. (2012) in Brazil; Dogan and Togcu (2015) in G-20 Countries; and Grimm et al. (2016) in Europe. Regarding the power transmission and distribution segments, there are several studies such as Lins et al. (2007), Pessanha et al. (2010), Leme et al. (2014), Pereira de Souza et al. (2014), Costa et al. (2015), and Xavier et al. (2015) in Brazil; Khodabakhshi (2010), Sadjadi et al. (2011), Azadeh et al. (2015) and Omrani et al. (2015) in Iran; Çelen (2013) in Turkey; Amado et al. (2013) in Portugal; Meenakumari and Kamraj (2008) and Yadav et al. (2013) in India; and Kuosmanen et al. (2013) in Finland. It is noteworthy that many studies do not specify if companies analyzed belongs to power transmission and/or distribution segment. It was considered that it is related to the electric sector characteristics in each country. Moreover, it was noted that the variable set vary from one study to another. The choice of variables depends on the goals of each specific study, as well as the existing characteristics of the electricity sectors of each country.

The contribution of the current work involves analyzing the efficiency of the power transmission and distribution segments in the Brazilian electricity sector. In order to measure the productivity, DEA-variable returns to scale (VRS) models were applied to evaluate the performance of companies and identify its benchmarks. An additional contribution seeks to perform a cost analysis to identify possible cost reduction that impact on consumer's charges. Moreover, a window analysis (WA) approach is used to investigate variations related to efficiency levels of companies analyzed throughout years. To do so, a sample of the main 18 firms among both segments (10 distribution and 8 transmission firms) from 2008 to 2014 was employed.

This paper is organized as follows: Section 2 presents the Brazilian electric sector and Section 3 shortly describes DEA and WA techniques. Section 4 shows a case study of a sample of Brazilian electricity power transmission and distribution firms. Section 5 compares and analyzes the results obtained for the transmission and distribution segments by the DEA-VRS models, cost analysis, as well as WA approach. Section 6 closes the paper with concluding remarks, and possible directions for further research.

2. BRAZILIAN ELECTRIC SECTOR

The Brazilian electric sector privatization process was initiated in 1990, aiming to increase investments within power industry through private capital (Melo et al., 2011; Tovar et al., 2011). During this period, other countries, including those developed and under development, accomplished reforms like that regarding their energy markets (Erdogdu, 2011). The main objective of these reforms was mainly to improve their power industry efficiency levels (Erdogdu, 2011; Tovar et al., 2011).

The privatization process occurred within the three segments of Brazilian power industry: Production, transmission and distribution. Nevertheless, this process of restructuring failed to attract new investments and promote the expansion of power industry. Moreover, in 2004, Laws No. 10,847 and No. 10,848 (through emphasis on stability and supply security in long term) were enacted, being both responsible for setting the bases for the current Brazilian electric sector model (Melo et al., 2011; Nagayama, 2007).

Regarding the Brazilian energy matrix, it is mainly composed of renewable sources (Santos et al., 2013), being, according to Pao and Fu (2013), one of the cleanest in the world. In this context, hydropower plants are highlighted since they have 70% of the installed capacity of the country (ABRADEE, 2015; Santos et al., 2013) and the lowest electricity generation costs (Silva et al., 2016). Furthermore, thermoelectric power plants are also used as a source of energy, in order to complement the generation of hydropower plants (Nogueira et al., 2014).

After being generated, the electricity is transported via high-voltage lines. This transport of energy features the transmission segment, which encompasses a range from 230 kV and 750 kV. According to ABRADEE (2015), there are 77 utilities to perform the energy transport and together they manage more than one hundred thousand kilometers of lines scattered throughout Brazil. The power transmission occurs through national interconnected system and is essential to ensure the continuous supply of electricity in the country, since it allows seasonal and regional complementation. Transmission segment transports electrical energy to the distribution sector, where the voltage is lowered to <230 kV, in order to make the connection to final users. Distribution segment has 64 power distributors firms, being 60% private and 40% public, and achieved approximately 77 million "consumer units" in 2015, of which 85% are residential (ABRADEE, 2015).

In the Brazilian electricity market, the purchase and sale negotiations occur in two environments: Regulated contracting environment (RCE) and free contracting environment (FCE). In RCE, distribution companies buy electrical energy from sellers in public auctions under set prices. On the other hand, in FCE, distributors are free to negotiate their own bilateral contracts with their suppliers outside auctions. In order to deal with those environments, the chamber of electricity trading (CCEE) was created (Araújo et al., 2007; Melo et al., 2011).

All segments from generation to distribution have impact over electricity tariff, which, according to Guardia (2007), is composed by: Transmission system usage tariff (TUST), distribution system usage tariff (TUSD), generation and commercialization tariff (TGC) and sectorial charges (SC). TUST involves costs related to capital expenditures and remuneration, operation and maintenance of transmission network. Thus, TUST is the sum of each component of the network costs weighted by the proportion of use of the component capacity. Regarding TUSD, it is similar to TUST, however with respect to distribution network. With respect to TGC, it is the result of a negotiation or auction, reflecting market expectations regarding the monetary value of electricity, i.e., it already includes costs regarding capacity, fuel, operation and maintenance of generation plants. Lastly, SC were created by laws to enable the implementation of public policies in the Brazilian electric sector. Their values are defined by ANEEL and collected by distributors through electricity bill.

Taking in account distribution companies, their costs, according to Lino et al. (2011), are divided in non-manageable (energy purchasing, transmission costs and sectorial charges) and manageable (operation, maintenance and repair costs). It means that the tariff paid by consumers should be enough to cover these costs and also provide a certain level of profit (set by ANEEL) to each distribution company. The tariff price is also set by ANEEL and reviewed each 5-year period (Tovar et al., 2011). With respect to these costs, they are multiplied by the inflation index discounted by a productivity level called X factor. The discount obtained by the X factor aims to promote efficiency and share productivity gains with consumers (Lino et al., 2011; Lins et al., 2007). Based on previous assessments regarding improvement of productivity, ANEEL estimates the X factor for the current tariff review. So, until the next review, if a company reduces its costs above the expected this reduction will be added to its profit.

In addition, since 2015 electricity bills started to be based on tariff flags (Silva et al., 2016). In this scenario, the color used is responsible for indicating generation costs, i.e., non-manageable costs. Thus, green, yellow and red flags indicate that costs of generation were considered low, medium or high, in this order. The main purpose is to aware each consumer when electricity price is higher, motivating reduction in energy consumption.

Therefore, based on all the factors involving the electricity tariff charged to the consumer, it becomes relevant DEA application as a methodology for efficiency assessment in this sector. Even though the electric power system is regulated by ANEEL, it is up to companies to reduce incurred costs through a better use of resources. It might be accomplished by taking as benchmarks those companies with high levels of efficiency. Thus, corporations within both systems (transmission and distribution) can achieve greater profitability by improving their efficiency, which will consequently reduce the values of tariffs.

3. DEA

3.1. Brief Literature Review

DEA is a mathematical procedure initially proposed by Charnes et al. (1978) in order to assess the efficiency of DMUs in a context of constant returns to scale (CRS). Thereby, given a set of DMUs, DEA is responsible for selecting those who play their roles more efficiently, grouping them in ERSs. Comparisons regarding these sets might be a manner to identify either failures or malfunctions in other DMUs, enabling improvement of activities, processes and services. Moreover, DEA provides among analysts and decision makers opportunities of collaboration which has its definition extended, being defined, according to Sherman and Zhu (2006) as the ratio between inputs and outputs. Nevertheless, propositions such as imperfect competition, government regulations, financial constraints, organizations size, etc., might lead to the inapplicability of CRS models. Thus, in order to treat these issues Banker et al. (1984) adapted the CRS model to the case of VRS. Coelli et al. (2005) point out that the VRS formulation allows a DMU to take as a benchmark only those that have similar size to yours. Therefore, the projection of this DMU on the efficient frontier will be obtained through a convex combination of the companies belonging to its ERS. Regarding this type of modeling, two of the most common formulations are the primal (envelopment) and dual (multiplier). Both are presented (with input orientation) in Table 1. For a more detailed discussion of DEA models and applications, see Coelli et al. (2005), Cooper et al. (2007) and Cooper et al. (2011).

It is worth noting the importance of μ_0 variable. It is responsible for indicating if the returns to scale are: (1) Increasing ($\mu_0 < 0$): The DMU being assessed holds production levels below its optimum capacity, (2) decreasing ($\mu_0 > 0$): The DMU is operating at production levels beyond its ability or capacity, (3) constant ($\mu_0 = 0$): Any increase regarding the organizational resources, levels of products and services will be enhanced in same proportion.

3.2. WA

In some cases, it is important to assess the efficiency of a particular DMU over a specific time period. WA is a technique which allows this kind of assessment. Thus, according to Cooper et al. (2011), for each time period (window) each DMU is treated as a different one. In accordance with Yang and Chang (2009), WA generalizes the notion of moving averages to detect efficiency trends and stability of a DMU over time. Although, as pointed out by Asmild et al. (2004), a window must be simultaneously small enough to minimize abusive comparisons and large enough to have an adequate sample size. Following Cooper et al. (2007), given a number of k periods, the length p of a window will be defined by

$$p = \begin{cases} \dfrac{k+1}{2} & \text{when k is odd} \\ \dfrac{k+1}{2} \pm \dfrac{1}{2} & \text{when k is even} \end{cases} \quad (1)$$

Furthermore, the number of windows will be w = k−p+1.

4. CASE STUDY

The data used in this paper consists of a sample of Brazilian electricity power distribution and transmission firms. We selected a sample of companies that could provide results sufficiently relevant in order to carry out further inferences regarding power distribution and transmission systems. Thereby, the sample is composed by the 8 and 10 major companies with respect to transmission and distribution systems, respectively. The data set constructed was based on ANEEL and Ministry of Mines and Energy (MME) reports. They were complemented by information provided by companies' annual reports. Regarding the power transmission system, the main selection criterion was the network length held by each organization. Thereby, the eight companies

Table 1: VRS formulations

Primal (envelopment)	Dual (multiplier)
$\text{Min}_{\theta B,\lambda}\theta_B$	$\text{Max}_{v,u,uo}\ Z=UY_O-U_O$
Subjected to:	Subjected to:
$\theta_B x_o - X\lambda \geq 0$	$V \times_0 = 1$
$Y\lambda \geq y_o$	$-vX+uY-u_0 e \leq 0$
$e\lambda = 1$	$v \geq 0,\ u \geq 0,\ u_o \in R$
$\lambda \geq 0$	

Table 2: Power distribution and transmission companies

Power distribution			Power transmission		
Company	Energy consumption (MWh)	Percentage of total	Company	Network length (km)	Percentage of total
ELETROPAULO	36,317,519.35	10.60	FURNAS	24,139	19.10
CEMIG-D	26,496,181.07	7.73	CHESF	18,563	14.70
COPEL-D	24,043,956.39	7.01	CTEEP	13,724	10.80
CPFL-PAULISTA	22,050,523.76	6.43	ELETROSUL	11,140	8.80
LIGHT	21,354,314.45	6.23	ELETRONORTE	10,702	8.50
COELBA	16,907,317.01	4.93	CEMIG	9,748	7.70
CELESC-D	15,801,694.59	4.61	CEEE	6,055	4.80
ELEKTRO	12,651,598.50	3.69	COPEL	2,204	1.75
CELG-D	12,039,804.53	3.51	-		
CELPE	11,445,289.84	3.34	-		
Total	199,108,199.49	58.09	Total	102,060	76.15

presented in Table 2 were selected. They represent together 76% of all network length used for power transmission purposes in 2014. With respect to the distribution system, energy consumption was the selection criterion adopted. The 10 distribution companies included in the study are also shown in Table 2. They correspond to about 58% of Brazil's energy consumption in 2014.

Regarding the choice of variables, it was carried out in accordance with the general consensus found in the current literature of distribution systems (Costa et al., 2015; Pereira de Souza et al., 2014; Leme et al., 2014). The outputs are network extension (km), number of customers and energy consumption (MWh) and the input is operational cost (R$). With respect to power transmission system, as suggested by Pessanha et al. (2010), operating costs (R$) were taken as a single input whereas processing capacity (MVA), network length (km), number of modules and number of transformers were defined as outputs.

Even though analyzes were performed separately for each sector, results are correlated since they both impact over electricity tariff pricing. Thus, the lower the performance of each segment, the higher will be the price paid by the final consumer. Thereby, considering the time interval from 2008 to 2014, 56 and 70 DMUs were evaluated in power transmission and distribution systems, respectively. According to Cooper et al. (2007), the number of DMUs should be at least equal to max $\{i \times o, 3(i + o)\}$, where i is the number of inputs and o is the number of outputs, meaning that for both scenarios this condition was satisfied.

5. RESULTS

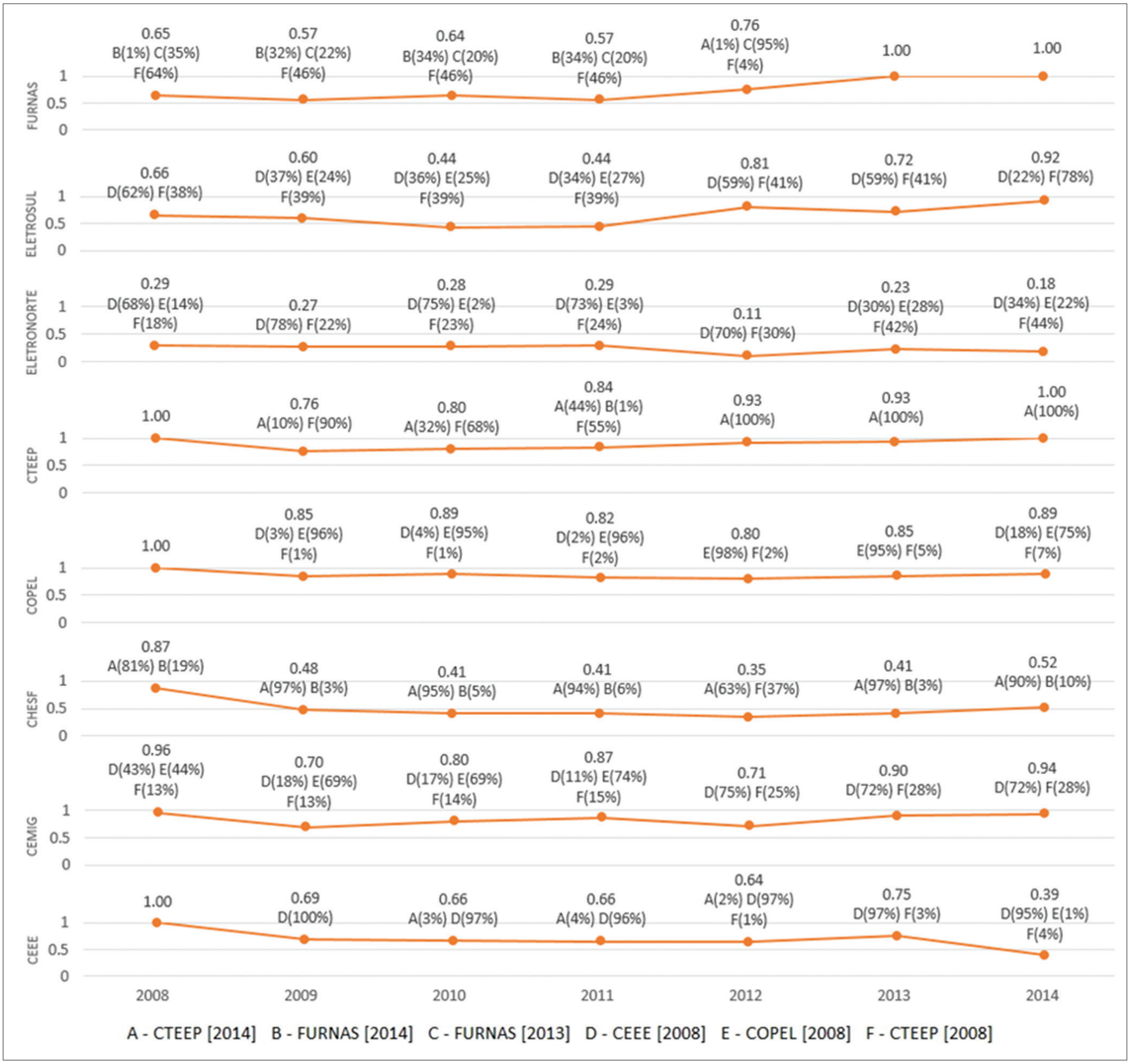
This study approach includes three steps. Firstly, the VRS models presented in Table 1 were applied for both scenarios (transmission and distribution) in order to assess the efficiency value for each DMU. This approach differs from the one used by ANEEL which consider non decreasing returns to scale. As discussed by Costa et al. (2015), taking in consideration this context, VRS approaches provide a better fit. Banker (2011) has already presented a report relating this issue but so far new methodologies approaches are still under discussion by ANEEL. Secondly, by using the efficiency values obtained for each DMU, it was possible to measure how much could have been saved by each company, and consequently, to infer about potential cost impact to Brazilian consumers. Finally, since DEA results might differ depending on the data set used, a WA approach was carried out in order to assess the stability of efficiency values for each firm in both segments as well, along different time intervals.

5.1. VRS Models Results

After appliance of the VRS models, efficiency values for companies within transmission and distribution systems were obtained. Furthermore, with respect to each company it was identified those DMUs belonging to its ERS. Results regarding transmission and distribution systems are shown in Figure 1 and 2, respectively. The x-axis represents time in years 2008-2014, whilst the y-axis shows companies performance over this time interval. Regarding Figure 1, six DMUs achieved maximum values of efficiency, being symbolized by letters from A to F, as follows: A - CTEEP [2014], B - FURNAS [2014], C - FURNAS [2013], D - CEEE [2008], E - COPEL [2008], F - CTEEP [2008]. With respect to the efficiency results, FURNAS, ELETROSUL, CTEEP, COPEL and CEMIG were considered positive highlights since they either improved their efficiency or achieved high performance along the time interval considered. As contrast, CHESF, CEEE and ELETRONORTE achieved poor results since the first two showed a performance decline and the third presented a performance far below the average. Furthermore, FURNAS and CHESF achieved positive values of μ_0 for all years of analysis, indicating decreasing returns to scale. It suggests that if these corporations intend to expand their activities, organizational restructuring will be required.

On the other hand, companies within distribution system presented better results since twelve DMUs achieved maximum performance, being represented by letter from A to L in Figure 2: A - ELETROPAULO [2014], B - CEMIG-D [2014], C - CELG-D [2014], D - ELETROPAULO [2013], E - CEMIG-D [2013], F - CPFL-PAULISTA [2013], G - ELEKTRO [2013], H – ELETROPAULO [2012], I - CEMIG-D [2012], J - CELPE [2011], K - COELBA [2010], L - CELPE [2008]. With respect to efficiency results, all performances were considered satisfactory, since all companies either improved their efficiency (such as CELESC-D and CELG-D) or achieved good results along the time interval taken in account. Nevertheless, it is valid to point out that CEMIG-D, CELESC-D and COPEL-D got positive values of μ_0 for all analyzes, indicating decreasing returns to scale.

Figure 1: Efficiency results for data envelopment analysis-variable returns to scale (transmission)



Regarding both scenarios, percentages of contribution to a corporation in a specific year is also shown and calculated as follows:

$$\text{Contribution DMU}_k = \frac{\lambda_k}{\sum_{i=1}^{n} \lambda_i}(100) \quad (2)$$

Values of λ are those obtained through the envelopment model. In this case, the greater the contribution of a DMU_k, the greater its organizational proximity (taking in account the other references) regarding the DMU being analyzed. Thus, taking in account the transmission system in Figure 1, CHESF [2014], for instance, has more similarities with CTEEP [2014] (contribution of 90%) than FURNAS [2014] (contribution of 10%). It means that, considering the efficiency frontier, CHESF [2014] is much closer to the first reference than to the second. With respect to distribution system, even though some DMUs achieved maximum efficiency, ELETROPAULO [2014], CELG-D [2014], CEMID-D [2013] and ELETROPAULO [2012]) had no contribution to any of the others DMUs, being part of none ERS.

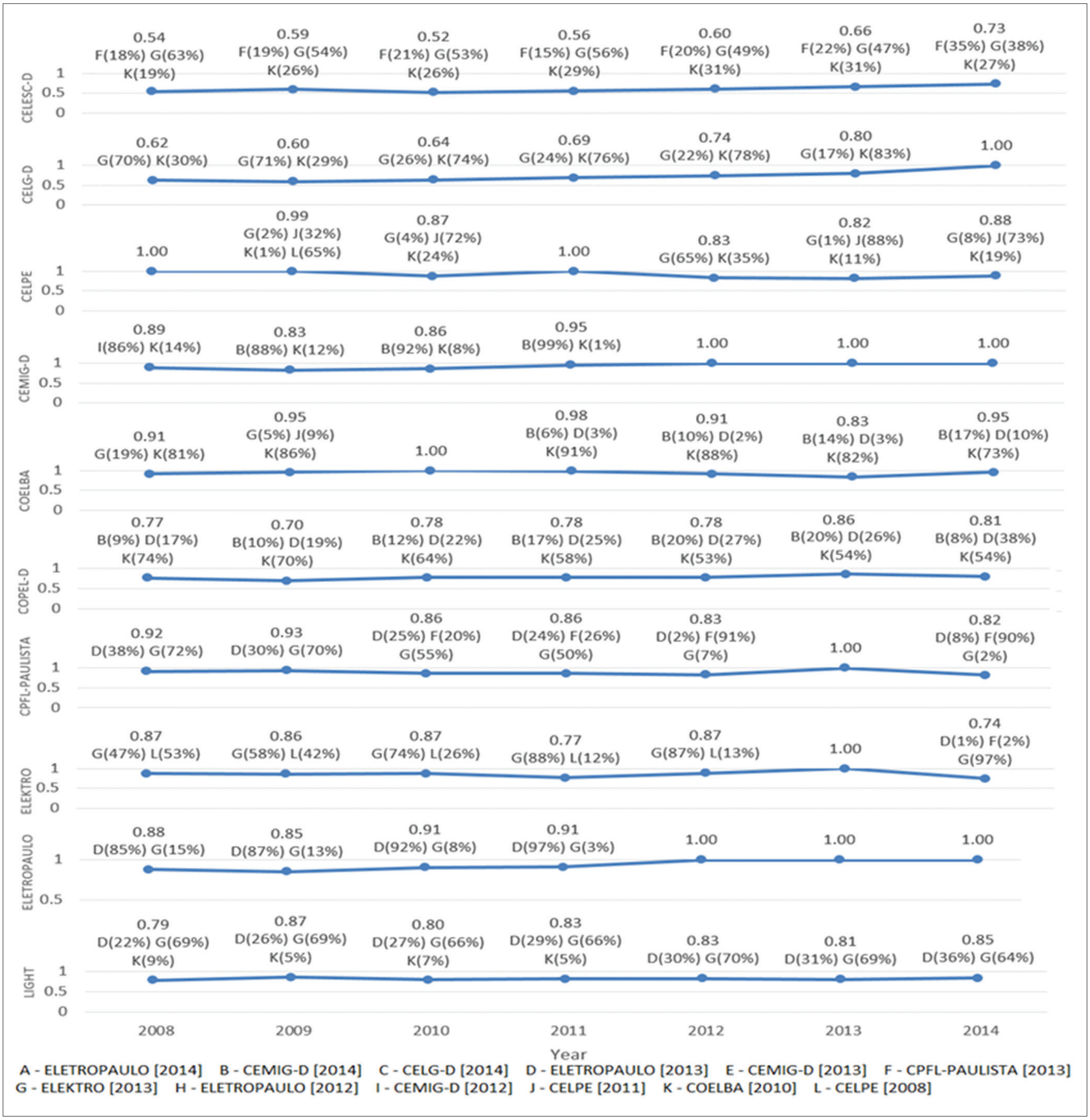
5.2. Cost Analysis Results

It is also relevant to assess the operational cost reduction required for each company in order to translate it to the efficiency frontier. Calculations of new input values for inefficient DMUs might be performed by using a procedure presented by El-Mahgary and Lahdelma (1995) and expressed in a generalized form below:

$$x_{ik} = \sum_{j=1}^{n} x_{ij}\lambda_j \ (i = 1,\ldots,m) \quad (3)$$

In this case, the new value x_{ik} of a specific input i related to a DMU_k is the summation of the same input i with respect to each DMU_j (j = 1,…, n) multiplied by λ_j. Thus, the less the efficiency

Figure 2: Efficiency results for data envelopment analysis-variable returns to scale (distribution)



of a DMU, the greater is the input (operational cost) reduction level required in order to make DMU_k efficient.

Possible costs saving for each company regarding the whole time interval are presented in Tables 3 and 4 for transmission and distribution systems, respectively. These tables show how much could have been saved if inefficient companies within both systems had operated with maximum level of performance. In both tables, the values regarding each company were accounted by following: The total cost was obtained by totaling total cost values of each analyzed corporation, the reduced cost was calculated through equation 3, cost reduction values were achieved by the difference between total cost and reduced cost, the percentage reduction was the ratio between cost reduction and total cost, and the percentage of contribution to total reduction was the ratio between each company cost reduction and total cost reduction.

In transmission system, taking in account the whole time interval, the saves could achieve approximately R$ 11 billion. It means that the low performance of certain companies represented R$ 11 billion in charges (through TUST) to consumers from 2008 to 2014. Furthermore, ELETRONORTE and CHESF are both the organizations that could have achieved higher cost reduction, about 80% and 53%, respectively. In contrast, CTEEP and COPEL

Table 3: Individual transmission cost

Company	Total cost (R$)	Reduced cost (R$)	Cost reduction (R$)	Cost reduction (%)	Contribution to total reduction (%)
CEEE	1,447,897,708.88	925,139,597.07	522,758,111.81	36.10	4.77
CEMIG	1,218,383,316.99	1,011,764,820.53	206,618,496.46	16.96	1.89
CHESF	5,214,927,115.59	2,452,121,490.02	2,762,805,625.57	52.98	25.22
COPEL	843,878,676.96	731,265,307.84	112,613,369.12	13.34	1.03
CTEEP	2,250,810,148.68	1,992,665,012.21	258,145,136.47	11.47	2.36
ELETRONORTE	5,576,249,596.04	1,154,532,582.62	4,421,717,013.42	79.30	40.36
ELETROSUL	2,093,322,871.45	1,305,506,366.78	787,816,504.67	37.63	7.19
FURNAS	7,019,161,025.08	5,137,246,505.21	1,881,914,519.87	26.81	17.18
Total	25,664,630,459.67	14,710,241,682.28	10,954,388,777.39	42.68	100.00

Table 4: Individual distribution cost

Company	Total cost (R$)	Reduced cost (R$)	Cost reduction (R$)	Cost reduction (%)	Contribution to total reduction (%)
CELESC-D	5,993,180,380.00	3,567,826,750.90	2,425,353,629.10	40.47	24.00
CELG-D	5,509,137,770.00	3,902,334,251.37	1,606,803,518.63	29.17	15.90
CELPE	3,763,264,470.00	3,410,066,231.57	353,198,238.43	9.39	3.50
CEMIG-D	14,653,366,690.00	13,629,672,664.27	1,023,694,025.73	6.99	10.13
COELBA	5,313,644,160.00	4,925,566,304.12	388,077,855.88	7.30	3.84
COPEL-D	8,218,177,020.00	6,438,686,040.17	1,779,490,979.83	21.65	17.61
CPFL-PAULISTA	5,018,188,900.00	4,434,674,926.89	583,513,973.11	11.63	5.77
ELEKTRO	3,428,232,320.00	2,904,100,329.63	524,131,990.37	15.29	5.19
ELETROPAULO	8,603,893,490.00	8,079,786,720.68	524,106,769.32	6.09	5.19
LIGHT	5,133,147,630.00	4,236,908,993.23	896,238,636.77	17.46	8.87
Total	65,634,232,830.00	55,529,623,212.83	10,104,609,617.17	15.40	100.00

got top levels of management regarding the relationship between inputs and outputs. Even though some organizations have shown significant levels of possible reductions, such as CEEE and ELETROSUL, the values found have low impact over the total amount of reduction. On the other hand, ELETRONORTE, CHESF and FURNAS, accounted together approximately 83% or R$ 9 billion regarding the total cost reduction.

Similarly, regarding the distribution scenario, as presented in Table 4, ELETROPAULO, CEMID-D, COELBA and CELPE were considered the companies with top levels of management regarding the relationship between inputs and outputs. Analogously to the transmission system, few companies, CELESC-D, COPEL-D, CELG-D and CEMIG-D, accounted together for approximately 67% of the total possible reduction of R$ 10.1 billion. On the other hand, the differences between cost reduction and contribution to total reduction are in general lower than those presented for transmission system, meaning that the difference of size among companies is also lower. Furthermore, with respect to distribution system, only 15% of costs could have been saved whilst this percentage is approximately 42% regarding transmission system. These findings suggest that even though distribution operations are the subsequent steps, they are performed with an overall efficiency greater than those related to transmission.

5.3. WA Results

A WA approach is also performed to assess stability of results considering different time periods (windows). Thus, taking in account (1) and a time interval of 7 years, both window length (p) and number of windows (w) are 4. It means that four different analyses should be carried out, considering four

Table 5: WA for transmission system

COMPANY	AVG	STDV	MRY	MR
CEEE	0.805	0.128	0.196	0.516
CEMIG	0.902	0.099	0.132	0.302
CHESF	0.516	0.147	0.132	0.638
COPEL	0.949	0.058	0.179	0.179
CTEEP	0.968	0.051	0.130	0.194
ELETRONORTE	0.268	0.081	0.070	0.241
ELETROSUL	0.685	0.203	0.122	0.560
FURNAS	0.930	0.124	0.410	0.410

WA: Window analysis, STDV: Standard deviation, AVG: Average

Table 6: WA for distribution system

COMPANY	AVG	STDV	MRY	MR
ELETROPAULO	0.973	0.038	0.092	0.094
CEMIG-D	0.944	0.061	0.052	0.170
COPEL-D	0.816	0.041	0.042	0.157
CPFL-PAULISTA	0.922	0.068	0.108	0.180
LIGHT	0.861	0.044	0.069	0.145
COELBA	0.956	0.050	0.017	0.157
CELESC-D	0.626	0.058	0.073	0.240
ELEKTRO	0.908	0.088	0.175	0.258
CELG-D	0.776	0.131	0.324	0.379
CELPE	0.919	0.077	0.057	0.182

WA: Window analysis, STDV: Standard deviation, AVG: Average

different time intervals (2008-2011, 2009-2012, 2010-2013, 2011-2014) for both cases (transmission and distribution). Both results are presented in Tables 5 and 6 where AVG represents the arithmetic average of efficiencies regarding a specific corporation, considering all its results through different windows. Furthermore, MRY indicates the maximum range for a year within the time interval of analysis whilst MR and STDV are, respectively, the maximum variation and the standard deviation, regarding all windows.

In Table 5, CTEEP held the highest efficiency average among all companies, followed by COPEL, FURNAS, CEMIG and CEEE which also achieved high values. However, it is worth noting that these last three organizations presented greater instability with respect to CTEEP and COPEL, since their values of STDV were all higher. Thereby, CTEEP were considered the corporation with both, best performance and highest stability. On the other hand, FURNAS was considered the less stable corporation regarding a specific year, since its value of MRY was the highest. Furthermore, with respect to all years and windows being analyzed, ELETROSUL and CHESF were accounted as the less stable companies, achieving high values of STDV and MR.

Regarding Table 6, ELETROPAULO achieved the best result of overall efficiency, followed by COELBA, CEMIG-D, CPFL-PAULISTA, CELPE and ELEKTRO. In addition, ELETROPAULO was considered the corporation with greatest stability, since it achieved the lowest STDV value among all companies. On the other hand, CELG-D was considered the company with worst stability and CELESC-D the one with worst performance, since its values for STDV and AVG are the highest and lowest, respectively. Moreover, comparing both scenarios, distribution and transmission of electrical energy, it is possible to infer that companies within distribution system presented higher stability compared to those within transmission system, since values of STVD are overall lower. Overall efficiency can also be assessed by averaging all efficiency values for each window. As shown in Table 7, distribution system achieved higher values of overall efficiency regarding all windows. Those findings suggests that in general corporations within distribution system have a better level of management regarding their operating costs than those within transmission system, verifying the results regarding cost reductions carried out previously.

6. CONCLUDING REMARKS

The objective of this paper is to analyze the performance of the power transmission and distribution segments in the Brazilian electricity sector. In order to assess these segments, DEA-VRS models, cost analysis and WA approaches were carried out for both cases. The data used in this paper consists of a sample of 18 power transmission and distribution firms of the Brazilian electricity sector over a 7-year period from 2008 to 2014.

The DEA-VRS models were used to assess the efficiency and the benchmarks for each company in transmission and distribution scenarios. The maximum value of efficiency was achieved by six DMUs in transmission system and by twelve DMUs in distribution system. Moreover, FURNAS and CHESF, in transmission segment, and CEMIG-D, CELESC-D and COPEL-D, in distribution segment, presented decreasing returns to scale, indicating that those companies are operating beyond its capacity.

With respect to the cost analysis, it was calculated the reduction in operational costs in both transmission and distribution scenarios in order to reach the efficiency frontier. The results showed that the cost reduction in the period analyzed (2008-2014) could achieve approximately R$ 21 billion, including distribution and transmission systems, which means how much could have been saved and not charged to the costumer. Analyzing each company individually, it was calculated the percentage of cost reduction and its contribution to total reduction. The results showed that ELETRONORTE and CHESF, in transmission system, and CELESC-D, COPEL-D and CELG-D, in distribution system, are the companies that could have saved the greatest monetary values. Besides that, percentages of cost reduction in transmission system are higher than in distribution system, suggesting that distribution companies are better managed regarding the relationship between inputs and outputs when they are compared to transmission firms.

Regarding the WA, the distribution systems achieved higher values of overall efficiency as well as higher stability compared to transmission systems. Those results confirm the ones obtained by cost analysis and also suggest that those companies have a better level of management regarding their operational costs. Furthermore, CTEEP (transmission system) and ELETROPAULO (distribution system) are the corporations with highest stability.

Transmission and distribution segments represent an important share in the tariff price charged to consumers. In medium and long term, improvement of efficiency level throughout those segments lead to reduction in consumers' bills, which may contribute to speed up economy growth and decrease companies' production costs. Moreover, it is noteworthy that the significant cost reduction achieved during the analyzed period (2008-2014) regards only the DMU sampled, which suggest that those results could be much important taking into account all the companies in both segments (transmission and distribution).

In terms of future research, an interesting line of research would be to conduct a sensitivity analysis in order to better understand the variations within the DMU set. We also intend to use all power distribution and transmission companies and perform a segmentation of the set of distribution utilities as well as transmission firms using cluster analysis techniques to establish more accurate comparisons between companies. Another interesting topic for future research might be to incorporate

Table 7: Overall efficiency

Window								AVG transmission	AVG distribution
Window 1	2008	2009	2010	2011				0.730	0.898
Window 2		2009	2010	2011	2012			0.769	0.873
Window 3			2010	2011	2012	2013		0.768	0.842
Window 4				2011	2012	2013	2014	0.743	0.867

AVG: Average

exogenous variables, such as rainfall, temperature and income level within the company region, in order to improve analysis once these variables may affect the efficiency.

7. ACKNOWLEDGMENTS

The authors would like to thank the PIP/UFOP (Federal University of Ouro Preto Research Program) and FAPEMIG for their financial support.

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