Sistematizando Práticas para Administrar 2

Grayce Kelly Bianconi
João Dallamuta
(Organizadores)

Atena Editora
Ano 2020

Sistematizando Práticas para Administrar 2

Grayce Kelly Bianconi
João Dallamuta
(Organizadores)

Atena Editora
Ano 2020

2020 *by Atena Editora*

Editora Chefe: Profª Drª Antonella Carvalho de Oliveira
Diagramação: Geraldo Alves
Edição de Arte: Lorena Prestes
Revisão: Os Autores

Atena Editora
Ano 2020

Atena Editora
Ano 2020

Dados Internacionais de Catalogação na Publicação (CIP)
(eDOC BRASIL, Belo Horizonte/MG)

S622 Sistematizando práticas para administrar 2 [recurso eletrônico] / Organizadores Grayce Kelly Bianconi, João Dallamuta. – Ponta Grossa, PR: Atena Editora, 2020.

Formato: PDF
Requisitos de sistema: Adobe Acrobat Reader.
Modo de acesso: World Wide Web.
Inclui bibliografia
ISBN 978-85-7247-981-3
DOI 10.22533/at.ed.813201002

1. Administração. 2. Gestão organizacional. I. Bianconi, Grayce Kelly. II. Dallamuta, João.

CDD 658.4

Elaborado por Maurício Amormino Júnior – CRB6/2422

Atena Editora
Ponta Grossa – Paraná - Brasil
www.atenaeditora.com.br
contato@atenaeditora.com.br

APRESENTAÇÃO

Esta obra é composta por pesquisas realizadas por professores e alunos na área de gestão, todas elas selecionadas e ordenadas pelas suas contribuições genuínas e relevantes dentro dos temas propostos.

Os desafios da gestão em nossos dias estão sobretudo relacionados ao enorme dinamismo e incertezas do ambiente de negócios, e suas rápidas e profundas transformações tecnológicas, culturais, sociais e econômicas.

A visão ampla do gestor, além dos temas diretamente associados a seus negócios é fundamental para a sobrevivência neste ambiente mutante. Esperamos que a leitura dos trabalhos selecionados nesta obra gere reflexões e novas ideias nos leitores, razão de ser de nosso trabalho.

Os organizadores gostariam de agradecer aos autores e editores pelo espírito de parceria e confiança.

Boa leitura

Grayce Kelly Bianconi

João Dallamuta

SUMÁRIO

DOI 10.22533/at.ed.81320100218

CAPÍTULO 1

HOW EFFICIENT ARE THE BRAZILIAN ELECTRICITY DISTRIBUTION COMPANIES?

Data de aceite: 20/01/2020

Sandra de Sousa Xavier
Federal Institute of Paraná, Brazil, sandraxavier@gmail.com

José Wanderley Marangon Lima
University of Itajubá, Brazil, jwmarangonl@gmail.com

Luana Medeiros Marangon Lima
University of Itajubá, Brazil, luana@marangonenergia.com.br

Ana Lúcia Miranda Lopes
University of Minas Gerais, Brazil, analopes.ufmg@gmail.com

ABSTRACT: During the last years, the electricity sector has experienced great changes, especially within the economic regulation. After receiving several criticisms, the rate of return regulation has been replaced by incentive regulation. The main objective of this regulation is to stimulate business efficiency. This paper proposes an alternative application of Data Envelopment Analysis to the Brazilian case, characterized by a large territory: the use of Unit Networks in the distribution segment to regionalize the concession area and then to analyse the efficiencies separately. Many regulators use the entire distribution company as a Decision Making Unit for price regulation when benchmarking is applied. However, in Brazil, quality performance is measured in detail using sets of consuming units; i.e., quality is measured using small parts of the company. Given that efficiency cannot be assessed without considering various aspects of quality performance and characteristics of the underlying environment in the utility's concession area, this paper tries to find the trade-off among management, quality, environment and costs. Therefore, the main contribution of this paper is twofold: the solution for Brazilian distribution companies' heterogeneity and the choice of variables that are better measures for an efficiency analysis. Some examples with Brazilian utilities are provided to show the advantages of the proposed approach.

KEYWORDS: Electricity Power Distribution, Incentive Regulation, Data Envelopment Analysis

1 I INTRODUCTION

Various reforms have been proposed for the electricity sector around the world to make utilities more efficient through competition, privatization and price mechanisms. In general, during the restructuring process the industry is divided into four distinguished activities: generation, transmission, distribution and

retailing. This paper focuses only on the economic regulation of the distribution companies.

One of the major problems of rate of return regulation is that companies are induced to over-capitalize to obtain higher remuneration of capital. Consequently, the tariffs paid by customers increase. The incentive regulation tries to force the companies to be more efficient (Ergas and Small, 2001) and try to avoid the Averch-Johnson effect (AVERCH-JOHNSON, 1962).

The incentive regulation uses benchmarking techniques to define the efficient companies. In general terms, this technique can be characterized as a method that compares a group of companies as they were subjected to a competitive environment (LOWRY and GETACHEW, 2009). Results from a survey conducted among energy regulatory agencies in 40 countries showed that there is a clear trend in the electricity industry towards the use of Data Envelopment Analysis (DEA) in both transmission and distribution (HANEY and POLLITT, 2009).

It is noteworthy that despite the popularity of the DEA, its application is restricted mainly to European countries characterized by small territorial distances and homogeneous environmental conditions. In Brazil, conditions are different:

“There is a large variation in sizes, scopes and environmental characteristics of the Brazilian distribution companies. It seems obvious that the diversity is higher in Brazil than in most other countries where benchmarking-based regulation has been traditionally used” (BOGETOFT, 2014).

This paper proposes a new approach to solve the heterogeneity constraint and to allow the inclusion of quality and environmental aspects; the approach combines the DEA with the Unit Networks (UN) concept. The UN is used for splitting a distribution company concession area into more homogeneous subgroups that are further considered as DMUs.

2 I DISTRIBUTION REGULATION

2.1 Price regulation

Since 2003, the distribution companies have been regulated using a price cap model based on RPI -X formula that is reset every 4 years. Price cap model typically specifies an average rate at which the prices that regulated companies charge for its services must decline, after adjusting for inflation. This rate is called the X-Factor.

During the third price revision, ANEEL changed from the bottom-up approach of Firm Reference Model to top-down methods such as DEA and Corrected Ordinary Least Square. Instead of analysing each activity, the efficiency is measured comparing outputs and inputs among distribution companies.

The two-stage DEA model was used to take the environmental aspects of

the distribution service into account. The model outputs were network length, energy delivered and number of customers. The inputs were operational costs. As environmental variables, it considered the local wage level, the precipitation rates, the customer density and a complexity index. The wage level measures the differences in labour costs at the utilities determined by the local markets. The complexity index measures the difficulty faced by each utility in reducing non-technical losses.

From this comparison with actual data from the utilities, the regulator sets different X-Factors for passing operational costs to customers through tariffs according to the average efficiency of the sector. The X-factor is applied on the value of the Parcel B of distribution companies. Thus, for more efficient companies it is possible to have earnings above actual costs, while for less efficient ones there are deficits not allowed to pass through to consumers (ANEEL, 2006).

2.2 Quality of supply regulation

In Brazil, the quality performance analysis is carried out based on divisions of the concession area called sets of consuming units. Thousands of sets are created; performance comparisons, formerly done company by company, changed to set by set (TANURE, TAHAN and LIMA, 2006).

One set of consuming units is composed of the units fed by the same distribution substations. The central idea is that the sets are more comparable than the distribution companies as a whole because the concession areas in Brazil usually cover a wide range of social, economic and environmental characteristics.

After defining the sets, a clustering process is carried out based on the characteristics of the sets. This is necessary because there are approximately 6,000 sets to analyse and for which to establish quality performance targets.

Quality of supply is assessed for each cluster using the collective indicators System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (BILLINTON and ALLAN, 1984). The first index measures the mean time during the observation period for which there was discontinuity in the electricity supply, Equation (1).

$$\text{SAIDI} = \frac{\sum U_i * N_i}{\sum N_i} \qquad (1)$$

Where:

U_i: Annual outage time;

N_i: Number of customers at load point *i*.

This indicator is used in this paper as a quality measure, after multiplication by the number of customers at the load point *i*.

2.3 Combined price and quality regulation

Regarding price regulation, the Brazilian regulator bases its analysis on the company as a whole; i.e., the DMUs are the distribution companies. However, for quality regulation, the regulator bases its analysis on the set of consuming units, which are divisions of the concession area. These perspectives are depicted in Figure 1.

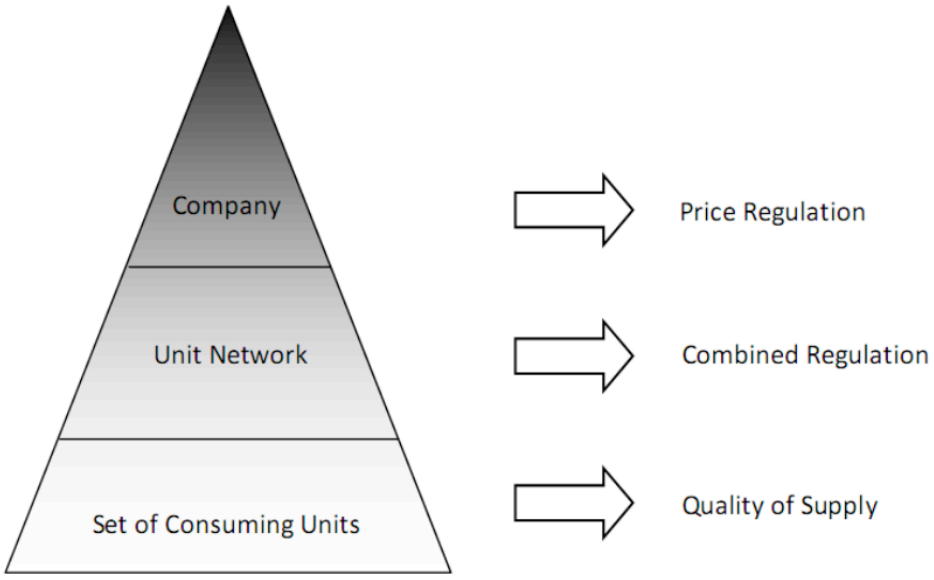

Figure 1. Regulatory perspective

Given that price regulation cannot be disconnected from the quality of the service, the company approach and the set of consuming units approach must converge to the same base.

Consider the case of the Brazilian company CEMIG. Its distribution network is over 460,000 kilometres in length (CEMIG, 2019). The company operates in the Minas Gerais state that has an area of approximately 586,528 km^2, larger than countries such as France, Spain and the United Kingdom (IBGE, 2019). For example, the average lightning rate, which may affect the continuity of supply, varies from 0.085 to 5.971 per km^2 per year within the concession area. All of these peculiarities shape the characteristics of CEMIG's distribution network, which requires different treatment for each region.

The use of sets of consuming units as DMUs considerably increases the number of DMUs. Moreover, the DMUs should represent organizational units, whereas the sets of consuming units represent portions of the electrical distribution network. The UN concept introduced in this paper tries to minimize the distance between the price regulation and the quality of supply regulation. The boundaries of UNs have strong connections to the regional organizations that are usually present at the distribution companies. Therefore, the regulator can consider the same unit of analysis both for the quality of supply and for price regulation. Additionally, the regulator may determine

whether the cost reduction is being done to the detriment of the quality of supply.

3 I METHODOLOGY

3.1 Data Envelopment Analysis

DEA is a nonparametric methodology that uses real data to measure the relative efficiency of a DMU. It was proposed by Charnes, Cooper and Rhodes in 1978 (Charnes, Cooper and Rhodes, 1978) to address the efficiencies of companies operating in constant returns to scale (CRS) and further extended by Banker, Charnes and Cooper (1984) to variable returns to scale (VRS).

This efficiency analysis can be focused on input reduction or output expansion. The result from an input-oriented model is the maximum reduction possible in the inputs level for a given level of output. With an output-oriented focus, the model seeks the maximum output quantities that can be generated by the actual level of inputs used by the company. The efficiency scores can vary from 0 to 1, where 1 denotes the efficient company.

The majority of the DEA models consider either constant (Charnes *et al.*, 1978) or variable returns to scale (Banker *et al.*, 1984). For constant returns to scale, outputs and inputs increase (or decrease) by the same proportion along the frontier. Where the technology exhibits increasing, constant or decreasing returns to scale along different segments of the frontier, the variable returns to scale model is indicated (SUBHASH and CHEN, 2010). The CRS model assesses the overall technical and scale efficiency, while a VRS model measures only the technical efficiency. For more details, see (CHARNES *et al.*, 1978) and (BANKER *et al.*, 1984).

A Two-Stage DEA model

Two-stage analysis is one of the most popular techniques in the literature to take environmental variables into account. We employed this technique as follows: in the first stage, we determined the technical efficiency performances of the Unit Networks (UNs) or distribution companies using DEA. In the second stage, treating these calculated efficiency scores as dependent variables, we used a regression technique to determine the environmental variables that may explain the efficiency scores. This approach is advocated by (CHILINGERIAN and SHERMAN, 2004), (SUBHASH, 2004) and (RUGGIERO, 2004).

Efficiency scores calculated from DEA take values between 0 and 1, making the dependent variable in the second stage limited. The Tobit model (Tobin, 1958) is frequently used to address such a limited dependent variable and is followed in this study.

The calculated efficiency score in the first stage (θ_i) will be corrected by environmental variables (z_i) in this second stage. Therefore, a latent (unobserved)

variable (θ_i^*) is calculated as in Equation 2:

$$\theta_i = \begin{cases} \theta_i^*;\ 0 \leq \theta_i^* \leq 1 \\ 0\ ;\ \theta_i^* < 0 \\ 1\ ;\ \theta_i^* > 1 \end{cases}$$

$$\theta_i^* = z_i\beta + \varepsilon_i \qquad (2)$$

Here z_i is an (r × 1) vector of environmental variables and β is an (r ×1) vector of parameters to be estimated.

3.2 Unit Network

The definition of a UN is a twofold process. The first step is to define the domain areas of each connection point between the transmission and distribution networks. The domain area of a connection point is defined as the set of buses that are reached by the power flow that cross the border transformer. The second step couples domain areas based on strong and weak links through network equivalents. In the presence of strong links, two or more UNs can be grouped to form a larger UN. Connections are strong if they have a low equivalent impedance value and are weak if the impedance is high.

Example of Unit Network Definition

Consider the system depicted in Figure 2. The red box represents the transmission grid and green box represents the distribution grid. Usually, the flow direction in the border transformers, which connects the grids, is from transmission to distribution. If a virtual generator is considered at the primary bind of the border transformer, it is possible to determine the domain of this connection point using the concept of a generator's domain introduced by (KIRSCHEN and STRBAC, 1997).

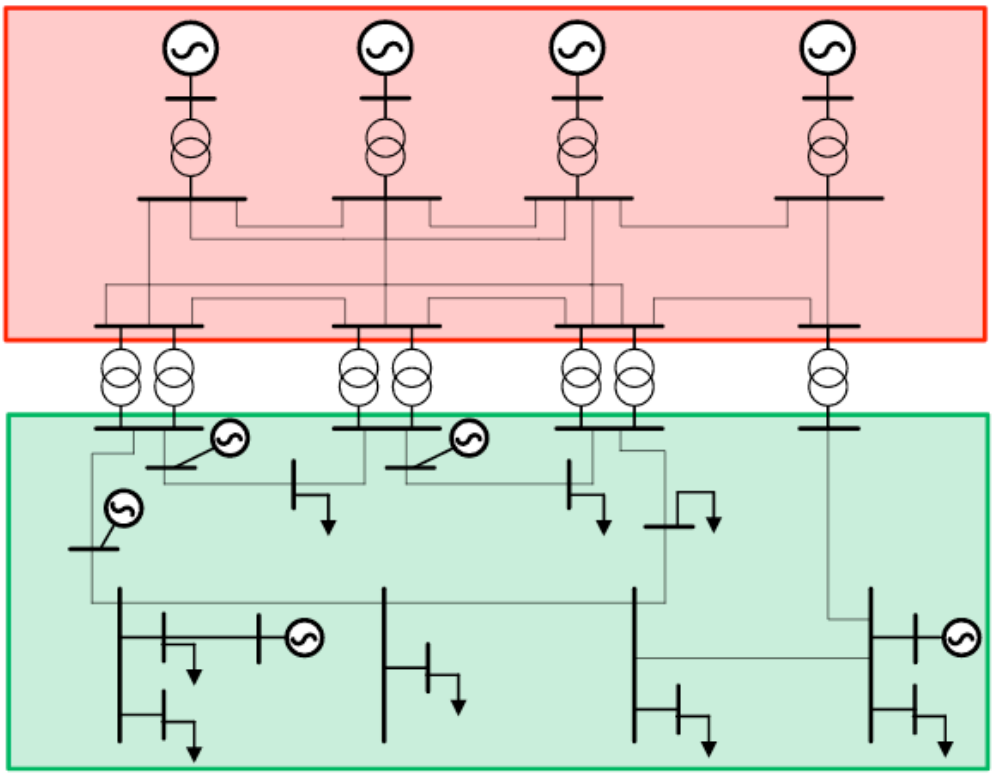

Figure 2. Transmission and distribution grids connection

The domain area of the connection point is the set of buses that are reached by the power flow that crosses the border transformer. The power flow reaches a specific bus if it is possible to find a path on the network going from the connection point to the bus where the flow direction remains unchanged. An example of the domain area for four connection points is depicted in Figure 3.

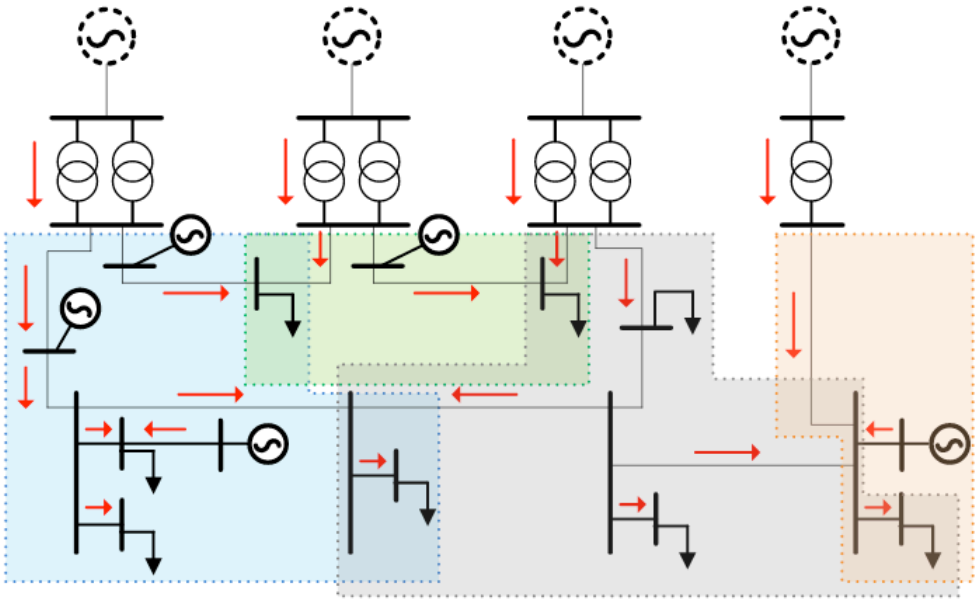

Figure 3. Connection point domain area

Some medium-voltage distribution networks have a mesh topology, so it is possible to have overlap between domain areas where the connection points to

transmission grid are close, as seen in Figure 3. When this is the case, the second step determines whether these two or more domain areas should be coupled, using the concept of Thevenin equivalent impedance. As represented in Figure 4, the equivalent impedance between the secondary bind of the border transformers is computed on a two by two basis.

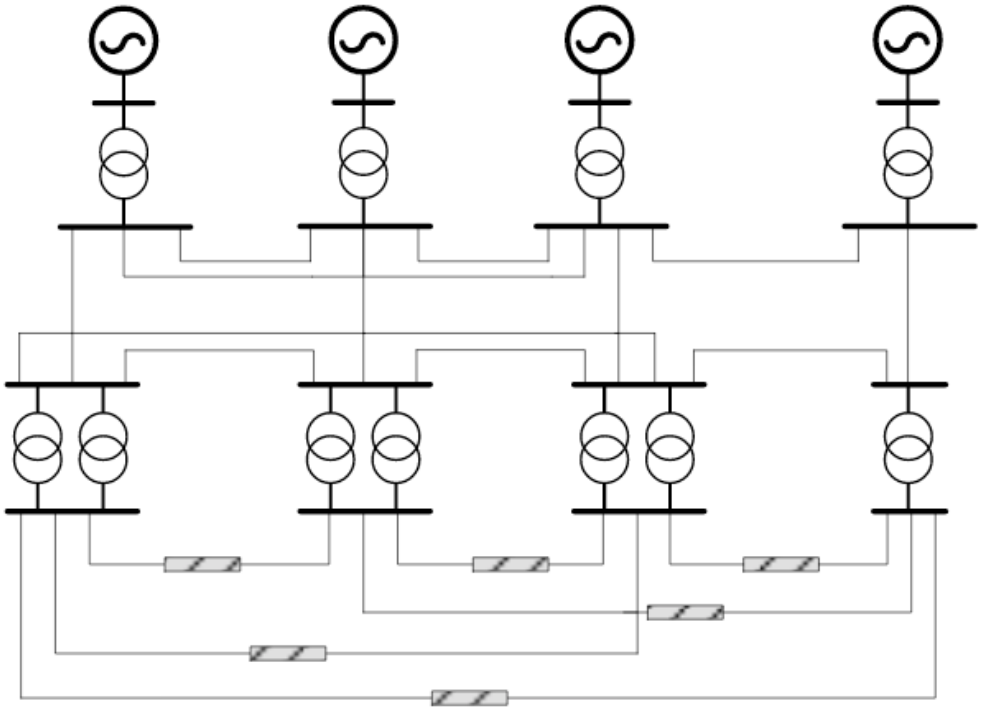

Figure 4. Equivalent impedance between two connection points

The equivalent impedance represents the electrical proximity of the two buses. If the equivalent impedance is small, there is a strong link between the two connection points. Therefore, they should be coupled to form a unique UN. Otherwise, if the equivalent impedance is large, they should remain separate. The concept of small or large impedance depends on the system characteristics (LIMA, QUEIROZ and LIMA, 2011).

4 I DATA AND MODELS SPECIFICATION

4.1 Choice of variables

The distribution company requires labour and capital inputs. The labour input was considered via number of employees (proxy). Capital input was taken into account by other two variables: network length and transformer capacity. Regarding to the outputs, we considered number of customers and energy delivered. We use physical measures of these inputs and outputs applied in benchmarking studies (JAMASB and POLLITT, 2001; ESTACHE, ROSSI and RUZZIER, 2004; POMBO and TABORDA, 2006; ÇELEN, 2013) together with quality of supply and environmental variables.

Many authors (GIANNAKIS *et al.*, 2005; YU, JAMASB and POLLITT, 2009; CAMBINI, FUMAGALLI and CROCE, 2012; GROWITSCH, JAMASB and POLLITT, 2009; JAMASB, OREA and POLLITT, 2012) have incorporated quality performance in the DEA analysis using the Total Time Lost Due To Interruptions (TINT) indicator as input instead of SAIDI directly. The TINT is calculated by multiplying SAIDI values (Equation 1) by the number of customers.

The most relevant environmental variables for efficiency analysis are customer density (to identify rural and urban areas), frequency of lightning (to identify climate influence) and ownership (represented by a binary variable that is zero for state-owned company and 1 for a private company).

4.2 Brazilian example

This paper compares the performance of 10 distribution utilities in the Brazil in the period from 2006 to 2007. The data can be found on the ANEEL website, where it was considered the latest consistent sample available for this period.

This sample comprises the states of São Paulo, Rio de Janeiro, Minas Gerais and Rio Grande do Sul. These four states are responsible for 61% of the Brazilian Gross Internal Product (IBGE, 2019). The ten companies that operate in these four states supplied approximately 56% of the total load of Brazil (ANEEL, 2019). These distribution companies have 712 sets of consuming units. They were grouped into 70 UNs using the method of Section 3.2.

Each set of consuming units has the following attributes: network length (x_1), transformer capacity (x_2), number of employees (x_3), TINT (x_4), energy delivered (y_1), number of customers (y_2), number of lightning, (z_1), customer density (z_2) and ownership (z_3). The attributes x_E (for E=1,2,3,4) are inputs, the y_M (for M=1,2) are outputs and the z_r (for r=1,2,3) are environmental variables.

With respect to the numbers of employees, the UNs' geographical limits are closely similar to the areas of activity of each utility's regional management offices. Therefore, it was not difficult to allocate the number of employees to each UN.

An overview of a summary of key statistics of the data for the 70 UNs is presented in Table 1 in the form of minimum, maximum, mean and standard deviation values.

Descriptive Statistics					
Description	**Unit**	**Minimum**	**Maximum**	**Mean**	**St. Deviation**
Network length (x_1)	km	284	53,456	9,576	13,740
Transformer capacity (x_2)	kVA	14,866	12,577,411	1,160,368	2,057,648
Number of employees (x_3)	Person	9	9,131	867	1,545
TINT (x_4)	Hours	171,980	40,862,936	4,356,342	5,808,652
Energy delivered (y_1)	MWh	26,191	24,763,333	1,839,310	3,592,334
Number of customers (y_2)	Person	4,988	4,850,254	391,979	706,657
Lightning (z_1)	Lightning/year	561	169,954	38,696	42,433
Customer density (z_2)	Person/km^2	2	1,631	147	313

Table 1. Brazilian Unit Networks (2006/2007) – Statistical summary

To validate DEA model, Table 2 was constructed from the correlation coefficients between the inputs and outputs. Its goal is to verify whether an increase in some input does not result in a reduction in some output (assumptions of monotonicity).

Variables	x_1	x_2	x_3	x_4	y_1	y_2
x_1	1					
x_2	0.49	1				
x_3	0.44	0.88	1			
x_4	0.54	0.90	0.88	1		
y_1	0.35	0.98	0.85	0.89	1	
y_2	0.44	0.98	0.90	0.94	0.99	1

Table 2. Correlation coefficients among inputs and outputs

Although there is a high correlation between energy delivered and number of costumers, both variables are kept in the analysis. It is possible for two UNs to deliver same amount of energy to distinctly different numbers of consumers (NEUBERG, 1977).

To support the choice of variables, a statistical analysis was carried out. Four distinct linear regressions were performed, one for each dependent variable (network length, transformer capacity, number of employees and TINT). The independent variables were energy delivered and number of customers. Table 3 presents the statistical parameters evaluated to ascertain the relevance of the choice of variables for accessing the performance of UN. R^2 values in Table 3 indicate that 41% of the variation in network length, 97% of the variation in transformer capacity, 86% of the variation in number of employees and 11% of the variation in TINT were subjected to the two independent variables: energy delivered and number of customers.

Aspect	Dependent Variable	R^2	Adjusted R^2	F-value	Significance
Capital Input	Network length	0.41	0.40	47.95	1.63338E-16
Capital Input	Transformer capacity	0.97	0.97	2147.68	3.7225E-104
Labour Input	Number of employees	0.86	0.86	412.82	9.95182E-59
Quality of supply	TINT	0.11	0.10	8.50	0.000331945

Table 3. R^2 and ANOVA results

The ANOVA (FISHER, 1918) results are also shown in Table 3 with independent variables that indicate F ratios of 47.95, 2147.68, 412.82 and 8.50 for the dependent variables network length, transformer capacity, number of employees and TINT, respectively. In the proposed model, the variables network length, transformer capacity and number of employees are well explained by the independent variables chosen ($p < 0.005$).

4.3 Model specifications

There are three different models shown in Table 4 that are all based on DEA considering input orientation and variable returns to scale (VRS).

Variables	Model 1	Model 2	Model 3
Network length	I	I	I
Transformers capacity	I	I	I
Number of employees	I	I	I
TINT		I	I
Energy delivered	O	O	O
Number of customer	O	O	O
Lightning			EV
Customer density			EV
Ownership			EV
I: Input, O: Output, EV: Environmental variable			

Table 4. Summary of evaluated models

It is noteworthy that in this Model 1, quality of supply can be compromised because utilities can reduce labour and capital inputs indiscriminately to pursue this efficiency. In Model 2, the TINT indicator was added as input based on the notion that DMUs should minimize the duration of interruptions (undesirable output). Model 3 used the same input and output variables as Model 2, but the environmental variables were included. This model tries to capture the extent to which the results are influenced by environmental variables.

5 I PRATICAL RESULTS

The proposed methodology was applied to the three models defined in Section 4.3 using data provided by ten Brazilian distribution companies (Aes Sul, Bandeirante, CEEE, CEMIG, Elektro, Eletropaulo, Light, Paulista, Piratininga and RGE). Two analyses were made: one treated the Unit Networks as DMUs, and the other treated the companies as DMUs.

5.1 Unit Network-oriented analysis

The technical efficiency scores were calculated for the 70 UNs over the period 2006 to 2007. Models 1 and 2 were carried out based on a one-stage DEA, whereas Model 3 was based on a two-stage DEA. For the last Model, in which environmental variables are included, the Tobit analysis described in Section 3.1 was applied; Table 5 presents the estimation results.

The lightning rate was statistically significant and produced a negative

coefficient in the model. A one-unit increase in lightning lead to 0.04 decrease in the efficiency score. The effect of lightning on efficiency of distribution companies was also confirmed by (JAMASB *et al.*, 2012).

Customer density is statistically significant also and produces a positive coefficient. A one-unit increase in customer density lead to 0.07 increase in the efficiency score. A positive effect of customer density on the efficiency of distribution companies was also confirmed by (ÇELEN, 2013). The ownership variable was statistically insignificant for this example and it was not considered.

Variable	Parameter	Coefficient	t-ratio	p-value
Constant	β_0	0.80	48.34	<0.00001 ***
Lightning	β_1	-0.04	-2.84	0.00455 ***
Customer density	β_2	0.07	3.19	0.00141 ***
Dummy for Ownership	β_3	-0.03	-0.84	0.39885
Number of observations	140			
Censored observations	0			
Log-likelihood	61.33			

Table 5. Tobit Analysis Results – Unit Network

Denotes significance at the 1% level using a two-tailed test

Table 6 presents the variable returns to scale efficiency scores (VRS), SAIDI index and environmental characteristics. By evaluating the environmental variables of Table 6, two types of heterogeneity can be identified:

- External heterogeneity is related to the different characteristics of distribution companies. For example, Light is predominantly urban with a high customer density, and CEMIG is predominantly rural with a low customer density;
- Internal heterogeneity is related to the different characteristics within a single distribution company. For example, Aes Sul has high, medium and low customer densities and various levels of lightning incidence.

The results indicate that the UNs are, on average, technically efficient by approximately 0.75 under Model 1, 0.79 under Model 2 and 0.79 under Model 3; these numbers reflect that there is room for improvement.

The 15 UNs in Model 1 are efficient; note that nine UNs belong to an area with a high customer density. The UNs with low customer density that reached the frontier are Aes Sul (UN 9, 12) and RGE (UN 8, 9), which implies that the management is relatively good in terms of resource use. The other UNs with low customer density had average efficiencies of 0.57. The inefficiencies of all of the low-customer-density areas may be mainly due to poor load characteristics and scattered households, which cause these areas to be expensive and challenging for a power supplier.

All of the UNs of Eletropaulo are efficient. It is noteworthy that Eletropaulo

operates in an area with the highest load density in the country with low lightning incidence, in other words, a favorable area. Thus, in this model that includes no environmental variables, this distribution company appears as the most efficient.

CEMIG (UN 9) has the worst score (0.38). The UN is compared to a linear combination of Aes Sul (UN 12), Eletropaulo (UN 3) and Light (UN 4). CEMIG (UN 9) has a strong rural character, while its latter two peers have an urban characteristic. Thus, it is expected that this Unit Network will increase its efficiency in Model 3, which includes customer density. From this comparison, the model results indicate that there must be a 65% reduction in the number of employees.

Company	RU	M 1	M 2	M 3	SAIDI	Density	Lightning	Company	RU	M 1	M 2	M 3	SAIDI	Density	Lightning
Aes Sul	1	0,39	0,41	0,42	28,6	Low	Medium	Cemig	10	0,76	0,76	0,84	23,9	Low	High
Aes Sul	2	0,39	0,41	0,49	41,6	Low	High	Cemig	11	0,73	0,73	0,76	13,7	Medium	Medium
Aes Sul	3	0,47	0,47	0,60	32,7	Low	High	Elektro	1	0,45	0,84	0,86	6,8	Medium	Medium
Aes Sul	4	0,62	0,62	0,75	21,9	Low	High	Elektro	2	0,59	0,64	0,63	11,7	High	Medium
Aes Sul	5	0,80	0,83	0,85	19,4	Low	Medium	Elektro	3	0,52	0,59	0,58	13,3	Medium	Medium
Aes Sul	6	0,55	0,55	0,59	24,8	Medium	Medium	Elektro	4	0,46	0,70	0,74	8,7	Medium	Medium
Aes Sul	7	0,59	0,62	0,62	19,8	Medium	Low	Elektro	5	0,42	0,51	0,53	16,4	Medium	Medium
Aes Sul	8	0,63	0,66	0,67	20,0	Medium	Medium	Elektro	6	0,45	0,80	0,82	8,8	Low	Medium
Aes Sul	9	1,00	1,00	1,00	16,7	Low	Low	Elektro	7	0,66	0,68	0,76	16,2	Medium	High
Aes Sul	10	0,71	0,75	0,73	10,9	High	Medium	Elektro	8	0,68	1,00	1,02	4,5	Medium	Medium
Aes Sul	11	0,99	0,99	0,90	12,7	High	Low	Eletropaulo	1	1,00	1,00	0,83	13,3	High	Low
Aes Sul	12	1,00	1,00	1,00	41,7	Low	Low	Eletropaulo	2	1,00	1,00	0,66	8,0	High	Medium
Bandeirante	1	0,72	0,76	0,72	10,8	High	Low	Eletropaulo	3	1,00	1,00	0,82	7,1	High	Low
Bandeirante	2	0,84	0,91	0,90	8,6	High	Medium	Eletropaulo	4	1,00	1,00	0,89	11,6	High	Low
Bandeirante	3	1,00	1,00	0,79	10,3	High	Low	Light	1	0,82	0,82	0,76	14,5	High	Low
Bandeirante	4	0,91	0,98	0,97	7,0	Medium	Medium	Light	2	0,81	0,89	0,90	8,6	Medium	Medium
Ceee	1	0,73	0,73	0,74	23,6	Medium	Medium	Light	3	1,00	1,00	0,69	9,0	High	Low
Ceee	2	0,82	0,82	0,81	19,3	Medium	Low	Light	4	1,00	1,00	0,96	14,5	High	Low
Ceee	3	0,65	0,65	0,68	48,4	Medium	Medium	Light	5	0,72	1,00	0,88	6,4	High	Low
Ceee	4	0,59	0,59	0,63	28,1	Low	Medium	Paulista	1	0,90	0,90	0,95	6,2	Medium	High
Ceee	5	0,69	0,69	0,77	41,5	Medium	High	Paulista	2	0,85	0,91	0,92	6,5	Medium	Medium
Ceee	6	0,47	0,47	0,48	50,9	Low	Medium	Paulista	3	1,00	1,00	1,14	6,9	Medium	High
Ceee	7	1,00	1,00	1,00	32,6	Medium	Medium	Piratininga	1	1,00	1,00	0,90	5,0	High	Low
Ceee	8	0,89	0,89	0,88	35,8	Medium	Low	Piratininga	2	0,82	0,82	0,82	9,6	High	Medium
Ceee	9	1,00	1,00	0,85	12,2	High	Low	Rge	1	0,70	0,70	0,79	19,9	Low	High
Ceee	10	0,68	0,68	0,68	38,6	Medium	Low	Rge	2	0,55	0,56	0,61	20,4	Low	High
Cemig	1	0,94	0,94	0,98	15,4	Low	Medium	Rge	3	0,58	0,74	0,73	8,7	Medium	Medium
Cemig	2	0,75	0,80	0,85	10,9	Medium	High	Rge	4	0,54	0,65	0,64	13,0	Medium	Medium
Cemig	3	0,72	0,73	0,77	16,1	Medium	Medium	Rge	5	0,79	0,79	0,82	22,4	Medium	Medium
Cemig	4	0,72	0,73	0,82	14,9	Medium	High	Rge	6	0,89	0,89	0,91	26,8	Medium	Medium
Cemig	5	0,86	0,86	0,87	14,9	Medium	Medium	Rge	7	0,93	0,93	0,95	21,6	Medium	Medium
Cemig	6	0,84	0,86	0,95	9,4	Medium	High	Rge	8	1,00	1,00	1,02	29,6	Low	Medium
Cemig	7	0,57	0,68	0,81	8,8	Low	High	Rge	9	1,00	1,00	1,06	26,0	Low	High
Cemig	8	0,46	0,52	0,59	13,1	Low	High	Rge	10	0,69	0,69	0,68	16,9	Medium	Low
Cemig	9	0,38	0,38	0,45	33,2	Low	High	Rge	11	0,66	0,66	0,68	20,9	Medium	Medium

Table 7 - Efficiency Score for Brazilian Unit Networks - 2006/07

Under Model 2, to which quality of supply was added to the analysis, 17 UNs are efficient, and 11 UNs are located in low lightning incidence areas. The average efficiency show that some Unit Networks rank high in Model 2 while they rank low in Model 1.

Elektro has better results. Elektro (UN 1) has an efficiency of 0.45 in Model 1, where quality is not included. In Model 2, the same UN has an efficiency of 0.84, an increase of 0.44 in efficiency score. This indicates that the Model 1 can penalize Unit Networks that are efficient in quality of supply. Elektro (UN 1) peers are Aes Sul (UN 9), Eletropaulo (UN 3) and Piratininga (UN 1); the latter belongs to the distribution

company with the lowest SAIDI in Brazil. Thus, Elektro (UN 1) showed an efficiency increase due to quality of supply because it has a SAIDI of 6.8 h, and its peers in Model 2 have 16.7, 7.1 and 5.0 h, respectively. Comparing UN 1 with other UNs of Elektro, it has the second smallest SAIDI of the company, surpassed only by UN 8, which operates in the most industrialised region of the concession area.

Light (UN 5) had an efficiency of 0.72 in Model 1; in Model 2 it achieved the efficient frontier, an increase of 0.28 in efficiency score. The UN has the smallest SAIDI of the company with 6.4 hours; the others have SAIDIs between 8.6 and 14.5 hours.

Model 1 may distort companies' incentive. For example, in Model 1, RGE (UN 4) had an efficiency of 0.54 (which would result in a high X-factor) while its efficiency score in Model 2 is 0.65.

These findings suggest that there is trade-off between labour and capital inputs and quality of supply. Thus, models with quality are more suitable for efficiency analysis (GIANNAKIS, JAMASB and POLLITT, 2005). In this way, models like Model 1 have no captured the quality of supply aspect of distribution companies.

Under Model 3, there are only seven efficient UNs that contrast with the results of Model 2. Some Units Networks have decreased their performance because they are located in a more favorable area. Some Units Networks have increased their performance because they are located in a less favorable area. For example, all four UNs of Eletropaulo have decreased performance. This is consistent with the reality that this company is in a high-density area.

Additionally, CEMIG improves its performance, but is still far from the efficient frontier. CEMIG (Unit Network 4) has an efficiency of 0.72 in Model 1 and 0.73 in Model 2, where environment is not considered. In Model 3, the same Unit Network has an efficiency of 0.82, an increase in efficiency score of 0.12 and 0.11, respectively. This change can also be explained because of its lower-density area and the lightning incidence in some of its regions. This result indicates that the Model 1 and 2 can penalize Unit Networks that are located in an adverse area.

Another interesting result from Table 6 is the differences in performance of UNs that belong to the same company. The manager can look more carefully for the worst UN and establish an improvement plan to take the UN to a better rank. For example, Aes Sul (UN 1 and 2) had an average efficiency of 0.41 in the Model 2. Their environment can explain part of this inefficiency: UN 2 has the third highest lightning incidence in the company and a density of 3 customers per km^2. These environmental characteristics are reflected in the quality of supply: Aes Sul (UN 2) customers on average suffer 42 hours per year without electric power. Aes Sul (UN 1) has a less adverse environment than Aes Sul (UN 2), with lower lightning incidence and 6 customers per km^2.

5.2 Company- oriented analysis

The results of the three models are compared under the two approaches: (i) UN as DMU and (ii) distribution companies as DMU. For the first approach, the results of Section 5.1 were weighted by the number of customers of each UN that belong to one company to produce a weighted average for each company.

For Model 3, in which environmental variables are included, the Tobit analysis described in Section 3.1 was applied and Table 7 presents the estimation results. The p-value is greater than 0.05, which means that the variables are not significant. This result was not observed for the Unit Network oriented approach (see Table 5 in Section 5.1).

Variable	Parameter	Coefficient	t-ratio	p-value
Constant	β_0	0.92	27.86	5,48E-15***
Lightning	β_1	4.43E-08	0.48	0,64
Customer density	β_2	7.31E-05	1.36	0,19
Dummy for Ownership	β_3	-0.04	-0.70	0,50
Number of observations	20			
Censored observations	0			
Log-likelihood	25.24			

Table 7. Tobit Analysis Results - Utilities

One possible reason is that the environment variables are treated as averages for the entire concession area, failing to represent the diversity among regions as observed, for example, in the CEMIG concession area.

This fact is shown in Table 8. For the utility-oriented approach, the efficient scores under Model 2 and Model 3 do not differ (columns 3 and 4 in the right table), whereas this is not true for the Unit Network-oriented approach (columns 3 and 4 in the left table).

Bogetoft (2014) states that the models that ignore important environmental variables may have biased results. If environmental factors have impact on operation, such as rain and lightning, they must be part of the efficiency analysis.

Unit Network			
Utility	Model 1	Model 2	Model 3
Aes Sul	0.68	0.70	0.72
Bandeirante	0.91	0.95	0.85
CEEE	0.83	0.83	0.79
CEMIG	0.76	0.79	0.87
Elektro	0.60	0.79	0.81
Eletropaulo	1.00	1.00	0.69
Light	0.88	0.98	0.79
Paulista	0.97	0.97	1.09
Piratininga	0.93	0.93	0.86
RGE	0.69	0.73	0.76
Average	0.83	0.87	0.82
St. deviation	0.14	0.11	0.11

Utility			
Utility	Model 1	Model 2	Model 3
Aes Sul	0.95	0.95	0.95
Bandeirante	1.00	1.00	1.00
CEEE	0.84	0.84	0.84
CEMIG	0.98	0.98	0.98
Elektro	0.66	0.78	0.78
Eletropaulo	1.00	1.00	1.00
Light	0.92	0.95	0.95
Paulista	1.00	1.00	1.00
Piratininga	1.00	1.00	1.00
RGE	0.92	0.92	0.92
Average	0.93	0.94	0.94
St. deviation	0.11	0.08	0.08

Table 8. Comparison of aggregate approaches

This is a very important result because many regulators, including that in Brazil, use the utility-oriented approach.

Based on the left table, CEMIG improves its position and efficiency score under Model 3. In Model 1 and 2, CEMIG occupies the seventh position, while in Model 3 the same company occupies the second position. CEMIG increased its efficiency by 0.11 compared to the Model 1 and 0.08 when compared to the Model 2.

Eletropaulo leaves the efficiency frontier when compared to Models 1 and 2, with a decrease of 0.31 in its efficiency score. This is because CEMIG has a wide concession area with different characteristics, particularly the environmental aspects. This is not observed at Eletropaulo, which has a small concession area characterized by a high-density load.

Paulista also had its efficiency increased with the addition of environmental variables. The company increased its efficiency by 0.12 compared to the Model 1 and 2. Despite an environment with medium customer density, the distribution company operates in an area with a high lightning incidence.

To evaluate the economic impact of different models presented in the left side of Table 8, a simulation was done with data from the Elektro distribution company. If we consider the Model 1, the reduction in Parcel B value is US$ 13,257,836. When evaluating the Model 2, Elektro has to reduce US$ 8,020,991 of the Parcel B value in the first year of the Third Price Revision, it means US$ 5,236,845 less than in Model 1. Model 3 imposes a reduction of $ 6,032,331 in the Parcel B value. This reduction is $ 7,225,520 lower than in Model 1 and $ 1,988,675 lower than in Model 2.

For a better view of the UN influence on the company performance, Figure 5 was generated from Table 6: each UN in CEMIG is mapped according to its effect (positive or negative) and its intensity (high and low) on the efficiency score of Model 3.

For the impact intensity, the number of consumers was used as a weight to address the relative importance of one UN to the company. For the positive and negative effects, the scores were divided into quartiles; the first quartile means the best performance and the fourth the worst. In this way, the UNs in the first quadrant have high positive impact, those in the third quadrant have low negative impact, etc.

From Table 6 and Figure 5, one can see that UNs 8 and 9 play an important role in lowering the position of CEMIG because they have an average efficiency of approximately 0.52 in Model 3. UNs 8 and 9 are located in Southwest and Northwest of Minas Gerais state, respectively. These regions are characterized by low customer density (5 customers per km^2) and high lightning incidence. This adverse environment is reflected in the quality of supply: UN 9 customers on average are without electricity 33 hours per year (highest SAIDI of CEMIG). Thus, the focus of the administration should be on UNs 8 and 9; every effort should be made to understand the problems

and make the necessary adjustments to reduce the negative influence of the environment.

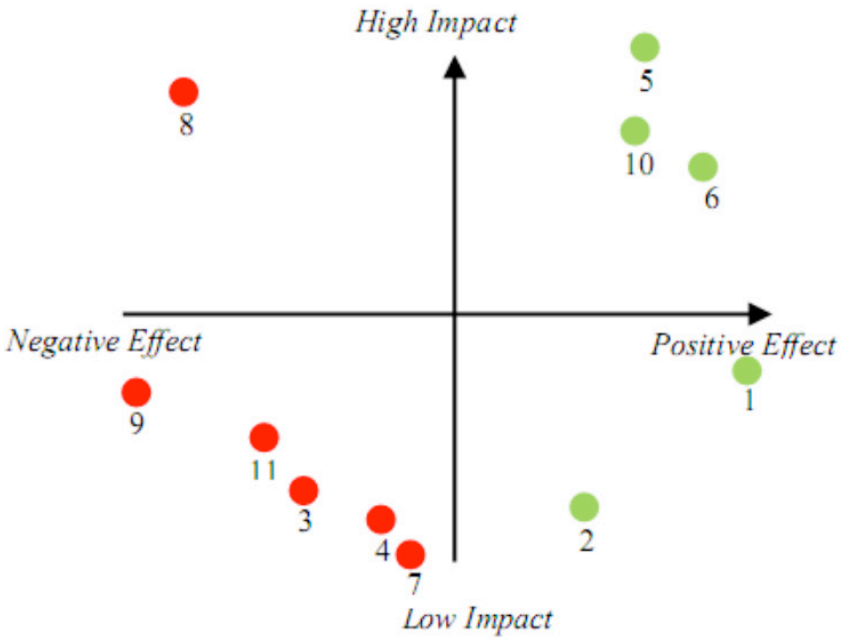

Figure 5. Unit Networks Map

UNs 1 and 6 contribute positively to the company rank because they have an average efficiency of 0.96. UN 1 is located in northeastern Minas Gerais state, which has a low customer density (6 customers per km^2). UN 6 is in the central region of the state, characterized by a greater customer density than UNs 1, 8 and 9 (42 customers per km^2) and high lightning incidence. It is noteworthy that UN 6 has the second best SAIDI of CEMIG. It is important that with the UNs approach, the CEMIG administration can compare performance among their regions, extract lessons from UNs 1 and 6 and apply them UNs 8 and 9.

Some companies such as CEMIG, Elektro and Light already split the administration into regions. Each region has its own management and the board of the company views each as independent; i.e., each can allocate resources (capital and operational costs) to accomplish the objectives of the company. Although the UN was originally formed using electrical characteristics, they try to delimit regional units by their physical aspects, which resembles the approach described in Section 3.2.

6 I CONCLUSION

Efficiency analysis is receiving considerable attention from the regulators of the electricity power sector, more specifically in the electricity distribution segment. Because of the natural monopoly characteristics of the distribution segment, utilities are not subjected to market forces. This paper simulated a virtual competitive scenario among utilities. Data Envelopment Analysis assists in this purpose by calculating the

relative efficiency of distribution companies. It constructs an efficient frontier from the input and output data of a Decision Making Unit. This analysis provides a framework to analyse the effect of environment on distribution performance, especially in case of countries with large territories.

The novel approach of this paper is in the use of Unit Network for split a distribution company concession area into more homogeneous subgroups that are further considered as Decision Making Units, being different from the traditional approach in which companies are seen as natural DMUs. Brazilian distribution companies are subject to external and internal heterogeneity due to its large concession area. This proposal solves the external and internal heterogeneity problem of Brazilian distribution companies.

Another important improvement of the proposed method is that quality and environmental characteristics can be better represented when the company is divided into UNs. We studied three different models (Models 1, 2 and 3) and two analysis were made: one treated the Unit Networks as Decision Making Units, and the other treated the companies as Decision Making Units.

Considering Unit Network-oriented analysis, we found that some UN that had a poor performance in Model 1 did score high in Model 2. These findings show that it is necessary to integrate quality of supply in benchmarking models. We find evidence of statistical significance in the relationship between environment variables and efficiency scores in Model 3. Thus, lightning and customer density in our case have an impact on the performance of UNs. The size of adjustment of efficiency scores in some UNs is remarkable.

Considering company-oriented analysis, we also found that efficiency scores are affected by the inclusion of quality. With regard to environmental variables, the effect on efficiency scores are insignificant. One possible reason is that the environment variables are treated as averages for the entire concession area, failing to represent the diversity among regions as observed.

The definition of the product “electricity” and its price cannot be disassociated from quality of supply and environment characteristics. The distribution charge must take into account location, voltage level, quality of supply and the environment. Given that DEA is used for determining the allowed revenue, the regulator cannot override these factors.

REFERENCES

A. B. Haney, M. G. Pollitt. “Efficiency Analysis of Energy Networks: An International Survey of Regulators”, Energy Policy, vol. 37, no. 12, pp. 5814-5830, 2009.

A. Çelen. “Efficiency and productivity (TFP) of the Turkish electricity distribution companies: An

application of two-stage (DEA&Tobit) analysis", Energy Policy, 2013.

A. Charnes, W. Cooper, E. Rhodes. "Measuring the efficiency of decision-making units", European Journal of Operational Research, vol. 2, no. 6, pp. 429-444, 1978.

A. Estache, M. A. Rossi, C.A. Ruzzier. "The case for international coordination of electricity regulation: Evidence from the measurement of efficiency in South America". Journal of Regulatory Economics, vol. 25, no. 3, pp. 271-295, 2004.

Agência Nacional de Energia Elétrica - ANEEL (2006), Second Price Control Review of distribution utilities of electricity in Brazil. Technical Note nº 262. [Online]. Available: http://www. aneel.gov.br

Agência Nacional de Energia Elétrica - ANEEL [Online]. Available: http://www. aneel.gov.br.

C. Cambini, E. Fumagalli, A. Croce. "Output-based incentive regulation: benchmarking with quality of supply in electricity distribution", Energy Economics, 2012.

C. Growitsch, T. Jamasb, M. Pollitt. "Quality of service, efficiency and scale in network industries: an analysis of European electricity distribution", Applied Economics, vol. 41, n. 20, pp. 2256-2570, 2009.

C. Pombo, R. Taborda. "Performance and efficiency in Colombia's power distribution system: effects of the 1994 reforms". Energy Economics, vol. 28, no. 3, pp. 339–369, 2006.

CEMIG, Companhia Energética de Minas Gerais. [Online]. Available in: http://www.cemig.com.br.

D. Giannakis, T. Jamasb, M. Pollitt. "Benchmarking and incentive regulation of quality of service: an application to the UK electricity distribution networks", Energy Policy, vol. 33, no. 17, pp. 2256-2271, 2005.

E. S. Tanure, M. O. Tahan, J. W. M. Lima. " Establishing Quality Performance of Distribution Companies based on Yardstick Regulation", IEEE Transaction on Power Systems, vol. 21, no. 3, pp. 1148 – 1153, 2006.

H. Averch, L.L. Johnson. "Behavior of the firm under regulatory constraint", American Economic Review, vol. 52, no. 5, pp. 1052-1069, 1962.

H. Ergas, J. Small. "Price Caps and Rate of Return Regulation". Network Economics Consulting Group, 2001.

IBGE, Instituto Brasileiro de Geografia e Estatística. [Online]. Available in: ttp://www.ibge.gov.br/

J. A. Chilingerian, H. D. Sherman. "Health care applications: from hospitals to physicians from productive efficiency to quality frontiers." In: Handbook on Data Envelopment Analysis. Kluwer Academic Publishers, Boston, 2004.

J. Ruggiero. "Performance evaluation in education: modeling educational production". In: Handbook on Data Envelopment Analysis. Kluwer Academic Publishers, Boston, 2004.

J. Tobin. Estimation of relationships for limited dependent variables. Econometrica, vol. 26, pp. 24–36, 1958.

Kirschen, R. Allan, G. Strbac. "Contributions to Individual Generators to Loads and Flows", IEEE Transactions on Power Systems, vol. 12, no. 1, pp. 52-60, 1997.

L. G. Neuberg. "Two Issues in the Municipal Ownership of Electric Power Distribution". Bell Journal of Economics, vol. 8, no. 1, pp 303-323, 1977.

L. M. M. Lima, A. R. Queiroz, A.R. and J. W. M. Lima. ”From voltage level to locational pricing of distribution network: The Brazilian experience”, Conference: Power Engineering Society, IEEE General Meeting, 2011.

M. N. Lowry, L. Getachew. “Statistical benchmarking in utility regulation: Role, standards and methods”, Energy Policy, vol. 37, no. 4, pp. 1323-1330, 2009.

P. Bogetoft. “Comments on the Brazilian benchmarking model for energy distribution regulation Fourth cycle of tariff review – NT 192/2014”. Available at: http://www.aneel.gov.br/, 2014.

R. A. Fisher. The correlation between relatives on the supposition of Mendelian Inheritance. Transactions of the Royal Society of Edinburgh, vol. 52, pp. 399–433, 1918.

R. Billinton, R. N. Allan. “Reliability Evaluation of Power Systems”. New York: 1984.

R. C. Subhash, L. Chen. “Data Envelopment Analysis for Performance Evaluation: A Child’s Guide”, Indian Economic Review, vol. 45, no.2, pp. 373-399, 2010.

R. C. Subhash. “Data Envelopment Analysis: Theory and Techniques for Economics and Operations Research”. Cambridge University Press, Cambridge, 2004.

R. D. Banker, R. F. Charnes, W. Cooper. “Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis”, Management Science, vol. 30, pp. 1078–1092, 1984.

T. Jamasb, L. Orea, M. G. Pollitt. “Estimating Marginal Cost of Quality Improvements: The Case of the UK Electricity Distribution Companies”, Energy Economics, vol. 34, 2012.

T. Jamasb, M. Pollitt. “Benchmarking and regulation: international electricity experience”, Utilities Policy, vol. 9, no. 3, pp. 107-130, 2001.

W. Yu, T. Jamasb, M. Pollitt. “Does weather explain cost and quality performance? An analysis of UK electricity distribution companies”. Energy Policy, vol. 37, no. 11, pp. 4177-4188, 2009.

ÍNDICE REMISSIVO

A

C

D

E

G

H

I

L

M

N

O

P

R

S

T

U

V

2020