AGENDA DA SUSTENTABILIDADE NO BRASIL:

Conhecimentos teóricos, metodológicos e empíricos

Clécio Danilo Dias da Silva
Milson dos Santos Barbosa
Danyelle Andrade Mota
(Organizadores)

Atena Editora
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APRESENTAÇÃO

Em um mundo ameaçado por problemas ambientais, impulsionar uma economia mais respeitosa com o meio ambiente não é uma opção e sim uma necessidade. Assim, perante das inúmeras consequências ambientais, as organizações, governos e comunidades científicas estão em constante busca de uma solução adequada. Isso faz com que as temáticas Meio Ambiente e Sustentabilidade tornem-se global. Diante disto, a Organização das Nações Unidas (ONU) em 1972 realizou a primeira Conferência das Nações Unidas sobre o Meio Ambiente, conhecida como Conferência de Estocolmo, na capital da Suécia. Em consequência disto, em 1983 foi criada a Comissão Mundial sobre o Meio Ambiente e Desenvolvimento, com propostas mundiais na área ambiental para a sobrevivência da espécie humana e a biodiversidade.

No ano de 2000, por meio da Declaração do Milênio das Nações Unidas, surgiram os "Objetivos de Desenvolvimento do Milênio (ODM)", os quais foram adotados pelos 191 estados membros, inclusive o Brasil. Os ODM tinham como objetivo dar continuidade as ações em prol do desenvolvimento sustentável. A partir do legado dos ODM, em 2015 os países signatários da ONU, assumiram o compromisso com os novos objetivos do milênio para o Desenvolvimento Sustentável, estabelecendo 17 Objetivos do Desenvolvimento Sustentável (ODS) e 169 metas a serem atingidos até o ano de 2030. Tratam-se de objetivos e metas claras, para que todos os países adotem de acordo com suas próprias prioridades uma parceria global que orienta as escolhas necessárias para melhorar a vida das pessoas, no presente e no futuro.

Nesse contexto, têm-se fomentado em diversos países, inclusive no Brasil, a proposição de aparatos legislativos ambientais e investimentos em ações e pesquisas em empresas e instituições de ensino em prol da Agenda da Sustentabilidade. Até o momento, o Brasil apresentou avanços consideráveis e cumpriu grande parte das metas estabelecidas, por exemplo, a melhorias nas matrizes energéticas e busca de alternativas aos combustíveis fósseis, o que pode facilitar o cumprimento desses objetivos até 2030.

Diante deste cenário, este e-book "Agenda da Sustentabilidade no Brasil: Conhecimentos teóricos, metodológicos e empíricos" foi produzido como um esforço para impulsionar as ações em direção à agenda da Sustentabilidade 2030, especialmente no Brasil que ainda carece de conhecimento e experiências com soluções práticas de Sustentabilidade para os desafios globais. O e-book contém um conjunto de com 17 artigos que agrupam estudos/pesquisas de cunho nacional envolvendo questões relacionadas ao desenvolvimento sustentável sob diferentes perspectivas e para diversos públicos. Portanto, são apresentados projetos práticos, experiências de pesquisas empíricas e métodos de ensino implementados no Brasil, que certamente contribuirão para o fomento da Sustentabilidade.

Por fim, agradecemos aos diversos pesquisadores por todo comprometimento para atender demandas acadêmicas de estudantes, professores e da sociedade em geral, bem como, destacamos o papel da Atena Editora, na divulgação cientifica dos estudos produzidos, os quais são de acesso livre e gratuito, contribuindo assim com a difusão do conhecimento.

Desejamos a todos uma boa leitura!

Clécio Danilo Dias da Silva

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METHODOLOGY FOR ASSESSING ENVIRONMENTAL EFFICIENCY IN MUNICIPALITIES USING DATA ENVELOPMENT ANALYSIS

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ABSTRACT: The present study aimed at measuring and evaluating environmental efficiency of municipalities located in Araguaia River Valley, in the Goiás State, Brazil. Forty-one municipalities from the river basin adjacent to Araguaia were included, with data of 2014 and 2016. For the analysis, we considered economic and environmental variables and used the Data Envelopment Analysis (DEA) in its CRS and VRS models with standard and normalized composite efficiency, both input-oriented models. Results showed low standard environmental mean efficiency in the CRS model, with the values of 0.45 (2014) and 0.44 (2016); in the VRS model, 0.51 for standard environmental efficiency and 0.58 for normalized environmental efficiency in the year 2014, and standard environmental efficiency of 0.47 with normalized environmental efficiency of 0.54 in the year 2016. This suggests the need for effective governance, with environmental planning, and well-established mechanisms and goals to achieve a desirable environmental efficiency that optimize water and energy consumption, and deforestation reduction, increasing GDP and the Municipal Development Index (IDM). In the comparison between models, VRS, which considers the variation in the normalized scale, because it better discriminates DMUs' false efficiencies, proved to be the most suitable for analyzing the municipalities' environmental efficiency.
KEYWORDS: Goiás State; sustainability; DEA; CRS model; VRS model.

1 I INTRODUCTION

The Araguaia River Valley region is located in one of the main Brazilian river basins and comprehends several municipalities. It is located on the river margins and adjacent to its affluents. From its headwaters at "*Serra do Cipó"*, in the *Mineiros*, Goiás State (GO) and *Alto Taquari*, Mato Grosso State (MT) municipalities, the Araguaia River is 2,114 km long. It is worth highlighting that the state economy grew above the national mean in the first trimester of 2019 at 1.3% against Brazil's 0.5% (IMB, 2019), and a substantial part of this growth came from the Araguaia Valley municipalities' participation. On the other hand, some activities, such as the agricultural, hunting and predatory fishing have been consistently affecting the river. The region also suffers with soil degradation and large gullies. Hence, hydric resources are of utmost importance for the state and the Central-West region, especially in regard to fluvial transport, tourism with touristic attractions at its margins, and the subsistence of many riparian dwellers through fishing (BRASIL, 2019).

In the face of an increasing demographic growth and the world's drinking water supply decrease, environmental impacts threatening natural resources in one of the most important regions of Brazil's Central-West, start to be the focus of public policies. Thus, it becomes important to measure and evaluate the mentioned environmental and economic efficiencies, as well as mitigating actions adopted in the Araguaia Valley municipalities.

In this sense, a methodology that has shown to be effective to the efficiency analysis in several countries is the Data Envelopment Analysis (DEA), which is frequently applied in energy, economic and environmental modelling (Begum et al., 2010). Despite it already being used for at least 40 years, it is still a constantly advancing field which allows its applications in different areas of knowledge (Wojcik et al., 2018).

Environmental efficiency studies have evaluated several situations of management, innovation and technology (Li et al., 2013). They aim to minimize the impact of given inputs on nature and have shown that more efficient cities will use resources adequately, which guarantees economic growth and development sustainably (Piña et al., 2016). China□s human resources and environmental efficiency assessment, in using the DEA methodology, showed that adequate ways of using urban resources and environmental efficiency will depend on technological innovation and effective governance (Xiaoping et al., 2014).

Some variables of our study were based on the papers of Xiaoping et al. (2014) and Zhao (2018), which consider cities as integrated systems of resources, economy and environments. To apply the DEA model, the authors defined that every city was constituted as a production decision-making unit using inputs to define outputs. They add that to simplify, inputs of a decision-making unit (DMU) are defined as capital, work, land, energy and water, with outcomes that influence GDP and other urban environmental and economic indicators.

Thus, the present study aimed at measuring and evaluating the environmental efficiency of municipalities located in the Araguaia River Valley, In the Goiás State, Brazil, one of the most important hydric resources of Brazil's Central-West region, via Data Envelopment Analysis.

2 I METHODOLOGY

The data used were from the years 2014 and 2016. They comprised 41 municipalities located in the Araguaia River Valley, close to its headwaters and at the margins of the river basin, composing the center-west, southwest and northwest regions of Goiás state (Figure 1).

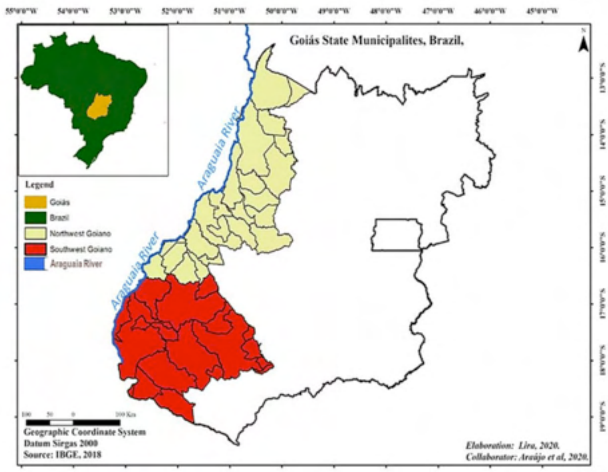

Fig. 1. Cartographic map of the location of municipalities evaluated in the Araguaia Valley, Goiás State, Brazil.Source: Authors of the present paper.

2.1 Study variables and data processing

Data corresponding to energy consumption and the Municipal Development Index (IDM) were collected from Goiás Statistic Database (BDE-Goiás, 2019); per capita Gross Domestic Product (GDP), on the website of the Brazilian Institute of Statistics and Geography (IBGE, 2019), and water consumption and deforestation, on the website of the National System of Information about Sanitation (SNIS, 2019) and on the database of the National Institute of Space Research (INPE, 2018).

The number of inputs and outputs was that suggested by the technique of Banker et al.(1989) and Cooper et al. (2000) for Data Envelopment Analysis – DEA, considering p the number of inputs and q the number of outputs used in the analysis. So, sample size (n) should satisfy the following: n >= Max {p × q, 3 (p + q)}. For the present study, we have 41> = Max {3 × 2, 3 (3 + 2)} =15.

For the definition of variables (Table 1), we used the compensatory method of normalization (single parameter) proposed by Angulo-Meza et al. (2007), which considers theoretically reachable extreme values. The combination of the set of variables chosen has great importance in the DMUs' efficiency acquisition (Thanassoulis et al., 1996).

Energy Consumption (MWh)	Water Consumption (m^3/year)	Cleared Area (km^2)	Per capita GDP ($)	Overall IDM
INPUT	INPUT	INPUT	OUTPUT	OUTPUT

Table 1 Variables (inputs and outputs) used in the study.

Source: Elaborated by the authors.

For data processing we used the software R with benchmarking package and ISYDS (Integrated System for Decision Support). To classify the efficiency interval, variables were organized as per Table 2.

Efficiency Interval	Efficiency Level
0.5999 – 0.0000	Low
0.6000 – 0.6999	Medium
0.7000 – 0.9999	High
1	Efficient

Table 2 Efficiency intervals adopted for result analysis Source: Adapted from Castelão, 2016.

2.2 The Data Envelopment Analysis (DEA) methodology

The data envelopment analysis model began with Debreau (1951), Koopmans (1951) and Farrell (1957), and was improved afterwards by Charnes, Cooper and Rhodes (1978), and by Banker, Chames and Cooper (1984) (Ferreira and Gomes, 2012).

There are two DEA models. The first is called CRS, or constant returns to scale, and the second, VRS, variable returns to scale. In addition, they can follow two types of orientation as for modification in variables: they are input-oriented and output-oriented. Therefore, there are four types of basic DEA models: CRS/Input, CRS/Output, VRS/Input and VRS/Output (Banker, Chames and Cooper 1984).

2.3 The CRS (constant returns to scale) model

The CRS model presented in equation 1 aims at minimizing input consumption by making the set level of production remain at least the same.

$$
\begin{aligned}
&\max \quad h_o = \sum_{j=1}^{s} u_j y_{jo} \\
&\text{subject to} \\
&\sum_{i=1}^{r} v_i x_{io} = 1 \\
&\sum_{j=1}^{s} u_j y_{jk} - \sum_{i=1}^{r} v_i x_{ik} \leq 1 \ , \quad k = 1,\ldots,n \\
&u_j, v_i \geq 0 \quad \forall i, j
\end{aligned}
\qquad (1)
$$

This mathematical formulation is known as Multipliers Model, because its decision variables are the weights uj and vi, and they are input-oriented (Mello et al., 2005).

2.4 The VRS (Variable Returns to Scale) model

The BCC model, also called VRS (variable returns to scale), considers production efficiency situations with scale variation and does not assume proportionality between inputs and outputs. The model obliges the frontier to be convex and allows DMUs which operate with low input values, to have increasing scale returns, and those that operate with high values to have decreasing scale returns (Banker et al., 1984). The Envelopment Model, which is input-oriented, is expressed by equation 2 as follows:

$$
\begin{gathered}
Max\ Eff_0 = \sum_{j=1}^{s} u_j y_{jo} + u_* \\
subject\ to \\
\sum_{i=1}^{r} v_i x_{io} = 1 \\
\sum_{j=1}^{s} u_j y_{jk} - \sum_{i=1}^{r} v_i x_{ik} + u_* \leq 0, \forall\, k \\
v_i, u_j \geq 0,\ u_* \in \mathcal{R}
\end{gathered}
\qquad (2)
$$

In the multipliers models of input-oriented variable yields, one adds the dual variables $u_* u_*$ and $v_* v_*$, which are connected to a convexity condition. DEA identifies efficient DMUs, and also allows measuring and locating inefficiency and assessing the linear production function in parts, which provides benchmark to inefficient DMUs.

2.5 Standard, inverse, composite and normalized composite efficiencies in the VRS model

The inverted frontier concept was initially used by Yamada et al. (1994) and Entani et al. (2002). The inverted frontier model allows identifying falsely efficient DMUs in the VRS model. VRS model is more comprehensive than CRS model in its reach of efficient DMUs, which can be actually false efficiencies (Yamada et al., 1994, Lima, 2018; Soares de Mello et al., 2005).

Therefore, the composite efficiency introduced by Angulo-Meza et al. (2005), is a combination of classic and inverted efficiency (Barreto and Soares de Mello, 2012; Tschaffon et al., 2014), as shown in equation 3:

$$\text{Composite Efficiency} = \frac{\text{Classic Efficiency} + (1 - \text{Inverted Efficiency})}{2} \qquad (3)$$

The normalized composite efficiency, in turn, is obtained by dividing the composite efficiency value by the greatest value among all composite efficiency values, as per equation 4:

$$\text{Normalized Composite Efficiency} = \frac{\text{Composite Efficiency}}{\text{Maximum}(\text{Composite Efficiency})} \qquad (4)$$

In the present study, we have used the following models: input-oriented CRS with standard efficiency calculation, and input-oriented VRS, using the techniques of standard, inverse, composite and normalized composite efficiencies, as well as the benchmark ranking of efficient DMUs (Adler et al., 2002).

3 I RESULTS AND DISCUSSION

Results contained in Table 3 show the behaviour of statistic variations in decision-making units (DMUs) used to process information in the data envelopment analysis (DEA).

Variables	Year	Mean	Standard Deviation	Maximum / Municipality	Minimum / Municipality
X1-Energy Consumption (MWh)	2014 2016	45,901 46,722	119,098 118,288	732,460 / Rio Verde 729,927 / Rio Verde	2,752 / Diorama 2,967 / Uirapuru
X2-Water Consumption (m^3/year)	2014 2016	911.46 842.41	1957.943 1699.008	9473.64 / Rio Verde 9254.00 / Rio Verde	56.02 / Baliza 58.37 / Baliza

X3-Cleared Area (km^2)	2014 2016	7,060 5,843	10,124 7,547	38,804 / Crixas 29,530 / Mineiros	0.042 / Castelândia 0.030 / Maurilândia
Y1-*Per capita* GDP ($)	2014 2016	6.75 7.96	4586.59 6158.13	24267.99/ Perolândia 32525.66/ Perolândia	2453.26/ Aragarças 2627.15/ Aragarças
Y2-Overall IDM	2014 2016	4.837 4.831	0.429 0.411	5.910 / Chapadão do Céu 5.660 /Aparecida do Rio Doce	3.550 / Baliza 3.480 / Baliza

Table 3 Descriptive statistics for the assessed years.

Source: Elaborated by the authors.

In Table 3 it is possible to verify that between 2014 and 2016 there was an increase of 1.78% in the assessed municipalities' mean energy consumption. According with CBCS (2019), in Brazil buildings project high electric energy consumption. Chiu et al. (2012) suggest that expenses can be expressively amortized with practices of efficiency measures.

In analyzing the mean water consumption, we observe that there was a non-significant reduction of 7.57% in the year 2006, as shown in Table 3. As regards the deforestation variable, there was a decrease of 17.23%. This is an important input with great influence on the preservation and conservation of the Araguaia River's headwaters and drainage basin. Environmental variables are variables external to the production technique, which can also affect resource use and availability (Takundwa et al., 2017).

3.1 CRS (Constant Returns to Scale) results of 2014 and 2016

It is possible, moreover, to see efficiency scores for each DMU (Fig. 2 and Fig. 3), as well as DMUs that presented inefficiency in the input-oriented CRS model. In this model the proportionality principle is applied and any variation in inputs implies the proportional variation of outputs (Tschaffon and Meza, 2014).

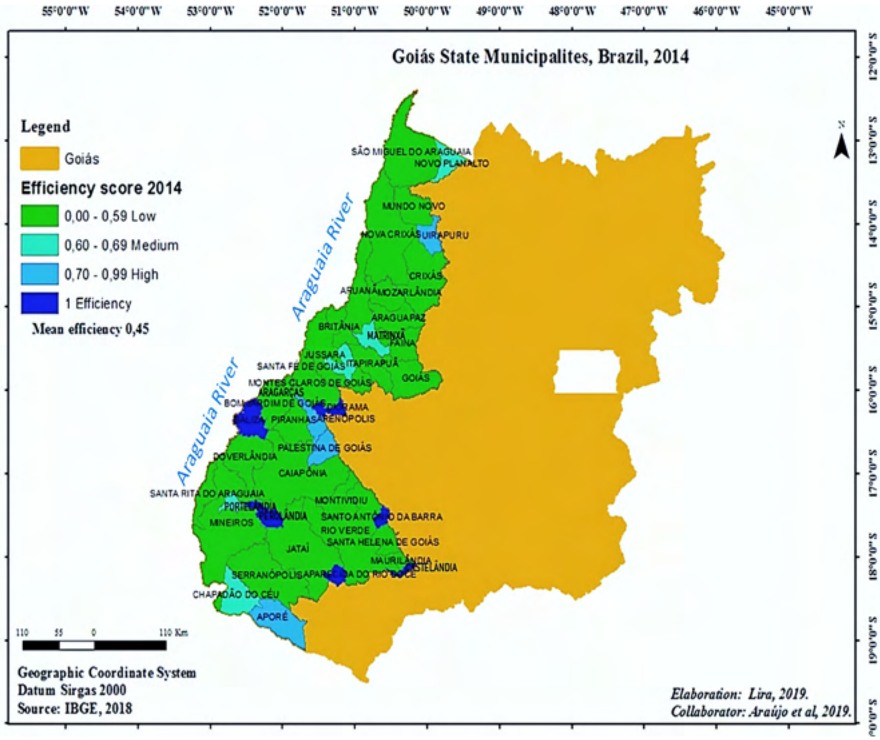

Fig. 2. Efficiency scores for each DMU in the year 2014 – input-oriented CRS model.

Source: Authors of the present study.

In assessing the input-oriented CRS model standard efficiency in 2014 (Fig. 2), and following the proportionality principle, in which any variation in inputs brings about a proportional output variation (Tschaffon and Meza, 2014), we observe that among cities with the environmental efficiency of 1, which totaled 14.63% of municipalities, the following DMUs stood out: *Aparecida do Rio Doce*, *Baliza*, *Castelândia*, *Diorama*, *Perolândia* and *Santo Antônio da Barra*. These DMUs work on constant scale returns (CRS) in activities. Efficiency results are important for allocating resources and for releases in environmental mitigation or recovery actions (Adeyemi, 2018; Benito, et al., 2010). Efficient cities showed an adequate use of resources, lower environmental impacts, better social conditions and guarantee of economic growth and development (Piña et al., 2016).

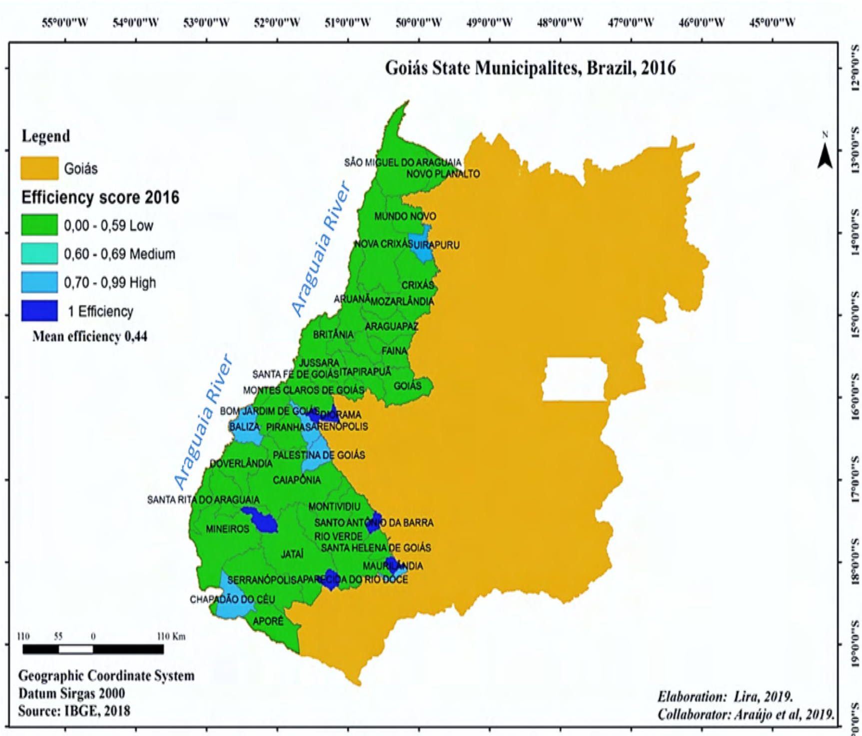

Fig. 3. Efficiency scores for each DMU in the year 2016 – input-oriented CRS model.

Source: Authors of the present work.

It was found that in 2016, municipalities with efficient results (Fig. 3) for this same model and interval were *Aparecida do Rio Doce*, *Diorama*, *Maurilândia*, *Perolândia* and *Santo Antônio da Barra*, which represented only 12.19% of the total of DMUs. It is worth highlighting that those were practically the same municipalities of 2014, with the exception of *Maurilândia*. Similar studies have shown the environmental efficiency of municipalities such as those found in the research of Wu et al. (2016).

Efficiencies achieved by reason of the low consumption of water, energy and deforestation reduction resulted in an increase of GDP and IDM, where the *Perolândia* municipality stood out with a GDP rise of 34.02% from 2014 to 2016. This growth is related to the cattle raising, farming, chalk extraction, ethanol production and cotton processing performances (IBGE, 2019). The environmental analysis has made it clear, once more, that it is possible to make more with less.

The 0.000 to 0.5999 interval (classified as low) accounted for the highest number of inefficient municipalities (Fig. 2 and Fig. 3), with 65.85% of inefficient decision-making units in 2014 increasing to 73.17% in 2016. It is worth highlighting that the *Mineiros* municipality (located in the Araguaia River headwaters), as well as touristic cities, are included in the interval. Variation in high and low efficiency correlations were found by Lee et al. (2014) for the world's main port cities.

Overall, in the CRS model we identified a mean efficiency of 0.45 in the year 2014 and 0.44 in 2016, values considered low for the 41 municipalities of the Araguaia Valley. These results indicate that environmental efficiencies can increase by 55% through a better use of available resources. This can be achieved by minimizing specific inputs of each municipality, including deforestation rate reduction, and lower water and energy consumption.

3.2 Benchmarks: CRS model efficiency

As regards ranking, data envelopment analysis (DEA) mathematical models select automatically weights that are more adequate for each DMU and do not recognize inferiorly adequate weights, attributing weight zero to them (Coelli et al., 1998; Lins and Meza, 2000; Macedo et al., 2011).

Ranking	Inhabitants	Benchmarks (quantity of references)
DMU_14 Diorama	2,546	26
DMU_31 Perolândia	2,950	22
DMU_1 Aparecida do Rio Doce	2,427	14
DMU_11 Castelândia	3,626	12
DMU_7 Baliza	3,714	8
DMU_38 Santo Antônio da Barra	4,430	1

Table 4 Ranking of the most efficient DMUs in 2014.

Source: Elaborated by the authors.

We observe in Table 4 that by the ranking of the most efficient DMUs, Diorama was a benchmark for 26 DMUs. However, this municipality is on the efficiency frontier. This DMU's ideal performance can be considered a goal for inefficient DMUs (Sebt et al., 2018; Rocha et al., 2015).

In relation to benchmarks in the input-oriented CRS model in 2016, DMUs that were references for the others are highlighted in Table 5. Similar results were obtained by Dariush (2015) by classifying efficient DMUs on the basis of cross efficiency methods and hierarchy process.

Ranking	Inhabitants	Benchmarks (quantity of references)
DMU_14 Diorama	2,546	31
DMU_31 Perolândia	2,950	21
DMU_1 Aparecida do Rio Doce	2,427	14

DMU_38	Santo Antônio da Barra	4,430	5
DMU_22	Maurilândia	13,170	1

Table 5 Ranking of the most efficient DMUs in 2016

Source: Elaborated by the authors.

It was found by the most efficient DMUs' ranking that the Diorama municipality was a benchmark for 31 DMUs in 2016 by virtue of a better use and optimization of its resources. According with IBGE (2019), its projected population for 2016 was 2,546 inhabitants, its area reaches 687,348 km², its economy is namely based on cattle raising and farming, and it stands out in tourism with its rainfalls and rivers. Though DMU 22 showed lower benchmark for a sole municipality, it nonetheless deforested less in the analyzed period. Similar benchmark classification studies have been done by Min (2006) and Sebt et al. (2018). Conversely, inefficient municipalities should adopt policies and techniques related to their benchmarks to become efficient.

3.3 VRS model efficiency and normalized composite efficiency in 2014 and 2016

Results presented in Table 6 show that nine municipalities achieved environmental efficiency with a percentage of 21.95% of the total of DMUs, while 32 reached inefficiency in the year 2014. The model used was variable return to scale (VRS), in which DMUs with lower levels of input or higher levels of output are classified as efficient (Cooper et al., 2000). On the basis of the previous information, it is highlighted in Table 6 that the *Aparecida do Rio Doce*, *Baliza*, *Castelândia*, *Diorama*, *Perolândia* and *Santo Antônio da Barra* municipalities were efficient in the CRS model and also efficient in the VRS model in 2014.However, other three municipalities (*Aporé*, *Arenópolis* and *Chapadão do Céu*) stopped being inefficient in the VRS model, which suggests that the assessed DMUs had variable scale returns, forming a convex frontier where there was no proportionality between inputs and outputs (Mello et al., 2008; Tschaffon and Meza, 2014).

Results of 2016 showed that the level of environmental efficiency remained the same as that in 2014. It was however different in some municipalities, in that nine DMUs were efficient reaching 21.95 % of the total of DMUs. Those municipalities were the following: *Aparecida do Rio Doce*, *Baliza*, *Castelândia*, *Chapadão do Céu*, *Diorama*, *Maurilândia*, *Perolândia*, *Santo Antônio da Barra* and *Uirapuru*. It is worth highlighting that results were based on the standard model, however, according with the DEA technology, and using the input-oriented VRS model, VRS efficiencies are higher or equal to CRS efficiencies, as mentioned by Lacko et al. (2018).However, as we have verified, the level of efficiency increases when the VRS model is used. This is in accordance with the found by Rodrigues et al. (2017).

DMUs	Std	Inv	Comp	Nor Comp.	DMUs	Std	Inv	Comp	Nor Comp.
Aparecida do Rio Doce	1.00	0.01	0.99	0.99	Maurilândia	0.26	0.31	0.47	0.47
Aporé	1.00	0.02	0.98	0.99	Mineiros	0.02	1.00	0.01	0.01
Aragarças	0.18	1.00	0.09	0.09	Montes Claros	0.34	0.05	0.64	0.65
Araguapaz	0.32	0.74	0.28	0.29	Montividiu	0.49	0.06	0.71	0.72
Arenópolis	1.00	0.05	0.97	0.98	Mozarlândia	0.20	0.12	0.54	0.55
Aruanã	0.16	0.36	0.39	0.40	Mundo Novo	0.47	0.20	0.63	0.64
Baliza	1.00	1.00	0.50	0.50	Nova Crixás	0.18	0.47	0.35	0.35
Bom Jardim de Goiás	0.30	0.34	0.48	0.48	Novo Planalto	0.66	0.42	0.61	0.62
Britânia	0.45	0.24	0.60	0.61	Palestina de Goiás	0.84	0.13	0.85	0.86
Caiapônia	0.13	1.00	0.06	0.07	Perolândia	1.00	0.06	0.96	0.98
Castelândia	1.00	0.04	0.97	0.99	Piranhas	0.18	0.14	0.52	0.52
Chapadão do Céu	1.00	0.07	0.96	0.97	Portelândia	0.66	0.02	0.81	0.82
Crixás	0.14	1.00	0.07	0.07	Rio Verde	0.08	1.00	0.04	0.04
Diorama	1.00	0.04	0.97	0.98	Santa Fé de Goiás	0.73	0.03	0.84	0.86
Doverlândia	0.28	0.57	0.35	0.36	Santa Helena de Goiás	0.61	0.38	0.61	0.62
Faina	0.41	0.63	0.38	0.39	Santa Rita do Araguaia	0.31	0.19	0.55	0.56
Goiás	0.08	0.54	0.26	0.27	Santo Antônio da Barra	1.00	0.02	0.98	1.00
Itapirapuã	0.37	0.09	0.63	0.64	São Miguel do Araguaia	0.09	1.00	0.04	0.05
Jataí	0.06	0.53	0.26	0.26	Serranópolis	0.30	0.16	0.57	0.57
Jussara	0.12	0.23	0.44	0.45	Uirapuru	0.96	0.46	0.75	0.76
Matrinchã	0.65	0.09	0.78	0.79					

Table 6 Efficiency of the VRS model for the year 2014.

*Std. = standard; *Inv. = inverted; *Comp. = composite; *Nor comp. = normalized composite.

Source: Elaborated by the authors.

With the aim of increasing discrimination between the assessed DMUs, we proceeded with the calculation of inverted frontier to identify municipalities showing the worst environmental management practices. In comparing the standard efficiency technique with the normalized composite (Table 6), we saw that the municipality of *Santo Antônio da Barra* achieved efficiency and presented the best performance. In the DEA method, this normalization is used to increase discrimination between compared units (Yamada et al., 1994; Entani et al., 2002).

DMUs	Std	Inv	Comp	Nor Comp	DMUs	Std	Inv	Comp	Nor Comp
Aparecida do Rio Doce	1.00	0.01	0.99	0.99	Maurilândia	1.00	0.45	0.77	0.78
Aporé	0.53	0.04	0.74	0.75	Mineiros	0.02	1.00	0.01	0.01
Aragarças	0.19	1.00	0.19	0.19	Montes Claros	0.33	0.07	0.62	0.63
Araguapaz	0.33	0.94	0.19	0.19	Montividiu	0.25	0.06	0.59	0.59
Arenópolis	0.98	0.07	0.95	0.96	Mozarlândia	0.20	0.13	0.53	0.53
Aruanã	0.16	0.64	0.25	0.26	Mundo Novo	0.47	0.25	0.61	0.62
Baliza	1.00	1.00	0.50	0.50	Nova Crixás	0.16	0.75	0.20	0.20
Bom Jardim de Goiás	0.31	0.86	0.22	0.23	Novo Planalto	0.64	0.25	0.69	0.70
Britânia	0.45	0.21	0.61	0.62	Palestina de Goiás	0.84	0.10	0.87	0.88
Caiapônia	0.13	0.97	0.08	0.08	Perolândia	1.00	0.02	0.98	1.00
Castelândia	1.00	0.03	0.98	0.99	Piranhas	0.16	0.18	0.49	0.49
Chapadão do Céu	1.00	0.11	0.94	0.95	Portelândia	0.59	0.04	0.77	0.78
Crixás	0.13	1.00	0.06	0.06	Rio Verde	0.03	1.00	0.01	0.01
Diorama	1.00	0.05	0.97	0.98	Santa Fé de Goiás	0.47	0.05	0.71	0.71
Doverlândia	0.28	0.27	0.50	0.51	Santa Helena de Goiás	0.43	0.40	0.51	0.52
Faina	0.37	1.00	0.18	0.18	Santa Rita do Araguaia	0.39	0.18	0.60	0.61
Goiás	0.09	0.64	0.22	0.22	Santo Antônio da Barra	1.00	0.03	0.98	0.99
Itapirapuã	0.30	0.12	0.58	0.59	São Miguel do Araguaia	0.11	0.34	0.38	0.38
Jataí	0.02	0.59	0.21	0.21	Serranópolis	0.32	0.18	0.56	0.57
Jussara	0.12	0.31	0.40	0.40	Uirapuru	1.00	0.77	0.61	0.61
Matrinchã	0.33	0.17	0.58	0.58					

Table 7 Efficiency with variable returns to scale for 2016.

*Std.=standard, *Inv.=inverted, *Comp.=composite, *Nor Comp.= normalized composite.

Source: Elaborated by the authors.

According with Table 7, the municipality of *Perolândia* has high normalized efficiency. In comparing DMUs with maximum standard efficiency indicators with those of minimum indicators, the importance of pondering the normalized efficiency becomes evident.

Steffanello et al. (2009) emphasize that this index is determined as an analogy between each unit's composite efficiency and the most efficient unit's composite efficiency. This could be verified with DMU 7 (*Baliza* municipality), which normalized efficiency was 0.50; it became inefficient with normalization. The same occurred with the municipalities of *Castelândia*, *Chapadão do Céu*, *Diorama*, *Maurilândia* and *Uirapuru*, which had a standard efficiency of 1 and normalized efficiency with values below 1. This confirms that the normalized composite frontiers will commonly better discriminate DMUs (Yamada et al., 1994; Entani et al., 2002; Pimenta et al., 2005; Almeida et al., 2007).

The 41 municipalities mean in the Variable Returns to Scale model was 0.51 for standard environmental efficiency and 0.58 for normalized environmental efficiency (year 2014), and standard environmental efficiency of 0.47 and normalized environmental efficiency of 0.54 (year 2016), which are means considered low and decreasing in the ranking order.

3.4 Benchmarks - Efficiency with variable returns to scale (2014/2016)

As regards benchmarks in the input-oriented VRS model, we highlight in Table 8, DMUs that were references for the others in the year 2014 using VRS.

DMUs	*Ranking*	*Inhabitants*	*Benchmarks* (quantity of references)
DMU_14	Aparecida do Rio Doce	2,427	24
DMU_1	Aporé	3,803	17
DMU_31	Arenópolis	3,011	14
DMU_7	Baliza	3,714	7
DMU_11	Castelândia	3,626	6
DMU_12	Chapadão do Céu	8,138	5
DMU_38	Diorama	2,546	4
DMU_5	Perolândia	2,950	2
DMU_2	Santo Antônio da Barra	4,430	0

Table 8 Ranking of the most efficient DMUs in the standard model (2014)

Source: Elaborated by the authors.

The more a DMU is used as benchmark, the more it will be considered a unit with optimal performance for the others. In this context, the *Aparecida do Rio Doce* municipality was benchmark for 24 DMUs, reaching maximum reference by 58.53%. Similarly, results obtained by Gomes et al. (2015) when analyzing benchmarks in municipalities with animal production systems, showed that the two more referenced possessed significant levels of revenue.Table 9 contains efficient DMUs' ranking results for the year 2016.

DMUs	*Ranking*	*Inhabitants*	*Benchmarks* (quantity of references)
DMU_14	Diorama	2,546	28
DMU_31	Perolândia	2,950	17
DMU_1	Aparecida do Rio Doce	2,427	16
DMU_7	Baliza	3,714	10
DMU_11	Castelândia	3,626	6
DMU_41	Uirapuru	2,973	5
DMU_38	Santo Antônio da Barra	4,430	4
DMU_12	Chapadão do Céu	8,138	1
DMU_22	Maurilândia	13,170	1

Table 9 Ranking of the most efficient DMUs in the standard model (2016).

Source: Elaborated by the authors.

We found that the *Diorama* municipality was a benchmark for 28 DMUs, with maximum reference of 68.29%. On the other hand, the *Chapadão do Céu* and *Maurilândia* municipalities were references for only 1 DMU (Table 9). Furthermore, they were the last in the ranking of most efficient municipalities. The environmental efficiency benchmark can be useful in the definition of public policies to preserve and conserve natural resources in relation to the resource investment (input and production). Environmental efficiency can act as an early warning or performance benchmark, providing better strategies for diverse areas, such as management, technology, social, environmental and economic (Othman et al., 2016; Wojcik et al., 2018).

4 I CONCLUSIONS

Results for the CRS model showed low standard environmental mean efficiency, 0.45 in 2014 and 0.44 in 2016. In the VRS model the result was 0.51 for standard environmental efficiency and 0.58 for normalized environmental efficiency (year 2014), and standard environmental efficiency of 0.47 with normalized environmental efficiency of 0.54 (year 2016). This suggests the need of effective governance, with environmental planning and well-established mechanisms and goals to achieve the desirable environmental efficiency that optimize water and energy consumption, and deforestation reduction, increasing GDP and the Municipal Development Index (IDM).

Among efficient municipalities, *Perolândia* stood out with the highest GDP and the lowest environmental degradation between DMUs in the two assessed years, which has proved possible to do more with less resources.

The benchmarking technique was important for determining the ranking of the most efficient DMUs and municipalities that were references for the others, with *Diorama* and

Perolândia standing out among those cities.

When comparing models used, VRS showed to be the most suitable for municipalities' environmental efficiency analysis; it better discriminated DMUs' false efficiencies.

The analysis with DEA was important in measuring and assessing which municipalities generated less environmental impact, and as information source for decision-making, which enables meeting public policies' needs.

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REFERENCES

Adeyemi, A.A., 2018. Efficient Frontier and Benchmarking Models for Energy Multicast in Wireless Network Coding. In: M. Matin (Ed.), *Network Coding*, IntechOpen. https://doi.org/10.5772/intechopen.79377

Adler, N., Friedman, L., Sinuany-Stern, Z., 2002. Review of ranking methods in the data envelopment analysis context. *European Journal of Operational Research* 140, 2, 249-265. https://doi.org/10.1016/S0377-2217(02)00068-1

Almeida, M.R., Mariano, E.B., Rebelatto, D.A.N., 2007. Análise de eficiência dos aeroportos internacionais. (Analysis of the efficiency of international airports). *Revista Produção Online* 7, 1-17. https://producaoonline.-org.br/rpo/article/view/51/51

Angulo-Meza, L., Biondi Neto, L., Soares de Mello, J.C.C.B., Gomes, E.G., 2005. ISYDS - Integrated System for Decision Support (SIAD - Sistema Integrado de Apoio à Decisão): a software package for data envelopment analysis model. *Pesquisa Operacional* 25, 3, 493-503. https://doi.org/10.1590/S0101-74382005000300011

Angulo-Meza, L., Mello, J.C.C.B.S., Gomes, E.G., Fernandes, A.J.S., 2007. Selecção de variáveis em DEA aplicada a uma análise do mercado de energia eléctrica. (Selection of variables in DEA applied to an analysis of the electricity market). *Investigação Operacional* 27, 1, 21-36. http://www.scielo.mec.pt/pdf/iop/v27n1/v27n1a02.pdf

Banker, R.D., Charnes, A., Cooper, W.W., 1984. Some models for estimating technical and scale inefficiencies in Data Envelopment Analysis. *Management Science* 30, 9, 1078-1092. https://doi.org/10.1287/mnsc.30.9.1078

Banker, R.D., Charnes, A., Cooper, W.W., Swarts, J., Thomas, D.A., 1989. An Introduction to Data Envelopment Analysis with Some of its Models and Their Uses. *Research in Governmental and Non-Profit Accounting* 5, 125-163.

Barreto, A.S., Soares de Mello, J.C.C.B., 2012. Benchmarks de eficiência no processamento de petróleo com produtos químicos. (Benchmarks efficiency in the processing of oil with chemicals). *Relatórios de Pesquisa em Engenharia de Produção* 12, 4, 41-52. http://www.producao.uff.br/conteudo/rpep/volume122012/RelPesq_V12_2012_04.pdf

BDE-Goiás - Banco de Dados Estatísticos do Estado de Goiás, 2019. IMB - Instituto Mauro Borges de Estatísticas e Estudos Socioeconômicos. Secretaria de Estado da Economia. Governo de Goiás. (Goiás State Statistical Database. Mauro Borges Institute of Statistics and Socioeconomic Studies. State Secretariat for the Economy. Government of Goiás.)

Begum, I.A., Buysse, J., Alam, M.J., Van Huylenbroeck, G., 2010. Technical, allocative and economic efficiency of commercial poultry farms in Bangladesh. *Worlds Poultry Science Journal* 66, 465-476. https://doi.org/10.1017/S0043933910000541

Benito, B., Bastida, F., García, J.A., 2010. Explaining differences in efficiency: An application to Spanish municipalities. *Applied Economics* 42, 4, 515-528. https://doi.org/10.1080/00036840701675560

BRASIL, 2019. Agência Nacional de Águas (ANA). Governo cria agenda para salvar o Rio Araguaia. Secretaria de Comunicação da Presidência da República. (Government creates agenda to save the Araguaia River. Communication Secretariat of the Presidency of the Republic). https://www.ana.gov.br/noticias-antigas/governo-cria-agenda-para-salvar-o-rio-araguaia.2019- 03-14.5223487350

Castelão, R.A., Souza, C.C., Frainer, D.M., 2016. Nível de desenvolvimento sustentável dos municípios de Mato Grosso do Sul. (Level of sustainable development in the municipalities of Mato Grosso do Sul). *Revista GeoPantanal* 11, 20, 93-104. https://periodicos.ufms.br/index.php/revgeo/article/view/1956/2304

CBCS - Conselho Brasileiro de Construção Sustentável, 2019. Eficiência Energética. (Brazilian Council for Sustainable Construction. Energy Efficiency). http://cidadeseficientes.cbcs.org.br/?page_id=484.

Charnes, A., Cooper, W.W., Rhodes, E., 1978. Measuring the efficiency of decision making units. *European Journal of Operational Research* 2, 429-444. https://personal.utdallas.edu/~ryoung/phdseminar/CCR1978.pdf

Chiu, C.R., Liou, J.L., Wu, P.I., Fang, C.L., 2012. Decomposition of the environmental inefficiency of the meta-frontier with undesirable output. *Energy Economics* 34, 5, 1392-1399. https://doi.org/10.1016/j.eneco.2012.06.003

Coelli, T.J., Prasada Rao, D.S., Battese, G.E., 1998. *An introduction to efficiency and productivity analysis*. Massachusetts: Kluwer Academic Publishers Group.

Cooper, W.W., Seiford, L.M., Tone, K., 2000. *Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References and DEA-Solver Software*. London: Kluwer Academic Publishers.

Dariush, A., 2014. Ranking All DEA-Efficient DMUs Based on Cross Efficiency and Analytic Hierarchy Process Methods. *Journal of Optimization* 2015: 594727. https://doi.org/10.1155/2015/594727

Debreau, G., 1951. The coefficient of resource utilization. *Econometrica* 19, 3, 273-290. https://doi.org/10.2307/1906814

Entani, T., Maeda, Y., Tanaka, H., 2002. Dual models of interval DEA and its extension to interval data. *European Journal of Operational Research* 136, 1, 32-45. https://doi.org/10.1016/S0377-2217(01)00055-8

Farrell, M.J., 1957. The measurement of productive efficiency. *Journal of the Royal Statistical Society Series A* 120, 3, 253-290. https://doi.org/10.2307/2343100

Ferreira, C.M.C., GOMES, A.P., 2009. *Introdução à análise envoltória de dados: teoria, modelos e aplicações.* (Introduction to data envelopment analysis: theory, models and applications). Viçosa: Editora UFV, 389p.

Gomes, E.G., Abreu, U.G.P., Mello, J.C.C.B.S., Carvalho, T.B., Zen, S., 2015. Economic and socio-environmental performance assessment of beef cattle production systems: a data envelopment analysis (DEA) approach with weight restrictions. *Revista Brasileira de Zootecnia* 44, 6, 219-225. https://doi.org/10.1590/S1806-92902015000600004

IBGE - Instituto Brasileiro de Geografia e Estatística, 2019. (Brazilian Institute of Geography and Statistics). http://www.cidades.ibge.gov.br/ IMB - Instituto Mauro Borges de Estatísticas e Estudos Socioeconômicos (2019). PIB de Goiás cresce acima da média nacional no primeiro trimestre. Comunicação Secretaria da Economia de Goiás. (Goiás's GDP grows above the national average in the first quarter. Communication Secretariat of Economy of Goiás). http://www.goias.gov.br/noticias/43-economia/65684-pib-degoi%C3%A1s-cresce-acima-da-m%C3%A9dia-nacional-no-primeirotrimestre%E2%80%8B.html. Accessed 11 March 2019.

INPE – Instituto Nacional de Pesquisas Espaciais, 2018. Detecção de Desmatamento em Tempo Real. (Deforestation Detection in Real Time). DETER 2018. Data available in: http://terrabrasilis.dpi.inpe.br/

Koopmans, T.C., 1951. An analysis of production as an efficient combination of activities. In: T.C. Koopmans (Ed.), *Activity Analysis of Production and Allocation*. New York: John-Wiley and Sons, Inc.

Lacko, R., Hajduová, Z., 2018. Determinants of Environmental Efficiency of the EU Countries Using Two-Step DEA Approach. *Sustainability* 10, 10, 3525. https://doi.org/10.3390/su10103525

Lee, T., Yeo, G.T., Thai, V.V., 2014. Environmental efficiency analysis of port cities: Slacks-based measure data envelopment analysis approach. *Transport Policy* 33, 82-88. https://doi.org/10.1016/j.tranpol.2014.02.009

Li, H., Fang, K., Yang, W., Wang, D., Hong, X., 2013. Regional environmental efficiency evaluation in China: Analysis based on the Super-SBM model with undesirable outputs. *Mathematical and Computer Modelling* 58, 5-6, 1018-1031. https://doi.org/10.1016/j.mcm.2012.09.007

Lima, V.A.M.O., Souza, C.C., Reis Neto, J.F., Frainer, D.M., 2018. Análise das eficiências ambiental, econômica e social de assentamentos rurais em Mato Grosso do Sul (MS) através de Análise Envoltória de Dados (DEA). (Analysis of environmental, economic and social efficiencies of rural settlements in Mato Grosso do Sul (MS) through Data Envelopment Analysis (DEA)). *Revista Ibero-Americana de Ciências Ambientais* 9, 4, 41-55. http://doi.org/10.6008/CBPC2179-6858.2018.004.0004

Lins, M.P.E., Moreira, M.C.B., 2000. Implementação com Seleção de Variáveis em Modelos de DEA. (Implementation with Selection of Variables in DEA Models). In: M.P.E. Lins and L. Angulo-Meza (Ed.) *Análise Envoltória de Dados e Perspectivas de Integração no Ambiente de Apoio à Decisão.* (Data Envelopment Analysis and Integration Perspectives in the Decision Support Environment). Rio de Janeiro: COPPE/UFRJ.

Macedo, M.Á.S., Cruz, C.F., Ferreira, A.C.S., 2011. Índice de Desenvolvimento Sustentável: uma análise apoiada em DEA para os municípios do Estado do Rio de Janeiro. (Sustainable Development Index: an analysis supported by DEA for the municipalities of the State of Rio de Janeiro). *Gestão & Regionalidade* 27, 81, 19-31. https://doi.org/10.13037/gr.vol27n81.1108

Mello, J.C.C.B.S., Angulo-Meza, L., Gomes, E.G., Biondi Neto, L., 2008. Estudo não paramétrico da relação entre consumo de energia, renda e temperatura. (Non-parametric study of the relationship between energy consumption, income and temperature). *IEEE Latin America Transactions* 6, 2, 153-161. https://doi.org/10.1109/TLA.2008.4609912

Mello, J.C.C.B.S., Angulo-Meza, L., Gomes, E.G., Biondi Neto, L., 2005. Curso de análise envoltória de dados. (Data envelopment analysis course). In: *XXXVII Simpósio Brasileiro de Pesquisa Operacional SBPO*, Gramado, p.2520-2547.

Min, H., Joo, S.J., 2006. Benchmarking the operational efficiency of third party logistics providers using Data Envelopment Analysis. *Supply Chain Management* 11, 3, 259-265. https://doi.org/10.1108/13598540610662167

Othman, F.M., Mohd-Zamil, N.A., Rasid, S.Z.A., Vakilbashi, A., Mokhber, M., 2016. Data Envelopment Analysis: A Tool of Measuring Efficiency in Banking Sector. *International Journal of Economics and Financial Issues* 6, 3, 911-916. https://www.econjournals.com/index.php/ijefi/article/view/2246/pdf

Pimenta, H.L.N., Soares de Mello, J.C.C.B., 2005. Modelo DEA-Savage para análise de eficiência do parque de refino brasileiro. (DEA-Savage model for efficiency analysis of the Brazilian refining park). In: *XXXVII Simpósio Brasileiro de Pesquisa Operacional SBPO*, Gramado, p.387-397. http://www.producao.uff.br/conteudo/rpep/volume52005/RelPesq_V5_2005_05.pdf

Piña, W.H.A., Martínez, C.I.P., 2016. Development and Urban Sustainability: An Analysis of Efficiency Using Data Envelopment Analysis. *Sustainability* 8, 2, 148. https://doi.org/10.3390/su8020148

Rocha, R.T., Rebelatto, D.A.N., Camioto, F.C., 2015. Análise da eficiência de fatores nos países do BRICS a partir da aplicação da Análise por Envoltória de dados. (Analysis of factor efficiency in BRICS countries from the application of the Data Envelopment Analysis). *Revista de Administração, Contabilidade e Economia da Fundace* 6, 1, 68-128. https://doi.org/10.13059/racef.v6i1.245

Rodrigues, M.V.S., Aquino, M.D., Thomaz, A.C.F., Pereira, R.F., 2017. Multicriteria Method in Data Envelopment Analysis: an application to measure the performance of the instrument of charging for water in the State of Ceará basins. *Brazilian Journal of Water Resources* 22, e8. https://doi.org/10.1590/2318-0331.011716070

RStudio Team, 2020. RStudio: Integrated Development for R. RStudio, PBC, Boston, MA. http://www.rstudio.com/

Sebt, M.V., Juybari, M.N., Soleymanfar, V.R., 2018. Investment projects ranking with DEA method considering feasibility study results. *International Journal of Research in Industrial Engineering* 7, 3, 320-335. https://doi.org/10.22105/riej.2018.147016.1058

SNIS - Sistema Nacional de Informações sobre Saneamento, 2019. Ministério do Desenvolvimento Regional. Diagnóstico dos Serviços de Água e Esgotos, Diagnóstico do Manejo de Resíduos Sólidos Urbanos e Diagnóstico anual de Águas Pluviais. (National Sanitation Information System. Ministry of Regional Development. Diagnosis of Water and Sewage Services, Diagnosis of Urban Solid Waste Management and Annual Diagnosis of Rainwater). http://www.snis.gov.br/

Soares de Mello, J.C.C.B., Gomes, E.G., Gomes, L.F.A.M., Biondi Neto, L., Angulo-Meza, L., 2005. Avaliação do tamanho de aeroportos portugueses com relações multicritério de superação. (Evaluation of the size of Portuguese airports with multicriteria relations of overcoming). *Pesquisa Operacional* 25, 3, 313-330. https://doi.org/10.1590/S0101- 74382005000300002

Steffanello, M., Macedo, M.A.S., Alyrio, R.D., 2009. Eficiência produtiva de unidades agropecuárias: uma aplicação do método não-paramétrico análise envoltória de dados (DEA). (Productive efficiency of agricultural units: an application of the non-parametric method of data envelopment analysis (DEA)). *Organizações Rurais e Agroindustriais* 11, 1, 40-56. https://doi.org/10.22004/ag.econ.62144

Takundwa, R., Jowett, S., McLeod, H., Peñaloza-Ramos, M.C., 2017. The Effects of Environmental Factors on the Efficiency of Clinical Commissioning Groups in England: A Data Envelopment Analysis. *Journal of Medical Systems* 41, 97. https://doi.org/10.1007/s10916- 017-0740-5

Thanassoulis, E., Boussofiane, A., Dyson, R.G., 1996. A comparison of data envelopment analysis and ratios as tools for performance assessment. *Omega* 24, 3, 229-244.

Tschaffon, P., Angulo-Meza, L., 2014. Assessing the efficiency of the electric energy distribution using Data Envelopment Analysis with undesirable outputs. *IEEE Latin America Transactions* 12, 6, 1027-1035. https://doi.org/10.1109/TLA.2014.6893996

Wojcik, V., Dyckhoff, H., Clermont, M., 2018. Is data envelopment analysis a suitable tool for performance measurement and benchmarking in non-production contexts?. *Business Research* 12, 2, 559-595. https://doi.org/10.1007/s40685-018-0077-z

Wu, J., Yin, P., Sun, J., Chu, J., Liang, L., 2016. Evaluating the environmental efficiency of a two-stage system with undesired outputs by a DEA approach: An interest preference perspective. *European Journal of Operational Research* 254, 3, 1047-1062. http://dx.doi.org/10.1016%2Fj.ejor.2016.04.034

Xiaoping, Z., Yuanfang, L., Wenjia, W., 2014. Evaluation of Urban Resource and Environmental Efficiency in China Based on the DEA Model. *Journal of Resources and Ecology* 5, 1, 011-019. https://doi.org/10.5814/j.issn.1674-764x.2014.01.002

Yamada, Y., Matui, T., Sugiyama, M., 1994. New analysis of efficiency based on DEA. *Journal of the Operations Research Society of Japan* 37, 2, 158-167.

Zhao, S.Q., 2018. Analysis of Urban Innovation Efficiency in Guangdong-Hong Kong-Macao Greater Bay Area. *Open Journal of Business and Management* 6, 539-550. https://doi.org/10.4236/ojbm.2018.63040

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