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Energy efficiency analysis of G7 and BRICS considering total-factor structure

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A B S T R A C T

Energy is the driving force of world economy, with the increase in the world's population and consumption, additional efforts must be made to guarantee energy availability for all economies and, consequently, to avoid a number of serious problems related to its scarcity. Therefore, measures to ensure energy efficiency are now a priority for any nation willing to develop its economy. Given the fast economic development seen in the BRICS group, which has played an important role in the global economy, the objective of this study is to measure and analyze energy efficiency in the countries that comprise the BRICS group (Brazil, Russia, India, China and South Africa) and the G7 group (Canada, France, Germany, Italy, Japan, United Kingdom and United States) considering the total-factor structure. For this, Data Envelopment Analysis was used, with Slacks-Based Measure model and the window analysis; and the total-factor energy efficiency index was calculated from the slacks provided by this tool for the countries analyzed. The model used as inputs gross fixed capital formation and workforce and energy consumption. Additionally, two outputs were used, carbon dioxide emissions (undesirable output) and Gross Domestic Product (desired output). Moreover, the factors that lead to better energy efficiency measures were sought using an econometric model. The results indicate that the BRICS and G7 are statistically different groups and therefore justify being analyzed separately. Energy efficiency in BRICS ranged from 23.54% to 99.95%, with Brazil as the country which had the highest total-factor energy efficiency index. In the analysis performed for the G7 group, every country had a total-factor energy efficiency index above 95%. The Tobit model was used, and the results show that patents are significant for energy efficiency in the BRICS countries; while in the G7 countries the Gross Domestic Product per capita (measured by purchasing power parity), life expectancy and years of schooling are significant. These findings indicate that in the BRICS countries the results of energy efficiency measures are more related to investments in low energy consumption technologies, while in the G7 countries, the energy efficiency tends to be better when countries have better social conditions, which in addition to high life expectancy, ensures a fair income distribution. The results of this study are important in terms of being useful for public policies related to energy efficiency, especially: (1) to contribute to the discussions related to evaluating the countries' energy use, helping to identify those with the best practices with regard to environmental and economic aspects in each group; and (2) to guide policy decisions regarding government incentives to promote the development of efficient countries in terms of economic growth with minimal use of resources (capital, labor, energy), without harming the environment.

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1. Introduction

There is a growing energy demand to sustain the development of countries; however, according to Narayan et al. (2007), with the pressure on the world's major economies to improve energy efficiency, societies are held responsible for finding ways to reduce energy consumption demands in order to prevent energy waste and pollution, thereby contributing to development with sustainability.

It is worth noting, however, the study of Belke et al. (2011), which suggest that energy consumption and economic growth are directly related. Thus, when planning efficient energy conservation policies, it is crucial to take into account the direct impacts of energy consumption on economic growth and the consequences of economic growth on energy consumption.

In light of the fact that the higher the level of economic activity, the higher the energy use, with greater environmental impacts from this use, energy efficiency can provide security and additional benefits, such as carbon dioxide (CO_2) emissions mitigating and reducing imported energy supplies (Selvakkumaran and Limmeechokchai, 2013).

Therefore, in order to move toward building a world economy that uses its resources efficiently, it is important to assess and estimate the potential of countries related to energy saving and emission reductions. Such analysis can provide useful information for energy and environmental policies, besides contributing to the sustainable development of countries that influence the world economy.

Historically, the OECD (Organization for Economic Co-operation and Development) countries are the largest energy consumers. There are works that have studied these countries, for example, the study of Rashidi et al. (2014), which assessed the eco-efficiency of OECD countries given the energy inputs, undesirable outputs, and nondiscretionary factors. This study concluded that countries producing high undesirable outputs may not operate eco-efficiently and thus have an extreme potential to save the optimum energy. Moreover, countries consuming low energy may operate eco-efficiently and have a low potential to reduce undesirable outputs.

The study of Niu et al. (2011), in turn, concluded that carbon emissions, per capita energy consumption and energy efficiency in developing countries are much lower than in developed countries of OECD. However, the participation of developed countries in world energy consumption has reduced over time. In developing countries however, over the past three decades the relative participation recorded cumulative increase higher than 100%.

Among developing countries, the BRICS group (Brazil, Russia, India, China and South Africa) has been gaining momentum. The BRICS countries, an alliance spanning across four continents, are composed only of emerging countries, with actions going beyond pure diplomacy. Yet separately, these countries have quite different economic, social, political and cultural characteristics, given their particular history, religion and climate. Furthermore, Leonova et al. (2007) argued that each country has its particularities with respect to clients, industries, growth trends, environmental governance and resources. Thus, Armijo (2007) reached the conclusion that this group of countries does not constitute a homogeneous cluster.

However, these countries have particular economic aspects which no relevant analysis should disregard. Among these characteristics it can be highlighted that together the BRIC countries (Brazil, Russia, India and China) account for a fifth of the world's economy and account for 43% of the world population (Yao et al., 2009). In 2011, South Africa became part of the group of countries with the highest growth potential, hence the letter "S" incorporated into the acronym BRIC, which is now BRICS.

Apart from its economic importance, the group will play a bigger role in the global political system. According to Amorim (2010), besides economic growth, the BRICS have significant land mass, considerable natural resources and energy and advanced technological development.

Therefore, there is concern over how these countries will develop, since according to Meadows et al. (1972), in his work entitled The Limits to Growth, if these countries consume the same level of resources as the current economic powers, the planet will soon be in a catastrophic situation.

According to the study of Pao and Tsai (2010), to reduce emissions while not undermining their economic growth, the BRIC countries should increase energy supply investment and energy efficiency measures, and also intensify conservation policies to reduce energy waste.

According to the World Bank (2014), in 2010, the five BRICS countries together consumed more energy than the seven G7 countries; 4.213,8 × 103 Ktoe against 3.927,5 × 103 Ktoe, respectively. Thus, it is important to analyze the efficiency of this high consumption to generate economic growth.

Customarily, macroeconomics uses a monetary basis for measuring the level of energy efficiency, referring to the energy consumption per unit of power output. A growing number of economic studies have been developed, such as in the USA (Mukherjee, 2008), Japan (Honna and Hu, 2008) or India (Mukherjee, 2010), which have contributed to measuring energy efficiency by focusing on the analysis of total-factor efficiency.

In China there is the largest amount of papers in this area, such as Wang et al. (2013), which investigated Chinese regional energy and emissions efficiency. Wang et al. (2012), in turn, evaluated the total-factor energy and emission performance of China's 30 regions; and Hu and Wang (2006) who used the data envelopment analysis (DEA) to find the target energy input of each region in China at each particular year.

It is important to mention that, in these studies, the production system can be seen as a joint production process, in which multiple energy inputs and other materials and resources are used to produce multiple desirable outputs (for example, GDP) and undesirable outputs (for example, CO_2 emissions) as products.

In this context, the objective of this study is to measure and analyze energy efficiency in the BRICS (Brazil, Russia, India, China and South Africa) and G7 (Canada, France, Germany, Italy, Japan, UK and US) countries, considering a total-factor structure by the data envelopment analysis (DEA). In addition, the factors that lead to better energy efficiency measures are sought using an econometric model.

It should be noted that the study of Chang (2015) has already compared the BRICS and G7 countries, however his work was focused on introducing a new data envelopment analysis method in order to provide environmental improvement suggestions, therefore it was based on the analysis of energy efficiency and the environmental Kuznets curve. With the results he concluded that the G7 group has greater room for improvement in its carbonization value than the BRICS group before 2005; and the latter has a greater margin for improvement in its carbonization value than the former after 2005.

Therefore, this study differs from the study of Chang (2015) by analyzing the BRICS and G7 countries specifically related to energy efficiency, measuring the performance and the factors that interfere in achieving better energy efficiency measures in each country of these groups using data envelopment analysis approaches and econometrics.

2. Method

In this paper the emerging countries (which constitute the BRICS group) were selected in order to analyze their energy efficiency based on the viewpoint of total-factor productivity.

The goal proposed in this paper is achieved using a mathematical programming method known as Data Envelopment Analysis (DEA), described in Topic 2.1, through the variant of the Slacks-Based Measure (SBM) model and the window analysis. It should be pointed out that most of the studies which evaluate energy efficiency at the macroeconomic level and apply a total-factor structure use the DEA method, since it provides an appropriate mechanism for dealing with multiple inputs and outputs to measure the relative efficiency of each decision making unit (DMU) under evaluation.

Correspondingly, an economics based production function is constructed using this method to analyze the energy efficiency considering a total-factor structure. Therefore, first the total-factor efficiency of BRICS and G7 was measured. For this, the energy factor is taken together with conventional inputs: workforce and capital. The latter are often used in economic productivity analyses such as inputs to produce an economic output (GDP). For the economy or region a GDP increase is preferable, with the simultaneous reduction of energy consumption in order to achieve production efficiency. Therefore, GDP growth and energy consumption efficiency targets must be placed together in order to sustain economic development (Hu and Wang, 2006).

Wu et al. (2012), Watanabe and Tanaka (2007) and Mandal (2010) point out that analyzing energy efficiency without considering environmental efficiency can lead to biased results of the energy efficiency evaluation. Wang et al. (2012), conducted a comparative analysis between the environmental efficiency and energy efficiency evaluation, and confirmed that this bias exists if the undesirable output (CO_2) is omitted from the evaluation. This study also considered the CO_2 emission levels of the BRICS countries, which is one of the most important unwanted outputs of energy consumption. It is worth noting that CO_2 emissions are considered from the burning of fossil fuels.

Therefore, three input variables are used for this analysis: workforce, gross fixed capital formation and energy consumption; and two output variables: GDP (desired output) and CO_2 emission (undesirable output). All variables were collected from the World Bank website for the 1993 to 2010 period. When energy and environmental efficiency are measured, the energy consumption, workforce and capital used should be reduced as much as possible, while simultaneously increasing the desirable output (GDP).

According to Sahoo et al. (2014) and Yang and Pollitt (2010), there are many ways to treat undesirable outputs in DEA, and these can be divided into two classes: strong disposability (SD) and weak disposability (WD). The WD models consider that CO_2 emissions cannot be reduced freely and are considered a cost for producing the desired outputs; in this type of approach, which tends to be more consistent with the assumptions of the production theory, the outputs do not need to undergo any transformation, therefore the mathematical models are fitted (Sahoo et al., 2014).

However, the SD models consider that emissions can be reduced regardless of what happens with the desirable inputs and outputs; therefore the original models are used and the undesirable output must undergo some sort of transformation, and the additive inverse transformation is mostly recommended (Sahoo et al., 2014). There is still no consensus on the best approach used to deal with undesirable outputs (Yang and Pollitt, 2010), since the comparative research already carried out for the different models tended to obtain very close results (Sahoo et al. 2014; Korhonen and Luptacik, 2004).

Since the objective of this study is the efficiency measurement of the BRICS and G7 countries using a total-factor structure, the SD was used, since in this work the variable CO_2 emissions was treated as an input.

In this study the SBM model with variable returns to scale was used, which enables analyzing the relative efficiency of the countries to simultaneously reduce inputs and increase outputs. This method also provides the values that the countries should increase or decrease, from each variable, to achieve greater efficiency. These values are also known as slacks.

According to Honna and Hu (2008) and Hu and Wang (2006), efficiency is usually defined as the best practice compared with the actual operation. The energy efficiency indicator should be the relationship between the energy added, which ideally should be consumed and the actual energy consumed. The amount of total adjustments of the "energy consumption" input is considered as the ineffective portion of the actual consumption. Thus, based on the slack adjustments of energy obtained from the DEA, the percentage of energy that must be saved can be calculated, while other factors are taken into consideration. If the slack is equal to zero, that is, if there are no adjustments for the "energy consumption" input, the country shows optimum energy consumption efficiency, when its output is maximized. Therefore, a country's energy efficiency is determined by expression (1), and is called total-factor energy efficiency (TFEE) for country i, at time t, since the index is set from the point of view of total-factor productivity.

$$TFEE_{(i,t)} = 1 - \left[energy\ slack_{(i,t)} \Big/ current\ energy\ consumption_{(i,t)} \right] \tag{1}$$

The TFEE index represents the energy consumption efficiency of a country. The slack of the variable "energy consumption" demonstrates how much the country should reduce its energy consumption to achieve the best practical level of this variable. Therefore, the current energy consumption is always greater than or equal to the slack. This causes the TFEE index to always be between zero and 1. In our study this index is shown in a percentage format.

Similarly, the TFEE can be analyzed for a group of countries, and in this paper the BRICS and the G7 groups are analyzed. Thus, the TFEE of a set of countries can be expressed by Expression (2), which considers the sum of the slacks and energy consumption of all countries belonging to the group that will be analyzed, represented by α:

$$TFEE(\alpha, t) = 1 - \left[\left(\sum_{iE\alpha} energy\ slack_{(i,t)} \right) \Big/ \left(\sum_{iE\alpha} current\ energy\ consumption_{(i,t)} \right) \right] \tag{2}$$

As this is a panel data, a window analysis was performed, explained in Section 2.2, which allows comparing units in different years.

After calculating the TFEE index, the factors that lead to better energy efficiency measures for each country group were measured using an econometric model, explained in Section 2.3.

2.1. Data envelopment analysis

The Data Envelopment Analysis (DEA) method has been successfully employed to assess the relative performance of a set of firms, usually known as Decision Making Units (DMUs) which use the same inputs to produce the same outputs (Ramanathan, 2006). The DEA originated in the work of Charnes et al. (1978) and Banker et al. (1984), both based on Farrell (1957).

Thus, the DEA evaluates the relative efficiency of a set of DMUs, in this work represented by the BRICS countries. The advantage of this approach is that it considers both multiple inputs and outputs that characterize a given production process. Additionally, the DEA allows the DMUs to have immediate information on their respective efficiency or inefficiency status, which in turn depend on the DEA model used (Oggioni et al., 2011).

The model chosen for this work, SBM (Slacks-Based Measure), was introduced by Tone (2001). It considers the simultaneous input–output orientations, and as a result provides an efficiency value that ranges from zero to 100%.

It was observed in this work that the simultaneous orientation to minimize inputs and maximize outputs is the most suitable, since in terms of total-factor productivity the goal is to reduce energy consumption, capital employed and workforce, while simultaneously increase the GDP of each country analyzed, in other words, decrease the need for production factors and increase economic growth. Note that the undesirable output "CO_2 emission" will be modeled as input and must therefore also be minimized.

In this study the SBM model with variable returns to scale was chosen because it allows to compare countries that operate at different scales, implying that reductions or increases in inputs do not necessarily generate changes in the outputs in the same proportion. Expressions (3)–(8) show the SBM model with variable returns to scale according to Tone (2001):

$$Min\tau = t - (1/n)\sum_{j=1}^{n} S_j/x_{j0} \tag{3}$$

Subject to:

$$\frac{1}{m}\sum_{i=1}^{m} S_i/y_{i0} + t = 1 \tag{4}$$

$$\sum_{k=1}^{z} x_{jk}\cdot\lambda_k + S_j - t\cdot x_{j0} = 0, \text{for j} = 1, 2\ldots\text{n} \tag{5}$$

$$\sum_{k=1}^{z} y_{ik}\cdot\lambda_k - S_i - t\cdot y_{j0} = 0, \text{for i} = 1, 2\ldots\text{m} \tag{6}$$

$$\sum_{k=1}^{z} \lambda_k = t \tag{7}$$

$$\lambda_k, S_j \text{ and } S_i \geq 0 \text{ and } t > 0 \tag{8}$$

where:

λ_k: Participation of DMU k in the DMU target under analysis;
x_{jk}: Amount of input j of the DMU k;
y_{ik}: Amount of output i of the DMU k;
x_{j0}: Amount of input j of the DMU under analysis;
y_{i0}: Amount of output i of the DMU under analysis;
z: Number of units under evaluation;
m: Number of outputs;
n: Number of inputs;
S_i: The slack variable of output i;
S_j: The slack variable of input j;
t: Linear adjustment variable

Besides allowing to measure the relative performance of the selected countries, this method also allows obtaining the slacks. They express how much each country should increase (or decrease) each variable to achieve efficiency. Each slack expresses to what degree the current performance of the DMU (e.g. the country) is distant, for each variable, from its ideal performance. This ideal performance can be considered a target for the inefficient DMUs. This target is symbolized by a virtual DMU (*benchmark*), which is at the efficient frontier and is calculated according to Expressions 9 and 10:

$$Input\ target = x_{j0} - S_j, for\ j = 1, 2, 3\ldots n \tag{9}$$

$$Output\ target = y_{i0} + S_i, for\ i = 1, 2, 3\ldots m \tag{10}$$

The relative slack can be determined from the current performance and the target, which expresses the percentage level of improvement required for each variable of each sector. The relative slack can be determined with Expression (11):

$$Relative\ Slack = (Target - Current)/Current \tag{11}$$

2.2. Window analysis

One way to include the time factor in the DEA technique is by performing the window analysis, as explained in Cooper et al. (2000). The window analysis separates the years being analyzed in different groups (windows), and from the data available, the size of each window and the number of windows to be constructed are determined. These two pieces of information can be obtained through Expressions (12) and (13), where k is the number of periods and p is the size of the window, which is rounded up, if necessary.

$$Size\ of\ window\ (p) = (k+1)/2 \tag{12}$$

$$Number\ of\ windows = k - p + 1 \tag{13}$$

In this investigation, in addition to the countries' efficiency result tables in each window, tables with the slack results of each variable are also presented for each DMU in each window. Similarly, the final result of the slack of each variable for each DMU will be the average slacks obtained every year and in all windows.

2.3. Econometric model

Given that the DEA technique returns a relative efficiency vector for the DMUs, the model is obviously censored, that is, limited to 100% in the dependent variable, justifying the use of a panel data Tobit model. Thus, the panel data Tobit model estimation was performed in the presence of fixed and random effects, for subsequent evaluation and selection of the best model through the Hausman test.

However, since no sample exhibited 0% efficiency after the DEA analysis, the sample was censored at the upper limit threshold (right-censored). Thus, the fixed effects (FE) Tobit model is described in Expressions (14) and (15).

$$Ef_{it} = X_{it}\beta + \mu_{it} + \nu_{it} \tag{14}$$

with,

$$\begin{aligned} Ef_{it} &= Ef_{it}^{*}\ \ if\ Ef_{it}^{*} < 1, \\ &= 1\ otherwise \end{aligned} \tag{15}$$

where,

$$\nu_{it} \sim IIN\left(0, \sigma^2\right);$$

μ_{it} is the fixed effect (individual heterogeneity of panel entities) that cannot be disregarded, otherwise the estimated parameters will present inconsistency;

X_{it} is the matrix of independent explanatory variables: GDP per capita, years of schooling, life expectancy at birth, and number of patents.

The variables 'life expectancy at birth', 'years of schooling' and 'GDP per capita measured by purchasing power parity', taken from the UNDP website (2011), were used as possible explanatory variables due to the fact that they are a constitutive part of the Human Development Index (HDI), which is an indicator of the level of individual freedom and the ability to live a healthy life (Klugman et al., 2011). According to Sen (1999), this ability turns people into agents of their own destiny, including being responsible for taking care of the environment they live in. Therefore it was speculated that this freedom could influence the positive or negative energy efficiency of a country. The number of patents, taken from the World Bank website, indicates the effects of technological innovation on energy efficiency.

The model is calculated by estimating the log-likelihood using iterative methods as proposed by Heckman and MaCurdy (1980), therefore the estimation of the proposed fixed effects Tobit model employed the Newton–Raphson method to maximize the likelihood function.

The Random Effects (RE) model is shown in (16) and (17).

$$Ef_{it} = X_{it}\beta + \nu_{it} \tag{16}$$

Again with,

$$\begin{aligned} Ef_{it} &= Ef_{it}^{*} \ \ if \ \ Ef_{it}^{*} < 1 \\ &= 1 \ otherwise \end{aligned} \tag{17}$$

It is assumed that the error term is independent of the matrix, whose variables are independent and identically distributed (i.i.d.). The parameters are also estimated by maximum likelihood using the Newton–Raphson method.

3. Analysis and discussion of results

From the application of the DEA SBM model and the window analysis, the behavior of the BRICS and the G7 countries was examined from 1993 to 2010 (nine windows), using the workforce, gross fixed capital formation and energy consumption inputs, and GDP outputs (desirable output) and CO_2 emission (undesirable output). Table 1 shows the ranking.

It is observed that the G7 countries, when compared with the BRICS, are more efficient at transforming gross fixed capital formation, workforce and energy consumption into GDP without increasing CO_2 emissions.

France, with 99.45% efficiency was first in the ranking. However, all of the G7 countries had average efficiency higher than 90%, with low standard deviations, indicating that these countries are very similar to each other with respect to the total-factor structure.

Among the BRICS, below the G7, Brazil had the highest average efficiency (89.03%), followed by South Africa (88.09%), Russian Federation (49.95%), India (32.13%), and China (22.21%).

It is important to mention that the results obtained were consistent with Chang's work (2015). Chang (2015) applied the DEA approaches by using the directional distance function (DEA-DDF) model to estimate their room for improvements in energy intensity, emission intensity, and carbonization value, and examines the shape of Environmental Kuznets Curve (EKC) on energy intensity, emission intensity, and carbonization value.

In Chang (2015) study the average overall efficiency score in G7 is always superior to that of BRICS. However, the two G7 countries with the best overall efficiency scores during the whole data period are France and the United States, and in this study, it was France and Italy.

In Chang (2015) study none of the BRICS countries present a better overall efficiency score during the whole data period, which was from 2000 to 2010. In his study, Brazil and South Africa have better overall efficiency scores versus China, India, and Russia, similar to the scores in the present paper. But in Chang (2015) study, Canada in the G7 group has lower overall efficiency scores versus the other G7 countries, different from this work, in which Germany had the lowest efficiency.

After calculating the efficiency, the TFEE index was calculated using the slacks provided by the DEA, in Table 2, which shows that the energy efficiency of the G7 countries is quite high. However, South Africa stands out among the BRICS countries, with 93.24% efficiency, even higher than Germany (93.07%). Brazil is another country that stands out among the BRICS with 89.45% in the TFEE index.

However, the results indicate that unlike the G7 group, which is quite homogeneous, all countries exhibit a TFEE index above 90%; the BRICS countries also exhibit quite different energy frameworks, with the TFEE index ranging from 18.99% (Russian Federation) to 93.24% (South Africa).

The 2010 data, which is the last year analyzed in this work, shows that China is the world's largest energy consumer (2.417 Mtoe), with a completely different energy level from other BRICS countries. Brazil, for example, has only 2% of energy consumption. On the other hand, China is very close to the level of the world's second-largest energy consumer, which is the United States (2.216 Mtoe). However, Table 2 shows that the United States is much higher than China and Brazil in the TFEE ranking, despite the high energy consumption. This shows that the United States is quite efficient in transforming energy into economic growth and would therefore need to reduce their energy consumption less than these countries to achieve a TFEE index of 100%.

Table 1
Total-factor efficiency of BRICS and G7 countries.

Ranking	Country	1	2	3	4	5	6	7	8	9	Mean	Standard deviation
		1993–2002	1994–2003	1995–2004	1996–2005	1997– 2006	1998–2007	1999–2008	2000–2009	2001–2010		
1	France	99.1%	99.3%	99.3%	99.5%	99.5%	99.7%	99.6%	99.6%	99.6%	99.45%	0.8%
2	Italy	99.6%	99.4%	99.1%	98.7%	98.4%	98.3%	98.2%	97.9%	97.9%	98.59%	1.6%
3	Canada	98.8%	98.8%	98.3%	98.3%	98.2%	97.6%	96.9%	96.3%	96.2%	97.72%	2.2%
4	UK	98.1%	97.1%	97.1%	97.4%	97.6%	97.7%	98.3%	97.6%	98.3%	97.68%	2.7%
5	United States	98.6%	98.3%	98.4%	98.7%	98.7%	97.4%	95.8%	95.9%	95.5%	97.49%	2.8%
6	Japan	97.2%	96.3%	95.3%	94.7%	94.4%	93.9%	93.9%	95.0%	94.9%	95.06%	3.6%
7	Germany	92.9%	92.0%	93.0%	93.4%	94.4%	95.2%	94.3%	90.9%	91.4%	93.07%	4.1%
8	Brazil	84.6%	89.2%	90.9%	92.1%	93.0%	93.0%	90.9%	85.4%	82.1%	89.03%	8.4%
9	South Africa	87.1%	90.8%	92.2%	94.2%	93.1%	90.1%	86.4%	80.7%	77.9%	88.06%	11.9%
10	Russian Federation	44.8%	48.5%	51.9%	55.8%	56.9%	54.6%	51.3%	43.9%	41.9%	49.95%	10.0%
11	India	34.7%	34.5%	34.3%	34.8%	34.2%	32.8%	31.6%	26.8%	25.5%	32.13%	5.2%
12	China	21.7%	21.7%	22.0%	22.4%	22.8%	23.2%	22.9%	21.5%	21.7%	22.21%	1.5%

Table 2
Total-factor energy efficiency (TFEE) of BRICS and G7 countries.

Ranking	Country	1	2	3	4	5	6	7	8	9	Mean	Standard deviation
		1993–2002	1994–2003	1995–2004	1996–2005	1997– 2006	1998–2007	1999–2008	2000–2009	2001–2010		
1	Italy	100.0%	99.9%	99.9%	99.8%	99.8%	100.0%	100.0%	100.0%	100.0%	99.93%	0.3%
2	Japan	99.6%	98.4%	99.2%	99.7%	99.8%	97.7%	98.0%	98.5%	100.0%	98.98%	1.3%
3	France	99.3%	99.2%	99.3%	99.2%	98.7%	98.8%	98.8%	98.1%	98.2%	98.85%	1.7%
4	UK	98.9%	99.5%	99.5%	100.0%	98.1%	98.9%	98.2%	96.0%	96.9%	98.44%	2.2%
5	United States	99.6%	99.4%	99.6%	99.7%	98.3%	93.8%	94.2%	94.0%	95.8%	97.16%	4.0%
6	Canada	99.6%	99.0%	97.8%	97.7%	96.6%	95.9%	95.1%	94.4%	92.4%	96.50%	4.2%
7	South Africa	92.2%	94.3%	95.5%	96.4%	95.6%	94.0%	91.9%	89.5%	89.9%	93.24%	6.3%
8	Germany	100.0%	99.9%	99.9%	95.6%	95.3%	96.2%	89.2%	96.2%	96.0%	93.07%	4.8%
9	Brazil	87.3%	88.5%	90.4%	93.1%	94.8%	93.1%	89.9%	86.1%	81.8%	89.45%	10.4%
10	India	34.0%	33.6%	33.7%	34.3%	34.1%	32.6%	31.0%	28.8%	28.6%	32.30%	3.5%
11	China	21.3%	20.6%	20.9%	21.3%	20.9%	23.1%	24.6%	29.7%	33.3%	23.97%	7.7%
12	Russian Federation	18.1%	18.4%	19.0%	19.6%	19.1%	19.2%	19.3%	19.0%	19.2%	18.99%	0.6%

Table 3
Total-factor efficiency of BRICS and G7 group.

Group	1	2	3	4	5	6	7	8	9	Mean
	1993–2002	1994–2003	1995–2004	1996–2005	1997–2006	1998–2007	1999–2008	2000–2009	2001–2010	
G7	99.6%	99.3%	99.4%	99.2%	98.2%	95.5%	95.1%	95.4%	96.5%	97.6%
BRICS	30.4%	30.4%	31.0%	31.7%	31.3%	32.1%	32.4%	34.6%	36.2%	32.2%

Table 4
Total-factor efficiency of the BRICS countries.

Ranking	Country	1	2	3	4	5	6	7	8	9	Mean	Standard deviation
		1993–2002	1994–2003	1995–2004	1996–2005	1997–2006	1998–2007	1999–2008	2000–2009	2001–2010		
1	Brazil	99.1%	98.9%	98.7%	98.7%	99.3%	99.8%	99.9%	99.9%	99.9%	99.4%	1.2%
2	South Africa	97.5%	98.2%	98.7%	99.5%	99.7%	99.6%	99.6%	99.1%	98.8%	99.0%	1.4%
3	China	74.6%	78.9%	81.0%	81.3%	81.5%	80.5%	81.1%	84.5%	86.5%	81.1%	14.2%
4	Russia	58.3%	58.3%	61.0%	62.8%	62.7%	61.9%	60.5%	58.9%	58.0%	60.3%	6.2%
5	India	41.8%	40.3%	40.4%	40.7%	41.4%	42.3%	43.5%	44.4%	46.1%	42.3%	4.0%

Moreover, another interesting fact is that although Russia was last in the TFEE ranking, the energy consumption (701 Mtoe) of this country is very similar to India (692 Mtoe) which is two positions ahead in the rankings, but it should be mentioned that their per capita values are quite different despite the Russian Federation being last in the TFEE ranking. Their per capita values are quite different (0.59 toe/inhabitant for India and 4.95 toe/inhabitant for Russia). However, South Africa, seventh in the ranking, the best placed among the BRICS countries, is at a lower energy level in relation to these countries, with an energy demand of 136 Mtoe, but a per capita consumption of 2.74 toe/inhabitant.

The BRICS countries also differ in relation to the main energy sources in the energy matrix. China, India and South Africa are fueled by coal, Russia is fueled by gas and Brazil by renewable fuels. Also noteworthy is the peculiar weight of plant and animal residues in the Indian matrix. This may have also affected the TFEE ranking, as it was prepared from the results of the Total-factor efficiency, which used the CO_2 emissions as an undesirable output.

Regarding the contribution to global CO_2 emissions, while China contributes with 8286 Mton, Brazil contributes with only 367 Mton. As for the other countries in the group, for India these emissions are of 2008 Mtoe, for Russia 1740 Mton and for South Africa 460 Mton.

It is then concluded that the very different energy realities of the BRICS countries will also result in different energy policies; therefore, although the results achieved serve as a basis for public policy related to improving the countries' energy efficiency, equating the energy security issue will develop differently depending on the country in question.

It is emphasized that although Brazil and South Africa move closer to the energy efficiency of the G7 countries, the energy efficiency of the two groups is quite different. This fact was confirmed by a nonparametric test (considering the sample sizes) – the Mann–Whitney U test – which found a statistically significant difference between the groups. This test strongly rejected the null hypothesis that the groups have similar efficiencies, $p < 4.1135e^{-005}$.

The measure of the TFEE index for the group of countries, according to Expression 2, also shows the difference of the two groups, in which the TFEE index is 97.6% for G7 and 32.2% for BRICS, according to Table 3. Which justifies analyzing the groups separately.

The next two sections present the data obtained using the DEA to calculate the total-factor efficiency of only BRICS and afterward only G7.

3.1. Efficiency of BRICS countries

Table 4 presents the total-factor efficiency ranking of only the BRICS countries.

Table 4 shows that by using the DEA for the BRICS countries separated from the G7 countries, the efficiencies shown are different from Table 1, since the efficiency frontier has changed.

The data envelopment analysis enabled to verify that Brazil is the most efficient in decreasing the undesirable inputs and outputs and increasing the GDP. Therefore, it is possible to assume that by increasing the inputs, the GDP output and sustainable growth will be higher.

South Africa is second in the ranking. Although this country has the smallest inputs and outputs, it holds one of the best positions in the efficiency index, with low standard deviation. Although internationally it has gained ground, national problems such as disease and violence still defer growth.

China, besides presenting a good average efficiency level, third in the ranking, has a fairly high standard deviation, explained by the fact that within a year there were significant and rapid improvements that led to ensuring that the most recent year of each window showed 100% performance in relation to the others, hence increasing variability. Therefore, it is concluded that in recent years China has shown improvements in relation to its capacity to transform energy, workforce and capital into GDP, without increasing CO_2 emissions. However, it should be noted that this is the country that most consumes fossil fuel energy and emits carbon gas. Ergo, though its sustainable growth is deemed possible, it is challenging.

Russia, the penultimate in the ranking, showed median input variables. But for a country that is no longer a globally isolated economy, a few decades ago, it shows a good scenario.

India, the last country in the ranking, showed no improvement or worsening over the years analyzed, constantly oscillating. It can be concluded that this country has not been efficient in its use of inputs for the GDP formation.

To better understand this result, the slacks of the countries of each variable considered in the analysis were examined. Using the overall mean slacks of each variable, a ranking of the variables that most impact the efficiency of countries considered in this work was created: CO_2 emissions (36.15%), energy consumption (32.13%), workforce (30.05%), GDP (14.51%) and gross fixed capital formation (5.16%), respectively. Table 5 presents the average slacks for each variable in each country.

As seen in Table 5, improving the reduction of energy consumption and CO_2 emissions are needed in almost all BRICS countries, especially concerning Russia and India. Thus, the focus of this study on each country's energy consumption is justified, because in addition to the high slacks of the energy consumption variable, the CO_2 emissions under consideration are derived from fossil fuels, hence measures to improve the energy efficiency of these countries would also lead to reducing these emissions.

The TFEE index was calculated for each BRICS country, in each window, thereby providing an energy efficiency ranking for the countries in this group (Table 6).

According to the results, considering the variables analyzed in this work, Russia is the last country in the energy efficiency ranking. However, notwithstanding this, it showed growth over the periods analyzed, with average TFEE rates higher that 21.1% in the first window (1993–2002) to 26.3% in the last window (2001–2010).

India is the next-to-last in the TFEE ranking, and though the performance of this country is higher than Russia, it does not show substantial variability, indicating that it did not show significant improvement or worsening, remaining at similar energy efficiency levels over the years under analysis. It is observed that the first window is the one with the largest percentage difference when compared with the other windows.

The third in the performance ranking is China, which showed growth in the TFEE index according to the more recent periods contemplated in the windows. Average performance increased from 60.11% in the first window to 79.14% in window 9. It is observed that over the years there has been significant growth, showing relatively large variability compared to the other countries, with deviation standard of 21.84%. Therefore, it is concluded that in recent years China has shown improvements with respect to energy efficiency measures, although as mentioned, it is still the country that most consumes energy.

South Africa, as shown in Table 6, had the second highest variability in relation to average performance (standard deviation of 3.36%) However, although still much lower when compared to China, it increased its energy efficiency from 93.9% in the first window to 96.9% in the last window.

3.2. *Efficiency of the G7 countries*

After analyzing the ranking of the FTEE index for the BRICS countries, the same analysis was performed for the G7 countries. Through the variant of the SBM method of the DEA, the efficiency ranking of each G7 country to decrease capital, workforce and energy consumption was obtained, generating GDP without increasing CO_2 emissions. Table 7 shows this ranking.

Similarly as in the efficiency analysis, which considered the G7 and BRICS; the efficiency analysis considering only the G7 countries showed that these countries are very efficient, considering a total-factor structure, with average efficiency over 90%.

According to Table 7, the most efficient country in increasing GDP considering better use of inputs is France (99.45%), followed by Italy (98.60%), UK (97.75%), United States (97.49%), Canada (97.22%), Japan (95.06%) and Germany (93.07%). Thus, the ranking order was very similar to that of Table 1, only Canada changed, going from third to fifth place, when compared with the countries of its own group.

France, besides being first in the ranking, in the last few years of each window it showed 100% efficiency levels when compared to the others, showing that this country has improved efficiency year after year. France, in addition to being the country with the lowest CO_2 emissions in the group, makes the best use of its resources to generate economic growth.

Italy is second in the ranking, with an average efficiency of 98.6%. The last year of the last three windows showed 100% efficiency, indicating this country's positive trend in increasing economic growth, using fewer resources, without increasing emissions.

The UK showed averages ranging from 97.1 to 98.5%. However, it was found that recently every year within each window there was a 100% efficiency compared to previous years, which shows the country has good policies.

Table 5
Average slacks of the BRICS countries.

Country	Workforce	Gross fixed capital formation	Energy consumption	CO_2	GDP
South Africa	0.03%	1.89%	2.73%	2.58%	0.55%
Brazil	0.04%	1.36%	0.05%	1.10%	0.30%
Russia	32.95%	0.02%	76.46%	78.33%	28.35%
China	38.72%	8.09%	25.76%	26.20%	4.03%
India	78.49%	14.42%	55.67%	72.53%	39.35%
Mean	**30.05%**	**5.16%**	**32.13%**	**36.15%**	**14.51%**

Table 6
Total-factor energy efficiency (TFEE) of the BRICS countries.

Ranking	Country	1	2	3	4	5	6	7	8	9	Mean	Ranking
		1993–2002	1994–2003	1995–2004	1996–2005	1997–2006	1998–2007	1999–2008	2000–2009	2001–2010		
1	Brazil	99.9%	99.9%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	99.8%	99.95%	0.0020
2	South Africa	93.9%	95.6%	98.1%	98.2%	98.5%	98.2%	98.2%	97.8%	96.9%	97.27%	0.0336
3	China	60.1%	66.8%	71.2%	74.3%	77.3%	77.0%	78.2%	84.1%	79.1%	74.24%	0.2184
4	India	41.6%	44.5%	45.3%	45.2%	44.9%	44.9%	44.5%	44.2%	44.0%	44.33%	0.0290
5	Russia	21.1%	21.8%	22.2%	22.7%	23.3%	24.0%	24.8%	25.7%	26.3%	23.54%	0.0266

Table 7
Total-factor efficiency of the G7 countries.

Ranking	Country	1	2	3	4	5	6	7	8	9	Mean	Standard deviation
		1993–2002	1994–2003	1995–2004	1996–2005	1997–2006	1998–2007	1999–2008	2000–2009	2001–2010		
1	France	99.1%	99.3%	99.3%	99.5%	99.5%	99.7%	99.6%	99.6%	99.6%	99.45%	0.8%
2	Italy	99.7%	99.4%	99.1%	98.7%	98.4%	98.3%	98.2%	97.9%	97.9%	98.60%	1.6%
3	United Kingdom	98.1%	97.1%	97.1%	97.5%	97.8%	97.8%	98.5%	97.6%	98.3%	97.75%	2.7%
4	United States	98.6%	98.3%	98.4%	98.7%	98.7%	97.4%	95.8%	95.9%	95.5%	97.49%	2.8%
5	Canada	98.8%	98.3%	98.3%	96.3%	96.2%	97.6%	96.9%	96.3%	96.2%	97.22%	2.4%
6	Japan	97.2%	96.3%	95.3%	94.7%	94.4%	93.9%	93.9%	95.0%	94.9%	95.06%	3.6%
7	Germany	92.9%	92.0%	93.0%	93.4%	94.4%	95.2%	94.3%	90.9%	91.4%	93.07%	4.1%

Japan and Germany had the largest deviations, 3.6 and 4.1, respectively. Japan, the second largest economy in the world, was the second-to-last least efficient country when compared to the others in the group (95.06%). Among the G7, this country is in second place for GDP, energy consumption, gross fixed capital formation, CO_2 emission and workforce, behind only the United States.

Germany, last in the ranking (93.07%), is considered one of the richest economies in Europe, but faced a difficult period after the 2008 crisis. This country, which was in a period of growth, was hit by the crisis, which directly impacted its efficiency.

The United States, the world's leading power, despite its average efficiency decrease in window 7, is in a period of increasing efficiency, with significant and rapid improvements in recent years, despite its high emission levels. This is corroborated by the fact that the last year of each window, without exception, had 100% performance in relation to the other countries. This occurred even in the windows that included the years when the country experienced the 2008 housing crisis and the calamity of September 11, 2001, which generated huge investments in the military together with the Iraq invasions.

Canada, fifth in the ranking (97.2%), is known for its stable economy, focused on technology investments. According to the data this country has the lowest GDP of the group, besides a small workforce, when compared with the other countries.

An analysis of the slacks of the G7 countries was performed. Since the efficiency of all countries was quite high, the variables had small slacks, as seen in Table 8.

The highest average slack was for the GDP variable, followed by gross fixed capital formation, energy consumption, CO_2 emission and workforce. Nonetheless, the difference between them is less than 1%, again demonstrating the similarity between these countries regarding the total-factor structure.

After the total-factor efficiency analysis, the next step was to calculate the total-factor efficiency (TFEE) index through the energy consumption slacks in order to identify the countries with better energy efficiency measures, as shown in Table 9.

All G7 countries were quite energy efficient considering a total-factor structure, with an average above 95%.

In the ranking of the TFEE index only the G7 countries were also quite similar to Table 2. However, it is noted that in the analysis of the G7 and BRICS, Germany, last in the ranking, showed lower efficiency than South Africa.

Italy leads in the energy efficiency ranking, 99.9%. Note that in its group it is the country with the lowest energy consumption, followed by France, which emits less CO_2. However, Japan (99%), France (98.9%) and the UK (98.9%), as well as Italy, have very similar positions in the ranking.

The United States (97.2%), Canada (96.5%) and Germany (96.5%) hold the last places in the ranking, but the difference between them and the others is minimal, which proves this group's high efficiency.

Analyzing the TFEE ranking, it is concluded that the G7 countries have similar positive characteristics, such as high efficiency and small standard deviation. These data demonstrate the small difference between these countries and their ability to convert the inputs considered into GDP, while assuming a position linked to the environment, characterizing them as energy efficient.

3.3. Econometric analysis of explanatory factors

Besides the analysis of the TFEE index, the factors that lead to better energy efficiency measures were quantified. Therefore, as mentioned in Section 2.3, a Tobit model estimation was performed by fixed and random effects, as shown in Table 10.

Table 10 presents all variables transformed into logarithms, a procedure that allows interpreting the parameters in terms of elasticity, while also reducing the heteroscedasticity.

According to Zhang et al. (2011), to address a possible autocorrelation across the residual terms on the panel time series, a time lagged dependent variable (efficiency) was introduced into the model, thus setting a Tobit dynamic approach.

Regarding the choice between the fixed and random effect models, the conducted Hausman test was unable to reject the null hypothesis that random effects provides consistent estimates ($p = 0.4737$). Furthermore, based on Honoré (1992), Greene (2004), Baltagi (2008), who argue that fixed effects Tobit model estimate by maximum likelihood is biased, underestimating parameters and standard errors, the random effects model was employed to assess the factors that lead to energy efficiency. Hence, the RE Tobit econometric model for the G7 and the BRICS countries was used in order to compare the estimated coefficients in each economic group, according to Table 10.

For G7 individually, just as in Zhang et al. (2011), the statistically significant coefficient of GNIPC squared suggests that there is a U-

Table 8
Mean Slacks of the G7 countries.

Country	Workforce	Gross fixed capital formation	Energy consumption	CO_2	GDP
Canada	0.00%	4.55%	3.49%	1.84%	1.09%
Italy	0.00%	1.29%	0.07%	0.38%	1.11%
France	0.12%	0.13%	1.15%	0.00%	0.49%
United Kingdom	0.41%	0.00%	1.15%	1.47%	2.25%
United States	0.83%	1.95%	2.84%	3.34%	1.84%
Japan	2.06%	5.61%	1.02%	0.24%	3.26%
Germany	5.80%	0.52%	3.52%	3.55%	5.78%
Mean	**1.32%**	**2.01%**	**1.89%**	**1.55%**	**2.26%**

Table 10
RE Tobit of BRICS and G7 group.

Variable	RE Tobit − BRICS		RE Tobit − G7	
	Coefficient	p-value	Coefficient	p-value
ln efficiency$_{it-1}$	0.997	0.000	0.948	0.000
ln number of patents	0.037	0.088	0.000	0.414
ln life expectancy at birth index	−0.124	0.655	0.370	0.003
ln years of schooling index	0.094	0.314	−0.074	0.018
ln GNIPC	0.470	0.557	−9.523	0.026
ln GNIPC^2	−0.030	0.533	0.455	0.025
_cons	−2.174	0.505	49.805	0.027

shaped relationship between TFEE and GNIPC, which means that energy efficiency first decreases with the income per capita increase due to the growth of industries up to a certain point, and after a certain level it increases. Unlike that found for the BRICS, in which this variable was insignificant.

On the other hand, for the G7 group the patent variable was statistically insignificant, while for the BRICS it was statistically significant for the TFEE. Thus, for the emerging BRICS countries, the highest number of patents contributes to the increased energy efficiency in the group, suggesting that in these countries research and innovations are contributing to technological advances in low energy consumption.

The opposite occurred with the variables life expectancy and years of schooling, which are negligible for the BRICS and significant for the G7, indicating that an increase in life expectancy in G7 increases the TFEE, while an increase in years of schooling decreases TFEE in the developed countries that compose this group.

These findings indicate that in the BRICS countries the results of energy efficiency measures are more related to investments in low energy consumption technologies, while in the G7 countries, the TFEE index tends to be better when countries have better social conditions, which in addition to high life expectancy, ensures a fair income distribution.

However, additional barriers can influence the energy efficiency of G7 and BRICS countries. The results of Kostka et al. (2013), for example, suggest that informational barriers are the core bottleneck inhibiting energy efficiency improvements in China's small- and medium-sized enterprises (SME) sector. Other barriers are: financial and organizational barriers, the role of family ownership structures, lax enforcement of government regulations and a lack of skilled labor and also the absence of government support also influence a company's energy saving activities.

In this regard, Jun Li and Bin Shui (2015) in their study, which analyzed the building of energy efficiency policies, highlight the importance of assuring the consistency between policies in the current regulatory framework to maximize the effectiveness of energy efficiency policies. For this, the authors claim that it is necessary to articulate measures to build and implement energy efficiency policies and broader energy and climate policies.

Jänicke (2012) also states that ambitious but realistic targets, flexible means and learning by doing can lead to a situation where even more ambitious targets become feasible due to increased capacity. The policy should be open to stimulate and use positive feedback mechanisms in a process of dynamic target setting.

In this context, the present study also emphasizes the need for government support, providing a coherent public policy framework that could contribute to maximize the effectiveness of energy efficiency in the G7 and BRICS countries. The analysis of the benchmark countries, identified by the DEA efficiency analysis and the TFEE index, as well as the factors identified by the econometric analysis can contribute to the formulation of successful policies.

4. Conclusion

It is known that energy is an essential component for the social and economic development of a nation, which should be closely linked to sustainable, safe and efficient energy use based on ecological and economically viable approaches for the future of society in the short and long term.

However, there are numerous problems that modern society must face to ensure a sustainable energy supply, while striving to reduce energy use. The rapidly increasing global energy consumption makes the problem even more complicated. The energy crises endured have shown how societies are vulnerable to geopolitical and climatic influences concerning their supplies.

In this investigation a comparison was performed between the BRICS and G7 countries by constructing, using the DEA, an efficiency index that measured the efficiency of these countries in transforming gross fixed capital formation, workforce and energy consumption into economic growth, without harming the environment with increased CO_2 emissions. As a result, this study showed that the G7 has a TFEE index well above the BRICS, 97.6% and 32.2%, respectively. Both groups are quite different, hence justifying the analysis of each group separately.

Therefore, considering the variables mentioned, the total-factor efficiency was first calculated for the BRICS using the DEA. Brazil

Table 9
Total-factor energy efficiency (TFEE) of the G7countries.

Ranking	Country	1	2	3	4	5	6	7	8	9	Mean	Standard deviation
		1993–2002	1994–2003	1995–2004	1996–2005	1997–2006	1998–2007	1999–2008	2000–2009	2001–2010		
1	Italy	100.0%	99.9%	99.9%	99.8%	99.8%	100.0%	100.0%	100.0%	100.0%	99.9%	0.3%
2	Japan	99.6%	98.4%	99.2%	99.7%	99.8%	97.7%	98.0%	98.5%	100.0%	99.0%	1.3%
3	United Kingdom	98.9%	99.5%	99.5%	100.0%	100.0%	100.0%	98.9%	96.0%	96.9%	98.9%	2.1%
4	France	99.3%	99.2%	99.3%	99.2%	98.7%	98.8%	98.8%	98.1%	98.2%	98.9%	1.7%
5	United States	99.6%	99.4%	99.6%	99.7%	98.3%	93.8%	94.2%	94.0%	95.8%	97.2%	4.0%
6	Canada	99.7%	99.0%	97.8%	97.7%	96.6%	95.9%	95.1%	94.4%	92.4%	96.5%	4.2%
7	Germany	100.0%	99.9%	99.9%	95.6%	95.3%	96.2%	89.2%	96.2%	96.0%	96.5%	4.8%

was placed first in the ranking (99.36%), followed by South Africa, China, Russia and India.

In addition, to better understand the results of the efficiency analysis, an analysis of the slacks of each variable was performed, which showed that the variables CO_2 emissions and energy consumption were the ones with the highest average slacks and therefore should receive more attention in order to ensure that measures are taken to improve the current efficiency levels. This result may indicate, among other things, that the BRICS countries need to invest more in renewable energy sources or take measures to improve energy efficiency, such as more efficient technologies or processes.

It is emphasized that the slack cannot be interpreted as a rigid target, as it is only an indication of which variable is more detrimental to the efficiency of countries in terms of productivity, in relation to the others. Therefore it is possible that a given country has no possibilities to increase or decrease the variables in the proportions indicated by the slacks, for example, given the country's current structure and its economic scenario.

Besides analyzing the slacks, provided by the DEA, of the variables considered in this study, a total-factor energy efficiency (TFEE) index was also calculated. Through this index, it was found that Brazil and South Africa stand out as the most energy efficient countries in the BRICS group, with a TFEE index of 99.95% and 97.27%, respectively, followed by China (74.24%), India (44.33%) and Russia (23.54%).

Brazil's good ranking, when compared to the BRICS countries, may be the result of mechanisms by the federal government to promote energy efficiency. Of the national programs implemented in previous decades and still in operation, the most important ones are PROCEL – National Program for Energy Conservation (since 1985), CONPET – National Program for the Rational Use of Oil Products and Natural Gas (since 1991) and the mandatory energy efficiency programs administered by ANEEL – supervised utilities and distribution companies.

The results corroborate the literature by showing that the BRICS countries have very different energy realities, which will also result in different energy policies. However, as already mentioned, what unites this group of countries in terms of energy is not so much the similarity of its energy contexts, but rather the fact that together or separately this group has an important role in the context of energy evolution worldwide.

The same analysis was performed for the G7 countries, which showed, unlike the BRICS, much homogeneousness within the group. With respect to total-factor efficiency, Italy was first in the ranking, followed by Japan, UK, France, USA, Canada and Germany. It should be noted that all the countries of the group showed over 90% average efficiency. With regards to the slacks of the variables analyzed, they were all quite small, less than 5%, which shows the similarity between the countries of the group with respect to total-factor structure.

The homogeneity of the G7 group is also evident in the ranking of the TFEE index, in which all countries also had an index higher than 95%, with Italy in first place, followed by Japan, UK, France, USA, Canada and Germany.

However, the index proposed in this paper has limitations, mainly related to the heterogeneity of the countries compared. Thus, the interpretation of this index requires taking into consideration the peculiarities of each country, the social, economic and environmental dimensions.

After the TFEE index was measured, the factors that contribute to better energy efficiency measures were calculated through the Tobit econometric model. The results showed that the factors are different for the two groups analyzed. For the BRICS, what influences the TFEE increase is the variable "patents". For the G7 group, the factors influencing energy efficiency are "GINIPC", "life expectancy" and "years of schooling". The Tobit estimation results suggest there is a U-shaped relationship between TFEE and GINIPC for the G7 group only, which means that energy efficiency first decreases with income per capita, and then after a certain level it increases.

Thus, according to the results presented, the benchmark countries could be identified with respect to total-factor energy efficiency, so that the G7, Brazil and South Africa can be good references for sustainable practices, and should be further examined. The other countries are worthy of more attention with respect to improvements, in order to reduce energy consumption without harming economic growth. Therefore, in these countries it is possible to guide government resources and give attention to policy incentives to implement energy efficiency measures.

The TFEE index is able to measure energy efficiency considering a total-factor structure. However, as with all DEA analysis, the TFEE index for a single country is often affected by the other countries in the sample given that the production frontier constructed depends on this sample. Therefore the results should be carefully interpreted.

Although its use requires attention, the index measured is important in terms of being useful for public policies related to energy efficiency, with the following potentials: contribute to the discussions related to evaluating the countries' energy use, to help identify those with the best practices with regard to environmental and economic aspects; and guide policy decisions regarding government incentives to promote the development of efficient countries in terms of economic growth with minimal use of resources (capital, labor, energy), without harming the environment.

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