



Energy efficiency analysis of BRICS countries: a study using Data Envelopment Analysis

Análise da eficiência energética nos países do BRICS: um estudo envolvendo a Análise por Envoltória de Dados

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Abstract: In a period of climate change and increased restriction of emissions, it is pivotal to focus on the development of countries towards an economy revolved on low carbon dioxide levels. The increase of energy consumption has become a serious problem; consequently, measures to ensure energy efficiency became a priority for any nation willing to develop their economy. Whereas the BRICS group has shown rapid economic development and played an important role in the world economy, this work aimed to measure and analyze total factor energy efficiency in BRICS countries (Brazil, Russia, India, China and South Africa), providing information on benchmark countries within this group and on how Brazil is situated in this scenario. To this end, Data Envelopment Analysis (DEA), Slack-based Measure (SBM) and variant analysis window were used; from the slacks provided by this tool, the total factor of energy efficiency index (TFEE) was calculated. The inputs used were gross fixed capital formation, labor and energy consumption; the outputs were CO₂ emissions (undesirable output) and Gross Domestic Product - GDP (desired output). From the results, it was possible to observe that Brazil is the country with the highest rate of TFEE, followed by South Africa, China, India and Russia.

Keywords: DEA; BRICS; Total factor energy efficiency.

Resumo: Num período de mudanças climáticas e restrições a emissões cada vez maiores, é importante focar o desenvolvimento das nações na direção de uma economia de baixo carbono. Neste contexto, o crescimento do consumo de energia tornou-se um problema grave; logo, medidas que garantam a eficiência energética tornaram-se prioritárias para qualquer nação que esteja disposta a desenvolver sua economia. Considerando que o grupo do BRICS tem apresentado rápido desenvolvimento econômico e desempenhado importante papel na economia mundial, este trabalho teve como principal objetivo medir e analisar a eficiência energética total de fatores nos países que compõem o BRICS (Brasil, Rússia, Índia, China e África do Sul), propiciando informações sobre países benchmark dentro desse grupo e sobre como o Brasil se encontra nesse cenário. Para isso, foi utilizada a Análise (DEA), modelo SBM variante e análise de janela, e, a partir das folgas fornecidas por esta ferramenta, foi calculado o índice de eficiência energética total de fatores (EETF) para os países analisados. Como inputs foram utilizados a formação bruta de capital fixo, trabalho e consumo energético e como outputs, a emissão de CO₂ (output indesejável) e o Produto Interno Bruto – PIB (output desejável). A partir dos resultados, observou-se que o Brasil é o país com melhor índice de EETF dentro do BRICS, seguido por África do Sul, China, Índia e Rússia.

Palavras-chave: DEA; BRICS; Eficiência energética total de fatores.

1 Introduction

Throughout history, humans have had a purely extractive attitude towards natural resources. Due to the problems generated by this operation, the United Nations (UN) created, in 1980s, the World Commission on Environment and Development (UNCED), known as the Brundtland Commission.

The commission criticizes the risk of overusing natural resources without considering the capacity of the ecosystems to meet these demands, pointing out the mismatch between sustainable development and the existing production and consumption patterns (Braga, 2007).

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There is a steady growth in energy demand to sustain the development of countries. At the same time, this energy demand increases the concentration of Greenhouse Gases (GHGs), especially carbon dioxide (CO₂) in the atmosphere, consequently intensifying the natural greenhouse effect and global warming. The results presented in the IPCC report (2007) confirms that the causes of global warming are largely attributed to human activities, especially those related to CO₂ emissions.

In this context, the increase in energy consumption has become a serious problem. According to Lucon & Goldemberg (2007), the current standards of production and energy consumption in the world are largely based on fossil fuels, which generate emissions of local pollutants, greenhouse gases and put at risk the long-term supply of natural resources in the planet, which are non-renewable. According to the IPCC (2007), about 90% of anthropogenic carbon dioxide (CO₂) emissions produced annually come from the burning of fossil fuels.

According to Narayan et al. (2007), the pressure on the world's major economies to improve energy efficiency has forced man to investigate ways to reduce the need for energy consumption in order to avoid energy waste and pollution, therefore contributing to development with sustainability.

Within this context, the long-term relationship between energy consumption and real GDP of 25 OECD countries were analyzed in the study of Belke et al. (2011). The authors suggest that economic growth is directly related to energy consumption. It is therefore important that the planning of efficient energy conservation policies consider the direct impacts of energy consumption on economic growth and the consequences of economic growth on energy consumption.

Thus, in order to advance towards the construction of an efficient world economy in the use of resources, it is important to evaluate and estimate the energy savings and emissions reduction potential of countries, considering their economic growth. This analysis can provide useful information for energy and environmental policymaking process, and contribute to the sustainable development of countries that impact world economies.

Macroeconomics generally uses a monetary base to measure the level of energy efficiency, referring to the current energy consumption per production unit. Recently, a growing number of studies on developed economies, such as USA (Mukherjee, 2008), Japan (Honma & Hu, 2008), China (Wang et al., 2012, 2013; Wu et al., 2012; Watanabe & Tanaka, 2007; Hu & Wang, 2006) and India (Mukherjee, 2010), has contributed to measuring energy efficiency focusing on the analysis of total efficiency factors, in which any production process of the economy can be seen

as a joint production process in which multiple energy inputs and other materials and resources are used for the production of multiple desired outputs (e.g. PIB) and undesired outputs (e.g. CO₂ emissions) as byproducts.

Based on this context, the objective of this study is to measure and analyze the Total-Factor Energy Efficiency index (TFEE) in the BRICS countries (Brazil, Russia, India, China and South Africa) providing information on benchmark countries in the BRICS group and the role Brazil has in this scenario.

In this study, the BRICS was chosen due to its economic stature and global influence. According to Amorim (2010), the BRICS, in addition to rapid economic growth, hold significant land mass, natural resources and considerable amounts and diversity of energy and technological advances.

In this work, the analysis tool used was the data envelopment analysis (DEA), through the SCM variant model and windows analysis, simultaneously maximizing the outputs and minimizing the inputs. Subsequently, with the slacks provided by the DEA, the Total-Factor Energy Efficiency (TFEE) index was calculated. It should be noted that most studies assessing the energy efficiency at the macroeconomic level using a total factor structure adopt the DEA method, as it provides an appropriate mechanism for dealing with multiple inputs and outputs to measure the efficiency ratio of each decision making unit (DMU) under evaluation.

2 Literature review

2.1 Energy efficiency and BRICS

Considering that the higher the level of economic activity, the greater the energy use and the environmental impacts of this use, energy efficiency can provide security and additional benefits, such as mitigating CO₂ emissions and decreasing energy imports (Selvakkumaran & Limmeechokchai, 2013). These benefits are complementary, implying a reduction in the energy required per unit of economic product, increasing the economic efficiency and ensuring that the same output can be obtained with less energy and thus less use of natural resources and less environmental damage.

Historically, the OECD countries are the largest consumers of energy. The study of Niu et al. (2011) conducted to assess the causality between energy consumption, GDP growth and carbon emissions for eight countries in the Asia-Pacific between 1971 to 2005, concluded that carbon emissions, per capita energy consumption and the efficiency of energy use in developing countries are much lower than those of developed countries. However, the participation of developed countries in the world's total energy consumption has receded over time. In developing

countries, the relative participation recorded a cumulative increase of more than 100% over the past three decades.

Among developing countries, the BRICS group (Brazil, Russia, India, China and South Africa) has been gaining attention. The BRICS countries are an alliance covering four continents and all members are emerging economies, with actions that go beyond pure diplomacy.

The five countries that form the block are generally grouped by their similarities. But separately, they have different economic, social, political and cultural characteristics, as well as differences in history, religion, geographies and climates (Almeida, 2009). Furthermore, Leonova et al. (2007) argued that each country has its peculiarities with regard to customers, industries, growth trends, environmental governance and resources. Accordingly, Armijo (2007) came to the conclusion that this group of countries does not form a homogeneous whole.

Furthermore, there are economic aspects of these countries that should not be disregarded. Together, the BRICS countries (Brazil, Russia, India, China and South Africa) account for a fifth of the economy in the world and account for 43% of world population (Duarte, 2014). As a matter of fact, South Africa, with the highest growth potential, only became part of the group of countries in 2011, thus the letter “S” incorporated into the BRIC acronym, changing it to BRICS.

Besides its economic importance, the group will greatly influence world politics. According to Amorim (2010), the BRICS, in addition to rapid economic growth, hold significant land mass, natural resources and considerable quantity and diversity of energy and substantial technological development

There is a concern about how these countries will develop, as mentioned in the work entitled “The Limits to Growth” by Meadows et al. (1972), if these countries consume the same level of resources as the current economic powers, the planet will reach a catastrophic situation.

According to Pao & Tsai (2010), to reduce carbon emissions without hurting economic growth, BRIC countries should increase investment in energy supply and energy efficiency, and intensify conservation policies to reduce energy waste.

According to World Bank data (Banco Mundial, 2013) in 2010, the energy consumption of the five BRICS countries was higher than the seven G7 countries; $4213.8 * 10^3$ Ktoe against $3927.5 * 10^3$ Ktoe, respectively. It is therefore important to look into the nature and characteristics of this high consumption. For that reason, this work uses the data envelopment analysis, and from the energy slacks provided by this tool the total-factor energy efficiency index was calculated for each of the BRICS countries.

2.2 Data envelopment analysis

The data envelopment analysis technique (DEA) has been successfully employed to evaluate the relative performance of a set of firms, usually known as Decision Making Units (DMU), which use the same inputs to produce the same outputs (Ramanathan, 2006). The DEA has its origins in the work of Charnes et al. (1978) and Banker et al. (1984), both based on Farrell (1957), who proposed an empirical model to measure the relative efficiency. According to Farrell (1957), it is more advisable to determine the efficiency of a firm or an administrative unit, comparing it to the best level of efficiency observed, than to compare it to some unattainable ideal.

Thus, the DEA evaluates the relative efficiency of a set of DMUs, which in this work is represented by the BRICS countries. This approach has the advantage of considering both multiple inputs and outputs that characterize a particular production process. In addition, the DEA allows DMUs to have immediate information on their respective efficiency or inefficiency status, which in turn will depend on the DEA model used (Oggioni et al., 2011). Each model, depending on the type of return to scale, on the frontier format and the orientation chosen, will lead efficiency to a different value, which should be construed in accordance with the hypotheses regarding the model used (Mariano, 2008).

Charnes et al. (1978), developed the first mathematical model for DEA called CCR, which adopted the Constant Return Scale (CRS) over the entire production line. Having constant return to scale means using the hypothesis that the inputs and outputs are proportional to each other, which means that the efficient frontier format of the CCR model is a straight line with an angle of 45 degrees. The CCR model calculates the efficiency of a DMU dividing its productivity by the productivity of the most productive DMU of a given set, without worrying about the scale.

The extent of the CCR model proposed by Banker, Charnes and Cooper, in 1984, formulated the BCC model, which features the Variable Return Scale (VRS). The BCC model compares only DMUs operating on a similar scale. Thus, in this model, the efficiency of a DMU is obtained by dividing its productivity by the highest productivity among the DMUs that have the same type return to scale. The frontier of the BCC model consists of a set of straight lines of various angles, which characterizes a linear frontier by parts.

According to Coelli et al. (1998), the CCR and BCC models may have two orientations: to maximize the outputs or minimize the inputs. When working with additive models, developed by Charnes et al. (1985), it is not necessary to choose an orientation, as the original template simultaneously considers maximizing the outputs and minimizing the inputs, when the additive model will provide a situation

where the DMU is expected to do less work, in terms of reducing the inputs and increasing the outputs, in order to achieve efficiency. It is seen that the additive model may be variant, variable return to scale, or invariant, with constant returns to scale.

However, the additive model does not calculate the performance index of the DMUs being compared; it only allows indicating the efficient DMUs and goals of the inefficient DMUs. Therefore, the interpretation of the results of this model should be carried out somewhat different from the BCC and CCR models, where 100% indicates an efficient DMU. In the additive model, the value of the objective function represents the distance from the DMU to the efficient frontier. Therefore, the DMU under consideration is efficient when the result of the objective function is zero, therefore the further away it is from zero, the more inefficient is the DMU.

Because of this limitation in the additive model, some improvements have been proposed, such as the SBM model (Slacks-Based Measure). This model, which was introduced by Tone (2001), is quite similar to the additive model, since it also considers a simultaneous orientation to the inputs and outputs, but provides, as a result, an efficiency value ranging from zero to 100%. Thus, the results of this model, although they originate from the same assumptions of the additive model, may be interpreted similarly as the results of the CCR and BCC models.

It should be mentioned that besides allowing to measure the relative performance of the selected countries, this method also allows to calculate the slacks, which express how much each country should increase or decrease each variable to achieve efficiency compared to other countries. The slack expresses how far the current performance of the DMU in each variable is from its ideal performance, which can be symbolized by a virtual DMU lying on the efficiency frontier (also referred to as benchmark). This ideal performance can be considered a target for the inefficient DMUs, which can be calculated according to Expressions 1 and 2:

$$\text{Target input} = x_{j0} - S_j, \text{ para } j = 1, 2, 3 \dots n \quad (1)$$

$$\text{Target output} = y_{i0} + S_i, \text{ para } i = 1, 2, 3 \dots m \quad (2)$$

The relative slack can be determined from the current performance and goal, the percentage expressing the level of improvement needed for each variable in each country. The relative slack can be determined by Expression 3:

$$\text{Relative slack} = (\text{Target} - \text{Current}) / \text{Current} \quad (3)$$

3 Method

In this work, emerging countries were selected (the BRICS group) in order to analyze the energy

efficiency based on the total factor productivity perspective. Thus, the units were considered to meet the present study were Brazil, Russia, India, China, South Africa.

To achieve the goal proposed in this paper, we used a mathematical programming method known as data envelopment analysis (DEA). This method was used to construct an economic production function to analyze the energy efficiency considering a total factor structure. Thus, the energy is taken in conjunction with conventional inputs: workforce and capital. The latter is typically used in economic productivity analyses as inputs to produce an economic output (GDP). For economy or region, it is preferred that the GDP increase occurs while simultaneously decreasing the energy consumption, so that it reaches the production efficiency. Therefore, the targets for GDP growth and efficiency in energy consumption should be put together in order to sustain economic development (Hu & Wang, 2006).

Wu et al. (2012), Mandal (2010) and Watanabe & Tanaka (2007) indicate that analyzing energy efficiency without considering environmental efficiency can lead to skewed results of the energy efficiency evaluation. The comparative analysis that evaluates the environmental performance and energy efficiency carried out by Wang et al. (2012), confirmed that this bias will be seen if the undesirable output (CO₂) is omitted in the evaluation. Thus, this work also considered the CO₂ emission levels of BRICS, which is one of the most important undesired outputs of energy consumption. It should be noted that the CO₂ emissions considered are the results from the burning of fossil fuels.

Therefore, this analysis used three input variables: workforce, gross fixed capital and energy consumption; and two output variables: GDP (desired output) and CO₂ emissions (undesirable output). All variables were collected from the World Bank website, from 1993 to 2010, the period in which the data for all countries was available. Moreover, when measuring the energy and environmental efficiency, our intention was to reduce energy consumption, workforce and capital used as much as possible, while simultaneously increasing the desirable output (GDP). With regard to unwanted output (CO₂ emissions), it is better when less emissions are generated. Therefore, in this paper, the unwanted output was modeled as an input, which consists of one of the DEA strategies for the treatment of undesirable outputs.

Accordingly, in this work it is observed that the simultaneous guidance for minimizing inputs and maximizing outputs is more appropriate. Therefore, for this study, we adopted the SBM variant model. This method also provides the values of each variable that countries should increase or decrease to achieve greater efficiency. These values, as already mentioned,

are also known as slacks. Additionally, this model allows comparing countries that operate at different scales, implying that reductions or increases in inputs do not necessarily produce changes in the same proportion as outputs. Expressions 4 to 9 show the SBM variant model according to Tone (2001):

$$Min \tau = t - \frac{1}{n} \sum_{j=1}^n S_j / x_{j0} \tag{4}$$

Subject to:

$$1 = t + \frac{1}{m} \sum_{i=1}^m S_i / y_{i0} \tag{5}$$

$$\sum_{k=1}^z x_{jk} \cdot \lambda_k + S_j = t \cdot x_{j0}, \text{ for } j=1,2,\dots, n \tag{6}$$

$$\sum_{k=1}^z y_{ik} \cdot \lambda_k - S_i = t \cdot y_{i0}, \text{ for } i=1,2,\dots, m \tag{7}$$

$$\sum_{k=1}^z \lambda_k = t \tag{8}$$

$$\lambda_k, S_j \text{ and } S_i \geq 0 \text{ and } t > 0 \tag{9}$$

Where:

λ_k : Participation of the DMU k for the goal of the DMU under analysis;

x_{jk} : Amount of input j of DMU k;

y_{ik} : Amount of output i of DMU k;

x_{j0} : Amount of input j of DMU under analysis;

y_{i0} : Amount of output i of DMU under analysis;

z: Number of unit assessed;

m: Number of outputs;

n: Number of inputs;

S_i : Slack variable of output i;

S_j : Slack variable of input j.

t: linear adjustment variable.

According to Honma & Hu (2008) and Hu & Wang (2006), efficiency is usually defined in terms of the relationship in which the best practice is compared to the actual operation. The energy efficiency indicator should be the relationship between the energy that should ideally be consumed and the current energy consumption. The amount of total adjustments of the input “energy consumption” is considered as the ineffective portion of actual consumption. Thus, based on the energy gap settings obtained from the DEA, the percentage of energy that must be conserved can be calculated, while considering other factors. If the gap is equal to zero, i.e., if there is no adjustment for the amount of input “energy consumption”, then the

country has optimum efficiency for energy consumption when its output is maximized. Therefore, the energy efficiency of a country is set by the Expression 10, which is called the total-factor energy efficiency (TFEE) for the country i at time t, since the index is built from the point of view of the total-factor yield.

$$TFEE(i,t) = 1 - \frac{\text{input_energy_slack}(i,t)}{\text{Energy_consumption_current}(i,t)} \tag{10}$$

The TFEE index represents the efficiency level of energy consumption in a country. As the slack variable “energy consumption” represents how the country should reduce energy consumption to achieve the best practical level of this variable, the current energy consumption will be always greater than or equal to the slack. This means that the TFEE index is always between zero and 1. In this study the index is shown in the form of percentage.

With this panel data, it was deemed interesting to conduct a window analysis, which is a way to include the time factor within the DEA, according to Cooper et al. (2000). The window analysis consists of a structured method to combine DMU data related to several different years in the same application, and this is done by performing multiple DEA applications considering different combinations of years (window). Thus, it can be concluded that the window analysis is also an important way to avoid the problem of low quantities of DMUs, which according to Cooper et al. (2000) should be at least three times the sum of the number of inputs to the number of outputs.

Therefore, window analysis consists of separating 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. This information can be obtained through expressions 11 and 12, where k is the number of periods and p is the window size, which is rounded up, if necessary.

$$\text{Size_of_window}(p) = (K + 1) / 2 \tag{11}$$

$$\text{Number_of_windows} = k - p + 1 \tag{12}$$

To illustrate how these formulas are used and the subsequent construction of windows for the analysis, which assesses the data available 1993-2010 (k = 18), the window size should be 10 and the number of windows must be 9, comprising, respectively, the data from (a) 1993-2002 (b) 1994-2003, (c) 1995-2004 (d) 1996-2005 (e) 1997-2006 (f) 1998-2007 (g) 1999-2008, (h) 2000-2009, (i) 2001-2010.

After constructing all windows, the DEA must be used for each of them, so that a table, which includes all data for each unit in each window, can be prepared later on. It should be noted that in this approach, the final efficiency result of each DMU should be the average of all efficiencies obtained in every year

and in all the windows, and the standard deviation of each DMU may also be calculated to verify the stability of efficiency over time.

In this work, besides the result tables that incorporate the efficiency obtained in each of the windows of countries, tables which incorporated the results of the slacks of each variable for each DMU in each window were also prepared. Similarly, the end result of each slack variable for each DMU was the average slack that was achieved in all years in all windows.

4 Results and discussion

First, an analysis using the boxplot graphic was performed to determine if the units used in this work are homogeneous. According to the results, one outlier was found, China. However, as DEA has no restrictions on the use of outliers, as an outlier can perform on equal terms with other DMUs, despite having a different performance, it was decided to keep China in the analysis in order to include all BRICS countries in the study.

From the application of the variant SBM Model of DEA and window analysis, the behavior of the BRICS countries in 1993-2010 was observed, considering the inputs workforce, gross fixed capital formation and energy consumption and the outputs GDP (desired output) and CO₂ emissions (undesirable output). Table 1 shows the rankings obtained.

The data envelopment analysis showed that Brazil is the most efficient in reducing inputs and undesirable outputs and increases GDP. Therefore, it can be assumed that increasing the inputs, this country can generate more GDP output and sustainable growth.

South Africa is second in the ranking. Although this country has the smallest inputs and outputs, it holds one of the best positions in relation to the efficiency index, and low standard deviation. Although S.A. is gaining ground internationally, national problems such as disease and violence still prevail.

China presented a good average efficiency level, third in the ranking. It also achieved a fairly high standard deviation, which can be explained by the fact that there were significant and rapid improvements from one year to the next, which culminated in ensuring that the most recent year of each window

showed 100% performance in relation to the other years, which increased the variability.

Russia, second to last in the ranking, showed average input variables. However, for a country which in recent decades has become a globally isolated economy, it is in a good scenario.

Finally, India, last in the ranking, showed no improvement or worsening over the years analyzed. Thus, it was concluded that the country has not improved its efficiency in the use of its inputs for GDP formation.

In order to better understand this result, an analysis of the slacks for each variable presented by the countries was carried out.

4.1 Analysis of slack variables

This topic enables analyzing the classification of countries in the ranking of total factor structure, according to the analysis of each variable through the slacks. To this end, a ranking (1-5) of the slack averages for each variable was built, indicating which country needed to change more the variable analyzed to improve the relative efficiency (5), and which country needed to change less the variable (1) in order to increase efficiency of the other countries, in this case appearing as benchmarking of this variable for the other members of the BRICS countries.

The overall mean efficiency of slacks in each variable showed that the ranking of the variable slacks was: CO₂ emissions (36.15%), energy consumption (32.13%), workforce (30.05%), GDP (14.51%) and gross fixed capital formation (5.16%), respectively.

Table 2 shows the mean slacks for each variable in each country.

As observed, as the variable CO₂ emissions generally showed the largest slacks for the countries, it should receive priority attention so that steps are taken to reverse the current trend. This result may indicate, among other things, that the BRICS need to invest more in renewable energy sources and measures to improve energy efficiency, such as processes or more efficient technologies.

Energy efficiency measures are justified because the CO₂ emissions considered in this work are related to fossil fuels. Therefore, actions intended to improve

Table 1. Total-factor efficiency of BRICS countries.

Ranking	Country	1	2	3	4	5	6	7	8	9	Mean Slacks	Standard Deviation
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%

the energy efficiency of countries would also result in a decrease of emissions. Thus, it emphasizes the importance of the focus of this work on the energy consumption of each BRICS country. In addition, the variable energy consumption showed high slacks, and it was second in the ranking of slacks.

The analysis of the data collected from CO₂ emissions showed that the level of CO₂ emissions of the BRICS increases over the years. The slacks provided by the DEA enabled to present a ranking of the BRICS countries, as shown in Table 3, which indicates how much each country should reduce this percentage variable to achieve the efficient frontier.

The most efficient CO₂ emissions, according to the average of the slacks, are Brazil and South Africa, with averages of 1.10% and 2.58% respectively. Both maintain a slack of 0% in most of the years analyzed, especially in recent years of each window.

Despite these results, according to the Banco Mundial (2014), although Brazil has made progress in reducing deforestation and has become a leader in climate negotiations stating they would voluntarily and progressively reduce these emissions, it has faced challenges in combining the benefits of agricultural growth, environmental protection and sustainable development.

India, as well as Russia, second to last and last in this variable slacks classification, respectively, showed higher average slacks. In addition, the analysis of each window shows that the mean slack ratio has increased in each window in recent years. With this data, it can be concluded that at a time when sustainability is sought, Russia and India are not improving their efficiency over time, that is, seeking to reduce carbon

emissions while maintaining or increasing the GDP through better use of alternative energy sources or energy efficiency measures.

May (2008) states that emissions are an obstacle to India’s development, since India’s production sector relies heavily on coal. Nassif (2006) claims that there is no evidence that this country seeks to ensure sustainable growth, which, according to the Banco Mundial (2014), is third in global carbon emissions.

On the other hand, in the pursuit to reduce emissions and focusing on the economy of their country, amid discussions on the future sales of Russian gas to Ukraine and to the European Union, Russia and China struck a billionaire gas supply contract. The agreement, effective for 30 years, establishes that the Russian Gazprom group will provide annually, from 2018, up to 38 billion cubic meters of natural gas to the neighboring country, according to the National Corporation of China Petroleum (CNPC). The deal is valued at 400 billion dollars (G1, 2014).

China, in turn, is third in the ranking of mean CO₂ emission slacks, averaging 26.20%. One of the most important aspects related to China’s economic growth is their dependence on thermal coal. Then came the finding by the International Energy Agency that China’s CO₂ emissions would exceed that of the U.S. in 2010, this in fact occurred much earlier than planned, in 2007 (Instituto Carbono Brasil, 2007).

However, improvements are taking place, which is reflected in the high standard deviation of 0.2501. According to the analysis, there is a considerable decrease in the percentage of the variable slack over the years, especially in recent years, with the mean

Table 2. Average slacks of 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%
General Average	30.05%	5.16%	32.13%	36.15%	14.51%

Table 3. CO₂ Emissions.

Ranking	Country	1	2	3	4	5	6	7	8	9	Mean	Standard Deviation
1	Brazil	0.7%	1.8%	2.6%	2.4%	1.5%	0.3%	0.3%	0.3%	0.0%	1.10%	0.0218
2	South Africa	4.4%	2.3%	2.8%	2.2%	1.6%	1.9%	1.9%	3.0%	3.1%	2.58%	0.0366
3	China	45.0%	35.2%	29.3%	24.6%	21.2%	22.2%	21.7%	15.1%	21.6%	26.20%	0.2501
4	India	73.0%	71.8%	70.5%	71.2%	72.2%	72.7%	73.3%	73.9%	74.1%	72.53%	0.0322
5	Russia	79.1%	78.3%	78.4%	77.7%	77.9%	78.0%	78.3%	78.4%	78.9%	78.33%	0.0112
General Average											36.15%	

slacks of this variable ranging from 45% in the first window to 21.6% in the second one.

In Table 4 the slacks of the variable energy consumption are classified the same as the variable CO₂ emissions. This is explained by the expected positive correlation between these variables, since the annual CO₂ emissions come from the burning of fossil fuels.

Thus, Brazil and South Africa lead the ranking of slacks for energy consumption, with an average 0.05% and 2.73% respectively. Over the years, energy consumption in these countries was mostly efficient, possibly due to the wide use of alternative energy and/or increased awareness by the people.

China has improved this aspect and has been able to decrease its average slack. However, at the beginning of the study period, it was observed that its consumption increased, therefore it still is third in the ranking, with an average of 25.76%. However, the last year of each window was efficient in relation to this variable, 0% slack. This change in China's energy consumption is seen in the standard deviation of 0.218, the highest among the BRICS countries for this variable.

However, India has increased the slack for this variable in each window in recent years, justifying the fourth place in the ranking with a slack average of 55.67% and standard deviation of 0.0209.

Finally, in Russia, the slacks for energy consumption have decreased. However, at a very low rate, since the difference between the first and last years of each window do not differ significantly. Therefore, this country is as last in the ranking with an average of 76.46% and a standard deviation of 0.0260.

GDP is the sum, in monetary terms, of all final goods and services produced in a given region over a given period. Its main objective is to measure the economic activity of a region. GDP counts only final goods and services, excluding all intermediate consumer goods.

The analysis of the data collected in the 1993-2010 period showed a GDP increase in all countries except Russia, due to the fall of the Soviet Union. According to the data, Russia can regain progress in 1998.

Table 5 shows the average ranking of the slacks for the variable GDP from the DEA analysis.

In relation to GDP, Brazil and South Africa are nearly efficient, with a considerable number of zero slacks over the periods analyzed. Therefore, they occupy the first and second position in the ranking of slacks, with an average of 0.30% and 0.55%, respectively, with standard deviation of 0.0083.

However, China is in third place in the ranking with a slacks average of 4.03% and standard deviation of 0.0481. It is seen that for the most recent year of each window, the GDP slack for that country is 0. This finding is consistent with the analysis of the other variables, which shows that this country has been seeking efficiency with respect to the conversion of gross fixed capital formation, workforce and energy consumption in GDP without increasing CO₂ emissions.

Russia ranks fourth, with a slack average of 28.35% and a standard deviation of 0.1689. The position could be better, if that country continued with the performance seen in the first three windows in which the slacks for this variable decreased over time. However, the fourth window (1996-2005) showed that Russia is moving away from the GDP variable

Table 4. Energy Consumption.

<i>Ranking</i>	<i>Country</i>	1	2	3	4	5	6	7	8	9	Mean	Standard Deviation
1	Brazil	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.05%	0.0020
2	South Africa	6.1%	4.4%	1.9%	1.8%	1.5%	1.8%	1.8%	2.2%	3.1%	2.73%	0.0336
3	China	39.9%	33.2%	28.8%	25.7%	22.7%	23.0%	21.8%	15.9%	20.9%	25.76%	0.2184
4	India	58.4%	55.5%	54.7%	54.8%	55.1%	55.1%	55.5%	55.8%	56.0%	55.67%	0.0290
5	Russia	78.9%	78.2%	77.8%	76.7%	77.3%	76.0%	75.2%	74.3%	73.7%	76.46%	0.0266
General Average											32.13%	

Table 5. PIB.

<i>Ranking</i>	<i>Country</i>	1	2	3	4	5	6	7	8	9	Mean	Standard Deviation
1	Brazil	0.4%	0.3%	0.9%	0.7%	0.4%	0.0%	0.0%	0.0%	0.1%	0.30%	0.0083
2	South Africa	0.7%	0.7%	0.7%	0.1%	0.3%	0.4%	0.4%	0.6%	1.0%	0.55%	0.0083
3	China	1.6%	0.9%	0.8%	2.3%	4.2%	6.6%	7.9%	8.4%	3.6%	4.03%	0.0481
4	Russia	29.4%	27.8%	22.9%	20.5%	22.9%	26.4%	30.7%	35.6%	38.9%	28.35%	0.1689
5	India	43.0%	46.8%	47.9%	45.3%	42.0%	38.3%	33.4%	31.2%	26.2%	39.35%	0.1862
General Average											14.51%	

efficiency, since the slack increases at every recent year of the window.

Finally, India, different from what it has shown in other variables, shows improvements in the mean slacks in relation to GDP, with a decrease in recent years in a window, reaching zero slack in recent years, in windows 8 (2000-2009) and 9 (2001-2010). This country ranks in fifth position, with an average of 39.35% and the highest variability (0.1862) among the analyzed countries.

4.2 Total-factor energy efficiency index

With the DEA results, the total-factor energy efficiency index (TFEE) was calculated from the slacks of energy consumption and current energy consumption for each BRICS country in each window, as shown in Table 6.

According to the results presented, considering the variables analyzed in this work, Russia is the last country in the ranking of the TFEE index. However, consistent with what was observed in the slacks analysis of the variable energy consumption, Table 4 can verify that this country grew over the periods analyzed, with the average TFEE index ranging above 21.1% in the first window (1993 to 2002) to 26.3% in the last window (2001-2010).

India is second to last in the TFEE ranking, showing that although this country has outperformed Russia, it does not show large variability, indicating no significant improvement or worsening, maintaining similar levels in the TFEE index over the years analyzed. Note that the first window is the one with the highest percentage difference compared to the other windows.

The third in the performance ranking is China, which grew in the TFEE index according to the most recent periods contemplated in the windows. The performances averages went from 60.11% in window 1, to 79.14% in window 9. Significant growth can be seen over the years. It is noteworthy that the variability of that country was relatively large when compared with those of other countries, and the standard deviation was 21.84%. Therefore, we conclude that China has brought about improvements in recent years in relation to its ability to transform energy, workforce and capital into GDP without increasing CO₂ emissions. However, it should be noted that this

is the country that most consumes fossil fuel energy and emits more carbon dioxide. Thus, their growth sustainably is possible, but challenging.

South Africa, according to Table 6, had the second highest variability compared to the average performance (standard deviation of 3.36%). However, although it is still much lower when compared to China, it increased in the TFEE index, from 93.9% in the first window, to 96.9% in the last window.

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

Today, there are two other instruments to promote more efficient technologies. One is the Law 9991 of July 24, 2000, determining that concessionaires and licensees of public services of electricity distribution are required to annually apply an amount of at least 0.75% of its net operating revenue in research and development of the electricity sector and at least 0.25% in end-use energy efficiency programs (Brasil, 2013).

Another instrument is the Law 10.295, of October 17, 2001, under which the Executive Power determines maximum levels of specific energy consumption or minimum energy efficiency of machinery manufactured or marketed in the country, based on relevant technical indicators (Brasil, 2013).

Therefore, although in that country investments in energy efficiency programs have been marginal compared with the investments allocated to promote available options for increasing the energy supply (production/import, transport and distribution), Brazil has the potential to reverse this situation in the future, depending on initiatives such as the inclusion of new energy efficiency programs in the national energy planning, competing with the increasing energy supply options (Brasil, 2007).

Moreover, it should be noted that the Ten Year Plan for Energy Expansion (PDE 2012-2021) foresees intense expansion of energy efficiency measures in

Table 6. Ranking TFEE-BRICS.

Ranking	Country	1	2	3	4	5	6	7	8	9	Mean	Ranking
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

this country in the coming years. The EPE forecast (EPE, 2012) projects a savings of 24.693×10^3 tep of total energy by 2021. The projections specifically related to electricity consumption indicate that 48 TWh per year will be saved by the end of this period, which corresponds to a hydro-electric power plant with installed capacity of 10.000MW or three Xingó power plants.

5 Conclusion

Energy is one of the essential components for social and economic development of a nation and must be closely linked to sustainable, efficient and safe use of energy from ecological and more economically viable approaches for future short and long-term partnerships.

However, there are numerous problems that modern society must face when seeking to ensure a sustainable energy supply while seeking to reduce energy use. The rapid increase in global energy consumption makes the problem even more complicated. The energy crises that many countries have experienced have shown how societies are vulnerable to geopolitical and climatic influences on their supplies.

In this study, the comparison between the BRICS countries was performed by constructing an efficiency index, using the DEA technique, which measured the efficiency of countries in gross fixed capital formation, workforce and energy consumption by economic growth without harming the environment through increased CO₂ emissions. As a result, considering the variables used, this study showed that Brazil had the highest total-factor efficiency (99.36%), followed by South Africa, China, Russia and India.

Also, to better understand the results of the efficiency analysis, the slacks of each variable were analyzed. This analysis showed that Brazil appeared as a benchmark for other countries in the variables: GDP, energy consumption and CO₂ emissions. Another highlight was the South Africa, always among the first positions in the ranking of the slacks variables.

It should be noted that the slacks 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 relation to others, from the point of view of productivity. Therefore it may be, for example, that there is no possibility to increase or decrease the variables, as indicated by the slacks, considering the current structure of the country and its economic scenario.

In addition to analyzing the slacks, provided by the DEA, the variables considered in this work were also used to calculate the Total-factor Energy Efficiency index (TFEE). Brazil was the country that presented the highest index within the BRICS, followed by South Africa, China, India and Russia.

This way, we achieved the research goal by showing which BRICS countries have the highest TFEE index, considering a total-factor structure, providing information on benchmark countries within the BRICS group and how Brazil stands in this scenario.

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 account the special features in each country, the social, economic and environmental dimensions.

Thus, according to the results, Brazil is a good reference of sustainable practices, therefore it should be further examined, but India may be worthy of further attention with respect to improvements.

In addition, based on the factors analyzed, there is a possibility to guide the allocation of attention and government resources by means of incentive policies to implement energy efficiency measures in the countries which ranked in low positions.

The objective of this study was to contribute to qualitative and quantitative information regarding the development of BRICS countries to achieve economic growth without harming the environment and with the least amount of production factors. The results can be valuable, and can also be used as guidelines to determine public policies with appropriate strategies to improve the efficiency of countries considering the context of sustainability.

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