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Efficiency evaluation of sustainable development in BRICS and G7 countries: a Data Envelopment Analysis approach

Análise do desenvolvimento sustentável nos BRICS e G7: uma abordagem com a Análise Envoltória de Dados

Flávia de Castro Camioto[1], Alícia Cristina Pulita[1]

[1]Universidade Federal do Triângulo Mineiro – UFTM, Department of Production Engineering, Uberaba, MG, Brasil.
E-mail: flaviacamioto@yahoo.com.br; aliciapulita@hotmail.com

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Abstract: In order to measure the impact of the economic growth over the years, the sustainable development concept works to balance three pillars of sustainability - economic, social and environmental. This paper has the objective to compare emerging countries (BRICS) with the most developed countries (G7) by analysing sustainable development. Data Envelopment Analysis (DEA) was used, thorugh the variant SBM (Slacks Based Measured) model. The inputs were CO_2 emission, percentage of unemployed and energy utilization. GDP and life expectancy at birth were used as outputs. The main result was a global average efficency ranking, having the emerging countries in top positions (India, China and Brazil, respectively). In addition, emerging countries have always stood out in the average of the slacks of each analyzed variable. These results are important in terms of being useful for public policies related to sustainable development, especially: (1) to contribute to the discussions related to evaluating the countries, helping to identify those with the best practices with regard to environmental, social 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 and welfare social without harming the environment.

Keywords: Sustainable development; DEA; Indicator; BRICS; G7.

Resumo: Para medir o impacto do crescimento econômico ao longo dos anos, o conceito de desenvolvimento sustentável busca equilibrar os três pilares da sustentabilidade - econômico, social e ambiental. Este artigo tem como objetivo comparar os países emergentes (BRICS) com os países mais desenvolvidos (G7), analisando o desenvolvimento sustentável. Foi utilizada a Análise Envoltória de Dados (DEA), por meio do modelo variante SBM (*Slacks Based Measured*). Os *imputs* foram emissão de CO_2, porcentagem de desempregados e utilização de energia. O PIB e a expectativa de vida ao nascer foram utilizados como *outputs*. O principal resultado foi um *ranking* global de eficiência média, com os países emergentes nas primeiras posições (Índia, China e Brasil, respectivamente). Além disso, os países emergentes sempre se destacaram na média das folgas de cada variável analisada. Esses resultados são importantes em termos de utilidade para políticas públicas relacionadas ao desenvolvimento sustentável, especialmente: (1) contribuir para as discussões relacionadas à avaliação dos países, ajudando a identificar aqueles com as melhores práticas em relação aos aspectos ambientais, sociais e econômicos em cada grupo; e (2) orientar as decisões políticas relativas aos incentivos do governo para promover o desenvolvimento de países eficientes em termos de crescimento econômico e bem-estar social sem prejudicar o meio ambiente.

Palavras-chave: Desenvolvimento sustentável; DEA; Indicador; BRICS; G7.

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1 Introduction

Currently, one of the greatest challenges of the world is the attempt to reach a consensus regarding economic growth, environmental sustentability and population's living conditions (Lira & Cândido, 2008). In this context, studies (Chang, 2015; Camioto et al., 2014; Frugoli et al., 2015; Santana et al., 2014; Verma & Raghubanshi, 2018; Zhou et al., 2019a) were carried out with the objective to check if the growth model considers environmental sustentability and population’s life quality as important variables. Other studies (Oliveira et al., 2012; Hervani et al., 2017) had the objective to align sustainability principles with organizations' strategy. In addition, countries are also using tools to achieve sustainable development, such as African countries (Omwoma et al., 2017).

Nevertheless, since the end of the 20th century, society was already aware that development was harming the environment, and the concept of sustainable development emerged (Bellen, 2004).

In this context, having a sustainable development in emerging countries such as the BRICS group (Brazil, Russia, India, China and South Africa) is important to contain the unsustainable trend by which the planet walks. Thus it is importante to analyse the way in which these countries are developing in order to measure their performance with respect to the sustainability and quality of life of its population.

The objective in this study is to compare the emerging countries (BRICS), composed by Brazil, Russia, India, China and South Africa, with the most developed countries (G7), composed by Italy, Germany, Japan, France, Canada, the United States and the United Kingdom, on sustainable development. As a main result and contribution, it is expected to obtain a global average efficiency ranking, in addition to the average of the relative slacks of each variable, being possible to know how each country is positioned in relation to each variable used. With these results, one can verify how each country behaves in relation to the sustainability pillars, being an important indicator so that the countries know in which of the pillars they should focus on.

For the design of the mentioned indicator, Data Envelopment Analysis (DEA) was used, which is a methodology that considers several linear programming methods to construct a nonparametric surface as frontier on the data (Coelli et al., 2005). The DEA can estimate the efficiency frontiers for a set of Decision Making Units (DMUs) and one of the characteristics of this methodology is that it allows the evaluation of multiple data (Gonzalez-Garcia et al., 2018).

The study was structured in five diferente sections. On the first one, the introduction was presented. The second section is the literature review in which the theme of sustainable development was contextualized, showing its evolution over time and the emergence of sustainability indicators. On the next section there is the method used in the study with the definition of the variables used. Then there is the section of results and discussion that focuses on the presentation of the results generated in the study and their respective analyzes. Finally, there is the conclusion that presents a closure of the study, showing how it can be used.

2 Literatura review

The concept of development sustainable was first used in 1972 in the Report of Rome Club - Growth Limits, which summarized the data on population growth, the impact of industrialization regarding pollution, food production and resource trends, as well as on economic issues (Cristu et al., 2016). According to Oliveira et al. (2012), the report was based on several mathematical models and concluded that the analyzed variables should be “frozen” so that growth would be contained, because if forms of production continued to increase in the pace rased during the study, the limits of growth would be reached within a period of one hundred years.

Twenty years after the publication of the report, the United Nations Conference on Environment and Development, Rio-92, was held to disseminate the concept of sustainable development. This conference justified the need for changes in the way humans relate to the environment, in addition to formulate, implement and evaluate public policies on development. These changes presuppose that the economic return should not be the only goal, but must also consider environmental and social situation (Guimarães & Feichas, 2009). It is noted that, even if the term sustainable development has different approaches, the concept of biosphere balance and population well-being is present in all definitions.

Up to know, the best-known definition is the Brundtland’s report. According to Brundtland (WCED, 1987), sustainable development is defined as a concept based on environmental integrity and the balance between economic, environmental and social dimensions. Thus, it seeks to meet current needs without compromising the environment and future generations.

However, according to Olawumi & Chan (2018), there are difficulties adapting to limits imposed by sustainable development, because of social issues, technological advances and ecosystem capacity. Thus a single model of sustainable development is not viable, and each country should develop its own policies and standards, however always having global goals in mind. In order to develop this global target to guide the countries, the Millennium Development Goals (MDGs) were developed in 2000 and include eight goals to reduce poverty by the end of 2015 (Nações Unidas, 2018). Subsequently, in Rio + 20, held in 2012, the concept of global goals was consolidated (Hák et al., 2015). Since it was not possible to end poverty, the 17 Sustainable Development Objectives (MDGs) emerged in 2015, which were based on the MDGs (Khalid et al., 2018). Thefore, several studies, such as Caiado et al. (2018) propose the creation of models that aim implementation, monitoring and continuous improvement of these 17 goals.

According to the Brundtland report (WCED, 1987), the efficiency of a country should be evaluated by indicators that take into account three aspects: economic, social and environmental. Table 1 sets out some definitions used for each pillar.

Table 1. Pillars of sustainability.

Pillars of sustainability	Definitions	References
Economic	There must be integration between economy and environment in all sectors, such as industry, government and domestic environment to be sustainable.	MacNeill et al. (1991)
	It considers issues related to economic efficiency, short-, medium- and long-term profitability in sectors, avoiding imbalances that may affect agricultural and industrial production.	Cristu et al. (2016)
	It considers the efficient use of resources to increase operating profit and maximize market value. It also focuses on the substitution of natural resources, human resources, reuse and recycling.	Olawumi & Chan (2018)
Social	It evaluates the well-being of the population, the human condition and the means to improve the quality of life.	Bellen (2002)
	It concerns the well-being of all members of a community, equity and social justice, inclusion, cohesion and social solidarity, health and education.	Cristu et al. (2016)
	It considers the social well-being of the population, balancing the need of an individual with the need of the group (equity), in addition to public awareness and cohesion, participation and use of local companies and workers.	Olawumi & Chan (2018)
Environmental	The impacts caused in nature by the human can be very harmful to the environment. The environmental pillar aims to maintain a stable base of natural resources and biodiversity.	Cristu et al. (2016)
	It is concerned with limiting human activity to the capacity of existing ecosystems in the locality and also puts emphasis on the quality of human life (air quality, human health).	Olawumi & Chan (2018)

According to Hammond et al. (1995), the term indicator, derived from the Latin nomare, means to discover, to point out, to announce, to estimate. In addition, indicators can communicate or report on progress toward a particular goal, such as sustainable development. According to Bellen (2004), the aim of indicators is to aggregate and quantify information, leaving its meaning more apparent and simplify information about complex phenomena, improving the communication process.

Thus, through the three aspects considered, it was noted the need to seek information and direction to achieve sustainable development through the adoption of new indicators that complement the traditional ones, which were typically economic (Wilson et al., 2007). Therefore, a set of sustainability indicators has the function of warning the community about risks and development trends (Guimarães, 1998). They are also a set of signs that facilitate the evaluation of the progress of a given region in the search for sustainable development (Guimarães & Feichas, 2009). Furthermore, with the information obtained from the indicators that planning, implementation and monitoring stages of environmental management policies will be carried out, ir order to better direct the rational use of natural resources and interventions in the environment (Kemerich et al., 2014). Sustainability indicators are a universal set of goals that the members of the United Nations will use to structure their policies over the next fifteen years (Hák et al., 2015).

In this context, in which there is a search for economic growth, it is important to analyse the way in which emerging countries such as the BRICS group (Brazil, Russia, India, China and South Africa) are developing in order to measure the performance of these countries with respect to the sustainability and quality of life of its population.

The BRICs emerged in 2001 initially as a concept (O'Neill, 2001), an acronym, without indications of the possibility or feasibility that the countries Brazil, Russia, India and China would constitute a formal group. As South Africa officially admitted to 2010, BRICs then passed to BRICS. However, there was an increase in the popularity of the term that became synonymous with the economic dynamism of emerging countries that revolutionise the global equilibrium, that for the former Brazilian minister, Celso Amorim, makes the world more multipolar and democratic, thus leaving the world less dependent on a single source of power (França, 2015).

The International crisis in 2008 was not perceived so dramatically by emerging countries, with the average growth of these countries in 2008 and 2009 of 4.3%, while developed countries had a negative growth of-1.3% (IMF, 2018), which impacted positively in the image of emerging countries. However, there are also different perspectives on the role of BRICS in the world scenario (Reis, 2012).

Doubts still arise as to the economic, historical and cultural differences between the BRICS, making the formation of a cohesive bloc unfeasible. However, still, the phenomenon of dynamism of the “South” countries in the “North” countries is real (Ribeiro & Moraes, 2015). A concern arises in the way in which these countries (Brazil, Russia, India, China, South Africa) will develop (Camioto et al., 2016).

In this way, some studies focused on comparisons between emerging (BRICS) and developed (G7) countries in order to analyse how each of these groups are evolving in terms of sustainable development. Liu et al. (2018b), for example, compares the industrial parks present in China and Canada, showing that there is a difference between the two countries in economic development, but it use these countries to analyze the sustainability of industrial parks, since both are references in this regard. The study by Liu et al. (2018a), compares Korea, Japan (developed countries) and China (emerging country) in relation to the ecological footprint. Wang & Sueyoshi (2018) compare pollution reduction targets for companies in developed countries (United States, the European Union members, Japan, Canada and Australia), and emerging countries (Brazil, China, India, South Africa and Turkey). Ye & Zhang (2018) use OECD countries and emerging countries (China, Brazil, India, Mexico, and South Africa) to analyze the relationship between health spending and economic growth. Chang & Hu (2019) analyzed long-term potential energy savings, potential emissions reduction, and long-term technology gaps on energy utilization and CO_2 emissions in G7 and BRICS during 2000–2014.

Despite these studies, there is still a gap in the literature to be filled by studies that seek to better understand whether the growth of emerging and developed countries goes against sustainable development.

3 Method

For this work, the countries that compose the G7 block and the emerging countries that compose the BRICS were selected, and a global average efficiency ranking was set up. In addition, it was obtained the mean of the relative slacks of each variable to verify how much each country needs to improve relative to each one.

The Data Envelopment Analysis (DEA) was used. This is a method used to evaluate comparative efficiencies of Decision Making Units (DMU), which are variables of relative performance of a production system. The calculation of the DMU's relative efficiency is performed by the ratio of the weighted sum of outputs to the weighted sum of inputs needed to generate them (Mello & Gomes, 2004). The DEA can be used in studies of different areas, such as agriculture (Geng et al., 2018), water treatment (Hernández-Chover et al., 2018; Longo et al., 2018), ecological efficiency of countries (Moutinho et al., 2018) and industrial sectors (Camioto et al., 2014; Cullinane et al., 2006; Zhou et al., 2019b; Park et al., 2018), to analyze efficiency of network systems (Kao, 2018)

It is also a methodology used to evaluate the sustainable development issues as the studies conducted in China (Zhang et al., 2008; Tian et al., 2019; Li et al., 2019; Wang et al., 2018; Zhu et al., 2018), France (Jradi et al., 2018) and United States (Sağlam, 2017).

Finally, there are analyzes using DEA to compare a group of countries in relation to sustainable development, as shown by Zurano-Cervelló et al. (2019), which assesses the electricity generation efficiency of the 28 members of the European Union, considering sustainability. Already Toma et al. (2017) analyzes the agricultural efficiency of the European Union countries using DEA, showing that the modification of inputs can result in a more efficient production, with reduction of environmental exploration. In this study it will be used in order to analyse the efficiency of the countries mentioned in promoting the development in terms of economic growth and social welfare without harming the environment.

In the DEA, as a DMU should be compared to its border projection, which represents the optimal standard for it, the efficiency value in the DEA method is always a value between 0 and 1. Thus, a DMU will be efficient if it's located over the border, containing the value 1 as efficiency (Charnes & Cooper, 1985).

In this study, the G7 countries (Japan, Italy, Canada, United States, United Kingdom, France and Germany) and BRICS countries (Brazil, Russia, India, China and South Africa) are considered DMUs and their relative efficiencies were calculated. Given the current performance of each country, a global average efficiency ranking was set up and it was possible to calculate the relative slacks, with the average of each country being found for each variable analyzed. The countries that obtained the smallest slack were considered benchmarks for a certain variable.

Regarding the variables used in this work, it was considered that the efficiency of a country should be evaluated by indicators that consider the three pillars of sustainability:

environmental, economic and social. Thus, as inputs it was used variables that should be reduce, in this case CO_2 emission (environmental), percentage of unemployed (social) and energy use (environmental); as outputs it was used variables that wish to increase, such as Gross Domestic Product - GDP (economic) and life expectancy at birth (social). The selected variables are shown in Table 2.

Table 2. Variables of inputs and outputs.

CATEGORY	SUSTAINABLE DIMENSION	VARIABLES
INPUT	Environmental	CO_2 emission
	Environmental	Energy use
	Social	Percentage of unemployed
OUTPUT	Economic	PIB
	Social	Expectativa de vida

In order to choose these variables, several studies on sustainability indicators were considered, such as Santana et. (2014), which used CO_2, life expectancy, percentage of the unemployed and GDP, as indicators of sustainability to determine the BRICS efficiency on the transformation of productive resources and technological innovation within sustainable development. Already Mardani et al. (2019) studies the relation of CO_2 emission and economic growth with other indicators, such as energy usage. GDP and CO_2 indicators are also analyzed in the G20 and OECD countries to evaluate the sources of economic growth as well as their sustainability (Rodríguez et al., 2018) and to evaluate the entrepreneurial activity's ability to improve economic growth, environmental objectives and social conditions (Dhahri & Omri, 2018). Viglia et al. (2017) used energy usage and CO_2 emission to develop and validate indicators of urban environmental sustainability. A study also used life expectancy and CO_2 emissions to develop a Sustainable Human Development Index (Biggeri & Mauro, 2018). Mikayilov et al. (2018) investigated the relationship between GDP and CO_2 of twelve Western European countries (from 1861 to 2015), showing their interconnection. Raza & Shah (2018) and Cai et al. (2018) used the variables GDP and CO_2 emissions, together with other variables, to analyze their relationship in G7. Table 3 shows other studies using the variables chosen.

Table 3. Studies that use the variables.

Variable	Meaning	Studies that use the variable
CO_2 emission	It comes from the burning of fossil fuels and the manufacture of cement. It includes carbon dioxide produced during the consumption of solid, liquid and gaseous fuels and gas burning	Abreu et al. (2018); Balados-Naves et al. (2018); Mardani et al. (2019); Sarkodie & Strezov (2019); Gonzalez-Garcia et al. (2018); Lima et al. (2017); Andrich et al. (2013)
Energy use	Refers to the use of primary energy prior to conversion to other end-use fuels	Sarkodie & Strezov (2019); Ayoo (2016); Andrich et al. (2013)
GDP	GDP at purchaser prices is the sum of the gross value added of all resident producers in the economy plus any taxes on products and less any subsidies not included in the value of the products	Mardani et al. (2019); Sarkodie & Strezov (2019); Juknys et al. (2018); Gorobets (2011); Duro & Padilla (2010)
Life expectancy at birth	Indicates the number of years a newborn would live if the prevalent patterns of birth-time mortality were the same throughout their lifetime	Zhang (2013); Gorobets (2011); Knight (2014)
Percentage of unemployed	Refers to the portion of the workforce that is out of work, but available to look for work	González-Mejía et al. (2014); Gonzalez-Garcia et al. (2018)

As justification for the use of these variables are the fact that they consider the three pillars of sustainability, as shown in the studies cited, and also because of the availability of data for all countries. The data was taken from the World Bank website and the analysis period was from 2005 to 2014, according to the data available on the website.

Data envelopment analysis is quite permissive with the variables used. Thus, was performed an analysis of the variables in order to verify the related input and output variables. First, a correlation matrix was performed in order to analyze the p-value. An econometric analysis was also performed in order to capture the statistical significance of each explanatory variable (input) in relation to each output. The equations has been estimated by the method of feasible generalized least squares (FGLS), with the variables expressed in natural logarithms, in order to not cause bias and inconsistency in the parameters. Stata 15.0 was used for these analyzes.

The model used is the SBM (Slacks Based Measured) variant, which, according to Tone (2001), aims to minimize inputs and maximize outputs simultaneously. It targets to reduce CO_2 emissions, unemployed percentage and energy usage. Also it has a goal to increase GDP and life expectancy at birth. This model allows a comparison of DMUs, since the countries work with different scales; in other words, a reduction in an input does not mean that there is a reduction in an output. Excel Solver was used to perform this analysis.

Equations 1 to 7 represent the SBM variant model of the DEA approach, according to Tone (2001):

$$Min\,\tau = t - \frac{1}{n}\sum_{j=1}^{n}\frac{S_j}{X_{J0}} \tag{1}$$

Subject to:

$$1 = t + \frac{1}{m}\sum_{i=1}^{m}\frac{S_i}{y_{i0}} \tag{2}$$

$$\sum_{k=1}^{z} x_{jk}.\lambda_k + S_j = t.x_{j0}, \qquad para\; j = 1,2,3,\ldots,n \tag{3}$$

$$\sum_{k=1}^{z} x_{ik}.\lambda_k + S_i = t.x_{j0}, \qquad para\, i = 1,2,3,\ldots,m \tag{4}$$

$$\sum_{k=1}^{z} \lambda_k = t \tag{5}$$

$$\lambda_k, S_j, S_i \geq 0 \tag{6}$$

$$t > 0 \tag{7}$$

In which: λ_k : DMU_k 's participation in the goal of the DMU analyzed; x_{ik} : Quantity of input j of DMU_k ; y_{ik} : Quantity of output i of DMU_k ; x_{i0} : Quantity of input j of the DMU under analysis; y_{i0} : Quantity of output i of the DMU under analysis; z: Number of units under evaluation; 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.

This model, in addition to measuring the relative efficiency of each DMU, allows the calculation of slacks, which demonstrate how much of each output should be increased and how much input should be reduced simultaneously, in order to obtain better efficiency in relation to the benchmark. The gaps between the benchmark and the other inefficient countries are calculated by Equations 8 and 9.

$$Input\,target = x_{j0} - S_j \qquad for\ j = 1,2,3\ldots n \tag{8}$$

$$Output\,target = y_{i0} + S_i \qquad for\ i = 1,2,3,\ldots m \tag{9}$$

With the countries' current performance and the benchmark, the relative gap in percentages is calculated, which means how much each DMU needs to improve to reach the goal. Relative gaps are calculated by Equation 10:

$$Relative\,slack = \frac{target - current}{current} \tag{10}$$

It was also used window analysis, which, according to Cooper et al. (2000), makes it possible to include time in the Data Envelopment Analysis. This analysis allows the mixing of DMU data from several years in the same application, using multiple DEA applications in which different combinations of years (window). According to Camioto et al. (2016), window analysis consists of separating the years used in the study in different groups (windows) and from the available data, the number of windows is determined, as expressed in Equations 11 and 12:

$$Size\,of\ window\_(p) = \frac{(k+1)}{2} \tag{11}$$

$$Number\,of\ windows = k - p + 1 \tag{12}$$

In which: k: number of periods; p: window size, which is rounded up if necessary.
In this study, the period from 2005 to 2014 (k = 10) was used, with window size being 6 and the number of windows being 5: 2005-2010; 2006-2011; 2007-2012; 2008-2013; 2009-2014.

4 Results and discussion

4.1 Analysis of input and output variables

First, in order to verify if the inputs and output variables are related, we performed a correlation matrix. The statistical significance between the variables is reflected by the p-value, which was also calculated. For the variable to be considered statistically significant, its p-value should be as close to zero as possible, if the null hypothesis is to be rejected. The confidence level of 95% was adopted in this work. Table 4 shows the correlation matrix.

Table 4. Correlation matrix between inputs and outputs.

	Percentage of unemployed	CO_2 emission	Energy use	Life expectancy at birth	GDP
Percentage of unemployed	1				
CO_2 emission	-0.3114*	1			
Energy use	-0.0672	0.0297	1		
Life expectancy at birth	-0.5965*	-0.0030	0.3717*	1	
GDP	-0.2807*	0.6611*	0.4186*	0.3178*	1

This table represents the correlation matrix between the model variables. Statistically significant coefficients: (*) 5% level.

As shown in Table 4, the inputs "percentage of unemployed" and "energy use" are significant for both outputs analyzed. The input CO_2 emission are significant only for "GDP" variable.

As mentioned, an econometric analysis was also performed in order to capture the statistical significance of each explanatory variable (input) in relation to each output. The equations has been estimated by the method of feasible generalized least squares (FGLS), with the variables expressed in natural logarithms, in order to not cause bias and inconsistency in the parameters. The first estimate was of the function that considered the inputs "CO_2 emissions", "energy use" and "Percentage of unemployed", and the output "GDP", from 2005 to 2014, according to Expression 13. After, the equations were estimated considering as output, instead of "GDP", the variable "Life expectancy at birth", according to Expressions 14.

$$ln(GDP) = \alpha + \beta_1 . ln(CO_2 Emissions) + \beta_2 . ln(Energy\ Consumption) + \beta_3 . \ ln(Percentage\ of\ unemployed) \tag{13}$$

$$ln(Life\ expectancy\ at\ birth) = \alpha + \beta_1 . ln(CO_2 Emissions) + \beta_2 . ln(Energy\ Consumption) + \beta_3 . ln(Percentage\ of\ unemployed) \tag{14}$$

Table 5. Econometric estimates for the variables.

VARIABLES	GDP	Life expectancy at birth
Percentage of unemployed	-0.515***	-0.028***
	(0.084)	(0.009)
CO_2 emissions	0.382***	-0.005
	(0.078)	(0.009)
Energy use	0.529***	0.061***
	(0.076)	(0.007)
Constant	19.916***	3.9897
	(1.434)	(0.130)
Observations	120	120
Number of num	12	12

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Similar to Table 4, Table 5 shows the inputs “percentage of unemployed” and “energy use” are significant for both outputs analyzed. The input CO_2 emission are significant only for “GDP” variable.

Note that though the p-value of the variable “CO_2 emissions” from fossil fuels was quite high for the variable "Life expectancy at birth", it was considered interesting to include it in the DEA, in order to incorporate the three pillars of the triple bottom line in the analysis, as it is an environmental variable.

Furthermore, the fact that the input variables are not fully independent was taken into account, since the consumption of fossil fuels is considered as information for the variable “Energy use”, as well as for the variable “CO_2 emissions”. Therefore, there is a bias for the countries in which the energetic consumption of fossil fuels is high, since for them any reduction in energy consumption suggested by DEA will also automatically generate a reduction in CO_2, and this cannot be considered in the analysis. This bias will ultimately penalize the countries that have an energy matrix that is more dependent on fossil energy sources, and its distance to the frontier estimated by DEA would be greater than the real one.

4.2 Efficency ranking

The global average efficiency ranking, expressed in Table 6, was set using the DEA with the variant SBM model as a mathematical programming method, from 2005 to 2014. In addition, the inputs used were CO_2 emission, unemployed percentage and energy usage; the outputs were GDP and life expectancy at birth.

Table 6. Overall average efficiency ranking.

Ranking	Country	1	2	3	4	5	Average	Standard deviation
1	India	97.97%	97.86%	97.86%	97.93%	99.45%	98.22%	4.13%
2	China	99.24%	99.73%	98.63%	98.37%	94.47%	98.09%	3.17%
3	Brazil	97.53%	96.42%	97.78%	97.78%	99.02%	97.71%	3.39%
4	Japan	97.19%	98.33%	97.23%	97.26%	96.03%	97.21%	4.11%
5	Italy	93.83%	96.42%	98.94%	98.13%	90.56%	95.58%	6.82%
6	France	92.19%	93.34%	95.44%	96.66%	92.87%	94.10%	6.13%
7	EUA	97.11%	96.65%	92.93%	90.36%	85.13%	92.43%	8.19%
8	United Kingdom	93.98%	93.03%	93.88%	94.25%	82.61%	91.55%	7.72%
9	Germany	74.74%	75.97%	80.50%	85.05%	84.04%	80.06%	8.84%
10	Canada	46.72%	50.25%	45.54%	52.33%	48.40%	48.65%	5.63%
11	Russia	25.90%	25.88%	28.18%	30.20%	31.43%	28.32%	5.58%
12	South Africa	13.24%	12.29%	12.93%	13.35%	13.75%	13.11%	1.74%

Table 6 shows that India is the most efficient country in terms of sustainable development, considering the variables used, ranked first with an overall average of 98.22%. During the analyzed period, the country remained stable, but grew at the last window reaching 99.45%. This result may be related to the fact that the country adopted Agenda 2030, focusing on sustainable development over the period, using policies aimed to use renewable energy sources, as an example (NIAS, 2018). Yet, according to UNEP (2017), India is one of the countries that is likely to reach its goals by 2030 if current policies are implemented.

In second place, China has 98.09% of average. The country had declined after window 3, which may be due to the increase in CO_2 emissions. However, even with this increase, the country still remains in second, as it stands out in all other indicators.

As an example, there is the fact that the country has the second highest GDP among the countries analyzed. In addition, the use of renewable energies, such as hydroelectric power, contributes to sustainable development (Penghao et al., 2018).

Brazil ranks third, with 97.71% of average. In the analyzed period, the country remained stable, growing at the last window when reached 99.02%. This growth may be related to the fact that the country is investing in policies aimed at sustainable development throughout the period, such as sustainable practices within Brazilian industries (Souza & Hilsdorf, 2018; Pinto et al., 2018). It is worth mentioning that in the last window the country was very close to the first place. Therefore, if Brazil continues to invest in sustainability, it tends to reach China in the area of sustainable development, considering the variables analyzed.

In fourth place is Japan with 97.21% of average. The country had some stability over the period, but had the lowest percentage in the last window, when it obtained a 96.03% average. This reduction may be the result of a fall in industrial production during the period under review, causing an increase in the percentage of the unemployed in the period and also a small increase in the use of energy.

Italy is in fifth place (95.58%). The country had a growth in windows 2 and 3, but had a decline in the last window, reaching 90.56%. This may be due to the increase in the percentage of unemployed people and the low performance of GDP over the period.

Sixth, France has 94.10% average. Note that the country had growth until window 4, but had declined in the last window. One reason for the decline may be the increase in energy usage in the country within the period of analysis. The USA is in seventh place (92.43%). The country had constant falls throughout the period, a fact that can be observed by the high standard deviation of 8.19%. The falls observed during the analyzed period may be associated to the increase in the percentage of unemployed, CO_2 emissions and energy usage. In eighth is the United Kingdom with 91.55% of average. The country remained constant up to window 3, having an increase in window 4; however, in the last window had a sharp decline. So, the country has a high standard deviation with 7.72%. This decline may be related to the increase in the percentage of unemployed, in the use of energy and in the emission of CO_2 over the period.

Germany is in the ninth place with 80.06%. The country grew steadily until window 4, but it had a reduction in the last window. With this oscillation over the period, the country had the highest standard deviation among all countries (8.84%). The country has improved over the period in some indicators, but still has a low efficiency near the other countries. In addition, the decline caused in the last window may be due to the increase in CO_2 emissions during the analysis period.

In tenth place is Canada with 48.65% of average, oscillating throughout the period. This may be associated with the worst performance in the variable energy usage and for not performing very satisfactorily in the GDP indicator. In addition, according to a study by Wang & Sueyoshi (2018), companies in Canada are lagging behind companies in emerging countries in adopting targets to reduce pollution because it is a country with weaker climate policies.

Russia penultimate place with 28.32%. The country had a constant growth from window 3, but even with growth, the country still has very poor performance in the variables, occupying the last or penultimate placement in all variables, except in the use of energy that occupied the tenth place. Lastly, there is South Africa with a 13.11% average. It was the country that remained stabler during the analyzed period, with the lowest standard deviation among all countries with 1.74%. The country has the worst indicators of sustainability, always occupying the worst positions in the variables.

It is noted that according to Santana et al. (2014), Brazil excelled in economic and social efficiencies, while South Africa excelled in environmental efficiency, considering the years from 2001 to 2007. The results of Gu et al. (2018) show that China and India are the most efficient countries in sustainable development among all BRICS countries, and can contribute to the development of South Africa. Thus, the result of the present work was, in general, similar to other studies in the literature.

In order to allow for greater discrimination in relation to efficiency between countries, as there appears to be concentration of countries in efficiency groups, the inverted frontier has been applied to discriminate such countries. The concept of inverted frontier was introduced by Yamada et al. (1994) and Entani et al. (2002). Its use as a method of increasing discrimination is made by Angulo-Meza et al. (2005) and Soares de Mello et al. (2008). This method evaluates the inefficiency of a DMU by constructing a frontier constituted by the units with the worst managerial practices, called the inefficient frontier. For the calculation of the inefficiency frontier, an exchange of inputs with the outputs of the original DEA model is made.

With the results of the inverted frontier, the composite index (CI) was calculated, as the Equation 15.

$$CI = \alpha * Efc + (1 - \alpha) * (1 - Efi) \tag{15}$$

In which CI is the composite index, Efc is the efficiency of the classic frontier, Efi is the efficiency of the interted frontier, α is the weight given for each criterion. The results of the efficiency obtained in the Inverted Frontier and the Composite Index normalized, with α=0.5, are shown in Table 7.

Table 7. Efficiency in different frontiers (SBM).

Ranking	Country	Classic Frontier	Inverted Frontier	Composite Index normalized
1	**India**	98.22%	16.12%	100.00%
2	**Brazil**	97.71%	17.00%	99.24%
3	**France**	94.10%	15.67%	97.98%
4	**Italy**	95.58%	17.36%	97.87%
5	**Japan**	97.21%	24.13%	95.04%
6	**United Kingdom**	91.55%	18.57%	94.99%
7	**Germany**	80.06%	26.08%	84.56%
8	**China**	98.09%	97.87%	55.03%
9	**EUA**	92.43%	92.66%	54.79%
10	**Canada**	48.65%	87.53%	33.56%
11	**Russia**	28.32%	71.05%	31.45%
12	**South Africa**	13.11%	98.68%	7.93%

Considering the composite index, India remained in the first place of the ranking and Brazil rose a position, the second in the ranking, with 99.24%. On the other hand, China reduced efficiency when compared to the classical frontier, moving from third to eighth position in the ranking, with 55.03%. Similarly, US fell two positions in the ranking with an efficiency of 54.79%. France, Italy, Japan, United Kingdom and German remained with an efficiency above 80%. Russia and South Africa remained the last of the ranking.

A sensitivity analysis of the countries was also carried out, by applying Equation 15, varying the value of the coefficient α from 1 to 0.1 in intervals of 0.1. Table 8 shows the efficiencies obtained. The values shown in the table are normalized.

Table 8. Efficiencies for different alpha values.

	Alpha - α (weight of each criterion)									
Countries	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
India	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Brazil	99.01%	99.07%	99.13%	99.18%	99.24%	99.29%	99.34%	99.39%	99.43%	99.48%
France	99.98%	99.46%	98.95%	98.46%	97.98%	97.52%	97.07%	96.64%	96.21%	95.81%
Italy	98.38%	98.24%	98.11%	97.99%	97.87%	97.75%	97.63%	97.52%	97.42%	97.31%
Japan	91.42%	92.37%	93.29%	94.18%	95.04%	95.88%	96.69%	97.47%	98.23%	98.97%
United Kingdom	96.63%	96.20%	95.78%	95.38%	94.99%	94.61%	94.24%	93.89%	93.54%	93.21%
Germany	87.37%	86.63%	85.92%	85.23%	84.56%	83.91%	83.28%	82.68%	82.08%	81.51%
China	13.74%	24.58%	35.06%	45.21%	55.03%	64.56%	73.79%	82.74%	91.43%	99.87%
EUA	18.58%	28.08%	37.27%	46.17%	54.79%	63.14%	71.24%	79.09%	86.71%	94.11%
Canada	18.85%	22.71%	26.45%	30.06%	33.56%	36.95%	40.24%	43.43%	46.53%	49.53%
Russia	33.86%	33.23%	32.62%	32.03%	31.45%	30.90%	30.36%	29.83%	29.33%	28.83%
South Africa	2.93%	4.24%	5.51%	6.74%	7.93%	9.08%	10.19%	11.28%	12.33%	13.35%

It is possible to observe that Brazil, Japan, China, United States, Canada and South Africa decreased efficiency as α decreased, giving greater emphasis to the bad practices of these countries. In this analysis, DMUs that maintained their high efficiency level regardless of the value of the α coefficient are considered to be true efficient, such as India, which remained the most efficient regardless of the value of α.

4.3 Relative slacks of the variables

From the overall mean efficiency expressed in Table 6, the relative gaps were reached. The average of the slacks of each variable used in the study expressed in Table 9 were calculated. It was obtained percentages that show how much it is necessary to increase (output) or decrease (input) of each variable. If the countriy had 0% as a result, it is considered as benckmark within the variable to the other countries.

Table 9. Average of the relative slacks of the variables.

Country	Percentage of unemployed	CO_2 emission	Energy use	Life expectancy	GDP
South Africa	66.80%	6.89%	50.10%	33.46%	677.19%
Brazil	1.28%	0.01%	0.45%	0.17%	3.52%
China	0.20%	4.72%	0.03%	0.00%	0.55%
India	1.09%	0.69%	0.00%	0.04%	2.65%
Russia	31.45%	28.45%	24.79%	20.71%	307.25%
Germany	22.20%	0.91%	18.04%	0.59%	15.97%
Canada	10.56%	1.04%	54.01%	0.06%	119.75%
EUA	12.47%	5.69%	3.88%	0.52%	0.00%
France	5.86%	0.11%	2.61%	0.12%	6.85%
Italy	1.81%	0.00%	0.00%	0.00%	8.94%
Japan	2.51%	0.27%	2.26%	0.05%	2.38%
United Kingdom	5.32%	1.70%	1.97%	0.15%	12.52%

China has the best average (0.2%) and it is considered a benchmark for other countries. The following are India (1.09%) and Brazil (1.28%). It is noted that none of the G7 countries were in the first place, a fact that may be related to the economic crisis of 2008 (Hippler & Hassan, 2015). In the last places are Russia (31.45%) and South Africa (66.80%). Therefore, according to the study, these countries need to invest in policies aimed to reduce unemployment in their countries and analyze possible unemployment reduction policies that the most well-placed countries used in the period analyzed, considering the characteristics of each country.

Regarding CO_2 emissions, Italy is considered a benchmark (0% of average), but it is noted that Brazil is very close (0.01%). France is the third (0.11%).

Brazil is a country that predominantly uses energy sources that do not release carbon dioxide, such as hydroelectric plants, and sugarcane to produce fuel. Therefore, it shows that the diversification of the energy matrix is associated with the participation of low-carbon sources (Freitas & Kaneko, 2011). In the case of France, the country uses nuclear energy as its main source of energy (Exame, 2016), which does not emit CO_2. Also according to Al-Mulali (2014), the consumption of nuclear and renewable energy can cause a significant reduction in CO_2 emissions, contributing to the good placement of France.

The USA (5.69%), South Africa (6.89%) and Russia (28.45%) are the worst placed. The US has a model of energy production based on coal-fired power plants that emits polluting gases, among them, CO_2 (Terra, 2015). South Africa, on the other hand, generates high-carbon energy for mining and heavy industry (Oke et al., 2017). Finally, Russia has energy production based on oil and natural gas, a fact that leads to the high emission of carbon dioxide (Zhang, 2011).

It is worth noting that the worst performing countries need to reduce CO_2 emissions, especially Russia that has a very high average emission compared to other countries. According Su et al. (2020), considering the period of 1990–2015, the G7 countries managed to decrease the CO_2 emission per capita, whereas the BRICS countries saw an increase in the GHG emission per capita. In this context, good practice in the benchmarking countries can be considered to improve the position of these countries.

For the variable energy usage, India and Italy are considered benchmark, with 0% of average. Followed by China (0.17%) and Brazil (0.32%). Among the worst performers is Russia (24.79%), which consumes a lot of energy, ranking third in the world in consumption in 2009. This fact may be associated with the economic reform and increase of oil and gas export revenues in the 21st century, causing the Russian economy to grow rapidly and, consequently, energy consumption (Zhang, 2011). Next is South Africa (50.10%) as a country dependent on the mining and heavy industry sectors that use a lot of electricity (Oke et al., 2017). Finally, there is Canada with a 54.01% average. In the case of Canada, one of the major problems facing the country is that there is greater growth in energy production compared to its consumption, as the country exports energy to other countries, especially the United States. In this energy production, Canada uses fossil fuels as its main source, such as coal, oil and natural gas (Hofman & Li, 2009).

It is important to highlight that the worst performers need to invest more in renewable energies in their energy matrix, especially Canada and South Africa, which had very high averages in this variable. In the same way, it is interesting to study what has been done in Italy and India regarding the use of energy.

Regarding the variable life expectancy, Italy and China are considered benchmark. Followed by India (0.04%) and Japan (0.05%), however it is noted that the other countries have averages close to the benchmarks. China is a country that has been concerned with the health of its population, translating economic-social development to benefit the health conditions of the majority of the population (Nogueira, 2013).

The exceptions to this good performance are Russia (20.71%) and South Africa (33.46%), which occupy the penultimate and last place, respectively. Both countries have a high mortality rate, a fact that leads to a reduction in life expectancy at birth. In Russia, excess mortality occurs due to cardiovascular diseases associated with risk factors such as smoking and alcohol consumption. In South Africa, AIDS is the main cause of death (Nogueira, 2013). These two countries need investment in policies aimed at improving the health of their population, and they can study what has been done in Italy na China regarding this variable.

In relation to GDP, the USA is benchmark with 0% of average. China (0.55%) and Japan (2.38%) are second and third. According to the IMF (2018), the USA is first on GDP during 2014, followed by China and Japan.

On the last places, there are Canada (119.75%), Russia (307.25%) and South Africa (677.19%). It is noted that Canada, even though it is a developed country, occupies the last place. This may occur as a consequence of an economic crisis from 1970 to 2000 (Kodja, 2009), followed by the 2008 economic crisis that affected its GDP. Russia had a deep recession from 1991 to 2000 due to the radical transition of its policy and economic reorganization and it has gradually recovered over the analyzed period (Zhang, 2011).

5 Conclusion

Nowadays, there is a need to focus on the three pillars of sustainability (economic, social and environmental) so that countries can have an economic development without degrading the environment and considering the well-being of the population.

Thus, it was decided to compare the more developed countries (G7) with the emerging countries (BRICS) in the scope of sustainable development. When analyzing the results of the global averages, it is noted that the first three countries are BRICS (India, China and Brazil, respectively), showing that these countries are the most sustainable within the analyzed period. However, it is noted that the latter are also BRICS (Russia and South Africa), showing that these countries should improve their sustainable practices by investing more in policies focused on sustainable development.

Moreover, when analyzing the variables separately, we can see the good performance of emerging countries. Regarding the percentage of unemployed, China stands out first, followed by India. For CO_2 emissions, Italy and Brazil are benchmark in this variable. Regarding energy usage, India and Italy are benchmark. For the variable life expectancy, Italy and China are benchmark. And, the USA is benchmark in the GDP variable, followed by China. Therefore, it is observed that in all variables there is at least one emerging country occupying the first or second place.

Therefore, when comparing the countries of the BRICS and G7, it is noted that the emerging ones have stood out in the sustainability question, showing that even though they are not so developed, they have policies that show sustainable awareness. In addition, the economic crisis of 2008 has impacted some more countries, especially the more developed ones, which should be taken into account. Thus, the G7 countries should invest more in order for economic development to take place in balance with the environment and the social part.

However, it should be noted that these analysis have some limitations, especially in relation to the development gap between BRICS and G7 countries, as well as cultural differences, territorial extent and number of inhabitants. It is also worth noting that the whole analysis of this article considers only the studied variables, so the results may be related to other variables that are not in the study; therefore the inclusion of more variables related to sustainable development may be of great value in future studies, as they may result in even more complete analyzes. The inclusion of other countries in the study can also be very interesting. Another suggestion of future work would be to study the policies that the benchmarking countries are adopting that are generating good results in the respective variables.

Finally, it is believed that the present study can provide important data on the sustainable development of the G7 and BRICS countries. The results obtained are important in terms of being useful for public policies related to sustainable development, especially: (1) to contribute to the discussions related to evaluating the countries, helping to identify those with the best practices with regard to environmental, social 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 and welfare social without harming the environment.

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