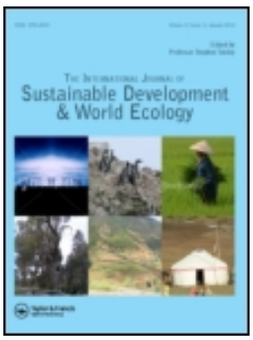

International Journal of Sustainable Development & World Ecology

ISSN: 1350-4509 (Print) 1745-2627 (Online) Journal homepage: http://www.tandfonline.com/loi/tsdw20

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To cite this article: Naja Brandão Santana, Daisy Aparecida do Nascimento Rebelatto, Ana Elisa Périco & Enzo Barberio Mariano (2014) Sustainable development in the BRICS countries: an efficiency analysis by data envelopment, International Journal of Sustainable Development & World Ecology, 21:3, 259-272, DOI: 10.1080/13504509.2014.900831

To link to this article: https://doi.org/10.1080/13504509.2014.900831

International Journal of Sustainable Development & World Ecology, 2014
Vol. 21, No. 3, 259–272, http://dx.doi.org/10.1080/13504509.2014.900831

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Sustainable development in the BRICS countries: an efficiency analysis by data envelopment

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(*Received 29 October 2013; final version received 28 February 2014*)

There is much concern about the social and environmental impacts caused by the economic growth of nations. Thus, to evaluate the socio-economic performance of nations, economists have increasingly addressed matters related to social welfare and the environment. It is within the scope of this context that this work discusses the performance of countries in the BRICS group regarding sustainable development. The objective of this study regards evaluating the efficiency of these countries in transforming productive resources and technological innovation into sustainable development. The proposed objective was achieved by using econometric tools as well as the data envelopment analysis method to then create economic, environmental, and social efficiency rankings for the BRICS countries, which enabled to carry out comparative analyses on the sustainable development of those countries. The results of such assessments can be of interest for more specific scientific explorations.

Keywords: BRICS; data envelopment analysis; economic growth; efficiency; sustainable development

1. Introduction

The socio-environmental impacts generated by the economic growth of countries have brought about increasing concerns in society. Such concerns can be seen in the various means of communication, and this signals the need for more responsible actions by the human race.

In the 1970s, in the work of Meadows et al. (1972) – The Limits to Growth – it was reported that the current development model was incompatible with the preservation of the environment. In other words, if developing countries started to consume the same level of resources as the developed countries, the planet would soon be in a catastrophic situation.

The fact is that economic growth, in most cases, is accompanied by the excessive use of natural resources and negative environmental and social impacts, such as, for instance, income inequality, exploitation of manual labor, and toxic gas emissions.

Thus, to evaluate the socio-economic performance of nations, economists have increasingly addressed matters related to social welfare and the environment. The progress of a nation, traditionally measured by economic indicators such as gross domestic product (GDP), needs new assessment modes.

Given the criticisms regarding the usefulness of GDP as a performance indicator of nations, the human development index (HDI) was created by the United Nations Program for Development to translate not only the economic aspect of various countries, but also issues related to the quality of life of populations. In addition to HDI, another example is the Gini coefficient, which according to Olmedo et al. (2009) is one of the inequality indicators used in studies about social development. Furthermore, life expectancy at birth, according to Sen (1998), is a decisive indicator to verify the full success of a society, a simple indicator that represents the overall health of a community and also the situation of its development.

However, it should be pointed out that these indicators do not account for the environmental impacts caused by human actions. In light of these circumstances, the concept of sustainable development was intentionally undertaken in this paper.

The literature points out that sustainable development is a multidimensional concept and that, in order to evaluate a system, the economic, social, and environmental aspects should be taken into account in an integrated manner (Pope et al. 2004). Seen from this perspective, evaluating the sustainable development of regions requires using other indicators, a measure to inform environmental performance, as for instance carbon dioxide emissions (CO_2).

It is worth noting that the discussion included in this work initiated in the idea of progress from the concept of economic growth to the concept of development and, more specifically, to the concept of sustainable development. Thus, considering the theoretical aspects of these concepts, the focus of this paper is to discuss the performance of the countries in the BRICS group with regards to sustainable development, in order to compare their efficiency in transforming productive resources and technological innovation

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into sustainable development, within a period of 8 years (2000–2007).

The proposed objective was achieved by using econometric tools as well as the data envelopment analysis (DEA) method to then create economic, environmental, and social efficiency rankings for the BRICS countries, which enabled to carry out comparative analyses on the sustainable development of those countries. The results of such assessments can be of interest for more specific scientific explorations.

2. Economic growth and de-growth/human and sustainable development

The core discussion contained in this work originated from the evolution of the economic growth concept in the human development concept and later in the sustainable development concept. Thus, while economic growth can be defined as the increase in production and per capita income, Sen (1999) defines human development as the process of expanding the freedoms enjoyed by people, such as economic, social, and political liberty, by expanding their ability to perform activities that are freely chosen and valued. According to Mariano and Rebelatto (2013), the product of human development, with its multidimensional nature, is quality of life, whereby to obtain a set of indicators that could encompass all the desires of an individual, which tend to be increasingly broader, is a very difficult task.

According to Cracolici et al. (2009), Ranis et al. (2000), and Suri et al. (2011), the increase in GDP per capita is a fundamental prerequisite to improve the quality of life of the population. On the other hand, economic growth can also result in poor development, producing social inequalities, unemployment, poverty, and environmental deterioration (Sachs 2001). Thus, it can be stated that it is not economic growth itself, but its quality that determines the well-being of the population, as good growth is that which reduces extreme poverty, decreases inequalities, and is capable of self-sustainment (Lopes et al. 2008).

In short, economic growth is a necessary condition, but not a sufficient condition for achieving a full and happy life for all (Ranis et al. 2000; Sachs 2001; Mariano & Rebelatto 2013). The relationship between economic wealth and quality of life was closely examined and systematized by Suri et al. (2011), and the efficiency in this relationship was determined by Morais and Camanho (2011) in cities of Europe and by Mariano and Rebelatto (2013) in 101 countries of the world.

Going a bit further, we arrive at the idea of sustainable development, which according to the definition conveyed in the Brundtland report, consists of promoting economic growth, with the ensuing satisfaction of the interests and needs of the current generations, without having to compromise the needs of future generations (World Commission on Environment and Development 1987). According to Fredericks (2012), this definition implies, above all, an ethical question, which can be better understood by the following excerpt:

> Dominant normative elements of the sustainability movement include the assumption that humans should take responsibility for their actions; that ecosystems, human societies, and sometimes individual species or entities are worthy of being sustained; and that equity or justice between people living today, between those presently alive and future generations, and potentially between humans and other biota are valuable. (Fredericks 2012, p. 2)

It is worth noting that the term sustainable development was first discussed by the World Conservation Union in the document entitled World Conservation Strategy, which states that 'for development to be sustainable, the aspects relating to the social and ecological scope as well as the economic factors must be considered, including the living and nonliving resources and the short- and long-term advantages of alternative actions' (International Union for Conservation of Nature and Natural Resources – IUCN 1980). In this context, Dittmar (2014) asserts that most countries, at least from the 1992 United Nations summit in Rio, have been adopting policies for sustainable development with the purpose of combining economic growth with social development and environmental protection.

Thus, Pope et al. (2004) express sustainability as a multidimensional concept in which the economic, social, and environmental aspects should be considered and integrated, which are called the three pillars of sustainability or Triple Bottom Line.

In fact, it should be noted that the positive integration of the three pillars of sustainability is needed to facilitate the achievement of sustainable development. Nonetheless, the integration of economic, environmental, and social dimensions is also frequently associated with conflicts between these aspects that tend to hinder the achievement of sustainable development (Hansmann et al. 2012).

The study by Kaivo-oja et al. (2013) indicated that the three dimensions of sustainability are far from being positively correlated. On the contrary, the authors argue, for example, that there is strong negative correlation between human well-being and environmental well-being. This finding is problematic, since it contradicts the three pillar's definition of sustainability presented in the Brundtland report of the World Commission on Environment (Kaivo-Oja et al. 2013). With regards to this, Bebbington and Larrinnaga (2014) argue that the familiar definition of sustainable development, presented in the Brundtland report, owing to its radical nature, can be appreciated only in the context of its creation, since this definition denotes that human development problems cannot be separated from environmental problems.

Further, to some scholars, sustainability cannot be achieved by a high level of economic growth, but rather seeking a lower level of production and consumption. So the idea of sustainable de-growth emerges, in other words, the scale reduction of production and consumption in the

pursuit of social well-being and improved environmental conditions. In the papers published by researchers in this field, such as Hueting (2010), Alier et al. (2010), Schneider et al. (2010), Trainer (2012), and Whitehead (2013), there are warnings to the risks of continued growth of countries at such pace, which will inevitably result in the planet not being able to withstand such a load of resource consumption, in addition to the production of waste and greenhouse gas emissions. All of this reaffirms the statements made by Meadows et al. (2004) on the limits to growth.

In this regard, considering the economic and environmental dimensions, Kaivo-oja et al. (2013) show the opposite, since, according to them, the trade-off relationship between economic and environmental development has decreased, and according to the authors, this trend is positive from the point of view of sustainability.

3. BRICS

It can be observed that the old order of international politics is dying; the system has been transformed from a unipolar to a multipolar system. The change of the North American power, perceived from the 2008 financial crisis, has occurred alongside a growing trend of regionalization in the global political economy, and the rise of BRICS is a clear illustration of this trend (Öniş & Kutlay 2013).

In their study, Dolgikh and Kokin (2009) report that the term 'BRIC' refers to the four emerging countries (Brazil, Russia, India, and China), whose economies indicate rapid growth trends. According to these authors, the BRIC acronym first appeared in November 2001 in a report entitled 'Building Better Global Economic BRICs', whose authorship was attributed to Jim O'Neill, an economist at Goldman Sachs investment bank. In that report, O'Neill (2001) reported that in the 10 years that followed, the weight of the BRIC countries – especially China – on the worldwide GDP would grow significantly, and this aroused interest about the impact of fiscal and monetary policies of these countries on the global economy.

However, according to Armijo (2007) and Dolgikh and Kokin (2009), it was in 2003, after the research report from Goldman Sachs was published, 'Dreaming with BRICs: the path to 2050', that the BRIC acronym was proclaimed as a part that assessed the perspective of economic growth of the BRIC countries and of their population. Wilson and Purushothaman (2003) highlighted in the report 'Dreaming with BRICs: the path to 2050' that in 2050 Brazil, Russia, India, and China would play a larger force and a new role in the world economy.

Amorim (2010) stated that the consolidation of the BRIC concept came about only because in the years following the release of the 2003 report, a significant economic growth was observed for the BRIC countries, higher than initially projected. To Amorim (2010), this economic growth encouraged Goldman Sachs bank to prepare another report, entitled 'BRICs and Beyond'. In this report's analysis, O'Neill (2007) presented some updated prognosis for the BRIC countries, acknowledging that the economic growth in these countries had been faster than originally forecasted.

In the data collection conducted by Yao et al. (2009), Brazil, Russia, India, and China collectively account for 28.9% of the world's land area and 43.2% of the world population. Therefore, Amorim (2010) warned that the BRIC group holds considerable land areas, abundant diversity and amounts of natural and energy resources, important technological development, and accelerated economic growth.

In 2011, the former BRIC acronym had a letter added, becoming BRICS, where S refers to South Africa. In August 2010, O'Neill claimed that South Africa could be considered the next country to join the BRIC group. In early 2011, at the invitation of the founding member countries, South Africa officially became part of the group of countries with the greatest growth potential.

Although these countries are presented as a block with similar characteristics, it should be pointed out that they also have economic, social, and cultural differences, which can be perceived with regards to population, territorial size, climate, religion, history, and so on. Moreover, according to Jacobs and Van Rossem (2013), the idea of grouping the BRICS countries based only on their economic growth perspectives has been questioned; they state that the overall strength of a country depends on factors that go beyond GDP, such as military and political resources. The authors warn that policy makers should be careful when extrapolating economic potential to actual power in the global system, since power is a multidimensional and relational phenomenon.

3.1. *Economic growth of BRICS*

For a more in-depth study on the economic growth of the BRICS countries, it is advisable to return to O'Neill (2001), who compared the GDP growth of the G7 countries with the GDP growth of the BRIC countries. According to O'Neill (2001), the initial prediction indicated that in 2001 and 2002, the GDP growth in the G7 countries would be low. However, China's GDP growth would be high, and Russia and India would have a higher real GDP growth than the G7 countries. In this analysis, Brazil was the only country in the group that would undergo low growth, similar to that of the G7 today.

In a later work, Wilson and Purushothaman (2003) reported that in the next 50 years, the BRIC economies together would become the biggest global economies. Moreover, according to Tseng (2009), Goldman Sachs projected that in less than 40 years, the combined GDP of these four economies would collectively exceed that of the G6 group.

To verify the proposed estimates regarding the economic growth of the BRIC countries, Wilson and Purushothaman (2003) developed a different analysis to project this long-term growth, based on econometric

research for several countries. Thus, the authors used the econometric model of Levine and Renelt to explain the average GDP growth over the next 30 years, as a function of initial income per capita, investment rates, population growth, and the number of secondary school enrollment.

Although the technique used in the Levine and Renelt model was different from that used in their projections, Wilson and Purushothaman (2003) showed similar results, corroborating earlier projections.

A possible alternative to confirm the theory defined by O'Neill (2001) and Wilson and Purushothaman (2003) is to present the work of Yao et al. (2009), who used the argument that in 2005 the BRIC countries generated about 27% of global GDP. According to these authors, the high economic growth potential of these countries could be attributed to their fertile lands and rich natural resources, including a large available and low cost workforce, combined with the high rate of foreign direct investment.

To reinforce the argument used by Yao et al. (2009), Dolgikh and Kokin (2009) presented results from a study conducted in 2008 by the Research Grant Thornton International, which for the first time calculated an index of fast-growing markets. The results showed that the BRIC countries are among the five high economic growth countries. What was observed, according to the authors, was that all BRIC countries had rapid economic growth; however, China stood out as the country with the most dynamic economic growth among the countries analyzed.

Among the statistical studies that confirmed the significant economic growth of the BRIC group, Yao et al. (2009) pointed out that crude oil production achieved by the group accounted for 20.6% of the world's oil production in 2004. Moreover, these authors observed that foreign direct investment provided the BRIC countries the capital needed for economic development.

In the search for other factors that could contribute to economic growth, Lawson et al. (2006) found that infrastructure is vital to growth while it plays an important role to solve income inequality. Based on their observations, the authors listed some important points in terms of the infrastructure of the BRIC countries: (1) significant growth in mobile telephony; (2) intense electricity consumption; (3) greater access to basic sanitation; (4) increased access to water sources, along with urbanization; (5) increased number of infrastructure projects.

A brief analysis of this information shows that BRICS countries have shown an economic growth trend, which can be seen by how these countries behave in the international market or by the advances in infrastructure that tend to bring socio-economic progress.

However, in spite of the aforementioned, over the years, there has been a slowdown in the economic growth of the BRICS group. In the work entitled 'Broken BRICs: why the rest stopped rising', Sharma (2012) states that the extravagant predictions about the BRICS group have been toppled, since the observed economic growth has slowed sharply. According to the author, it is possible that the new global economic order is more similar to the earlier one than what most observers expect, and there will be economic growth for emerging countries; however, this will occur slowly and different from the experts' forecasts.

3.2. *Social and environmental development of BRICS*

According to May (2008), the argument used for looking into the accelerated growth rates of BRIC countries is the ability to lift millions of people out of absolute poverty. However, the author also found that in this path, the trend is that desirable economic growth is accompanied by unsustainable levels of consumption. The author highlighted that the pursuit of rapid growth could bring as a consequence the future scarcity of natural resources, which according to him is contradictory to sustainability, since the pressures weighing on the systems that support life are significant.

Thus, Plotnikova (2011) indicates that the economic growth of BRICS must be based on sustainable development, seeking to provide qualitative improvements to their systems, in view of the great responsibility to promote sustainable development in light of the projected economic growth potential.

In terms of population, Lastres et al. (2007) pointed out that the population representativeness of the BRIC group, in terms of world population, can be considered a challenge. These authors also added that the challenges seen in large populations relate primarily to infrastructure, health, and education services. In addition to these, the authors reported there are other problems related to population issues, such as unemployment and high income distribution inequality.

To validate all of these issues related to the population problems of BRICS countries, the projections of Wilson and Purushothaman (2003) indicated that despite their rapid economic growth, the populations of these countries are still, and will remain until 2050, likely to be poorer on average than the G6 population.

Lastres et al. (2007) analyzed the HDI and noted that in the 1990–2002 period, the four countries that made up the BRIC group at that time were in the medium human development category (HDI between 0.5 and 0.8). However, according to the authors, the analysis allowed to assert that over that period the country had a slight and continuous HDI improvement, becoming the highlight of progress because of India. According to Lastres et al. (2007), India's HDI evolved from 0.297 in 1990 to 0.595 in 2002, despite its significant population growth.

To complement the previous information on the HDI of the BRIC countries, we turn to May (2008) to state that, as a whole, these countries have an average index of 0.708. Thus, the BRIC group was ranked in the 'low-medium' classification of countries in terms of development.

As stated by May (2008), the BRIC countries are culturally heterogeneous, with religious, ethnic, and racial diversity. However, as explained by the author, the BRIC countries have similar aspirations to achieve human

development and improved quality of life, although some invest more than others in education, health, and infrastructure.

With regards to the environment, May (2008) noted that annual CO_2 emissions of the BRIC countries account for approximately two thirds of the global average. The author also reported on the ecological footprints of these countries, which are considered heavy and involve considerable costs due to the damage caused by the inability of the ecosystems to provide services. However, Lawson et al. (2007) presented evidence that urbanization and industrialization are particularly responsible for environmental degradation, also including agricultural-related activities as a significant source of pressure on the environment. According to these authors, atmospheric pollution is a growing problem and a predictable growth consequence of the BRIC countries, given their current high energy intensity phase.

Thus, it can be acknowledged, as did Tamazian et al. (2009), that over the past few years, the BRIC economies have experienced episodes that have contributed to increased CO_2 levels, which implies adverse consequences to global mitigation strategies concerning this dire trend. In this way, looking for solutions regarding the problem of greenhouse gas emissions, May (2008) identified some alternative behavior options to consider the accelerated growth of the BRIC countries sustainable:

> […] (i) allow the scarcity resulting from excessive growth to signal the correct use of the remaining resource reserves through the price system or (ii) invest heavily in education and technological innovation to separate development from resource exhaustion. The position of ecological economics is that there needs to be a third option: (iii) seek a path to stability, initially ensuring a better income distribution so that everyone can benefit from a sustainable economy. (May 2008, p. 4)

According to May (2008), the aforementioned behavioral options do not repudiate the actions that take advantage of market opportunities or investments in human capital and technological innovation. The goal, according to the author, is the need for caution with rapid growth due to the imminent uncertainties of their effects.

To justify the negative consequences that the accelerated economic growth of the BRIC countries has brought to the world, in their work, Pao and Tsai (2010) presented the Environmental Kuznets Curve hypothesis for the BRIC countries. Based on the work of these authors, it was concluded that increased environmental pollution occurs together with economic growth; however, it stabilizes and begins to decrease after a certain level of income per capita. In addition to these authors, Tamazian et al. (2009) also conducted studies on the adequacy of the Environmental Kuznets Curve for BRIC countries and concluded that economic development would reduce environmental degradation after high economic growth.

Moreover, according to Plotnikova (2011), though the BRICS (1) have negative scale impact on a global ecosystem, (2) show level of ecological efficiency of economic systems at a low enough level, and (3) have the need and duty of global scale to strengthen a transition policy to ecological-oriented models of economic development, this group of countries could collectively represent the world leader of sustainable development direction driving.

It bears repeating that the rising levels of environmental pollution cannot be considered normal, as well as the exploitation of natural resources resulting from economic growth. The technological innovation initiatives, when properly assimilated, represent a promising path to reduce these detrimental trends that plunder the planet, as they may find productive alternatives that could minimize the social–environmental damage across the globe.

In terms of environmental protection, we resorted to the Kyoto Protocol, a Protocol that took effect in February 2005 with the goal of reducing Greenhouse Gas (GHG) emissions and mitigating the negative impacts of global warming. Two groups of countries were created to implement this protocol: (1) 'Annex I', developed countries accountable for the current GHG levels, requiring them to reduce their emissions, and (2) 'Non-Annex I', developing countries, large emitters but not required to reduce their emissions (United Nations 1998).

Thus, with regards to the member countries of the BRICS group, it was perceived that the only 'Annex I' country is Russia, and therefore, it committed to reduce its GHG emissions between 2008 and 2012; however, the other members of the BRICS countries (South Africa, Brazil, China, and India) are 'Non-Annex I', since they are considered developing countries and therefore are not obliged to commit to emissions reduction targets, though little by little they are adopting voluntary actions.

4. Method

The main objective in this work is to compare the efficiency of the BRICS countries in transforming productive resources and technological innovation into sustainable development. For this, the DEA technique was used, that is an Operational Research method, developed by Charnes et al. (1978), which through the empirical construction of a piecewise-linear boundary aims to determine the productive efficiency of a set of DMUs – Decision Making Units (Mariano & Rebelatto 2013).

Three DEA applications were performed, each referring to one of the sustainability dimensions: economic, environmental, and social. The initial proposal of this work predicts the presence of four variables for each analysis (economic, environmental, and social), three input variables, and one output variable. Applying the criteria proposed by Nunamaker (1985) that the number of units analyzed should be at least three times the sum of inputs and outputs used, the number of units analyzed should be at least 12. To perform this DEA processing step, the software Frontier Analyst Professional was used in the three subdivided applications.

The data collection and analysis considered the period that begun in 2000 up to 2007. To determine this, the

criterion used was the availability of data and the history of the object of study (the BRICS group), that only began to be widespread in the international market in 2001. Thus, 2000 was set as the starting point for the analysis period, that is, one year prior to the creation and dissemination of the BRIC term.

According to the classification proposed by Lyytimäki et al. (2013), the three sustainability indicators generated in this work from the efficiency calculated using DEA can be classified as strategic long-term usage, since they allow identifying long-term priority and strategic action areas for the BRICS countries. Taking the work of Lyytimäki et al. (2013) as a reference, great care was taken in choosing the indicators in order to avoid the risks cited by the authors.

As the goal of the present study is to compare the efficiency of the BRICS countries in transforming productive resources and technological innovation into sustainable development, the variables selected seek to portray such issues in order to develop the analysis model. The Cobb–Douglas production function was used as a reference in this choice. Thus, with respect to the input variables, the variable chosen was the 'Gross Fixed Capital Formation' to represent the capital variable, of the original Cobb–Douglas production function; the variable 'employed population' to represent the work variable, also from the original Cobb–Douglas production function; and the 'R&D spending' to represent the countries' technological innovation, chosen based on the work of Ruffoni et al. (2004).

It is important to mention that the use of the variable R&D spending had a 1-year lag since the return for this type of spending needs a period of time to materialize. Therefore, the analysis period was adjusted by excluding the year 2000, thereby including seven periods (2001–2007) and no longer eight periods.

In the set of output variables, the 'GDP' variable was chosen to specify the countries' economic development, and this variable was chosen based on its use in studies that evaluate the sustainability of regions, as for instance in the works of Shi et al. (2004) and Zhen et al. (2009).

The second output variable chosen to translate the countries' environmental development was the 'CO_2 emission' indicator. This indicator has been constantly used in studies evaluating the environmental sustainability of regions, as for example in Lee and Huang (2007), Tamazian et al. (2009), Zhen et al. (2009), Boggia and Cortina (2010), Pao and Tsai (2010), and others. Furthermore, the use of 'CO_2 emission' was chosen as a variable for environmental development based on the Environmental Kuznets Curve (Grossman & Krueger 1991) that shows the relationship between a country's pollution and GDP per capita. Thus, as CO_2 is the main greenhouse gas responsible for intensifying the greenhouse effect, the emission of this pollutant was then adopted to conduct the work described herein.

It should be noted that output variables that relate to waste and pollutants are termed 'undesirable outputs' that need to be reduced to improve the countries' performance; thus, the variable CO_2 emission fits in this category (Seiford & Zhu 2002). To solve this question, in this work, the method used to treat the variable CO_2 emission was to multiply each undesirable output by '−1'. As the DEA analysis does not allow using negative values, the value obtained by multiplying by '−1' was added to a set translation vector, ensuring that the values achieved would become positive.

And the third output variable chosen, which represents social development, was 'life expectancy at birth'. This variable was chosen based on its use in works such as in Mahlberg and Obersteiner (2001), Despotis (2005), Ramanathan (2006), Lee and Huang (2007), Zhen et al. (2009), Mariano and Rebelatto (2013), and also in the work of Sen (1998), which pointed to life expectancy as a decisive indicator to measure the success and progress of a society. In this context, and according to Gisbertt and Pallejá (2006), life expectancy at birth is one of the most commonly used indicators for international comparisons.

The variables were validated by the multiple regression technique and correlation analysis, inspired by the stepwise method. The basic feature of the multiple regression technique is to identify the relationships between variables, determining the theoretical model for the three proposed analyzes (economic, environmental, and social). The stepwise method is one of the first procedures suggested by Norman and Stoker (1991) to conduct the validation of pre-selected variables and uses the correlation analysis, starting from an initial pair of the highest correlation. The result analysis achieved with the validation by linear regression and stepwise method determined how each DEA application should be conducted, that is, which inputs and outputs would be examined in the economic, social, and environment applications. Table 1 summarizes the variables used.

4.1. *DEA's models and tools*

The DEA has basically three options regarding the orientation of the models, input orientation, output orientation, and input–output orientation. Specifically, in this work, the use of the input orientation or doubly oriented model is considered unfavorable because the countries analyzed did not seek to reduce their inputs. As one of the objectives is to increase the countries' outputs, in other words, increase

Table 1. Variables used.

Application	Type of efficiency	Input	Output
1	Economic	Gross fixed capital formation; employed population, and R&D expenditure	GDP
2	Environmental	Gross fixed capital formation and expenditure on R&D	CO_2 emission
3	Social	Gross fixed capital formation; employed population and R&D expenditure	Life expectancy

$$Min \sum_{j=1}^{n} v_j \cdot x_{j0} - w$$

$$Subject\ to:$$

$$\sum_{i=1}^{m} u_i \cdot y_{i0} = 1$$

$$\sum_{i=1}^{m} u_i \cdot y_{ik} - \sum_{j=1}^{n} v_j \cdot x_{jk} + w \leq 0, \quad for\ k = 1, 2, \ldots, h$$

$$w\ without\ restriction\ of\ signal$$

Figure 1. Output-oriented DEA-BCC model.

Notes: Wherein x_{jk} represents the amount of input j of DMU k; y_{ik} represents the amount of output i of DMU k; x_{j0} represents the amount of input j of the DMU under analysis; y_{i0} represents the amount of output i of the DMU under analysis; v_j represents the weight of input j for the DMU under analysis; u_i represents the weight of output i for the DMU under analysis; w represents the scale factor; m represents the number of outputs analyzed; n represents the number of inputs analyzed; and h represents the number of DMUs analyzed.

the BRICS group's sustainable development, the DEA model with output orientation was chosen.

The DEA model to be selected regards the relationship established between input and output, that is, the type of return to scale. In this work, the BCC model was used, which means that the outputs increase or decrease at a different rate than the inputs, respecting the issue regarding the size of the units analyzed. That means that input reductions or increases do not generate changes in the outputs in the same proportion. Figure 1 presents the output-oriented DEA-BCC model.

In general, the DEA analysis can show similar scores between efficient units, since it does not take into account factors such as the balance between variables, prior information about the weights, attributing zero weights, and others (Mariano & Rebelatto 2013). Based on this understanding, it was necessary to develop methods to differentiate these units. The research was conducted using the inverted frontier method, consisting of the following steps:

(1) Switch the place of inputs and outputs
(2) Solve the resulting model
(3) Calculate the composite index, considering the classical and inverted frontiers (Leta et al. 2005).

According to Leta et al. (2005), the composite index is calculated from the arithmetic mean between the classical frontier index ($E_{\text{classical}}$) and the inverted frontier index subtracted from one ($1 - E_{\text{inverted}}$). To obtain values between 0 and 1, the composite index results must be standardized. According to the composite index, the most efficient DMU will be that which can show a good performance in its strong points, which is evaluated by the standard efficiency level, not showing a very bad performance in its weak points, which is measured by the efficiency obtained in the inverted frontier subtracted from one (Leta et al. 2005).

In this study, each country at a specific time was considered as a separate unit. According to Cooper et al. (2000), time-dependent analysis of DEA is known as 'window analysis', a technique that considers units of time as if it were a separate unit. The window analysis is a process similar to the moving average, where each time a new unit enters another unit exits, usually the first one that entered in the previous analysis. Cooper et al. (2000) used the following relationship to calculate the number of windows and their amplitude.

$$W = k - p + 1 \tag{1}$$

$$p = \frac{k+1}{2} \tag{2}$$

wherein

W = number of windows; k = number of years and p = window amplitude.

In the work reported herein, the analysis period corresponded to 7 years (k = 7). Thus, the calculations determined that the number of windows for DEA would be four and the window amplitude would also be four.

5. Results

The present study focuses on the efficiency analysis of the BRICS group to transform productive resources and technological innovation into sustainable development through the DEA. Thus, through the analysis window, the efficiency indexes of the countries studied in each window and also a total average efficiency index for each application (economic, social, and environmental) were obtained and are presented below.

The economic efficiency indices for each of the four windows constructed are shown in Table 2. It was observed

Table 2. Efficiency results of windows, economical application.

	Window				
Mean efficiency	1 (2001–2004)	2 (2002–2005)	3 (2003–2006)	4 (2004–2007)	Mean total
South Africa	0.67	0.65	0.65	0.65	0.66
Brazil	0.98	0.98	0.99	0.99	0.98
China	0.67	0.65	0.65	0.65	0.65
India	0.49	0.48	0.49	0.51	0.49
Russia	0.54	0.52	0.50	0.50	0.51

Table 3. Efficiency results of windows, environmental applications.

	Window				
Mean efficiency	1 (2001–2004)	2 (2002–2005)	3 (2003–2006)	4 (2004–2007)	Mean total
South Africa	0.99	0.99	0.99	0.99	0.99
Brazil	0.88	0.90	0.91	0.93	0.90
China	0.28	0.23	0.18	0.14	0.21
India	0.80	0.81	0.81	0.81	0.81
Russia	0.76	0.77	0.79	0.80	0.78

Table 4. Efficiency results of windows, social applications.

	Window				
Mean efficiency	1 (2001–2004)	2 (2002–2005)	3 (2003–2006)	4 (2004–2007)	Mean total
South Africa	0.81	0.79	0.75	0.69	0.76
Brazil	0.97	0.99	0.99	0.99	0.99
China	0.57	0.57	0.56	0.55	0.56
India	0.51	0.50	0.49	0.48	0.49
Russia	0.86	0.88	0.90	0.92	0.89

that of the BRICS countries, Brazil had the highest average economic efficiency, followed by South Africa, China, Russia, and India, in descending order of efficiency.

In turn, Table 3 shows the efficiency indices of the DEA environmental application. It should be highlighted that China was classified as the country with the lowest environmental efficiency, with an average efficiency ratio of 21%, well below the average of the group of countries studied.

Finally, Table 4 shows the results of the DEA social application. As noted, with regards to the average social efficiency, Brazil leads with almost 100% of efficiency; followed by Russia, South Africa, China, and India, in order of decreasing efficiency.

The DEA results are explained in two tables, which are the basis to analyze the results. Table 5, the first table, summarizes the efficiency ranking of each country in each of the pillars of sustainability analyzed.

Table 6 was built to respond to the issues that would probably emerge from the results shown in Table 5, which shows the data referring to 2007, the input and output variables used in the DEA, for each country.

Table 5. Mean efficiency ranking of BRICS, from 2001–2007.

	Economic application	Environmental application	Social application
South Africa	2nd	1st	3rd
Brazil	1st	2nd	1st
China	3rd	5th	4th
India	5th	3rd	5th
Russia	4th	4th	2nd

The idea of presenting only the data for 2007 was based on the fact that, in most cases, year to year stable data behavior was observed; therefore, it was decided to present the data from the most recent analysis years.

After the DEA analysis results were shown, the discussion for each individual country began.

5.1. China

Going back to the information shown in Table 6, it was noticed that China was the country of the BRICS group with the highest fixed capital, with the largest manual labor and highest investment in technological innovation. However, the economic application of DEA showed an average efficiency ratio of 65%.

Over the past three decades, China has shown rapid economic growth, going from a planned economy to a market economy through the reforms adopted in 1978 (World Bank 2011c). According to the World Bank (2011c), China currently holds the second highest world economy position and is expected to reach the first position, overtaking the United States (Wilson & Purushothaman 2003).

However, despite its comfortable economic position when compared to other BRICS countries, the analysis in this study revealed that China failed to efficiently transform its high inputs into GDP outputs, although this country presented the highest GDP in the BRICS group.

With regards to the environmental aspect, it was observed that China has the highest CO_2 levels among the BRICS countries. It therefore makes sense that this country was ranked the least efficient of the group.

In the literature consulted, we cite the work of Armijo (2007), who reports that the lack of natural resources and

Table 6. Input and output, 2007.

	Gross fixed capital formation[a]	Population employed[b]	R&D[c]	Gross domestic product[d]	CO_2 emission[e]	Life expectancy[f]
South Africa	38,298,311,187	13,887,854	3,975,582	178,644,321,362	433,172	51.43
Brazil	138,994,881,914	89,950,866	16,420,804	815,703,390,474	368,015	72.16
China	930,624,500,534	740,235,780	84,043,907	2,456,684,033,218	6,533,018	72.94
India	245,751,962,059	423,228,908	21,393,437	773,393,372,039	1,611,042	63.39
Russia	100,484,784,168	71,473,738	19,630,811	410,505,209,128	1,536,099	67.50

Sources: UNESCO and World Bank. [a]Gross fixed capital formation (constant 2000, US$); [b]Labor force – Unemployment; [c]Gross domestic expenditure on R&D (constant 2005, US$); [d]Gross domestic product (constant 2000, US$); [e]$CO_2$ emissions (kt); [f]Life expectancy at birth, total (years).

environmental pollution represents two factors that tend to limit China's economic progress. Another author, May (2008), added that this could result in a bigger ecological footprint that this country could bear. Moreover, as Grumbine (2007) pointed out, China's energy production composition (dependent on power plants and coal) and its consumption are troubling aspects of this country's accelerated economic growth. According to the Central Intelligence Agency, CIA (2012a), air pollution, water scarcity and pollution, deforestation, soil erosion, desertification, and the trade of endangered species are the highlighted issues regarding China's environment.

Analyzing China's efficiency with regards to its social aspect, the data inserted in the economic and environmental analyses is reiterated. That is, despite having the highest input values in the group analyzed, China's average social efficiency is only 56%.

It is surprising to note that this occurred despite the country's highest life expectancy in the group, which is of 72.9 years. This served to demonstrate that China has the potential to achieve greater life expectancy, given the inputs considered. However, the high life expectancy is not positive in all aspects. The aging Chinese population can be considered a limiting factor to the projected economic growth, since the trend is a decrease in the working population, due to increased longevity and also due to the nationally promoted one-child policy (Qiao 2006).

China's poverty reduction coupled to economic growth observed in the last three decades was, according to the World Bank (2011c), globally acknowledged. As Dolgikh and Kokin (2009) state, China is the country with the lowest unemployment rate and the highest capacity to generate employment of the BRICS countries. Notwithstanding, according to the World Bank (2011c), poverty reduction remains this country's major challenge, since coupled to its economic rise, rural–urban migration, social inequality, and rapid urbanization also ensued. Furthermore, the per capita income in China is below the world average (CIA 2012a).

5.2. *India*

Returning to the data presented in Table 6, India is the second ranking country in fixed capital, manual labor, and investment in technological innovation. However, its mean efficiency ratios show that the country has not been efficient in its use of high inputs to create its outputs.

In terms of the economic aspect of the BRICS group, India was the country that had the lowest average efficiency, 49%. Thus, it was concluded that this country can achieve, by optimizing the use of its high inputs, higher GDP levels, while also achieving better economic efficiency levels.

According to Nassif (2006), India's economic growth was evidenced between 1985 and 1990, when policy measures were adopted by the government in order to end the protectionist scenario of an inefficient industry that showed little ability to compete in the global market. Thereafter, the growth of India's economy was observed, one of the fastest growing economies, particularly based on the expansion of information technology services, according to Vieira and Veríssimo (2009). However, as reported by the CIA (2012b), the marks of former autarchic policies remain, as well as inadequate physical infrastructures, persisting high inflation, high interest rates, and the little progress of economic reforms, all of which tend to limit the country's economic growth.

The environmental analysis showed that India achieved an average efficiency ratio of 81%. However, it is plausible to declare that this rate could be higher if the use of its gross fixed capital formation inputs and R&D investments are optimized in order to reduce the levels of CO_2 emission, whose current rate is the second highest in the group studied.

Furthermore, the productive sector's excessive dependence on coal has required, according to May (2008), investments in renewable energy sources and also in alternative energy to lower the CO_2 emission levels.

Analyzing India's social aspect, it was found that the country's average efficiency ratio of 49% was the lowest in the BRICS group. This is because in spite of the fact the country holds the second to last place in input levels (after China), India ranks second to last in life expectancy, of 63.4 years.

India's economic growth brought, according to May (2008), certain social benefits, for example, the increase in per capita income, increased life expectancy and literacy rate, and also a drop in the number of people living below the poverty line. On the other hand, the World Bank (2011d) reported that poverty remains to be India's main

challenge, one-third of the world's poor population. Income disparity was observed, and most of the population has not benefited from the country's economic growth; moreover, there are limited non-agricultural employment opportunities and poor access to basic education, some of the factors indicated by the CIA (2012b).

It is assumed that some factors may be related to India's low efficiency in the current analysis. One of these concerns the need to liberalize trade, and other factors are related to rural–urban migration, education, environment, and infrastructure, in addition to the permanent popular conflicts that must also be considered within the Indian context (Armijo 2007; Poddar & Yi 2007).

5.3. *Brazil*

Brazil was the country of the BRICS group that showed median input levels, while achieving higher efficiency rates than the other countries in the group. In the economic analysis, Brazil ranked the most efficient, with an average efficiency of 98%. That is, despite not having high levels of fixed capital, labor, and technological innovation, the country had the second highest GDP of the group and the highest economic efficiency.

Brazil, whose economy leads in South America, is a country which, according to the CIA (2012c), is characterized by having good agricultural, mining, manufacturing, and service sectors. Leme (2006) reports that the measures adopted, with emphasis on macroeconomic stability aiming to increase the country's economic growth, resulted in reduced inflation and public debt. Thus, although in recent decades Brazil has presented the lowest GDP growth rate of the BRICS countries, Vieira and Veríssimo (2009) attributed this performance to the measures implemented to cool the economy and curb inflation. In this study, Brazil stood out as the most efficient country in the economic application. Thus, we can assume that if Brazil increases its inputs, while maintaining its economic policy, it can achieve higher GDP output values.

The environmental analysis of Brazil made it clear once again that it is possible to do more with less. Despite its median input levels, the country managed to stand out as the country that emitted less CO_2 levels and achieved an average efficiency ratio of 90%. This was not the highest efficiency index of the group, which belongs to South Africa, but it was a satisfactory efficiency value.

The World Bank (2011b) pointed out that, while the country has made progress in reducing forest deforestation and has become one of the leaders in climate negotiations – pledging on a voluntary basis to further reduce greenhouse gas emissions – Brazil has faced challenges to combine the benefits from agricultural growth, environmental protection, and sustainable development. Deforestation of the Amazon region, the illegal wildlife trade, soil degradation, water pollution, and oil spills represent some of the other problems related to the Brazilian environment (CIA 2012c).

In the social aspect, Brazil stood out in the BRICS group with the highest efficiency level, which was 99%. This is because, despite having median inputs, the country had the second highest life expectancy of the group, of around 72.16 years.

With regard to Brazil's social aspect, some observations are made. According to May (2008), because of Brazil's colonial legacy, it is considered one of the most unequal countries in the world, although there has been a decrease in income inequality and has also achieved the lowest unemployment rate in its history, of about 4.7% in December 2011, according to the data from the CIA (2012c). On the other hand, the stable economic growth policy has benefited the low-income population with improved social welfare, despite the social disparities still observed. In addition, there have been innovative social programs that seek inclusive economic growth, which resulted in a reduction of social inequality, as for instance the Social Assistance *Bolsa Família* Program (World Bank 2011b).

5.4. *Russia*

With regard to Russia's input and output levels, the country fell within the median level category in the group. Considering its inputs, this country showed a great similarity with Brazil, which also showed median input levels.

However, the data obtained in the economic analysis showed that Russia achieved a low level of average efficiency (51%). This is because when compared with the other BRICS countries, the country had a low GDP value.

According to the CIA (2012d), Russia has undergone significant changes with the collapse of the Soviet Union, as the country is no longer an isolated global economy, and became a market-based economy, meaning that it is globally inserted. Thus, authors such as Macfarquhar (2007) recognized that, despite the deep economic depression that occurred during the 1990s, since 1999, Russia has had a rapid expansion. According to the opinion of other authors, such as Vieira and Veríssimo (2009), this economic growth was achieved on account of the high oil prices, the production growth of industries and services, and also by stimulating the domestic market. However, Russia has not yet achieved its best economic phase, since the vulnerability of its economy is mainly attributed to the fact that it focuses exclusively on the exploitation of natural resources, which tends to limit its economic growth (Armijo 2007).

In the environmental analysis, Russia obtained an average efficiency ratio of 78%. This index is due to the country's CO_2 emission levels, which are very high when compared with their median input levels.

According to Armijo (2007) and Dolgikh and Kokin (2009), Russia's intense economic growth was supported by the exploitation of energy resources. Thus, caution and attention are required for the environmental problems facing the country, regarding its energy matrix that is significantly dependent on fossil fuels. This causes the

CO_2 emission level per capita to be similar to the largest world emitters and the largest among the BRICS countries, according to May (2008). Deforestation, erosion and soil contamination, water contamination, and the lack of efficiency in municipal solid waste management are, according to the CIA (2012d), some of the other environmental problems facing the country.

In the social aspect, Russia obtained an average efficiency index of 89%. This ratio was considered good, since it classified Russia in second place for the social analysis efficiency. This ranking was achieved due to the fact that, despite the country's median input levels, of the BRICS group, Russia ranks third in life expectancy, 67.5 years.

According to the World Bank (2011e), there were gains in the living conditions of the Russian population since the turn of the century, with strong growth in employment, wages, and income for most of the population. Moreover, between 1999 and 2003, a significant decline in poverty was observed, placing the country in first place in GDP per capita of the BRICS group (UNDP 2006; Dolgikh & Kokin 2009). All these factors may have contributed to Russia achieving second place in social efficiency, as reported in this study.

However, in conclusion, it can be assumed that this country can do more with their inputs to maximize their outputs and therefore achieve a higher efficiency level. In addition, there is the vulnerability of the Russian economy, which is mainly due to the concentrated exploitation of natural resources. This also seems to be hindering development, insofar as it can result in a de-industrialization process and a consequent currency devaluation (Armijo 2007).

5.5. *South Africa*

South Africa is undoubtedly the BRICS country that showed the lowest levels of inputs and outputs.

One of the initiatives of the South African government was launching a strategic plan for the period of 2009–2014, choosing priorities such as more inclusive economic growth, infrastructure, rural development, food security, agrarian reform, education, crime reduction, improved public services, sustainable management of resources, and their proper use, among other factors (World Bank 2011a).

However, the economic analysis for this country showed an average efficiency index of 66%. This was due to their low levels of inputs and also low GDP output.

The fact is that little by little the country has gained prominence in the international economic scenario, becoming more active in events such as meetings of the International Monetary Fund and G20 (19 largest economies plus the European Union). However, South Africa still suffers from the influences of its complex history of oppression and violence (World Bank 2011a). According to reports from the CIA (2012e), it can be admitted that South Africa's outdated infrastructure also tends to limit its economic growth.

With regards to the environmental analysis, it was observed that South Africa is considered the most efficient country in the group, with an average efficiency ratio of 99%. It is not difficult to find the answer to this high level of efficiency, since South Africa is the country with the lowest levels of inputs, and it is possible that due to this it has the lowest level of CO_2 emissions of the BRICS group.

Socially, South Africa achieved an average efficiency index of 76%. The low input levels resulted in a low output level for life expectancy (51.4 years). This country had the lowest life expectancy of the BRICS group, much lower than the group average. However, it should be noted that the low life expectancy in this country may be due to the numerous cases of HIV and tuberculosis, violence, and other problems inherited from the apartheid regime (World Bank 2011a). In addition to the low life expectancy, unemployment was also taken into consideration by the CIA (2012e), a serious problem for the country's social development.

Thus, it is reasonable to say that despite South Africa's position as a leader in the sub-regional and continental levels, the country continues to have significant income and wealth differences. The economic growth observed in the country's post-apartheid resulted in increasing social inequality and also high unemployment rates and the limited access of the poor population to basic services, which are some of the problems this country faces (World Bank 2011a).

6. Conclusions

The international economic scenario has demonstrated a new dynamics with respect to the accelerated economic growth of some countries to the detriment of others; countries that in the past were considered unshakable economic powers are currently losing ground to those which in the past showed no prominence whatsoever. On the other hand, the emerging countries deserve recognition, formerly called underdeveloped countries, but which are currently gaining space in the international economic arena, as for instance the countries that make up the BRICS group.

What is observed is that the current world order and its requirements demonstrate that the way to grow is no longer considered sustainable, in other words, economic growth measured by GDP should no longer be the only performance parameter of nations. The constant battles for diligence and attention to social and environmental issues have demanded a new behavior from countries in order to ensure sustainability.

Therefore, this work sought to determine the efficiency of the BRICS countries with regards to transforming productive resources and technological innovation into sustainable development. The efficiency ratings in the three DEA applications (economic, environmental, and social)

brought to light some results that can be of interest for more specific scientific explorations.

Among the findings, the main highlight of the BRICS group was Brazil, whose results suggest that GDP growth may be the result of a more humane production mode, with a simultaneous increase in income distribution and environmental attention. It should be emphasized that the DEA is an analysis technique for relative efficiency, thus the focus on Brazil only refers to a comparative analysis within the BRICS group.

On the other hand, the development of this work helps to reflect on China's productive mode, which despite having the highest GDP of the group, was, surprisingly, the third of the group in economic efficiency because its inputs are very high. This suggests that China should work more efficiently in order to reduce its inputs to continue its high economic growth in the long term. In addition, the high levels of CO_2 emissions, the predatory productive mode adopted by the country long ago, and its social problems were highlighted.

With regard to India, it was highlighted that this country is in a scenario of little progress in economic reforms and also a compromised social scenario due to poverty. Thus, India has serious social issues that may be impacting its economic efficiency. Therefore, it is suggested that India should primarily address the problem of poverty in their society through social programs, as was observed in Brazil in recent years.

As for Russia, it can be emphasized that despite its economic improvement after the recession of the 1990s, the country is still affected by the vulnerability of its economy. Additionally, it is the largest CO_2 emitter per capita of the BRICS group, and its economy depends on the exploitation of natural resources. Thus, it is suggested that Russia should invest in sustainable technology to jointly solve their economic and environmental problems. However, since the turn of the century, this country has seen social gains.

Finally, South Africa is a country that emits low levels of CO_2 when compared with other BRICS countries, and this is because their production levels are also low. Moreover, the country shows significant improvement in its social setting, despite the persistence of problems inherited from the Apartheid era. As shown earlier, South Africa joined the BRICS group by presenting economic growth potential. However, its economy is still smaller than that of other countries in the group. Therefore, the great challenge for this country is to grow, maintaining their low CO_2 levels and social improvements.

The goal of the comparative study of the BRICS countries' efficiency to transform productive resources and technological innovation into sustainable development had no intention to bring definitive conclusions. Nevertheless, this work has enabled the construction of an interesting comparison chart between the BRICS countries, and this analysis could be replicated for other groups of countries in different situations from those observed in the BRICS group.

We believe this study represents an initial step for performing new analysis works on the subject. It is reasonable to assume that adding other variables, or even replacing some variables, new and relevant results can be achieved. Furthermore, implementing other research methods, with new tools, could also be helpful to attain results that could be compared with the results that were achieved in the present work.

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