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The efficiency of BRICS countries in sustainable development: a Data Envelopment Analysis

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Master's in International Management

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Marketing, Operations, and General Management

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Resumo

O crescimento económico tem sido tradicionalmente a principal forma de avaliar o desenvolvimento dos países, e a sua busca intensa por parte das nações traz consigo grande custo ambiental. A crescente preocupação com as consequências adversas do crescimento económico sobre o meio ambiente e o bem-estar das pessoas tem encorajado economistas a buscar novas abordagens para avaliar o desenvolvimento dos países, considerando métricas ambientais e sociais e não apenas económicas.

Países emergentes se tornaram atores relevantes no sistema internacional devido às suas economias em rápido crescimento, grandes populações e abundantes recursos ecológicos. Os BRICS são compostos por um grupo heterogéneo de nações, distintas em sua estrutura política e atividades económicas, cujos líderes se reúnem frequentemente com o objetivo de articular políticas e estratégias cooperativas para melhorar o seu crescimento coletivo. Eles não apenas se transformaram em grandes economias, como também em grandes emissores de gases poluentes. Portanto, torna-se necessário analisar se os países conseguem proporcionar um crescimento económico que vá ao encontro do desenvolvimento sustentável.

Esta tese tem como objetivo analisar a eficiência dos países dos BRICS na transformação dos seus recursos produtivos, que também são considerados motores do seu crescimento económico, em desenvolvimento sustentável. O objetivo foi alcançado por meio da técnica de análise envoltória de dados, para criar *rankings* de eficiência de acordo com cada um dos três pilares da sustentabilidade (económico, ambiental e social). Os resultados comparativos permitem compreender melhor os desafios dos países rumo ao desenvolvimento sustentável e serem objetos de novas explorações científicas.

Palavras-chave: crescimento económico, sustentabilidade, BRICS, desenvolvimento sustentável, eficiência

Classificação JEL: F63, O57, Q01, Q56.

Abstract

Economic growth has traditionally been the main way to evaluate a country's development, and its intense pursuit usually comes at a great environmental cost to the nations. The growing concern regarding the adverse consequences of economic growth on the environment and people's well-being has encouraged economists to find new approaches to assess the countries' development, considering environmental and social metrics rather than only the Gross Domestic Product.

Emerging countries have become relevant players in the international system due to their fast-growing economies, large populations, and abundant ecological assets. The BRICS are composed of a heterogeneous group of nations, distinct in their political structure and economic activities, whose leaders have often met aiming to articulate cooperative policies and strategies to improve their collective growth. Not only have they turned into major economies, but also major greenhouse gas emitters. Therefore, it becomes necessary to analyze if their economic growth meets sustainable development.

This thesis aims to analyze the BRICS countries' efficiencies in turning their productive resources, which are also considered to be drivers of their economic growth, into sustainable development. The objective was achieved by using the data envelopment analysis technique, to create efficiency scores according to each of the three pillars of sustainability (economic, environmental, and social). The comparative results enable the possibility to better understand the countries' challenges towards sustainable development, and to be subject to further scientific explorations.

Keywords: economic growth, sustainability, BRICS, sustainable development, efficiency.

JEL Classification: F63, O57, Q01, Q56.

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1. Introduction

Economic growth, traditionally measured by the Gross Domestic Product (GDP), has long been a primary indicator of a country's overall development. The understanding of economic growth differs between neoclassic theories, which prioritize exogenous factors, namely capital accumulation as a determinant of growth, and endogenous growth theories, which include internal factors such as investments in innovation and human capital.

Economic growth also differs between developed and developing countries. While in developed economies, economic growth determinants include physical capital, fiscal policy, human capital, trade, demographics, monetary policy, and financial and technological factors, in developing countries, determinants include not only those but also great importance is given to external factors, such as Foreign Direct Investment (FDI) and foreign aid (Chirwa & Odhiambo, 2016). As developed countries' growth occurs at a steadier pace, marked by incremental increases in productivity, technological advancements, and improvements in the welfare of the populations, in developing economies it is frequently marked by rapid and uneven expansions, often with shifts from agriculture-based economies to industrialization and services.

The constant pursuit of economic growth is often accompanied by overuse of natural resources, environment degradation, and unrestrained consumption of goods and energy, consequently aggravating social inequalities, threatening the peoples' welfare, and raising profound concerns about the future of the world. The concept of Sustainable Development emerged in 1975 as an approach to pacifying the relationship between economic growth and the environment (Almeida et al., 2017). Defined by the Brundtland Commission as "the development that meets the needs of today's generation without limiting the ability to meet the needs of future generations" (Brundtland, 1987), sustainable development embraces three main perspectives: social, economic, and environmental.

The emergence of Brazil, Russia, India, China, and South Africa as fast-growing economies with large populations and abundant natural resources has challenged Western dominance in the international economic system. Since their official establishment in 2009, they have often met aiming to develop cooperative policies and strategies to enhance their collective growth. The BRICS have not only turned into major economies but also major greenhouse gas (GHG) emitters, placing them as central players in global climate discussions (Downie & Williams, 2018).

The focus of this work is to discuss the performance of the BRICS regarding sustainable development from 2010 to 2018. The scope is to compare the countries' efficiency in turning determinants of their economic growth into sustainable development. The objective was achieved using the Data Envelopment Analysis method, by the construction of three efficiency rankings, each in accordance with a pillar of sustainability (economic, social, and environmental). The outcomes enable the possibility to draw conclusions about the countries' quality of growth and impact in the international scenario.

The results reveal insights into the challenges faced by the BRICS countries in their pursuit of sustainable development. Brazil demonstrated estimable efficiency in the conversion of its resources and foreign direct investment into sustainable development but requires efforts to be directed to internal issues such as deforestation, social disparities, and political instability, to enhance its output potential. Russia stood out as the most efficient country in the group, although the country faces issues that challenge its path to sustainability such as its dependency on oil and gas exploitation. Results suggest that Russia's GDP could benefit from strategic investments in human capital. India and China's rapid economic growth has come at an environmental cost, resulting in increased CO₂ emissions and lower quality of life for their populations. To address these challenges and enhance their economic performance, they should prioritize their industrial growth, improve working conditions, and optimize their use of foreign direct investment and R&D expenditure to reduce greenhouse gas emissions and elevate living standards. South Africa's low carbon dioxide emissions secured its top position in the environmental application, and its commitment to addressing social disparities and health issues resulted in its top position in the social application. Recommendations for South Africa include further actions promoting social initiatives and health-related policies to continually enhance the population's quality of life.

This thesis is composed of an introduction, which provides an overview of the scope of the study, followed by a literature review that explores empirical studies about economic growth and its determinants, the concept and understanding of sustainable development, and the economic development of the BRICS countries. The methodology part outlines the research design, variables explanations, and the analytical technique employed in the study. Subsequent parts present the findings and results analyses, followed by the conclusion, which summarizes the key findings and suggests avenues for future research.

2. Literature Review

2.1 Economic Growth

The progress of nations is generally measured and explained by their economic growth. The neo-classical growth model developed by Solow (1956) in the mid-50s laid the groundwork for our current conception of economic growth, in which capital accumulation is a leading factor taken into consideration (Kniivilä, 2007). This theory sustains that a steady economic growth rate would result from the combination of labor, capital, and technology, mainly external factors.

In his work, Elhanan Helpman presented the Endogenous Growth approach, in which economic growth is not only influenced by the exogenous factors of neoclassic theories, such as population growth and capital concentration but also and mainly by internal factors, such as investment in research and development, innovation and education, therefore giving a higher importance to national policies implemented around incentives in these sectors (Helpman, 1991). Barro (1991) also explored the importance of endogenous factors in economic growth. He concluded that human capital, physical investment, and political stability are factors that contribute to economic growth in different countries.

There are many variables in literature believed to determine the economic growth of countries. While classical and neoclassical economic theories considered capital accumulation to be the main influencer of economic growth, more recent theories, such as the Endogenous Growth theory, emphasize the importance of human capital (Choudhry et al., 2020). Doré and Teixeira (2023) synthesize many factors found in literature into seven main areas, being “(1) human capital; (2) labor and demographic conditions; (3) technology, innovation, and structural change; (4) macroeconomic conditions; (5) international trade and foreign direct investment (FDI); (6) natural resources and geography; and (7) institutional conditions”.

Chirwa and Odhiambo (2016) concluded that key macro-economic factors linked to economic growth can differ not only between developing and developed countries but also between each country's economic, political, and social context, and today it is still unclear which factors are the principal drivers of economic growth within and among countries. According to them, determinant macroeconomic factors associated with economic growth in developed countries “include physical capital, fiscal policy, human capital, trade,

demographics, monetary policy, and financial and technological factors” (Chirwa & Odhiambo, 2016). Additionally, in developing countries, great attention is given to external factors such as Foreign Direct Investment (FDI) and foreign aid. Natural resources, and geographic, regional, and political factors are also determinants in developing countries.

Lustig et al., (2002) perceive economic growth as a powerful tool for improving the quality of life and reducing poverty, however, it is often accompanied by the overuse of natural resources and negative environmental and social impacts, such as income inequality, labor exploitation, deforestation, and toxic gas emissions. Therefore, it is the quality, not the economic growth per se, that reflects the well-being of the population (López et al., 2008).

To Ranis et al., (2000), although economic growth is a necessary condition to achieve human well-being, it is not sufficient. Not only does economic growth usually lead to environmental degradation, but the most commonly used indicator to measure economic growth, the Gross Domestic Product (GDP), fails to account for environmental issues or even the quality of life of the population, which reflects the need of new assessment methods (Santana et al., 2014).

New indicators were created to fill this gap concerning human well-being, such as the Human Development Index (HDI) created by the United Nations Program for Development to include the life quality with economic aspects, the Gini Coefficient, used to measure income inequality (Hasell, 2023), and life expectancy at birth, which not only evaluates the human being’s health but also the economic development, education, and healthcare systems quality (Chen et al., 2021). Nonetheless, these metrics do not consider the environmental impact caused by the consequences of economic growth (Santana et al., 2014). Those issues were addressed by the concept of Sustainable Development, which emerged as an approach to pacifying the relationship between economic growth and the environment (Almeida et al., 2017).

2.2 Sustainable Development

Awareness based on the poor use of natural resources and the fear regarding the future of humanity were reflected in the birth of the concept of Sustainable Development, though its essence was already present in the work of classical economists.

In the late 1800s, Malthus postulated that economic growth would eventually lead to starvation, as food production would not keep up with the growth of the population. In the shadow of the Industrial Revolution, other political economists such as Smith, Ricardo, and Mill have also questioned the limits of economic growth and its consequences for future generations (Purvis et al., 2019).

It was not until the 1972 Conference on the Human Environment in Stockholm that international representatives got together exclusively on behalf of environmental issues. The conference was attended by 113 UN member states and originated the United Nations Environmental Program (UNEP). Although a set of principles was created for the sound management of the environment, the transition from theory to practice didn't materialize, and not much was actually done to incorporate environmental concerns into actions (Chasek, 1994). It became clear at the conference that environmental protection and the need for development were conflicting necessities, especially from the point of view of developing countries (Prizzia, 2017).

Fifteen years after the conference, the concept of Sustainable Development was first formally defined by the Brundtland Commission in the Brundtland Report "Our Common Future", as "the development that meets the needs of today's generation without limiting the ability to meet the needs of future generations" (Brundtland, 1987). The report stated that the transition into a sustainable society would be a difficult task since various institutions and practices would need to change on behalf of both developing and developed countries.

The term "sustainability" is still very debated in the literature, with many different meanings and applications depending on its context. One widespread interpretation of 'sustainability' considers three interconnected pillars: social, economic, and environmental. Purvis et al. (2018) found no singular source from which this three-pillar model derives, but affirm that it has been accredited to the Brundtland Report, Agenda 21, and the 2002 World Summit on Sustainable Development, even though none of these documents directly present a framework or theoretical background for the model (Purvis et al., 2019; Moldan et al., 2012).

From the various meanings that the word 'sustainability' may represent, Brown et al. (1987) identified 3 main perspectives, or definitions: the social aspect, which encompasses the satisfaction of basic human needs, such as food and water. She also includes cultural aspects such as security, freedom, education, and employment. The environmental definition focuses on the protection of the ecosystem and requires means for the conservation of genetic resources and biological diversity. The economic definition explores the need for economists to address the issue of sustainability in economic growth (Brown et al., 1987). According to Pope et al., (2004), the positive integration of these three pillars promotes the implementation of sustainable development.

2.3 Economic Growth and Sustainable Development of the BRICS

The term “BRIC” was first mentioned by Jim O’Neill in 2001 in his report named “Building Better Global Economic BRICs”, in which Brazil, Russia, India, and China were considered the nations with the greatest growth potential in the early 21st century. In the 10 following years, the weight of the BRICs on the worldwide GDP would significantly increase, though there was no prospect that they would work closely together (Lowe, 2016). The group acquired its present shape when South Africa joined, in 2010.

The current importance of the BRICS cannot be underestimated. They represent around 40% of the world's population, 30% of global land coverage, 18% of world trade, and hold one-fourth of the world’s GDP, which makes their combined economy more prominent than the United States or the European Union (O’Neill, 2021). Additionally, due to their large production and consumption of fossil fuels, the BRICS are among the largest greenhouse gas emitters in the world, therefore having a great impact in re-shaping global climate governance challenges (Downie & Williams, 2018).

Since their official establishment in 2009, leaders of the BRICS have often met intending to develop cooperative policies and strategies to enhance their collective growth. It is worth noting that even though their significant growth has drawn a lot of international attention, since 2011 it has been stagnant and inconsistent (Fisher, 2022).

The BRICS are formed by a heterogeneous group of nations with different political structures and economic activities. Each country is marked by its strengths, creating a sense of complementarity within the group. Brazil and Russia are major exporters of raw materials, heavily dependent on their mineral reserves, while China and India rely on cheap labor. Brazil is a great exporter of agricultural commodities, whereas Russia is a large exporter of energy resources. China is a global supplier of manufactured goods, and India is a global supplier of services (Streltsov et al., 2021). South Africa is the most industrialized African country, a low-risk destination for investment in Africa, and has abundant mineral resources (Lowe, 2016). Although the BRICS countries’ economies differ substantially regarding their growth potential (Basu et al., 2013), there are key aspects explored in the empirical literature that have contributed to their economic growth.

Macroeconomic factors influencing economic growth in the BRICS countries include fiscal policy, exchange rates, trade openness, FDI inflows, and inflation (Bezerra & Silva, 2021). It

is commonly believed that FDI positively contributes to economic growth, leading developing nations to find ways to attract it (Khalid & Marasco, 2019). However, while some studies report that there is little or no significance between FDI and economic growth in developing countries, others state that the impact is positive and significant because it provides technology transfer and capital accumulation (Choudhry et al., 2020; Saini & Singhania, 2018). Borensztein et al., (1998) found the impacts of FDI inflows on economic growth to be beneficial, but dependent on the capacity of absorption by the host country. Khan and Nawaz (2019) found that trade openness and FDI positively affect income distribution. Prabhakar et al., (2015) and Agrawal (2015) concluded that in the long term, it's possible to verify the benefits of FDI in the BRICS economies because it is accompanied by technical cooperation. Udi et al., (2020) consider FDI inflows to be a key factor for the economic growth of South Africa. It's important to highlight that the BRICS represent a significant market potential to attract FDI, they had a 19% share of the total global FDI inflow in 2017 (UNCTAD, 2018).

A critical factor for economic growth in developing countries is human capital. It may positively influence trade openness as well as enhance knowledge transfer, promoting economic development (Nakabashi & Figueiredo, 2005). According to Barro (1991), human capital accelerates growth by absorbing and spreading technology from other countries, which enables poor countries to grow even faster than wealthier countries. Fisher (2022) found a significant and positive relationship between labor force participation and GDP per capita growth rate in the countries of the BRICS between 2009 and 2019. Hartman and Kwon (2005) found human capital to be conducive to reducing environmental pollution in China. According to the findings of Nakabashi and Figueiredo (2005), human capital's indirect impact on income growth per worker is via the speeding of the process of technological diffusion, which is intensified by imports and FDI. Technological progress is perceived as the main factor in determining the level of income growth per worker in the long term. As another indirect effect that impacts economic growth in the group, improvements in human capital enhance the relationship between imported-related spillovers and technological innovation (Hu, 2021).

The impact of infrastructure investment, including transportation, energy, telecommunications, and other essential facilities, on the economic performance of countries has also been analyzed in the literature. Studies found a significant association between infrastructure investment and economic growth (Calderón & Servén, 2015; Kodongo & Ojah, 2016). Telecommunications infrastructure and market size are factors found to impact the

economic growth of developing countries (Meidayati, 2017). Apurv and Uzma (2020) found no statistical significance between infrastructure investment and economic growth in Brazil and South Africa, whereas in Russia, India, and China, infrastructure investment and development variables were found to be statistically significant.

Technological advancements, research and development spending, and knowledge spillovers are highlighted as important factors for BRICS economies due to their impact on productivity and competitiveness (Franco & Oliveira, 2017; Hu, 2021). Gyedu et al., (2021) analyzed the impact of research and development expenditure, trademarks, and patents on the economic growth of BRICS and G7 countries and concluded that investments in innovation efficiently improve economic growth. The difference in the impact of R&D expenditure on economic growth among BRICS countries was also studied by Ndlovu and Inglesi-Lotz (2020).

The prospects of accelerated economic growth reflected by the BRICS raised some criticism about their indefinite use of natural resources as if they were unlimited or easily replaceable. Due to their dimensions, the BRICS countries stand out for their potential to affect the global environment. The countries of the bloc are among the ones that release the most greenhouse gases, which raises pressure from sustainably engaged sectors on them to implement strategies that mitigate the effects of global pollution (Gomes & Silva, 2017).

The ecological assets and rich biodiversity of the BRICS carry great value for the world, and the group is constantly present in international conventions on the environment. However, they lack consensus on their transition to more sustainable policies and strategies, based on the principle of "common but different responsibilities". Brazil and South Africa value policies aiming for sustainable development, while China and India prioritize economic development. Despite those differences, the BRICS countries have actively shown their concern for sustainable growth (Cavalcanti, 2018).

When it comes to climate change, some authors defend that the BRICS do not have enough common interests to form a lasting coalition (Brütsch & Papa, 2013). Indeed, the group has not yet implemented any specific mechanism for cooperation on the matter, though they have held environment and energy minister meetings (BRICS, 2015). The heterogeneity of their commitment to sustainable development is reflected in their national efforts, as they are all susceptible to the impacts of climate change individually. Russia confirms its use of traditional energy resources, prioritizing other issues such as inequality and poverty. On the other hand,

Brazil, India, and China have been encouraging the adoption of renewable energy sources by developing new legislation (Basile & Cecchi, 2019). South Africa struggles in its transition to a low-carbon society but has carried out important institutional arrangements to promote social inclusion and mitigate climate change impacts (Cavalcanti, 2018).

The countries in the group provide reports with detailed information on their commitments to the UN's Sustainable Development Goals (SDG) and Millennium Development Goals (MDG). However, according to Basile & Cecchi (2019), their unbalanced engagement with the SDGs and the Paris Agreement demonstrates several inconsistencies in their practices of sustainable development. While China and India's efforts present hopeful results, they still rely heavily on traditional energy resources.

The BRICS confront great challenges to maintain their rapid economic growth without significantly increasing carbon emissions levels. Therefore, looking into their past and exploring the determinants of their growth and their impacts on the environment as well as the population welfare may provide significant insights into their future.

3. Methodology

This work aims to analyze and compare the BRICS countries' efficiency in transforming their productive resources and innovation into sustainable development, based on three pillars: economic, social, and environmental. To run this analysis, the Data Envelopment Analysis (DEA) model was used.

The DEA is a nonparametric approach presented by Charnes et al., (1978) for measuring the efficiency of decision-making units (DMU) in comparison with one another, creating an efficiency ranking. The DMUs in this work are represented by the countries of the BRICS, and the data analysis considers the period from 2010 to 2018. To perform the model, the software STATA 17 was used, and data was gathered from the World Development Indicators Data Bank. Three applications of DEA were performed, regarding each of the pillars of sustainable development: economic, social, and environmental.

Regarding the input variables, “Gross Fixed Capital Formation (GFCF)” was chosen to represent the capital variable. It was also taken into consideration the importance of its relationship with economic growth, examined by the studies of studies Meyer and Sanusi (2019) and Topcu et al., (2020). To represent human capital, the “unemployed population” variable was used based on the works of Santana et al., (2014) and Bekun et al., (2019). Following Bayarçelik and Taşel (2012) and Costantini et al., (2023), we used the variable entitled “Research and Development (R&D) expenditure” to proxy for technological innovation when analyzing its impact on economic growth and environmental development. The variable “Foreign Direct Investment (FDI) inflows” was added considering the previously mentioned importance that FDI represents in developing countries and its outcomes in innovation and sustainable development, as applied in the studies of Lee et al., (2021), Chai et al., (2021), Sarkodie and Strezov (2019) and Sunde (2016).

Concerning the output variables, the “Growth Domestic Product (GDP)” was used to proxy the countries' economic growth and the economic pillar of sustainability, as it is considered a common measure for economic growth, and applied in the works of Apergis and Payne (2011) and Sanz-Díaz et al., (2017). The variable used to proxy the social pillar is “life expectancy”, which is a commonly used indicator to measure the overall health of a population (Luy et al., 2020; Mariano and Rebelatto, 2014; Magombeyi and Odhiambo, 2018). The variable entitled “CO2 emissions” is the third output variable, proxying the environment. It is commonly used as a metric to evaluate the environmental sustainability of countries (Shikwambana et al., 2021;

Lee et al., 2021; Maryam et al., 2017). Variables related to pollution are called “undesirable variables” and should be treated differently in the application of the methodology.

The stepwise method was applied to the validation of pre-selected variables for DEA applications. The method begins by selecting the most statistically significant variable and then sequentially adding or removing variables based on specified criteria. Table 1 shows the variables used in the three applications: economic, social, and environmental.

Table 1. Variables used.

Application	Type of efficiency	Inputs	Output
1	Economic	GFCF, R&D, FDI, Unemployed Population	GDP
2	Environmental	GFCF, R&D, FDI, Unemployed Population	CO2
3	Social	GFCF, R&D, FDI	Life expectancy

For the first and second applications, the economic and environmental efficiency were tested, using GDP and CO2 as the outputs, respectively, and GFCF, R&D, FDI, and unemployed population as inputs for both applications. The third application concerns the social pillar. Its output is the life expectancy, and the analysis was made considering the inputs GFCF, R&D, and FDI.

The Data Envelopment Analysis (DEA) is a non-parametric linear programming method used to measure the efficiency of Decision Making Units (DMUs) when facing multiple inputs and multiple outputs. One of the most commonly used models is the BCC model (Banker et al., 1984). The BCC model allows for variable returns to scale (VRS), meaning that as inputs are increased, outputs do not necessarily increase in a fixed proportion. Since the BRICS countries aim to increase the outputs, i.e. aim for their sustainable development, the model BCC-output-oriented is used to analyze the economic, social, and environmental applications. The output-oriented DEA-BCC model is defined as follows:

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

$$\text{Subject to } \sum_{i=1}^m u_i \cdot y_{i0} = 1,$$

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

Where n and m are the number of inputs and outputs analyzed, respectively; h is the number of decision-making units (DMUs) analyzed; w is the scale factor; v_j is the weight of input j for the DMU being analyzed; u_i is the weight of output i for the DMU being analyzed; x_{j0} is the amount of input j of the DMU being analyzed; y_{i0} is the amount of output i of the DMU being analyzed; x_{jk} is the amount of input j of DMU k ; and y_{ik} is the amount of output i of DMU k .

As it is not desired to increase the pollution output variable, “CO2 emissions”, the variable was multiplied by “-1”. DEA analysis does not compute nonpositive values, therefore it was found and added a translation vector to the transformed negative variable, in a way in which the values become positive without compromising the relationship between the variables.

By not taking into account the balance between the variables, prior information about the weights, and other factors, the DEA may present similar scores among the DMUs. To increase discrimination between efficiency scores, the Inverted Frontier method was employed. In this method, first introduced by Angulo Meza et al., (2003), the inputs and outputs are switched in the original model. Then, to sort the units, it is created a composite index, calculated by the mean between the classic frontier efficiency score and 1 minus the efficiency score of the inverted frontier. All values are divided by the highest calculated value to get a normalized ranking (Leta et al., 2005).

Additionally, it is important to analyze how efficiency changes over the years in consideration. This analysis was performed using the ‘window analysis’ technique, in which, according to Cooper et al., (2007), each unit for each year is considered a different DMU. A moving average is calculated, in which each time a new DMU enters, another DMU exits. The number of windows and their amplitudes are calculated as follows:

$$w = k - p + 1$$

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

In which, w represents the number of windows; p represents the window amplitude, and; k represents the number of years. As the years taken into consideration for this analysis are 9, the number of windows corresponded to 5, and the amplitude corresponded to 5 years.

4. Analysis of Results

The scope of this work is to analyze the BRICS countries' efficiency in transforming their productive resources, innovation, and foreign direct investment into sustainable development. Three applications of the DEA were run, according to the three pillars of sustainability: economic, social, and environmental. Average efficiency scores were calculated for each country for each window, and a total average index was created for each application.

The results for the economic application are presented in Table 2, for the social application in Table 3, and for the environmental application in Table 4. The tables are composed of 5 lines, one line for each country under analysis and each of the five first columns represents one window with the amplitude of 5 years. The last column shows the total average index.

Table 2. Economic Application.

Country	Window					Mean Total
	1 (2010-2014)	2 (2011-2015)	3 (2012-2016)	4 (2013-2017)	5 (2014-2018)	
Brazil	79.62%	78.16%	77.80%	78.60%	72.58%	77.35%
Russia	90.18%	92.16%	91.69%	91.79%	92.14%	91.60%
India	68.26%	68.45%	70.76%	71.68%	70.03%	69.84%
China	72.42%	70.57%	70.57%	70.75%	68.27%	70.52%
South Africa	74.03%	72.52%	71.77%	71.14%	68.23%	71.54%

Table 3. Social Application.

Country	Window					Mean Total
	1 (2010-2014)	2 (2011-2015)	3 (2012-2016)	4 (2013-2017)	5 (2014-2018)	
Brazil	90.36%	89.09%	89.31%	89.53%	89.21%	89.50%
Russia	93.49%	93.50%	93.95%	94.13%	95.70%	94.16%
India	89.63%	88.14%	88.44%	87.98%	87.76%	88.39%
China	52.91%	52.63%	53.87%	53.18%	53.23%	53.16%
South Africa	89.54%	97.81%	98.49%	98.40%	99.03%	96.65%

Table 4. Environmental Application.

Country	Window					Mean Total
	1 (2010-2014)	2 (2011-2015)	3 (2012-2016)	4 (2013-2017)	5 (2014-2018)	
Brazil	94.54%	94.20%	93.33%	92.11%	89.04%	92.65%
Russia	95.76%	96.57%	97.48%	98.19%	97.69%	97.14%
India	47.58%	47.46%	47.51%	47.75%	47.13%	47.49%
China	16.45%	15.21%	14.77%	14.20%	13.51%	14.83%
South Africa	99.65%	99.47%	99.40%	99.41%	97.63%	99.11%

Table 2 presents the results of the economic application and shows that only India and China had average efficiency scores increasing between the first and third window, and all of them except for Russia decreased from the third to the fourth window. Russia leads the group with a mean total of 91.6%, followed by Brazil, South Africa, and China. India is the last country with a mean total of 69.84%.

Social application results are shown in Table 3, where South Africa has the highest efficiency score, followed closely by Russia. Both countries increased their efficiency between 2010 and 2018. In third place in the ranking is Brazil, which showed a decrease in its scores over the selected period, followed by India and China in the last place with a mean total of 53.16%.

Table 4 presents the results of the DEA analysis for the environmental application, in which South Africa leads the group with almost 100% efficiency (99,11%), followed closely by Russia, with a 97,14% score. Brazil is placed on 3rd, followed by India. China is in the last place, with an average efficiency score of 14.83%, way below the average of the other countries for this study.

Table 5 was built to better visualize the ranking results based on the three applications. It can be observed that the best-ranked countries were Russia and South Africa, followed by Brazil, and the worst-ranked countries in the analysis were India and China.

Table 5.

Mean efficiency rankings of BRICS from 2010-2018			
	Application		
	Economic	Social	Environmental
Brazil	2nd	3rd	3rd
Russia	1st	2nd	2nd
India	5th	4th	4th
China	4th	5th	5th
South Africa	3rd	1st	1st

Table 6 shows the input and output values of the variables used in the DEA, for each country. The values were calculated as the mean value between 2010 and 2018.

Table 6.

Country	Mean total (2010-2018)						
	GDP ^a	CO2 ^b	Life Expectancy ^c	GFCF ^d	R&D ^e	FDI ^f	Unemployed Population ^g
Brazil	1,790,640.45	454540.79	74,1	329,921,331.99	21,565.3	65,892,09	9,21
Russia	1,359,389.57	1628548.22	71,9	291,458,527.51	14,454,58	25,851.68	4,29
India	2,002,225.282	2062884.15	68,9	609,207,470.49	14,053.51	33,945.33	37,85
China	10,413,780.02	9741657.54	76,7	4,483,614.96	208,971.73	249,339.79	35,36
South Africa	338,802.96	430355.03	63,0	59,412.47	2,376.60	3,561.31	5,10

Source: World Data Bank. ^aGross Domestic Product (constant 2015, million US\$); ^bCO2 emissions (kt); ^cLife expectancy at birth (years); ^dGross fixed capital formation (constant, million 2015,US\$); ^eR&D Expenditure (constant 2015, million US\$); ^fFDI inflows (constant 2015, million US\$); ^gUnemployed Population (million).

The overall results of the DEA applications analysis were presented, it will now be discussed and analyzed the results for each country.

4. 1. Brazil

Brazil's input levels were median within the group, except for its FDI inflow levels, which were the second highest. The country has achieved high-efficiency scores but was placed in the

middle of the rankings. This result suggests Brazil can make better use of its inputs in order to maximize its outputs.

For the past decade, Brazil's levels of GDP growth have been uneven. According to the Brazilian Institute of Geography and Statistics (IBGE), from 2001 to 2010 the Brazilian GDP grew on average 3,6% a year, whereas from 2011 to 2018 the growth fell to an average of 0,7% a year. From 2008 to 2010, in the context of the global financial crisis, the Brazilian GDP grew on average 4,1% a year. This growth represents the positive reaction from the Brazilian economy in light of the national economic policies, which aimed to increase private consumption and boost aggregated demand. This stimulus had a positive outcome until 2013, when the deterioration of this type of fiscal policy negatively affected the Brazilian economy (Costa Jr. et al., 2017). Between 2014 and 2016 there was a serious economic recession in Brazil, and the country entered a slow recovery from 2017 onwards.

Even though Brazil represented low GDP growth rates among the BRICS in the period under analysis, it was placed 2nd in the economic efficiency ranking, which means Brazil can achieve higher levels of output with median levels of input. This result may suggest Brazil can increase its GDP output value by maintaining similar input levels and making improvements in national fiscal policies.

Brazil was placed 3rd in the environmental ranking with a satisfactory efficiency score of 92,68%. The country possesses one of the world's largest renewable energy sectors, with about 70% of its energy mix being renewable, mainly by hydropower (Udemba & Tosun, 2022). Brazil, however, is one of the largest GHG emitters in the world (Timperley, The Carbon Brief Profile: Brazil, 2018). This contradiction can be explained by the fact that CO₂ emissions in Brazil are mostly generated not by the energy sector, but due to large levels of deforestation.

Considering its CO₂ emissions levels are the lowest within the BRICS for the period under analysis, and its FDI input levels are the highest, it can be concluded that FDI plays an important role in reducing CO₂ emissions and contributes to the environmental development of the country, in accordance with the findings of Khatoon, et al., (2022). Whereas FDI and R&D levels have increased over the years and CO₂ emissions have decreased, specifically from 2015 to 2018, Brazil's environmental efficiency has slightly decreased, which can also be explained by deforestation levels that have only increased. According to the National Institute for Space Research (INPE), levels of deforestation grew by 50% from 2015 to 2018, a period shadowed by great political instability. The country's efficiency ranking result suggests that Brazil can

achieve better results regarding CO2 emissions with similar input levels by fighting the issue of deforestation.

Regarding social efficiency, despite having the second highest life expectancy rate among the BRICS, of around 75 years in 2018 (just after China, with around 77), Brazil was placed 3rd in the ranking, with an efficiency score of 89.5%. Brazil is a country largely marked by social inequality due to its colonial past (May, 2008). Political instability highly affects levels of social inequality. During the years in which the Worker's Party (PT) was elected, more government attention was drawn to social issues, as the State was the driver of the economic development policy, and social development policies were created to fight poverty (Oliveira, 2023).

Since the Fund for the Maintenance and Development of Basic Education and the Valorization of Education Professionals (FUNDEB) was created, education has had more weight in the government budget. Additionally, the creation of the program Bolsa Família in 2003 greatly improved the life quality of millions of Brazilians. Campoli et al., (2019) found a significant relationship between the transference of government resources to the program and the increase of life expectancy. However, in 2016, social inequality and poverty levels rose again following a political transition, when President Dilma Rousseff was impeached and the new government body did not keep up with the social initiatives created and enhanced by the prior party (Costa, 2019).

4.2. Russia

Russia has presented median levels of GFCF and R&D inputs within the group, similar to Brazil, with median levels of FDI inflows and the lowest unemployed population levels. The country achieved the highest efficiency rates within the group, representing its effective use of inputs to generate the outputs.

Following the collapse of the Union of Soviet Socialist Republics (USSR) in 1991, the Russian economy underwent significant changes as it transitioned from a centrally planned economy to a market-based economy. Even though the economy became more open and resulted in a period of high economic growth in the early 2000s, economic power and wealth are still concentrated in the hands of a few oligarchs who influence the political and economic scenario (Dabrowski, 2023). The Russian GDP is mainly composed of the agricultural, service,

and industry sectors, and the country is highly dependent on its oil production, which accounts for around 20% of Russia's GDP (Orazalin & Mahmood, 2018).

Russia stood out with the highest efficiency level in the economic analysis, with a 91,60% efficiency level, even though its GDP is low compared to other countries in the group. This is due to the fact that with low levels of input, the country managed to get median levels of GDP output. Factors that may have contributed to it are the low unemployment levels of input, which reinforces human capital as a key factor in the development of the Russian economy and the implementation of infrastructure projects in the transport sector, considered in the studies of Serbian et al., (2023) as a powerful tool for the country's economic development. Additionally, it corroborates the findings of Lee and Yu (2022) who stated the positive effects of FDI inflows on Russian sustainable economic growth.

Russia also presented a good ranking in the environmental application as the 2nd place, with a 97.14% average efficiency rate. This satisfactory ranking can be explained by looking at Russia's output levels of CO₂ emissions, the third lowest in the group, generated by median levels of inputs. It can be assumed that Russia can optimize its use of R&D expenditure and FDI inputs to reduce CO₂ emission levels since the country is the fourth largest GHG emitter in the world (Zagoruichyk, 2022).

In the social analysis, Russia obtained an average ranking score of 94.16%, being the 2nd most efficient, even though its life expectancy of around 72.7 is the second lowest in the group. Over the past few decades, Russia has made notable advances in reducing poverty levels within the country. In 2012, Russia reached its minimum poverty level (10.7%), which rose again in the crisis scenario in 2015 to 13.5% and was reduced again to 12.6% by 2018 (Rudenko & Satre, 2018).

4.3. India

India holds the highest number of unemployed population inputs, second highest in fixed capital and R&D expenditure, and median levels of FDI inflow inputs. India's efficiency scores, however, represent that the country is not as efficient in turning its inputs into high levels of output. Despite its high GDP levels, India is in the last place in the economic ranking, with a 69.84% efficiency score. Therefore, by optimizing its use of inputs, India can achieve better GDP output results.

After the 1991 economic crisis in India, the government had no choice but to implement tough reforms, which were characterized by globalization, privatization, and liberation (Anand, 2014). Due to these reforms, India's economic growth increased enormously in the 2000s, placing India among the fastest-growing economies in the world. This growth acceleration, however, came with a shift in the structure of the Indian economy from agriculture to services, instead of industry-based, as expected from developing countries. The share of agriculture in the country's GDP went from around 27.6% in 1990 to 16% in 2018, whereas the share of services rapidly increased from 37% in 1990 to 48.8% in 2018. On the other hand, the share of industry rose from around 26.4% of GDP in 1990 to 30.7% in 2010 and fell to 26.4% in 2018, lower levels than in the 90s (The World Bank, 2018). Half of the Indian labor force is still allocated to agriculture, with services being the second largest sector to generate employment (Raihan, 2020). This premature deindustrialization may be the explanation for India's low economic efficiency score, since the country has not benefited from the advantages of industrialization such as employment generation, technology transfer, and improvement in people's welfare.

Concerning the environmental analysis, India is the 4th ranking country with a 47.49% score. The country's rapid economic growth was followed by a massive increase in CO₂ emissions, confirming the findings of Zameer et al., (2020), which concluded that economic growth increases CO₂ emissions in India. Greenhouse gas emissions in India are majorly generated by the energy sector, largely fueled by coal; and agriculture, mainly rice cultivation and methane from cattle, and gases emitted from fertilizers (Timperley, 2019). Zameer et al., (2020) also concluded that increases in FDI and R&D contribute to the decrease in levels of CO₂ emissions in India, due to the generation of renewable energy. Therefore in this work, it can be concluded that the country is not being efficient in the use of its inputs, and by optimizing them, it could generate lower levels of CO₂ emission.

The rapid economic growth was not inclusive of the Indian population and brought increased levels of social inequality and poverty, which may indicate why the country was also placed 4th in the social application ranking. This result can also be understood by India's life expectancy output levels, which are the second lowest in the group. The Indian government initiated projects aiming to reduce direct and indirect poverty in the country via better food distribution and generation of jobs. Pattayat et al., (2022) found a positive relationship between the increase of non-farm related jobs and income increase in India. This may be one of the factors that explain the 4th place in the ranking since more than half of the Indian population lives in rural areas, and a trend of failing job opportunities in rural areas is observed, along with stagnation in real wages (Pattayat et al., 2022).

4.4. China

China is the country in the group with the highest levels of inputs and highest levels of output. Regardless, the country presented the worst efficiency scores, suggesting that China can achieve greater levels of output by optimizing the use of its high inputs.

Despite being the world's second-largest economy, China found itself ranked 4th in the economic efficiency ranking, just ahead of India. A factor that may contribute to this ranking is, similar to India, the process of deindustrialization and large levels of unemployed population. For the past decades, as China has developed and transitioned into a more service-oriented and technologically advanced economy, it has faced challenges associated with the decline of the industry sector. Since 2015, the services sector has composed over half of the country's GDP, and increased yearly, whereas the industry sector experienced a moderate decline from 46.5% in 2010 to 39.7% in 2018 (The World Bank, 2018).

Additionally, according to the findings of Du and Wei (2022), while product innovation has a negative and significant relationship with unemployment in China, a positive and significant relationship between process innovation and unemployment was observed, as a large-scale robot implementation raises unemployment rates. This points to the need for China to better optimize its investments in technological innovation.

China was ranked last place in the environmental application ranking, with only 14.83%, way below the other countries' efficiency scores. China's administrative management system is characterized by being vertical, which means that local governments carry out policies and decisions taken by the central government. To Chai et al., (2021), this system increases competition among local offices, causing them to set aside environmental standards in order to achieve higher levels of economic growth. Consequently, negative effects on air quality are observed. According to the authors, an increase in FDI also increases air pollution, as this competitive scenario attracts low-quality FDI with high levels of air pollution and energy use. The ranking also confirms the findings of Azam et al., (2019) and Chai et al., (2021), who stated that FDI has a positive association with CO₂ emissions in China, therefore concluding that the government should redirect and optimize its use of FDI inflows to reduce its CO₂ emissions and achieve a better efficiency score.

Air quality is a major issue in China, which is currently the 13th world's most polluted country according to the Air Quality Life Index Annual Report (2023). Besides posing serious

threats to the country's ecological environment, it also threatens the physical and mental health, and socioeconomic development of the people (Maji et al., 2018). Moreover, going back to the process of deindustrialization, it may lead to a descending economic growth as it displaces workers from high-salary jobs in the industry sector into less-payment jobs in the service sector (Ebenstein et al., 2015). The development of human capital is also affected by distorted market factors, due to unfair labor compensation, and reduction in educational expenditures (Chai et al., 2021). Therefore, those may be factors contributing to China's last position in the social application ranking.

4.5. South Africa

South Africa was the country with the lowest levels of both inputs and outputs of the group and has achieved good levels of efficiency in the three rankings. Its lowest rank was 3rd in the economic application with a 70,52% efficiency score, which may be explained by the country's low levels of GDP output. It is, however, a surprising score considering it's not that divergent from the other countries' scores and South Africa's GDP output was the lowest.

According to the findings of Makhoba et al., (2019), gross fixed capital formation has a positive and significant impact on the economic growth of South Africa. Not only the country's GFCF hasn't been at a good pace, but also hasn't suffered any significant improvements over the years. Therefore, it can be concluded that growth the country is going through is not at its full potential, and the government should implement better policies to allow both domestic and foreign investments to bring benefits to the South African economy. The result also confirms the findings of Sunde (2016), who studied the relationship between South Africa's economic growth and foreign direct investment. He concluded that the relationship is positive and FDI stimulates the country's economic development, and also recommended that the government boosts the attraction of FDI, as well as increase the gross fixed capital formation and employment. Results in the economic application suggest that by optimizing its FDI and R&D inputs, South Africa can achieve better GDP output results.

South Africa's 1st place in the environmental ranking can be explained by its levels of CO₂ outputs, which are the lowest among the BRICS. South Africa is the largest industrialized economy in Africa according to the African Development Bank (Quaynor et al., 2022). The country is the 14th largest emitter of Greenhouse Gases (McSweeney & Timperley, 2018), and its emissions account for 42% of the African continent's emissions, mainly due to its economic dependence on coal resources (Bekun et al., 2019). In spite of this, the optimization of inputs, namely FDI, can also explain the country's good ranking, confirming the findings of Udi et al., (2020) that FDI has a positive impact on the environment's quality of South Africa by hampering CO₂ emissions.

Regarding the social application, South Africa also had the highest efficiency score among the group even with the lowest average life expectancy output levels. This success rate can be explained by the sharp rise in the country's life expectancy. The World Health Organization reported that life expectancy increased by almost 10 years between 2000 and 2019, mainly due

to improvements in health services and progress in fighting infectious diseases (WHO Africa, 2022). Nevertheless, South Africa still has a long way to go when it comes to fighting poverty and inequality. Even though the country has made great progress in reducing poverty in early post-apartheid, rates of inequality and poverty have increased in recent years to levels higher than at the end of apartheid (Francis & Webster, 2019). According to the World Bank, South Africa is one of the most unequal countries in the world, and poverty is normally higher among less educated, unemployed, large families and children (The World Bank, 2018), adverting the need for the government to take more action in implementing policies that promote inclusive growth and job promotion.

5. Conclusions

Understanding economic development in the current global context goes well beyond the traditional assessment of Gross Domestic Product. While it remains a very important metric, it is crucial to consider the maintenance of other factors that improve the quality of life. Nations follow the natural tendency to seek economic growth, and by recognizing that the way economic growth takes place is often accompanied by environmental degradation, it's important to analyze the ways in which countries are able or not to tackle this issue and provide growth that meets sustainable development.

Emerging nations have gained a lot of global attention due to their fast-growing economies, large populations, and abundance of natural resources. They challenge the Western dominance in the international system and its monopoly over international agenda, they reshape trade dynamics and occupy a space in which their actions and decisions affect and influence other countries. As their growth impacts the world economy and the global environment, it becomes necessary to explore what it is based on, and its impact on future generations. Endogenous determinants drivers for their economic growth can also contribute to their sustainable development.

This work analyzed the efficiency of the BRICS countries regarding the transformation of their resources, namely gross fixed capital formation, R&D expenditure, unemployed population, and foreign direct investment into sustainable development. Three applications of DEA were estimated: economic, social, and environmental between 2010 and 2018. The results highlighted Russia and South Africa as the best-ranked countries, followed by Brazil.

Russia, despite possessing intermediary levels of inputs and outputs, secured high-ranking scores on the three applications. Considering the country's economic dependence on the exploitation of natural resources, specifically oil and natural gas, Russia should direct efforts in technological development focused on alternative energy resources to reduce CO₂ emission levels. The results suggest that GDP in Russia can benefit from strategic investments in human capital, which not only contribute to the reduction of CO₂ emissions but also improve the quality of life of the population.

South Africa is distinguished by its comparatively low levels of carbon dioxide emissions, thereby placing it 1st in the environmental application. Their production levels are low compared to other BRICS countries, contributing to their ranking. Despite their history of

pervasive social inequality and poverty, the country emerged in 1st position in the social application, suggesting the country's commitment to addressing social disparities and promoting the well-being of the population. It's recommended South Africa promotes actions toward the implementation of social initiatives and health-related policies to keep improving the population's life quality.

Brazil has good efficiency scores and the results from the DEA applications suggest that even though the country is relatively efficient in the conversion of productive resources and foreign direct investments into sustainable development, it still faces internal challenges including deforestation, social disparities, and political instability, which demand attention and effort to fully optimize its productivity and output potential.

India's outcomes indicate that its rapid economic growth had adverse consequences on the environment. It significantly increased CO₂ emissions, which, in turn, affected the population's quality of life. India had relatively low scores in the three applications. To address these challenges and enhance its economic performance, India should focus on improving working conditions, especially beyond the agricultural sector, and prioritize growth in the industrial sector. By optimizing its use of foreign direct investment and R&D expenditure, India can effectively reduce greenhouse gas emissions while simultaneously improving the life quality of its population.

China's surprisingly low score results point to the urgent need for the country to improve the quality of its industrial sector, as well as employment conditions, and better target its investments related to technological innovation, to reach full industrialization and foster sustainable economic growth. The country should reinforce its policies related to air quality management. Additionally, by improving working conditions in the industrial sector and optimizing its use of foreign direct investment, China can be able to achieve better output results, rather than 5th place in the social and environmental applications, and 4th place in the economic application.

While this study provides insights into the economic, social, and environmental efficiency of BRICS countries, some limitations should be acknowledged. First, this analysis was based on available data from 2010 to 2018, due to a lack of consistent data from 2019. Newer data might reveal different trends, and new scopes of studies would have to be considered due to recent major events such as the COVID-19 pandemic and the Russia-Ukraine war, that certainly

had worldwide impact. Second, the research relied on official statistics, which can be subject to measurement errors and inconsistencies. Additionally, this study focused on a specific set of variables and did not consider all possible determinants of economic growth and sustainable development. Future research could expand the scope to address these limitations and provide a more comprehensive understanding of the topic.

It is worth noting that new results can be achieved by adding new variables or using different tools. Furthermore, recent global events have undoubtedly shaken the sustainable development of these nations by redirecting the countries' priorities, resulting in possibly significant alterations in the outcomes. Therefore it's advisable to conduct further studies considering the impact of these events and their ramifications in the sustainable development of the countries.

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