Efficiency of BRICS countries in sustainable development: a comparative data envelopment analysis

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Abstract

Purpose – This study aims to assess the efficiency of Brazil, Russia, India, China, South Africa (BRICS) countries in achieving sustainable development by analyzing their ability to convert resources and technological innovations into sustainable outcomes.

Design/methodology/approach – Using data envelopment analysis (DEA), the study evaluates the economic, environmental and social efficiency of BRICS countries over the period 2010–2018. It ranks these countries based on their sustainable development performance and compares them to the period 2000–2007.

Findings – The study reveals varied efficiency levels among BRICS countries. Russia and South Africa lead in certain sustainable development aspects. South Africa excels in environmental sustainability, whereas Brazil is efficient in resource utilization for sustainable growth. China and India, despite economic growth, face challenges such as pollution and lower quality of life.

Research limitations/implications – The study's findings are constrained by the DEA methodology and the selection of variables. It highlights the need for more nuanced research incorporating recent global events such as the COVID-19 pandemic and geopolitical shifts.

Practical implications – Insights from this study can inform targeted and effective sustainability strategies in BRICS nations, focusing on areas such as industrial quality improvement, employment conditions and environmental policies.

Social implications – The study underscores the importance of balancing economic growth with social and environmental considerations, highlighting the need for policies addressing inequality, poverty and environmental degradation.

Originality/value – This research provides a unique comparative analysis of BRICS countries' sustainable development efficiency, challenging conventional perceptions and offering a new perspective on their progress.

Keywords Sustainable development, Data envelopment analysis, Efficiency, BRICS

Paper type Research paper

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1. Introduction

Economic growth theories have evolved from emphasizing capital accumulation, as in classical and neoclassical theories, to highlighting the importance of human capital in more contemporary frameworks such as the Endogenous Growth theory (Choudhry *et al.*, 2020). Doré and Teixeira (2023) synthesized these factors into seven categories: human capital, labor and demographic conditions, technology and innovation, macroeconomic conditions, international trade and FDI, natural resources and institutional conditions. However, the relative influence of these factors varies significantly between and within countries, as noted by Chirwa and Odhiambo (2016). In developed countries, key factors include physical capital, fiscal policy and human capital, among others, while developing countries focus more on external elements such as FDI and foreign aid. The complex interplay of these factors is further complicated by issues such as income inequality, labor exploitation and environmental degradation, underscoring the need for quality growth that reflects true well-being (López *et al.*, 2008; Ranis *et al.*, 2000). This recognition has led to the development of new indicators such as the Human Development Index, the Gini Coefficient and life expectancy at birth, which include aspects of life quality, income distribution and health, but often overlook the environmental costs of economic growth (Santana *et al.*, 2014; Chen *et al.*, 2021; Hasell, 2023).

The concept of Sustainable Development emerged as a response to these challenges, aiming to harmonize economic growth with environmental conservation (Almeida *et al.*, 2017). Its roots can be traced back to classical economists such as Malthus, Smith, Ricardo and Mill, who expressed concerns about the sustainability of economic growth and its implications for future generations (Purvis *et al.*, 2019). The concept gained prominence after the 1972 Stockholm Conference, which led to the formation of the United Nations Environmental Program. However, the conference highlighted the tension between environmental protection and the development needs of different countries (Chasek, 1994; Prizzia, 2017). Sustainable development was formally defined as meeting current needs without compromising future generations' ability to meet their own (Brundtland, 1987). The term "sustainability" has since been interpreted in various ways, often encompassing social, economic and environmental dimensions. This three-pillar model, while not explicitly outlined in foundational documents such as the Brundtland Report or Agenda 21, has become a widely accepted framework for understanding sustainability (Purvis *et al.*, 2019; Moldan *et al.*, 2012). Brown *et al.* (1987) and Pope *et al.* (2004) further explored these dimensions, emphasizing the integration of social needs, environmental protection and economic growth as key to implementing sustainable development.

Brazil, Russia, India, China and South Africa (BRICS) countries account for approximately 40% of the global population, 30% of the land area, 18% of international trade and a quarter of the world's GDP, surpassing the economies of both the USA and the European Union, as highlighted by O'Neill (2021). Moreover, their substantial role in fossil fuel production and consumption ranks them among the largest emitters of greenhouse gases (GHGs), significantly impacting global climate governance, a challenge discussed by Downie and Williams (2018). The BRICS face the complex task of maintaining rapid economic growth while controlling carbon emissions. Exploring their historical growth determinants, environmental impacts and population welfare offers crucial insights for their future development paths.

Following Santana *et al.* (2014), this study examines how well the BRICS countries are doing in terms of sustainable development, using the data envelopment analysis (DEA) method that allows to rank the BRICS countries based on their economic, environmental and social efficiency. We specifically look at how efficiently these countries have been using their productive resources and technological innovations to achieve sustainable development over an eight-year period (2010–2018). The motivation for extending the data for Santana *et al.*'s (2014) paper stems from the dynamic nature of economic, social and environmental development across the BRICS. Santana *et al.*'s (2014) study provided critical insights into the efficiency of these countries in converting inputs into sustainable development outcomes over the period 2001–2007. However, the global economic landscape, environmental challenges and social dynamics have undergone significant changes since then. Extending the data set beyond 2007 allows for an updated analysis that reflects recent developments, including technological advancements, policy reforms and shifts in global economic power dynamics. This extension aims to capture the evolving nature of sustainability efforts within the BRICS, offering a more current understanding of their progress and challenges in achieving economic growth, environmental protection and social welfare. It acknowledges the importance of continuous monitoring and evaluation in the context of sustainable development, providing stakeholders with relevant data to inform policymaking and strategic planning in an ever-changing global environment.

The results of this study show the different challenges the BRICS countries have in achieving sustainable development. Brazil is efficient in using its resources and foreign investment for sustainable growth but needs to work on issues such as deforestation, social inequality and political instability. Russia is the most efficient of the group but relies heavily on oil and gas, which affects its sustainability. It could improve by investing more in human resources. India and China have grown economically but this has led to more pollution and a lower quality of life. They need to focus on cleaner industrial growth and better working conditions and use foreign investment and research to reduce pollution and improve living standards. South Africa has low pollution levels and is doing well in addressing social and health issues, but it needs to keep working on these areas to improve people's lives.

This paper is organized as follows. Section 2 starts discussing BRICS countries' economic development. The methodology section given in Section 3 explains the research design and analysis techniques used. The findings and analysis along with the results are presented in Section 4. The discussion is presented in Section 5. The paper ends with a conclusion given in Section 6 which summarizes the main points and suggests areas for future research.

2. Economic growth and sustainable development of the Brazil, Russia, India, China, South Africa

Since their formal recognition as a cohesive group in 2009, although they did not initially collaborate closely, as noted by Lowe (2016), BRICS leaders have convened regularly to formulate cooperative policies and strategies aimed at bolstering their joint economic growth. Despite attracting global attention for their economic prowess, growth within the BRICS has seen a period of stagnation and inconsistency since 2011, as observed by Fisher (2022).

The BRICS consist of a diverse set of countries, each with unique political and economic frameworks (Chatterjee and Naka, 2022). Brazil and Russia, for instance, are primarily exporters of raw materials, dependent on their rich mineral reserves. In contrast, China and India have leveraged their vast labor forces, with China emerging as a major manufacturer and India as a significant service provider (Streltsov *et al.*, 2021). South Africa stands out as the most industrialized nation in Africa, with substantial mineral wealth and a reputation as a stable investment destination (Lowe, 2016). Despite their differences, these countries share certain common economic traits (Basu *et al.*, 2013). For instance, a large proportion of trade in intermediates occurs among BRICS countries (De Mello-Sampayo, 2017a, 2017b).

Key macroeconomic factors shaping the BRICS' economic growth include fiscal policy, exchange rates, trade openness, FDI inflows and inflation rates (Bezerra and Silva, 2021). The role of FDI in economic development is debated; some studies, such as those of Khalid and Marasco (2019), suggest it is beneficial, while others present a more nuanced view. Choudhry *et al.* (2020) and Saini and Singhania (2018) indicate that the impact of FDI can be significant, especially when coupled with technology transfer and capital accumulation. Borensztein *et al.* (1998) found FDI's impact to be positive but contingent on the host country's absorptive capacity. Further, Khan and Nawaz (2019) observed a positive correlation between trade openness, FDI and income distribution. Long-term benefits of FDI in BRICS, aligned with technical cooperation, were noted by Prabhakar *et al.* (2015) and Agrawal (2015). Joshua *et al.* (2020) identified FDI as a crucial element for South Africa's economic growth, noting that in 2017, BRICS attracted 19% of global FDI inflows (UNCTAD, 2018).

Human capital is another pivotal factor for economic development in these countries. It enhances trade openness and fosters knowledge transfer, as noted by Nakabashi and Figueiredo (2005). Barro (1991) posited that human capital facilitates growth by disseminating technology from more developed countries, allowing less wealthy nations to accelerate their economic expansion. Fisher (2022) confirmed a strong positive relationship between labor force participation and GDP per capita growth rate in BRICS from 2009 to 2019. Hartman and Kwon (2005) found that human capital significantly reduces environmental pollution in China. Nakabashi and Figueiredo (2005) further argued that human capital indirectly bolsters income growth per worker through the acceleration of technological diffusion, intensified by imports and FDI. Hu (2021) echoed these findings, emphasizing the role of human capital in enhancing the benefits of imported technology and innovation.

Infrastructure investment, encompassing transportation, energy, telecommunications and other critical facilities, also plays a crucial role in economic performance. Calderón and Servén (2015) and Kodongo and Ojah (2016) identified a strong link between infrastructure investment and economic growth. Meidayati (2017) highlighted the impact of telecommunications infrastructure and market size on developing countries' economies. However, Apurv and Uzma (2020) found mixed results regarding the significance of infrastructure investment in economic growth, particularly in Brazil and South Africa compared to Russia, India and China.

Technological advancements, R&D expenditure and knowledge spillovers are key contributors to the BRICS' productivity and competitiveness, as outlined by Franco and Oliveira (2017) and Hu (2021). Gyedu *et al.* (2021) analyzed the influence of R&D, trademarks and patents on economic growth, concluding that innovation investments significantly bolster growth. Ndlovu and Inglesi-Lotz (2020) explored variations in the impact of R&D expenditure on economic growth across BRICS countries.

The BRICS' rapid economic expansion has raised concerns about their seemingly limitless exploitation of natural resources, as discussed by Gomes and Silva (2017). Their significant environmental footprint and GHG emissions underscore the urgency of implementing strategies to mitigate global pollution. While the BRICS are active participants in international environmental conventions, they lack a unified approach to sustainable policy transition, operating under the principle of "common but different responsibilities". Brazil and South Africa emphasize sustainable development, whereas China and India prioritize economic growth, as noted by Cavalcanti (2018).

Regarding climate change, Brütsch and Papa (2013) argued that the BRICS lack sufficient common interests to form a lasting coalition. Although the group has convened environment and energy minister meetings (BRICS, 2015), they have yet to establish specific cooperation mechanisms. Each nation faces unique challenges related to climate change. Russia continues to rely on traditional energy sources, addressing issues such as inequality and poverty. Brazil, India and China are moving towards renewable energy through legislative changes (Basile and Cecchi, 2019). South Africa, while transitioning to a low-carbon society, has implemented strategies to promote social inclusion and address climate change (Cavalcanti, 2018). Each BRICS country provides detailed reports on their commitments to the UN's Sustainable Development Goals and Millennium Development Goals. However, Basile and Cecchi (2019) noted inconsistencies in their engagement with these goals and the Paris Agreement, with a continued dependence on traditional energy sources in some countries.

3. Methodology

In this study, we aim to evaluate the efficiency of BRICS countries in channeling their productive capacities and innovative capabilities into sustainable development. The DEA model is used to measure and compare the efficiency of BRICS countries over the period from 2010 to 2018. We conducted three separate DEA analyses, each focusing on one of the sustainable development pillars: economic, social and environmental sustainability. The source of the data is the World Data Bank.

The selection of input variables was grounded in existing literature. The variable entitled Gross Fixed Capital Formation (GFCF) was chosen to represent the capital variable, reflecting its established correlation with economic growth as discussed in the studies by Meyer and Sanusi (2019) and Topcu *et al.* (2020). Following Santana *et al.* (2014) and Bekun *et al.* (2019), the unemployed population was used as a proxy for human capital. Research and development (R&D) expenditure was used to assess the effect of technological innovation on sustainable development (Bayarçelik and Taşel, 2012; Costantini *et al.*, 2023). The variable foreign direct investment (FDI) inflows are included in our analysis acknowledging its significant role in innovation and sustainable development in developing countries, as evidenced in studies by Lee *et al.* (2021), Chai *et al.* (2021), Sarkodie and Strezov (2019) and Sunde (2016).

For output variables, gross domestic product (GDP) was selected to represent economic growth (Apergis and Payne, 2011; Sanz-Díaz *et al.*, 2017). The variable life expectancy was chosen to reflect the social dimension, aligning with its use as a general health indicator in studies by Luy *et al.* (2020), Mariano and Rebelatto (2014) and Magombeyi and Odhiambo (2018). To proxy environmental sustainability, CO_2 emissions were used as a standard metric for assessing environmental impact (Maryam *et al.*, 2017; Shikwambana *et al.*, 2021; Lee *et al.*, 2021).

The stepwise method was applied to validate the chosen variables for DEA applications. This process starts with selecting the most statistically significant variable, followed by a sequential addition or removal of variables based on set criteria. The variables used in the three DEA applications are detailed in Table 1, categorized by the type of efficiency they represent (economic, environmental, social), their inputs and outputs.

For the first and second applications, the economic and environmental efficiency was tested, using GDP and CO_2 as the outputs, respectively, and GFCF, R&D, FDI and unemployed population as inputs for both applications. The third application concerns the

Application	Type of efficiency	Inputs	Output
1	Economic	GFCF, R&D, FDI, unemployed population	GDP
2	Environmental	GFCF, R&D, FDI, unemployed population	CO_2 emissions
3	Social	GFCF, R&D, FDI	Life expectancy

Source: Table by authors

Table 1. Variables used

social pillar. Its output is the life expectancy, and the analysis was made considering the inputs GFCF, R&D and FDI.

The 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 (Charnes *et al.*, 1978). 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. As the BRICS countries aim to increase the outputs, i.e. aim for their sustainable development, the BCC–output-oriented model is used to analyze the economic, social and environmental applications. The output-oriented DEA-BCC model is characterized by its objective function and constraints, with a focus on maximizing output efficiency given a set of inputs and outputs, defined as follows:

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

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

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

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; u_i is the weight of output i for the DMU; x_{j0} is the amount of input j of the DMU; y_{i0} is the amount of output i of the DMU; x_{jk} is the amount of input j of DMU k; and y_{ik} is the amount of input i of DMU k. The nature of the output CO_2 emissions, which is undesirable was transformed to fit the DEA framework. This transformation involved multiplying the emissions data by "−1" and adding a translation vector to ensure the transformed values remained positive without altering their relational dynamics.

To enhance discrimination between DMU efficiency scores, we used the inverted frontier method (Angulo Meza *et al.*, 2003). This approach involves reversing the roles of inputs and outputs in the DEA model and then creating a composite index to rank the units. This index is computed by averaging the classic frontier efficiency score and the inverted efficiency score, normalized against the highest value obtained (Leta *et al.*, 2005).

Finally, the study includes an analysis of efficiency trends over the years using the "window analysis" technique as described by Cooper *et al.* (2007). This approach treats each unit per year as a distinct DMU, with a moving average calculated as new units are added and old ones removed. The number of windows and their respective amplitudes are determined based on the total number of years analyzed, in this case, resulting in five windows with a five-year amplitude, 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. Results

The results of the DEA across three sustainability dimensions: economic, social and environmental are presented in Tables 2, 3 and 4, respectively. Efficiency scores for each country were computed for every analysis window, leading to a comprehensive average index for each sustainability aspect. Table 5 ranks the countries according to the average index. Finally, Table 6 provides data on gross domestic product (GDP), CO_2 emissions, life expectancy, GFCF, research and development (R&D) expenditure, foreign direct investment (FDI) inflows and the unemployed population of BRICS countries, offering insights into their development trajectories and policy focuses.

The economic dimension results are outlined in Table 2, showing efficiency trends across five-year windows from 2010 to 2018 for each BRICS country, alongside their average total

Country	Window 1 (2010/14) (%)	2 (2011–15) (%)	3 (2012–16) (%)	4 (2013–17) (%)	5 (2014–18) (%)	Mean total (%)
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

Source: Table by authors

Table 2. Economic application

Country	Window 1 (2010/2014) (%)	2 (2011–2015) (%)	3 (2012–2016) (%)	4 (2013–2017) (%)	5 (2014–2018) (%)	Mean total (%)
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

Source: Table by authors

Table 3. Social application

Country	Window 1 (2010/2014) (%)	2 (2011–2015) (%)	3 (2012–2016) (%)	4 (2013–2017) (%)	5 (2014–2018) (%)	Mean total (%)
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

Source: Table by authors

Table 4. Environmental application

efficiency. Russia emerges as the leader in this category, with Brazil, South Africa and China following and India trailing. Notably, India and China displayed increasing efficiency scores in the initial windows, but most countries except Russia experienced a decline in the subsequent window.

Table 3 details the social sustainability findings, positioning South Africa at the forefront, closely followed by Russia. Both these countries improved their efficiency scores over the study period. Brazil, occupying the third rank, showed a declining trend, with India and China at the lower end, China recording the least efficiency at 53.16%.

Environmental efficiency, as per Table 4, places South Africa at the top with near-perfect efficiency, closely followed by Russia. Brazil, India and China round out the rankings, with China significantly lagging behind others with a mere 14.83% efficiency.

To synthesize these results, Table 5 was constructed, offering a consolidated view of the efficiency rankings across all three applications. Russia and South Africa consistently rank high, while India and China are positioned at the bottom of the efficiency scale.

Table 6 provides a breakdown of the input and output values for the variables used in the DEA, averaged over the period 2010–2018. Table 6 serves as a quantitative foundation, underpinning the DEA analysis and offering deeper insights into the variables influencing each country's sustainable development efficiency. Notably, China leads in GDP, CO_2 emissions and life expectancy, reflecting its rapid industrial growth and large population. India, with significantly high CO_2 emissions, also has a high unemployed population, suggesting economic growth may not be equitably translating into job creation. Russia and Brazil present moderate figures in most categories, though Brazil's relatively high

Table 5.
Mean efficiency rankings of BRICS from 2010 to 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

Source: Table by authors

Table 6.
Descriptive statistics

	Mean total (2010–2018)						
Country	GDP[a]	CO_2 emissions[b]	Life expectancy[c]	GFCF[d]	R&D[e]	FDI[f]	Unmployed 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

Notes: World Data Bank; [a]gross domestic product (constant 2015, million US$); CO_2 emissions (kt); [c]life expectancy at birth (years); [d]gross fixed capital formation (constant, million 2015, US$); [e]R&D expenditure (constant 2015, million US$); [f]FDI inflows (constant 2015, million US$); [g]unmployed population (million)
Source: Table by authors

unemployment rate stands out. China's substantial R&D expenditure and FDI inflows underline its position as a global economic powerhouse with a strong emphasis on innovation. In comparison, there are relatively low R&D investments in Russia and South Africa.

The comparative analysis shown in Table 7 underscores the diverse trajectories of BRICS nations in balancing economic growth with social welfare and environmental sustainability.

Brazil has seen a shift in its sustainability landscape, with its economic efficiency slightly declining from the top position, indicating slight decline in its economic management effectiveness. Socially, Brazil experienced a significant drop in efficiency, moving from first to third place, suggesting challenges in sustaining its previously achieved social welfare gains. Environmentally, Brazil improved its efficiency score but fell in rankings, implying that while it has intensified its environmental conservation efforts, other BRICS nations have made more substantial strides in this domain.

Russia has demonstrated remarkable progress, especially in economic terms, where it leaped from the lowest to the highest efficiency score, showcasing significant improvements in economic management and output efficiency. Socially, Russia maintained its second-place ranking with an enhanced efficiency score, indicating steady advances in social welfare. The country also made notable gains in environmental efficiency, moving up in both score and ranking, which underscores Russia's effective strategies in environmental management.

India has remained at the lower end of economic efficiency among the BRICS, with only a minor improvement in score, highlighting ongoing difficulties in efficiently converting inputs into economic outputs. In the social domain, despite maintaining a low ranking, India's improved score signals progress in social development. However, India faced a sharp decline in environmental efficiency, suggesting escalating challenges in managing environmental sustainability amid its economic and demographic growth.

Economically, China saw a slight improvement in its efficiency score but dropped in ranking, suggesting that while there has been some progress, other BRICS countries have outpaced China in economic efficiency. Socially, China's efficiency score and ranking both

Country	Application	Efficiency score (2001–2007)[a] (%)	Rank (2001–2007)[a]	Efficiency score (2010–2018)[b] (%)	Rank (2010–2018)[b]
Brazil	Economic	98	1st	77	2nd
	Social	99	1st	90	3rd
	Environmental	90	2nd	93	3rd
Russia	Economic	51	4th	92	1st
	Social	89	2nd	94	2nd
	Environmental	78	4th	97	2nd
India	Economic	49	5th	70	5th
	Social	49	5th	88	4th
	Environmental	81	3rd	48	4th
China	Economic	65	3rd	71	4th
	Social	56	4th	53	5th
	Environmental	21	5th	15	5th
South Africa	Economic	66	2nd	72	3rd
	Social	76	3rd	97	1st
	Environmental	99	1st	99	1st

Sources: [a]Santana *et al.* (2014) results; [b]our results; table by authors

Table 7. Evolution of BRICS countries' efficiency in economic, social and environmental: a comparative analysis

declined, reflecting significant hurdles in addressing social disparities despite its rapid economic growth. Environmentally, China experienced the most considerable decline in efficiency, remaining the least efficient, which highlights the severe environmental challenges it faces, underscoring the urgent need for sustainable environmental policies.

South Africa experienced a drop in its comparative economic ranking but socially, the country has made remarkable strides, a testament to its effective strategies and policies aimed at enhancing social welfare and addressing societal challenges. Environmentally, South Africa has upheld its premier status, demonstrating a consistent dedication and effective approach to environmental management and sustainability initiatives.

5. Discussion

In Brazil, median input levels, coupled with the second-highest foreign direct investment (FDI) inflows, have resulted in a paradox of high-efficiency scores and a mid-range ranking. This dichotomy points to a potential for Brazil to enhance its output maximization. Economic growth data from the Brazilian Institute of Geography and Statistics highlight uneven GDP growth, notably a decline from an average of 3.6% annually between 2001 and 2010 to just 0.7% between 2011 and 2018. This fluctuation reflects the impact of fiscal policies aimed at stimulating private consumption and demand, which, despite initial success, led to economic downturns post-2013 (Costa *et al.*, 2017).

Economically, Brazil's efficient conversion of median inputs into high outputs places it second in economic efficiency among the BRICS. This suggests that maintaining input levels while refining fiscal policies could elevate GDP output. Environmentally, Brazil ranks third with a 92.68% efficiency score, reflecting its substantial renewable energy sector, primarily hydropower (Udemba and Tosun, 2022). However, high GHG emissions because of deforestation counter this achievement (Timperley, 2018). The correlation between rising FDI and decreasing CO_2 emissions (Khatoon *et al.*, 2022), amidst increasing deforestation, underscores the need for focused environmental policies.

Socially, Brazil's life expectancy of around 75 years (2018) and significant strides in reducing inequality during the Worker's Party (PT) governance (Oliveira, 2023) contrast with its third-place social efficiency ranking. Programs such as Bolsa Família have substantially improved living conditions (Campoli *et al.*, 2019), yet political shifts and reduced focus on such initiatives (Costa, 2019) have stalled progress, emphasizing the imperative of sustained social policies.

Considering the comparative analysis with Santana *et al.*'s (2014) findings, Brazil's trajectory in sustainability shows a moderate downturn in economic efficiency from its previously top position, a significant drop in social welfare efficiency from first to third place and an enhancement in its environmental endeavors. However, this progress is shadowed by more substantial advancements made by other BRICS nations in environmental management during the same period.

Russia's median Global Fixed Capital Formation (GFCF) and research and development (R&D) inputs, combined with the lowest unemployment, have yielded the highest efficiency rates in the group. Post-USSR, the Russian economy's transition to a market-based system saw concentrated economic power and reliance on oil, accounting for 20% of GDP (Orazalin and Mahmood, 2018; Dabrowski, 2023). Despite a modest GDP, Russia's efficient use of inputs, especially in using human capital and infrastructure development (Serbian *et al.*, 2023), has led to a top economic efficiency ranking.

Environmentally, Russia stands second with a 97.14% efficiency rate, managing low CO_2 outputs from median inputs. However, as the world's fourth-largest GHG emitter (Zagoruichyk, 2022), optimizing R&D and FDI towards reducing emissions is crucial.

Socially, Russia's advancements in poverty reduction, despite a lower life expectancy of 72.7 years, reflect a 94.16% efficiency rating, underscoring the role of government initiatives in social development (Rudenko and Satre, 2018).

In comparison to Santana *et al.*'s (2014) earlier analysis, Russia demonstrates remarkable progress, moving from the lowest to the highest in economic efficiency, steadfastly holding its rank in social welfare and making notable strides in environmental efficiency. This upward trajectory signifies Russia's successful implementation of effective management strategies and policy advancements, distinguishing its comprehensive growth and sustainability efforts among the BRICS nations.

India's high unemployment and R&D inputs, juxtaposed with median FDI inflows, have not translated into proportional outputs, placing it last in economic efficiency. Post-1991 reforms propelled growth, shifting the economic structure towards services over industry (The World Bank, 2018a, 2018b, 2018c; Anand, 2014). However, this premature deindustrialization might explain India's low economic efficiency, as the advantages of industrialization remain unexploited.

Environmentally, India ranks fourth with a 47.49% score, reflecting increased CO_2 emissions alongside economic growth (Zameer *et al.*, 2020; Timperley, 2019). The primary emission sources, including energy and agriculture, suggest inefficiencies in input utilization. Socially, India's rapid growth has not inclusively benefitted its population, evident in its fourth-place social efficiency ranking and life expectancy of around 69 years. Initiatives aimed at reducing poverty and promoting non-farm employment (Pattayat *et al.*, 2022) indicate potential areas for improvement.

Relative to Santana *et al.*'s (2014) results, India's journey reflects ongoing challenges in economic efficiency and environmental sustainability. Despite slight enhancements in economic performance and social development, India has experienced a discernible deterioration in environmental efficiency. This contrast highlights the persistent difficulties India faces in aligning its rapid economic and demographic expansion with effective environmental governance and sustainability practices.

China, despite its high inputs and outputs, demonstrates suboptimal efficiency scores. As the world's second-largest economy, its fourth-place economic efficiency ranking might stem from its shift to a service-oriented economy and rising unemployment influenced by technological advancements (Du and Wei, 2022; The World Bank, 2018a, 2018b, 2018c).

In environmental terms, China ranks last with a 14.83% efficiency score, exacerbated by a vertically managed administrative system that prioritizes economic growth over environmental standards (Chai *et al.*, 2021). Addressing FDI's role in pollution (Azam *et al.*, 2019; Chai *et al.*, 2021) is essential for environmental improvement. Socially, China's challenges in poverty, inequality and labor market distortions (Ebenstein *et al.*, 2015) contribute to its last-place social ranking.

When juxtaposed with Santana *et al.*'s (2014) findings, China's path reflects incremental progress in economic efficiency and a decline in social welfare efficiency, alongside facing pronounced environmental hurdles. These dynamics underscore the pressing necessity for China to devise and implement more robust policies that reconcile its swift economic ascent with the imperatives of environmental protection and social equity.

South Africa, with the lowest inputs and outputs, has attained notable efficiency across all domains. Its third-place economic ranking, with a 70.52% score, suggests potential for growth through enhanced FDI and R&D (Makhoba *et al.*, 2019; Sunde, 2016; Quaynor *et al.*, 2022). Environmental leadership is evident in its top ranking, reflecting the lowest CO_2 outputs among BRICS and the impact of optimized inputs on environmental quality (Joshua *et al.*, 2020). Socially, despite low life expectancy, South Africa's high efficiency score is attributed to significant improvements in health and a need for policies promoting inclusive growth (WHO Africa, 2022; Francis and Webster, 2019; The World Bank, 2018a, 2018b, 2018c).

Comparing South Africa's sustainable development from 2000–2007 to the latest data, the country shows a nuanced evolution. Economically, there is a slight improvement in efficiency, but its ranking among BRICS nations has fallen, indicating faster progress by others. Socially, South Africa has moved to the top in efficiency, reflecting strong efforts in addressing social issues. Environmentally, it continues to lead, showing consistent commitment to sustainability. This comparison reveals South Africa's progress in social and environmental areas, despite economic challenges relative to other BRICS countries.

6. Conclusions

This study delves beyond traditional gross domestic product metrics to understand economic development, emphasizing the importance of sustainable growth that harmonizes economic expansion with quality-of-life improvements. Emerging countries, particularly the BRICS countries, have gathered global attention because of their rapid economic growth, substantial populations and rich natural resources. Hence, analyzing their growth bases and impacts on future generations is crucial, especially regarding how endogenous growth drivers can bolster sustainable development.

Focusing on the BRICS countries' resource conversion efficiency into sustainable development, this research used DEA across economic, social and environmental facets from 2010 to 2018. Compared to the previous study that used the 2000–2007 period, Russia and South Africa emerge as leaders, with Brazil also performing well. Russia's success highlights the impact of strategic investments in human capital and green technologies. South Africa's leading environmental efforts and top social ranking demonstrate progress in overcoming social challenges. Brazil shows effective resource and FDI conversion but faces challenges such as deforestation and social inequality. India needs to address CO_2 emissions and improve working conditions, leveraging FDI and R&D for environmental and social gains. China's low efficiency underscores the need for better industrial practices, employment conditions and targeted technological investments. Despite differing time frames, the studies collectively illustrate the ongoing efforts of BRICS nations to balance economic advancement with environmental protection and social inclusion, highlighting both achievements and areas requiring further attention.

While insightful, this study misses recent global events, notably the COVID-19 pandemic and the Russia–Ukraine conflict, that have likely impacted BRICS' sustainable development trajectories. Thus, future research must incorporate these developments, expanding variables and methodologies to offer a more complete understanding of the BRICS' sustainable development paths.

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