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BRICS, Sustainability and Green growth: Unveiling the Impact of Macroeconomic Metrics on Carbon Emissions Reduction

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ABSTRACT
The BRICS nations—Brazil, Russia, India, China, and South Africa—are pivotal in promoting worldwide sustainable economic progress and eco-friendly growth. This research investigates the influence of various macroeconomic metrics, including GDP expansion, renewable energy usage, public spending on education, and initiatives aimed at eradicating hunger, on carbon dioxide emissions during the timeframe of 2010 to 2022. Employing sophisticated econometric methodologies, such as the Panel ARDL framework and Johansen-Fisher Cointegration analysis, this study uncovers substantial long-term connections among these factors, emphasising the revolutionary impact of investments in renewable energy and educational spending on reducing greenhouse gas emissions. In spite of obstacles like regulatory shortcomings, socio-economic inequalities, and environmental decline, the research highlights the potential for employment generation, global collaboration, and eco-friendly financing to promote sustainable progress within BRICS countries. Decision-makers are encouraged to focus on allocating resources towards renewable energy, sustainable farming practices, and educational initiatives, all while strengthening global partnerships. Through tackling systemic shortcomings and socio-economic disparities, BRICS has the potential to spearhead the worldwide transition towards a more sustainable future.

Keywords: Sustainable Development, Green Growth, BRICS, Renewable Energy, CO2 Emissions, Education, Macroeconomic Indicators

1. Introduction

The BRICS nations—Brazil, Russia, India, China, and South Africa—are instrumental in influencing the worldwide path of sustainable economic advancement and eco-friendly progress. These countries, together embodying a substantial segment of the global populace and economic productivity, encounter the simultaneous challenge of attaining vigorous economic advancement while tackling environmental sustainability and fostering social inclusivity. The necessity for a harmonious strategy is highlighted by the increasing imperative to achieve the United Nations Sustainable Development Goals (SDGs), which stress the importance of alleviating poverty, enhancing educational quality, guaranteeing access to clean energy, and tackling climate change. In this framework, grasping the relationship among macroeconomic metrics, including GDP expansion, utilisation of renewable energy, public investment in education, and initiatives aimed at eradicating hunger, as well as their influence on carbon dioxide (CO2) emissions, is essential. The economic landscape in these nations frequently showcases swift industrial growth, considerable energy usage, and dependence on fossil fuels, positioning them as key players in the global greenhouse gas emissions arena. Nonetheless, these identical economies also demonstrate significant promise for shifting towards more sustainable growth trajectories by channelling resources into renewable energy, enhancing human capital, and embracing cutting-edge technologies.

This research endeavours to examine the intricacies of sustainable development within BRICS nations by analysing the impact of significant macroeconomic variables on environmental results, specifically focussing on CO2 emissions, throughout the timeframe of 2010 to 2022. Employing sophisticated econometric methodologies like the Panel Autoregressive Distributed Lag (ARDL) model, this study explores the intricate short-term and long-term dynamics between these variables, aiming to offer a comprehensive insight into their interrelations. The results are anticipated to uncover essential understandings regarding the efficacy of eco-friendly growth approaches, the significance of education in promoting sustainability, and the possibilities for renewable energy to separate economic advancement from ecological harm. Additionally, the research aims to provide practical suggestions for decision-makers in the BRICS countries to formulate cohesive strategies that align economic growth with ecological sustainability and social fairness. Through tackling these urgent issues, the study enriches the wider conversation surrounding sustainable advancement, emphasising the distinct hurdles and prospects that BRICS nations encounter in realising an eco-friendly economy while fulfilling their developmental goals.

Key Research Question: What is the impact of GDP growth, quality of education, renewable energy use, and hunger elimination initiatives on CO2 emissions in BRICS countries?

Objectives:

1) To analyze the impact of macroeconomic indicators on carbon emissions (2010–2022).
2) To investigate short-term and long-term relationships using the Panel ARDL model.
3) To provide insights for policymakers on green growth strategies.

2. Literature Review

2.1 Sustainable Economic Development in BRICS

The BRICS nations—Brazil, Russia, India, China, and South Africa—play a crucial role in fostering worldwide sustainable economic progress, owing to their combined economic prowess, substantial populations, and varied ecological environments. These countries have embarked on a variety of efforts to harmonise swift industrial growth with the essential principles of ecological sustainability and social fairness. As the foremost contributor to global greenhouse gas emissions, China has established itself as a frontrunner in the realm of renewable energy investments and low-carbon initiatives. The nation has enacted comprehensive policies, including the Renewable Energy Law, to facilitate its shift towards a more sustainable economy (The World Bank, 2022; UNCTAD, 2023). In contrast, Brazil has made significant strides in sustainable farming by implementing agroecological methods, strategic land-use planning, and initiatives aimed at conserving biodiversity, as noted by Gramkow and Anger-Kraavi (2019) and Mazzaro de Freitas (2017). India has concentrated its efforts on fostering social inclusion, highlighting advancements in education, reforms in healthcare, and initiatives in renewable energy like the National Solar Mission. These endeavours collectively strive to elevate marginalised communities and encourage sustainable development (Kumar, 2023; Kumar & Majid, 2020). Russia, while heavily dependent on fossil fuels, has slowly begun to integrate renewable energy sources into its energy mix, simultaneously channelling investments into innovative solutions to foster sustainable green development (Overland & Loginova, 2023). South Africa stands as a leader in eco-friendly growth efforts, highlighted by initiatives such as the Green Economy Accord, which advocates for sustainable resource utilisation and creative advancements (Steenkamp, 2018).

In spite of these progressions, the BRICS countries encounter considerable obstacles in their pursuit of enduring development. Striking a harmonious equilibrium between economic advancement, ecological preservation, and societal objectives continues to be a recurring challenge. Deficiencies in institutions, shortcomings in regulations, and socio-economic inequalities intensify these obstacles, hindering the efficacy of strategies designed to fulfil the Sustainable Development Goals (SDGs) (Siddiqui, 2016; Suhrab, Chen, & Ullah, 2024). The swift expansion of urban areas and the surge in industrial activities, especially in nations like India and China, have resulted in significant harm to the environment, exerting tremendous strain on natural resources and ecosystems (Silva, 2023; The World Bank, 2022). Nevertheless, these obstacles offer significant prospects for change and evolution. The transition towards sustainable economies holds the promise of creating job opportunities, stimulating creativity, and enhancing economic variety, as highlighted by scholars like Yadav et al. (2024) and Nguyen & Khominich (2023). Collaborative efforts on a global scale in the realm of technology exchange and financial instruments such as green bonds can significantly expedite advancements, allowing the BRICS nations to harmonise their developmental approaches with worldwide sustainability goals (Wei, 2016; BRICS, 2020).

The BRICS countries have showcased their dedication to sustainable growth via cohesive policy initiatives and substantial funding in renewable energy, educational advancement, and social fairness. To truly unlock the possibilities of sustainable development, it is essential to tackle institutional shortcomings, promote innovative solutions, and strengthen global partnerships. Through harnessing their combined capabilities and drawing insights from one another's exemplary methods, these countries can pave the path towards attaining sustainable economic advancement, playing a significant role in worldwide initiatives aimed at fostering a green and just future (Ali et al., 2018; Cecchi & Basile, 2018). This holistic strategy highlights the significance of enduring practices throughout economic, social, and ecological aspects, as expressed by the World Commission on Environment and Development (1987) and Barbier & Burgess (2015).

2.2 Green Growth Strategies

The BRICS countries have energetically embraced eco-friendly growth initiatives by integrating environmental sustainability into their economic development models, with each nation adopting unique policies designed to address their particular challenges and priorities. The National Solar Mission of India has played a pivotal role in positioning the country as a frontrunner in the realm of solar energy generation (Kumar & Majid, 2020; Dey et al., 2022). This endeavour emphasises establishing bold objectives for solar energy capacity, promoting creativity, and encouraging the uptake of renewable energy

via financial incentives. The push for renewable energy in India has propelled not just low-carbon advancement but has also sparked innovation, attracted foreign capital, and generated employment opportunities (Yadav et al., 2024; Ali et al., 2018).

China, utilising its Renewable Energy Law, has established itself as a leader in the shift towards a low-carbon economy (The World Bank, 2022; UNCTAD, 2023). This legislation requires the incorporation of sustainable energy sources into the national power grid, along with financial support and tax benefits to promote renewable energy initiatives (Zhongxiu & Qingxin, 2020). Consequently, China has emerged as the foremost manufacturer of solar panels and wind turbines worldwide, exemplifying the strength of innovation supported by policy (Nguyen & Khominich, 2023). These initiatives have greatly diminished dependence on fossil fuels and empowered China to play a substantial role in global climate objectives (Huang, 2024; Wei, 2016).

Brazil has made significant strides in promoting sustainable development via its Forest Code and initiatives aimed at adopting circular economy principles (Gramkow & Anger-Kraavi, 2019; Mazzaro de Freitas, 2017). The Forest Code imposes rigorous guidelines aimed at reducing deforestation, requiring the safeguarding of indigenous flora on privately owned properties while promoting sustainable land management practices and the conservation of biodiversity (Barbier & Burgess, 2015). Brazil's dedication to agroecological methods and sustainable farming has bolstered its environmental robustness, complemented by efforts focused on minimising waste and optimising resource utilisation (Dickey & Fuller, 1981; Perron, 1988).

Both Russia and South Africa have enthusiastically adopted the principles of sustainable development, prioritising investments in eco-friendly technologies and innovative solutions (Steenkamp, 2018; Overland & Loginova, 2023). Russia, although reliant on fossil fuels, has embarked on initiatives to incorporate renewable energy sources, advance clean technologies, and enhance energy efficiency (Silva, 2023; Cecchi & Basile, 2018). South Africa has launched the Green Economy Accord, focussing on the advancement of renewable energy initiatives and environmentally conscious industrial methods to promote sustainability (Isheloke et al., 2020; Viktorija & Silvija, 2022). Both nations have acknowledged the significance of harmonising their economic strategies with ecological goals to tackle worldwide sustainability issues (Suhrab, Chen, & Ullah, 2024; Ali et al., 2018).

By employing a variety of approaches, the BRICS countries have showcased their dedication to eco-friendly development, highlighting the importance of innovative policies, global collaboration, and sustainable methods in reaching worldwide sustainability goals (UN, 2015; Brundtland & Khalid, 1987). Nonetheless, obstacles remain, such as regulatory deficiencies, socio-economic inequalities, and institutional shortcomings, which need to be tackled to completely harness the possibilities of sustainable economies (Siddiqui, 2016; Bobylev, Grigoriev, & Beletskaya, 2021). Through harnessing cooperative avenues, including platforms for knowledge exchange and eco-friendly funding strategies like green bonds, these countries can expedite their shift towards sustainable economic frameworks (Yadav et al., 2024; The World Bank, 2020).

2.3 Challenges and Opportunities

The BRICS countries encounter a multifaceted array of obstacles as they chart their course towards eco-friendly advancement and enduring progress. Striking a harmonious equilibrium between economic advancement and the pursuit of environmental and social objectives stands as a critical challenge for these swiftly industrialising nations. The swift acceleration of urban development and industrial growth in nations such as China and India has exerted tremendous strain on natural resources and ecosystems, frequently compromising environmental sustainability (Silva, 2023; The World Bank, 2022). Moreover, balancing the urgency for swift economic benefits with enduring ecological goals presents a formidable obstacle, especially in countries that are deeply dependent on fossil fuel resources, like Russia and South Africa (Overland & Loginova, 2023; Barbier & Burgess, 2015).

Institutional and regulatory deficiencies amplify these obstacles, as inadequate governance frameworks and disjointed policies obstruct the successful execution of sustainable development efforts (Nguyen & Khominich, 2023; Siddiqui, 2016). As an illustration, the erratic application of environmental laws in Brazil has weakened initiatives aimed at tackling deforestation, whereas the varied socio-political environment in India has complicated the consistent implementation of eco-friendly policies (Gramkow & Anger-Kraavi, 2019; Cecchi & Basile, 2018). Additionally, the absence of thorough structures to incorporate sustainability into economic strategies constrains the ability of BRICS nations to synchronise their domestic objectives with the United Nations Sustainable Development Goals (SDGs) (UN, 2015; Brundtland & Khalid, 1987).

Socioeconomic inequalities exacerbate the shift towards eco-friendly economies, with underprivileged communities in BRICS countries frequently suffering the consequences of environmental harm while being deprived of the advantages that come with sustainable progress (Suhrab, Chen, & Ullah, 2024; Yadav et al., 2024). These disparities are particularly evident in nations

such as South Africa and India, where financial divides and limited resource accessibility hinder equitable development (Viktorija & Silvija, 2022; Ali et al., 2018). Tackling these inequalities is essential to guarantee that environmentally sustainable growth efforts do not worsen current social injustices but instead foster inclusive and fair advancement.

In spite of these obstacles, the BRICS countries possess considerable prospects to ignite revolutionary transformation. A significant avenue for advancement is found in the realm of employment generation via green economies, where capital infusions into renewable energy, sustainable farming practices, and environmentally conscious industries hold the promise of creating millions of job opportunities across a wide array of sectors (Dey et al., 2022; Huang, 2024). For example, India's National Solar Mission alongside China's Renewable Energy Law has effectively catalysed job creation within the renewable energy industry, showcasing the employment opportunities that arise from eco-friendly investments (Kumar & Majid, 2020; Zhongxiu & Qingxin, 2020).

Global collaboration in the realms of technology exchange and financial support presents an essential avenue for advancement. Joint ventures, including information-exchange networks and the implementation of eco-friendly bonds, can equip BRICS countries with the necessary tools and knowledge to hasten their shift towards sustainable progress (Wei, 2016; Isheloke et al., 2020). Green bonds, specifically, serve as a formidable financial instrument for financing extensive renewable energy initiatives, infrastructure advancements, and conservation endeavours (Yadav et al., 2024; UNCTAD, 2023). Furthermore, collaborations with advanced countries and international entities can enhance the exchange of eco-friendly technologies and groundbreaking innovations, allowing BRICS nations to bypass conventional development routes and embrace more sustainable methodologies (Bobylev, Grigoriev, & Beletskaya, 2021; Steenkamp, 2018).

Through tackling systemic shortcomings and promoting equitable strategies, the BRICS countries have the potential to convert these obstacles into avenues for advancement and enduring development. Allocating resources towards human development, strengthening regulatory structures, and fostering global partnerships can lead to a more sustainable and just future. The initiatives undertaken will serve not just the respective nations but will also enhance worldwide sustainability endeavours, highlighting the BRICS countries as frontrunners in the quest for equitable and comprehensive growth (The World Bank, 2020; Ali et al., 2018).

Table 1: Summary of Literature Review

Reference	Focus/Objective	Key Findings	Challenges Addressed	Implications/Opportunities
Ali et al. (2018)	Implementation of SDGs in BRICS	BRICS nations show varying degrees of success in integrating SDGs into national policies.	Institutional gaps and resource constraints.	Need for harmonized strategies across BRICS to achieve SDGs.
Barbier & Burgess (2015)	Economic perspective on sustainable development	Highlights principles of resource efficiency, equity, and innovation in development.	Balancing environmental goals with economic growth.	Promoting interdisciplinary cooperation to achieve long-term sustainability.
Bobylev et al. (2021)	Post-COVID SDG framework in BRICS	Identifies BRICS' readiness to transition to a sustainable model.	Addressing post-pandemic socio-economic disparities.	Leveraging green growth to bridge development gaps in emerging economies.
Brundtland & Khalid (1987)	Foundations of sustainable development	Defined sustainable development as meeting current needs without compromising future generations.	Global environmental degradation and resource overuse.	Advocates global cooperation and balanced resource management.

Cecchi & Basile (2018)	Role of BRICS in global sustainable development	Explores potential of BRICS to lead global sustainability efforts.	Institutional and economic disparities among BRICS nations.	Collaboration among BRICS could create a unified force for global green growth.
Dey et al. (2022)	Renewable energy status and future in India	Renewable energy can drive low-carbon growth and create jobs.	Financial and technical barriers in renewable energy projects.	Expanding renewable energy infrastructure to achieve SDG targets.
Dickey & Fuller (1981)	Econometric tools for analyzing stationarity of data	Developed the Augmented Dickey-Fuller test for unit root analysis.	Ensuring accurate econometric evaluations for sustainable development studies.	Reliable econometric tools improve policy decision-making.
Gramkow & Anger-Kraavi (2019)	Green growth in Brazilian manufacturing	Green stimulus policies accelerate low-carbon transitions.	Balancing industrial modernization with emissions reduction.	Fiscal policies and incentives can modernize manufacturing sustainably.
Huang (2024)	Role of resources and innovation in BRICS' green growth	Innovation is key to achieving financial and ecological sustainability.	Lack of innovation frameworks across BRICS nations.	Technology transfer and innovation hubs can drive green transformation.
Isheloke et al. (2020)	Multidisciplinary perspective on BRICS economic development	Highlights the importance of resource sharing and cooperation among BRICS nations.	Uneven resource distribution and industrial disparity.	Knowledge-sharing and collaboration platforms can enhance resource efficiency.
Kumar (2023)	Indian healthcare system and sustainability	Social inclusion is crucial for equitable sustainable growth.	Limited access to healthcare in marginalized communities.	Strengthening social infrastructure improves overall human development.
Kumar & Majid (2020)	Renewable energy's role in India's sustainable development	Renewable energy reduces carbon emissions and stimulates economic growth.	Policy implementation challenges in renewable energy.	Investment in renewables enhances economic resilience and sustainability.
Levin et al. (2002)	Panel data techniques for econometric analysis	Established Levin-Lin-Chu test for panel unit root analysis.	Handling heterogeneity in large panel datasets.	Accurate data analysis enables better understanding of sustainable development trends.
Mazzaro de Freitas (2017)	Brazilian land-use policies and ecosystem services	Agroecological practices improve land-use efficiency and biodiversity conservation.	Challenges in balancing economic development and environmental preservation.	Integrated land-use policies promote ecological and economic resilience.

Nguyen & Khominich (2023)	Environmental economic performance in BRICS	Developed a Green Economy Index to evaluate sustainability performance.	Balancing economic, environmental, and social priorities.	Prioritizing green financing and policy innovations enhances sustainability outcomes.
Overland & Loginova (2023)	Russian coal industry and sustainability	Examined the challenges of transitioning from fossil fuels to renewables.	Heavy reliance on coal in regional economies.	Gradual diversification into renewable energy ensures long-term stability.
Perron (1988)	Statistical tools for trend analysis	Enhanced econometric modeling for dynamic macroeconomic studies.	Addressing data irregularities in long-term analyses.	Improved modeling techniques refine assessments of sustainable economic development.
Siddiqui (2016)	BRICS' influence on global economic balance	Explores BRICS' role in reshaping global economic policies.	Managing socio-economic disparities within BRICS.	BRICS can lead global green policy formulation with a unified voice.
Silva (2023)	Wastewater treatment and reuse for sustainability	Demonstrates how wastewater management supports resource conservation.	Pressure on water resources due to urbanization.	Expanding wastewater treatment infrastructure fosters sustainable resource management.
Steenkamp (2018)	South Africa's transition from Kyoto to Paris climate frameworks	Transitioning mechanisms like CDM to SDM improves climate mitigation efforts.	Limited adoption of international climate mechanisms.	Aligning domestic policies with global frameworks enhances climate action impact.
Suhrab et al. (2024)	Digital financial inclusion and income disparity in BRICS	Digital inclusion reduces income gaps and fosters equitable growth.	Technological access disparities among BRICS populations.	Investing in digital infrastructure enhances inclusive development.
UN (2015)	Transforming our world: The 2030 Agenda	Advocated integrated approaches to achieve SDGs.	Institutional weaknesses in implementing SDGs.	Multilateral partnerships can bridge implementation gaps.
UNCTAD (2023)	China's policy strategies for low-carbon development	China leads global low-carbon development through robust policies.	Economic dependency on traditional industries.	South-South cooperation enhances policy diffusion and technology transfer.
Viktorija & Silvija (2022)	Decent work and economic growth in BRICS	BRICS countries face employment challenges in transitioning to green economies.	Balancing labor demands with sustainability goals.	Green job training and capacity building can address employment gaps.
Wei (2016)	Customs cooperation in BRICS	Enhancing customs integration facilitates trade sustainability.	Regulatory fragmentation across BRICS nations.	Capacity-building initiatives improve economic competitiveness.

World Bank (2020)	Overview of sustainable development	Highlights key elements of integrating sustainability into economic policies.	Overexploitation of natural resources.	Strengthening resource management ensures long-term ecological and economic balance.
World Commission (1987)	Our Common Future	Conceptualized sustainable development as balancing present and future needs.	Lack of global frameworks to address resource depletion.	Calls for global cooperation and intergenerational equity.
Yadav et al. (2024)	Fintech and green finance in BRICS	Explores green finance as a means to transition resource-based economies to sustainable models.	Limited access to green financing tools.	Green bonds and fintech innovations can drive sustainable investments.
Zhongxiu & Qingxin (2020)	Promoting BRICS cooperation for economic development	BRICS cooperation fosters shared economic growth and sustainability.	Managing inter-country policy differences.	Leveraging BRICS partnerships enhances collective resilience and sustainability efforts.

3. Data and Methodology

This study utilises panel data extracted from the economic environments of the BRICS countries, covering the timeframe from 2010 to 2022. A portion of the information regarding SDG indicators reaches as far as 2020/21. The examination focusses on five distinct nations within the expansive BRICS structure, specifically Brazil, Russia, India, China, and South Africa. This research zeroes in on five Sustainable Development Goals (SDGs), specifically Goal 02, dedicated to the elimination of hunger; Goal 04, which strives to deliver quality education; Goal 07, focused on guaranteeing affordable and clean energy; Goal 08, aimed at fostering decent work and stimulating economic growth; and Goal 13, which is committed to tackling climate change. Table 2 illustrates the metrics employed for the examination of diverse objectives.

"Table 2 Detail of Variables and its sources

SDGs	Indicator/Variable	Source
Goal No.02 Zero Hunger	Agriculture, Forestry, and Fishing, Value added (annual % growth)	WDI
Goal No. 04 Quality Education	Government expenditure on Education (total % of GDP)	WDI
Goal No. 07 Affordable and Clean Energy	Renewable Energy Consumption (% of total final energy consumption)	WDI
Goal No. 08 Decent Work and Economic Growth	GDP growth rate	WDI
Goal No. 13 Climate Action	CO2 Emissions (metric tons per capita)	WDI"

Source: compiled by the authors.

This research utilised panel data analysis to assess the progress of BRICS nations in achieving the Sustainable Development Goals, focussing specifically on economic aspects, particularly the encouragement of environmentally sustainable growth. The study utilised a collection of five distinct variables to symbolise each Sustainable Development Goal (SDG), specifically REC, GDP, QEC, CO2EM, and ZERHUNG. These factors relate to the utilisation of renewable energy, overall economic output, educational excellence, carbon dioxide output, and the goal of eradicating hunger, in that order. The information was sourced from a secondary reference referred to as the World Development Indicator (WDI).

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4. Results and Analysis

4.1. "Descriptive Statistics

The descriptive statistics with the number of observations (Obs.), means, standard deviations (Std. Dev.), minimums (Min), and maximums (Max) for quantitative variables, and frequencies and percentages for the research variables are represented in Table 3

Table 3 Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
CO2EM	65	6.0234	3.7145	1.3380	11.8849
GDP	65	3.4723	3.7882	-5.9633	10.6358
QEC	65	4.6540	1.0204	3.2978	6.56206
REC	65	20.951	16.424	3.1800	50.0500
ZERHUNG	65	3.3840	5.0754	-11.980	19.0803

Source: Estimated by the authors.

Figure 1 Illustrates the GDP growth rates of the BRICS countries—Brazil, Russia, India, China, and South Africa—over the period from 2010 to 2023. Overall, the graph highlights the economic volatility and varying growth patterns among the BRICS countries, particularly noting the impact of global events such as the COVID-19 pandemic around 2020, which caused sharp declines in GDP growth for all countries, followed by varying degrees of recovery.

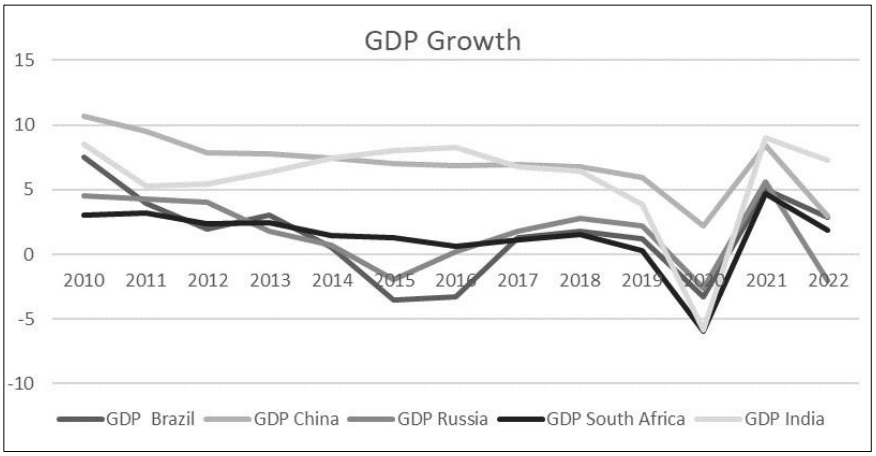

Figure 1 GDP Growth

Figure 2 Depicts the renewable energy consumption (REC) as a percentage of total final energy consumption for the BRICS countries—Brazil, Russia, India, China, and South Africa—over the period from 2010 to 2020. Overall, the chart indicates a positive trend towards increased renewable energy consumption in most BRICS countries, with Brazil leading significantly, while Russia shows minimal change in its renewable energy usage.

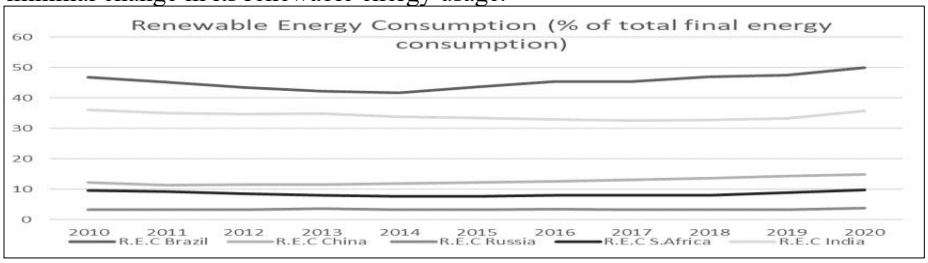

Figure 2 Renewable Energy Consumption (% of total final energy consumption)

Figure 3 Depicts the annual data of government expenditure on education (total % of GDP) in the BRICS countries over the period from 2010 to 2020-2022.

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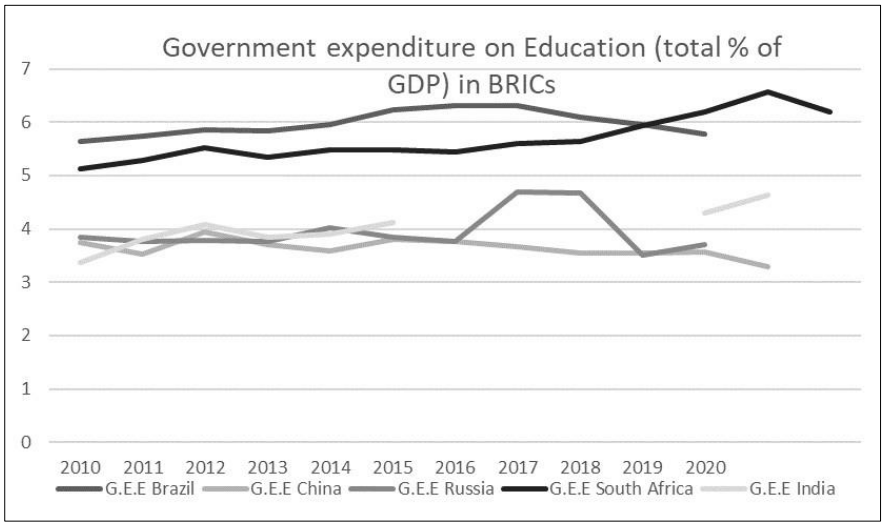

Figure 3 Government expenditure on Education (total % of GDP) in BRICs

Annual data of agriculture, forestry, and fishing, value added (annual % growth) in the BRICS countries over the period from 2010 to 2022 is presented in Figure 4. Overall, the graph highlights the variability and instability in the agriculture, forestry, and fishing sectors across the BRICS countries. While some countries like China and South Africa exhibit more stable growth, others like Brazil, Russia, and India show significant volatility, reflecting varying impacts of economic conditions, climate factors, and policy changes on these critical sectors.

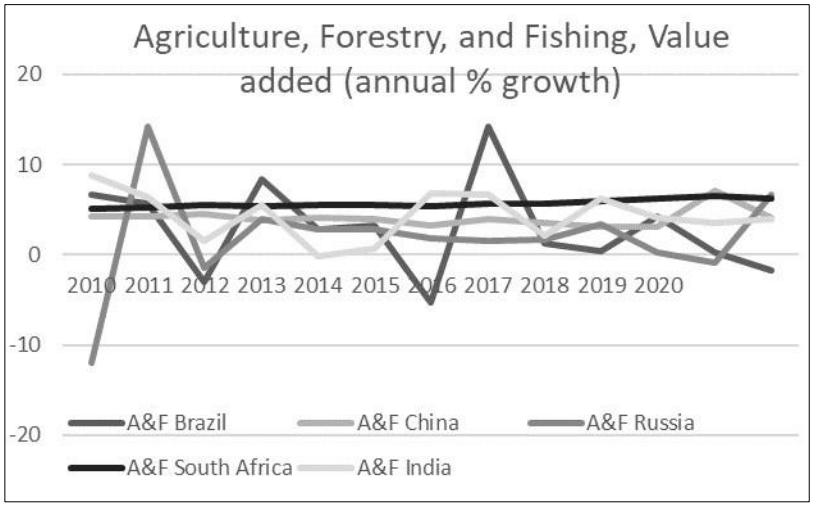

Figure 4 Agriculture, Forestry, and Fishing, Value added (annual % growth)

Figure 5 Represents CO2 Emissions (metric tons per capita) in the BRICS countries from 2010 to 2020. As can be seen from the data, there is a consistent pattern of emissions, with China showing the most significant increase

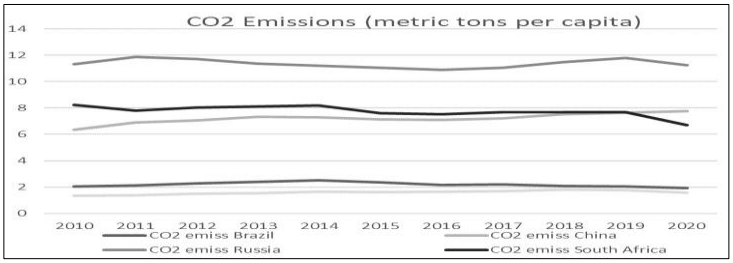

Figure 5 CO2 Emissions (metric tons per capita)

Table 4 represents correlation analysis among the studied variables. The most notable correlations from the matrix are the strong negative correlation between renewable energy consumption and CO2 emissions, and the moderate correlations between GDP and quality education (negative) and renewable energy consumption and quality education (positive). These relationships highlight the critical role of renewable energy in reducing carbon emissions and the complex interactions between economic growth, education quality, and efforts to eradicate hunger. The further analysis is presented in the sections below.

Table 4 Results of Correlation Matrix

	GDP	REC	CO2EM	QEC	ZERHUNG
GDP	1.0000				
REC	0.0290	1.0000			
CO2EM	-0.1685	-0.9304	1.0000		
QEC	-0.4712	0.3999	-0.3284	1.0000	
ZERHUNG	0.0229	0.0327	-0.0939	-0.0092	1.0000

Source: Estimated by the authors.

4.2. Panel Unit Root Test

Table 5 Results of LLC unit root test

Variable	Level I (0)	Trend I (1)
GDP	0.0016***	
CO2EM	0.0633*	
ZERHUNG	0.0000***	
QEC		0.0000***
REC		0.0053***

Note: ***, **, and *, represents 1%, 5%, and 10% level of significance respectively. Source: Estimated by the authors.

In this section, the panel unit root test was employed with the help of the Levin, Lin & Chu (LLC) unit root test. While different tests can be used to find the stationarity of the variable such as the Augmented Dicky-Fuller (ADF) [Dicky & Fuller, 1981], Phillips Perron (PP) [Perron, 1988], Levin, Lin & Chu test (LLC) [Levin et al., 2022] and Im. Pesaran & Shin tests (IPS) [Im et al., 2003]. The decision rule is that if the p-value of ADF and PP are less than 5% its critical value then it means that the tested variable is stationary or does not have unit roots. If the absolute p-value greater than its critical value, then it means that the tested variable is non-stationary or has unit roots. Table 5 shows the results of panel unit root tests. The results of the LLC unit root test indicate that GDP is stationary at level with p-value of 0.0016, carbon dioxide emissions is also stationary at level with p-value of 0.0633, and zero hunger is also stationary at level while quality of education and renewable energy consumption are stationary at first difference.

4.3. Johansen-Fisher Cointegration:

To assess the long run relationship among the variables, the study employed the Johansen-Fisher Cointegration test. Table 6 shows the result of Johansen-Fisher cointegration test. The results indicate that there is cointegration among all the variables which mean that there exists long run relationship between variables.

The results of Table 7 show the individual cross-section results. The results indicate that the presence of a long-run equilibrium relationship among the variables for each of the five countries. Thus, it can be concluded that all variables, namely GDP, REC, QEC and ZERHUNG, are cointegrated with CO2EM in all five countries that were selected.

Table 6 Johansen-Fisher Cointegration

Hypothesized	Trace Test Value	Probability	Max Eigen Test Value	Probability
None	51.36	0.0000	39.57	0.0000
At Most 1	33.25	0.0002	33.25	0.0002

Source: Estimated by the authors.

Table 7 Individual Cross Section (Hypothesis of No Cointegration)

Cross Section	Trace Test Value	Probability	Max Eigen Test Value	Probability
Brazil	18.1272	0.0196	15.1575	0.0360
China	20.2719	0.0088	18.6454	0.0095
Russia	14.6277	0.0673	9.8236	0.2238
South Africa	30.6988	0.0001	21.8907	0.0026
India	22.0487	0.0045	17.8808	0.0128

Source: Estimated by the authors.

4.4 Panel ARDL Estimation Results (Short Run Coefficients)

The short-run dynamics of the Panel ARDL estimation investigate changes in GDP, QEC, REC, ZERHUNG do not significantly impact CO2 emissions in the BRICS economies. Both current and lagged changes in these variables show high p-values, indicating no substantial short-term effects. Additionally, the error correction term, which suggests adjustment towards long-term equilibrium, is not statistically significant. Overall, short-term variations in these economic and social indicators do not have a significant influence on CO2 emissions in the BRICS countries.

Table 8 Panel ARDL Estimation Results (Short Run Coefficients) Dependent Variable: ΔCO2EM

Variable	Coefficient	Std. Error	T-Statistic	Prob
ΔGDP	0.080	0.0753	1.071	0.3068
ΔGDP (-1)	-0.022	0.073	-0.310	0.7620
ΔQEC	0.155	0.661	0.235	0.8181
ΔQEC (-1)	0.081	0.194	0.418	0.6839
ΔREC	0.542	0.365	1.483	0.1660
ΔREC (-1)	-0.498	0.584	-0.852	0.4119
ΔZERHUNG	0.080	0.058	1.377	0.1958
ΔZERHUNG (-1)	0.157	0.129	1.211	0.2512
C	2.164	1.473	1.469	0.1698
Cointeq (-1)*	-0.245	0.172	-1.424	0.1819

Note: *, ** and *** show significance at 1, 5 and 10% level respectively. Cointeq (-1) * is Error Correction Term. Source: Estimated by the authors."

5. Discussion

The BRICS nations—Brazil, Russia, India, China, and South Africa—have surfaced as pivotal contributors in the worldwide quest for sustainable advancement and environmentally friendly growth, owing to their combined economic power and remarkable ecological variety. These countries demonstrate a variety of growth trajectories and encounter distinct obstacles in shifting towards sustainable economic frameworks, all while tackling environmental issues and promoting social fairness. China, as an example, has emerged as a worldwide frontrunner in investments related to renewable energy, propelled by regulations like the Renewable Energy Law, which prioritises the incorporation of clean energy into its power grid (The World Bank, 2022; UNCTAD, 2023). India has likewise made significant progress via programs such as the National Solar Mission, which stimulates technological advancements and fosters employment opportunities within the renewable energy domain (Kumar & Majid, 2020; Ali et al., 2018). The Forest Code of Brazil exemplifies the nation's dedication to preserving biodiversity while promoting sustainable agricultural practices, harmonising economic advancement with responsible environmental management (Gramkow & Anger-Kraavi, 2019; Mazzaro de Freitas, 2017). In spite of these initiatives, the swift industrial growth in nations such as Russia and South Africa has continued to uphold their dependence on fossil fuels, posing an ongoing obstacle in harmonising with international climate objectives (Overland & Loginova, 2023; Steenkamp, 2018).

Striking a harmonious equilibrium between economic advancement and ecological goals continues to be a significant hurdle for the BRICS countries. The swift growth of cities and industries in India and China has intensified the deterioration of the environment, endangering natural ecosystems and resources (Silva, 2023; The World Bank, 2022). Systemic inefficiencies,

regulatory discrepancies, and socio-political inequalities continue to obstruct the successful execution of sustainability initiatives (Nguyen & Khominich, 2023; Siddiqui, 2016). As an illustration, Brazil encounters challenges in implementing its Forest Code, whereas India's socio-political environment hinders the consistent application of environmental policies (Gramkow & Anger-Kraavi, 2019; Cecchi & Basile, 2018). Moreover, the socio-economic chasm prevalent among these countries significantly impacts under-represented groups, constraining their opportunities to partake in the advantages of sustainable progress (Suhrab, Chen, & Ullah, 2024; Viktorija & Silvija, 2022). The existing voids highlight the pressing necessity for systemic transformations, strong regulatory structures, and comprehensive policy initiatives to guarantee the fair allocation of the advantages associated with sustainable development.

In spite of these obstacles, the BRICS nations are distinctly poised to seize prospects for revolutionary transformation. Investing in renewable energy infrastructure, for instance, has shown remarkable promise in reducing carbon emissions and fostering economic development (Yadav et al., 2024; Dey et al., 2022). The embrace of eco-friendly bonds and global financing frameworks bolsters extensive renewable energy and conservation initiatives, allowing BRICS countries to harmonise with the Sustainable Development Goals (SDGs) (Wei, 2016; UNCTAD, 2023). Joint initiatives such as South-South collaboration promote the exchange of knowledge and the transfer of technology, enabling these countries to bypass conventional development routes (Bobylev, Grigoriev, & Beletskaya, 2021; Steenkamp, 2018). Additionally, efforts such as India's commitment to advancing renewable energy technologies and China's supremacy in the worldwide solar panel market illustrate how strategic policies can elevate BRICS countries to the forefront of sustainable innovation (The World Bank, 2022; Zhongxiu & Qingxin, 2020).

The intricate relationship among economic expansion, sustainable energy sources, educational advancement, and ecological sustainability is clearly reflected in the econometric results. Extensive longitudinal studies indicate an inverse relationship between the utilisation of renewable energy sources and the levels of CO2 emissions, highlighting the significant impact that investments in clean energy can have on mitigating greenhouse gas outputs (Nguyen & Khominich, 2023; Huang, 2024). Investment in education stands out as a vital catalyst for sustainable growth, nurturing human capital that propels innovation and the embrace of environmentally friendly technologies (Ali et al., 2018; Kumar, 2023). Nonetheless, immediate economic endeavours continue to be heavily reliant on carbon emissions, especially in resource-dependent nations such as Russia and South Africa. This underscores the urgent necessity for holistic approaches aimed at separating economic advancement from ecological harm (Barbier & Burgess, 2015; Overland & Loginova, 2023). These revelations offer crucial guidance for decision-makers to synchronise national development strategies with enduring sustainability objectives.

In the end, the BRICS countries possess significant capability to spearhead the worldwide shift towards a more sustainable future. Through the identification of systemic deficiencies, promoting global collaboration, and channelling resources into innovative solutions, these nations can bridge socio-economic divides and tackle environmental obstacles (Brundtland & Khalid, 1987; Cecchi & Basile, 2018). Deliberate allocations towards renewable energy, enhancement of skills, and eco-friendly farming present avenues for comprehensive progress, guaranteeing that the advantages of sustainable growth are fairly shared (Gramkow & Anger-Kraavi, 2019; Mazzaro de Freitas, 2017). Joint platforms and strategies such as eco-friendly bonds offer monetary and technical support for realising these goals, highlighting the significance of collective efforts among BRICS countries (Wei, 2016; UNCTAD, 2023). Through the utilisation of their collective advantages and the promotion of creativity, the BRICS countries have the potential to establish a remarkable framework for attaining equitable and enduring progress worldwide (The World Bank, 2020; Yadav et al., 2024).

6. Conclusion

The BRICS countries find themselves at a pivotal juncture, navigating the intricate interplay between economic growth, ecological preservation, and social justice. This research highlights the crucial significance of macroeconomic metrics in influencing sustainable economic growth and reducing CO2 emissions. Investing in sustainable energy sources and educational initiatives stands out as a revolutionary approach, providing enduring advantages like diminished greenhouse gas emissions and increased potential for innovation. Nonetheless, obstacles like organisational inefficiencies, socio-economic inequalities, and excessive dependence on fossil fuels impede advancement. By tackling these deficiencies and harnessing prospects like sustainable finance and global collaboration, the BRICS nations can expedite their shift towards environmentally friendly economies. Efforts such as India's progressive renewable energy initiatives and China's prominent role in solar technology underscore the possibilities for focused, effectively executed approaches to stimulate sustainable development. Cooperative platforms, strong regulatory structures, and skill-enhancement programs are crucial for harmonising national strategies with worldwide sustainability objectives. Through the implementation of cohesive and inclusive approaches, BRICS countries have the potential to rise as frontrunners in sustainable advancement, establishing a standard for harmonising economic expansion

with ecological conservation. Their achievements will not solely enhance their communities but will also play a pivotal role in realising worldwide climate and development goals.

6.1 Policy Recommendations

- Strengthen investments in renewable energy and grid infrastructure.
- Expand education and capacity-building initiatives focused on sustainability.
- Enforce robust regulatory frameworks for environmental conservation.
- Promote sustainable agricultural practices and biodiversity preservation.
- Increase R&D and innovation in green technologies.
- Address socio-economic disparities for inclusive green growth.
- Enhance international cooperation for technology transfer and funding.

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