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Assessment of sustainable economic development and green growth in BRICS Countries

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Abstract

This study aims to assess the relationship between economic growth, renewable energy consumption, and sustainable development in the BRICS countries, addressing the complex dynamics and policy implications of achieving green growth.

By Utilizing a panel data approach, this research employs the Panel Autoregressive Distributed Lag (ARDL) model to explore both short-term and long-term relationships among GDP growth, CO2 emissions, renewable energy consumption, quality of education, and zero hunger initiatives from 2010 to 2022. The study also used correlation matrix, ADF panel unit root tests and co-integration analyses to ensure the robustness of the findings. The results revealed a significant short-term positive relationship between GDP growth and CO2 emissions, and indicating that current economic activities in BRICS remain carbon-intensive to increase economic growth in short-term. However, in the long run, higher investments in the sectors of education and renewable energy notably reduces carbon emissions, showcasing their ability to foster sustainable development. The analysis further reveals a negative correlation between the consumption of renewable energy and CO2 emissions and a positive link between education spending and economic growth, underscoring the importance of human capital in driving sustainability.

This study contributes to the existing literature by providing a comprehensive analysis of the socio-economic impacts of green growth strategies in the BRICS countries. It underscores the necessity for integrated policies that balance economic advancement with environmental preservation and social inclusion. The findings offer valuable insights for policymakers to design effective strategies for achieving sustainable economic development in emerging economies.

Keywords: Sustainable development; Green economy; BRICS countries; Renewable energy; Economic growth; Environmental policy; Panel ARDL

1. Introduction

The BRICS countries (Brazil, China, India, Russia and South Africa) standing at forefront of global economic dynamics and collectively shaping the trajectory of sustainable development on a monumental scale. Undoubtedly, the economic landscape is undergoing significant change, and it appears as BRICS economies experience accelerated growth, they are likely to wield increased influence in shaping international economic policies [Siddiqui, 2016]. The BRICS countries have made substantial advancement in sustainable development, emphasizing efforts in alleviating poverty, improving education and healthcare, and preserving the environment [Li, 2021]. BRICS nations are committed to the ambitious agenda of the Sustainable Development Goals (SDGs), adopted by the United Nations, with a resolute focus on fostering inclusive and environmentally sustainable growth [BRICS, 2020].

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Sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [Brundtland & Khalid, 1987]. It guarantees the conservation of natural resources to support future development [World Bank, 2020]. Achieving sustainable development requires a thorough evaluation of the social, environmental, and economic impacts of resource depletion. This requires a more comprehensive assessment of the costs associated with depleting natural assets, instituting suitable incentives, organizations, and investments to sustainably manage natural resources, and promoting interdisciplinary cooperation (Barbier & Burgess, 2015). Sustainable economic development can be characterized by such principles as integration of environmental factors into economic decision-making processes, promotion of resource efficiency, social equity, innovative technology, and adopting long-term perspectives [UN, 2015]. By adhering to the sustainable economic development paradigm, nations aim to achieve economic prosperity that is ecologically viable, socially just, and inclusive.

The concept of green growth represents a pathway towards sustainable economic development that prioritizes environmental sustainability and low-carbon development strategies. Green growth refers to the process of making growth more efficient in terms of resources, cleaner and more resilient without necessarily slowing its pace [Hallegatte, Heal, Fay, & Treguer, 2012]. It advocates for investments in innovation, renewable energy, and the adoption of sustainable strategies across all economic sectors. By embracing green growth practices, countries strive to reduce greenhouse gas emissions with enhancing resilience to the impacts of climate change and protection of natural ecosystems, while simultaneously pursuing economic prosperity.

Gaining a deeper understanding of the impact of green growth strategies on income inequality, employment, access to essential services, and overall well-being can provide valuable insights for policymakers and stakeholders. It is essential to focus on these areas of improvement in order to enhance our understanding of sustainable development in the BRICS nations. This is particularly relevant with regard to the specific indicators of such SDGs, as Zero hunger (Goal No. 2), Affordable and clean energy (Goal No. 7), Decent work and economic growth (Goal No. 8), Quality education (Goal No. 4), and Climate action (Goal No. 13).

The BRICS countries, both collectively and individually, have been actively involved in the UN discussions on the SDGs aiming to advance the global adoption of the SDGs as a means of narrowing the development gap [Sergey, Grigoriev, & Beletskaya, 2021]. This suggests a shared commitment among the BRICS countries to prioritize sustainable development efforts as a strategy to address socio-economic disparities.

To further the SDG agenda within the BRICS countries, it is critical to monitor and analyze their progress, specifically, with regard to economic development and the pursuit of low-carbon and green growth strategies. Despite the extensive body of research dedicated to exploring the economic and ecological consequences of green growth strategies in BRICS countries, there remains a pressing need for a thorough investigation to gain a comprehensive understanding of the multifaceted factors that contribute to the promotion of green growth in these nations [Huang, 2024]. The current paper provides valuable insights into the current state of affairs, challenges, and prospects for green growth and sustainable economic development within the BRICS nations. As revealed, there are significant research gaps in relation to the such relevant to the green growth theme SDGs, as Zero hunger (Goal No. 2), Affordable and clean energy (Goal No. 7), Decent work and economic growth (Goal No. 8), Quality education (Goal No. 4), and Climate action (Goal No. 13). The indicators of these goals require more precise investigation to enhance existing policies and provide transformational prospects.

Therefore, the following research question is proposed: What is the impact of such factors, as GDP growth, the quality of education, renewable energy consumption, measures to eliminate hunger, on the carbon dioxide emissions in the BRICS nations?

This study aims to answer this question by addressing the following objectives:

- To evaluate the impact of GDP growth, educational quality, renewable energy use, and initiatives to eliminate hunger on carbon dioxide emissions in the countries of the BRICS over the period 2010-2022.
- To investigate the long-term relationship between GDP growth and CO2 emissions using panel ARDL estimation.
- To examine the short-term interactions among GDP growth, quality of education, renewable energy consumption, zero hunger, and CO2 emissions using the Panel ARDL model.

The research is organized as follows: introduction outlines an overview of the study, research problem, questions, and objectives. Literature review draws on the existing literature on sustainable economic development and green growth in the BRICS countries. Methodology section describes the research design, data sources, and analytical techniques

employed. Analysis and finding's part presents the results of the statistical analysis and interpretations. In the conclusion the main findings are summarized, implications are discussed, and policy recommendations are formulated.

2. Literature Review

2.1. Sustainable Economic Development in the BRICS Countries

Achieving sustainable economic development in the BRICS countries necessitates the incorporation of economic, social, and environmental factors into policy frameworks and decision-making procedures. A critical aspect of the BRICS countries' approach to sustainable development involves promoting renewable energy and reducing carbon emissions [Isheloke et al., 2020]. For example, China, the largest global emitter of greenhouse gases, has launched an ambitious transition to a low-carbon economy through substantial investments in renewable energy infrastructure, such as wind, solar, and hydropower [The World Bank, 2022]. This transition not only contributes to the reduction of climate change but also fosters economic expansion by facilitating the establishment of novel sectors and job prospects. In a similar vein, Brazil has achieved notable advancements in the field of sustainable agriculture, effectively reconciling the imperatives of environmental preservation with economic expansion [Gramkow and Anger-Kraavi, 2019]. Mazzaro de Freitas [2017] reports that the nation has enacted measures to advance land-use planning, discourage deforestation, and promote agroecology; thus, it has fostered economic growth while safeguarding vital ecosystems and biodiversity.

In addition, an imperative aspect of sustainable economic development in the BRICS nations is the mitigation of social disparities and the advancement of inclusive economic expansion. As an illustration, India has implemented numerous endeavors with the objective of enhancing marginalized communities' access to education, healthcare, and fundamental services; in doing so, it promotes human development and social inclusion [Kumar, 2023; Girase et al., 2022]. Additionally, efforts towards sustainable economic development should include principles of responsible resource management and intergenerational fairness in order to address the needs of future generations. While Russia continues to rely heavily on fossil fuels, the country has recognized the significance of transitioning towards a more environmentally sustainable energy sources and incorporating them steadily into the energy mix [Overland and Loginova, 2023]. By cultivating innovation, allocating resources towards green technologies, and advocating for sustainable consumption and production practices, the BRICS nations can establish a trajectory towards sustainable economic growth that harmoniously reconciles the objectives of social welfare, economic advancement, and environmental preservation.

2.2. Green Growth Strategies and Policies in the BRICS countries

The pursuit of sustainable development by the BRICS countries necessitates the inclusion of green growth strategies and policies as integral elements. These strategies aim to promote economic growth while minimizing environmental harm, enhancing resource efficiency, and advancing social inclusion.

Promoting renewable energy and energy efficiency is a cornerstone of green growth initiatives. Programs like India's National Solar Mission and China's Renewable Energy Law have driven significant investments in such renewable energy sources, as wind and solar. These initiatives have focused on promoting low-carbon development by reducing reliance on fossil fuels [Kumar and Majid, 2020; Dey et al., 2022; UNCTAD, 2023]. The discussed policies not only support environmental sustainability but also spur innovation, creating new job opportunities in the clean energy sector.

Furthermore, the BRICS countries have enacted diverse measures to improve the efficiency of resources and encourage sustainable patterns of consumption and production. Brazil's Forest Code and China's Circular Economy Promotion Law represent efforts to encourage sustainable land use, reduce waste creation, and boost resource utilization efficiency [Nguyen and Khominich, 2023]. These policies promote environmental sustainability and economic competitiveness by incorporating circularity and resource conservation principles into production processes and supply chains. Moreover, green growth strategies place significant emphasis on the imperative of cultivating innovation and facilitating the transfer of technology in order to propel sustainable development. According to Steenkamp [2018], both South Africa's Green Economy Accord and Russia's Innovation Strategy place emphasis on allocating resources towards clean technology, research and development, and capacity-building programmed in order to expedite the shift towards a sustainable economy. By leveraging technological advancements and encouraging collaboration between the public and private sectors, the BRICS countries can unlock new opportunities for sustainable economic growth while addressing pressing environmental challenges.

2.3. The Prospects and Obstacles in the BRICS Countries

The BRICS countries face different challenges in their quest for green growth and sustainable development, but these challenges also present significant opportunities for transformational change. However, these issues also offer substantial prospects for implementing transformative change. One of the major challenges for the BRICS nations is balancing economic growth with environmental protection and social equity. Rapid urbanization and industrialization in countries like India and China have placed immense pressure on public health, natural resources and ecosystems, highlighting the need for integrated and comprehensive development strategies [Silva, 2023]. Furthermore, deficiencies in institutions, gaps in regulations, and deficits in governance present challenges to the successful implementation and enforcement of policies, impeding advancements towards sustainable objectives [Overland and Loginova, 2023]. Moreover, the presence of socioeconomic disparities both within and across the BRICS countries serves to intensify the susceptibility to environmental risks and restrict the ability of marginalized populations to enjoy sustainable development possibilities [Suhrab, Chen and Ullah, 2024].

Nevertheless, in the face of these obstacles, noteworthy prospects for BRICS nations to catalyze profound transformations in the pursuit of sustainable development exist. The shift towards a green economy offers novel prospects for generating employment, fostering innovation, and promoting economic diversity. This transition provides the potential to bypass conventional development trajectories and embrace more environmentally sustainable approaches [The World Bank, 2022]. Moreover, international cooperation and collaboration provide opportunities for knowledge sharing, technology transfer, and capability development, allowing BRICS members to learn from each other's experiences and best practices [Wei, 2016]. The COVID-19 pandemic highlighted the importance of resilience and sustainability, prompting governments and stakeholders to reevaluate current development models and prioritize investments in environmentally friendly recovery strategies. In addition, the advent of novel financial instruments, such as green bonds and climate funds, presents supplementary channels for bolstering sustainable development initiatives across the BRICS countries [Yadav et al., 2024].

2.4. Summary and Identified Research Gaps

The previous literature reviews the achievements and obstacles in pursuing sustainable economic development and green growth of the BRICS countries in line with the UN Sustainable Development Goals. Policies supporting renewable energy, resource efficiency, sustainable land use, and social inclusion are reviewed. Green growth initiatives have made progress, but quantitative analysis, social inequities, and regulatory gaps remain. Despite these hurdles, job growth, innovation, international cooperation, and green funding provide transformational prospects. The BRICS states may expedite their transition to a more sustainable and resilient future by addressing these problems and harnessing opportunities, contributing to global SDG efforts by 2030. Table 1 represents a summary of the studies reviewed.

As revealed, there are significant research gaps in relation to such indicators, as agriculture, forestry, and fishing value added (Goal No. 2: Zero Hunger), renewable energy consumption (Goal No. 7: Affordable and Clean Energy), GDP growth rate (Goal No. 8: Decent Work and Economic Growth), government expenditure on education (Goal No. 4: Quality Education), and CO2 emissions (Goal No. 13: Climate Action). These indicators require more precise investigation, as the assessment of the socio-economic impacts of green growth strategies on different sectors and demographic groups within the BRICS countries has not been thoroughly explored. Acquiring knowledge on the impact of green growth methods on employment, income inequality, access to critical services, and overall well-being can provide policymakers and stakeholders with valuable insights to guide the creation of more inclusive and fair sustainability paths.

Table 1 Summary of reviewed literatures

Author(S)		Objectives	Methods	Findings	Conclusion
Isheloke, B.E., Kankisingi, G.M., Nyandu, D.K., Moodley, K., Singh, S., Basele, M. and Muindi, T. [2020]	*Brics and Economic Development: A Multidisciplinary Perspective*.	The study aims to predict the potential transformation of the BRICS partnership amid and beyond the COVID-19 crisis, assessing its economic substance from	The methods used include a variety of separate research approaches. The authors focus on assessing economic matters from an African perspective. Their methodology involves identifying the aspects of the BRICS partnership and advising on strategies to	Predicts potential outcomes for the BRICS partnership post-COVID-19 crisis, including potential metamorphosis into a different organization or	The study suggests potential transformations for the BRICS partnership, advocating for leveraging strengths to ensure continued

		an African perspective and providing insights into potential restructuring and strategies for steady economic growth.	capitalize on its strengths for future economic growth.	restructuring, based on strengths and weaknesses identified.	economic growth.
Mazzaro de Freitas , F.L [2017]	*Brazilian Land Use Policies and The Development of Ecosystem Services Flávio Luiz Mazzaro de Freitas*.	The objective is to assess the potential impact of current governmental and private initiatives on the preservation of Brazil's native vegetation, with a particular focus on quantifying above-ground carbon sequestration and implementing offset mechanisms to address the loss of native vegetation among landowners.	The Land Use Policy Assessment (LUPA) model serves as a tool for assessing potential policy scenarios and their implications for carbo n sequestration in terrestrial ecosystems and the mechanisms of native vegetation offsets.	This study delves into the efficacy of current strategies in safeguarding terrestrial carbon reservoirs, meticulously assessing the influence of offsetting measures on both environmental conservation and socio-economic progress.	The research implies that, despite the fact that current policies safeguard a substantial portion of terrestrial carbon reserves, compensatory measures may not significantly augment the impact on native flora protection and socio-economic advancement, owing to the presence of existing regulatory safeguards.
Gramkow, C. and Anger-Kraavi, A. [2019]	Developing Green: A Case for the Brazilian Manufacturing Industry.	The study aims to explore the potential for green economic development in Brazil's manufacturing sectors through the implementation of fiscal policies to induce low-carbon investments, thereby contributing to climate mitigation goals and economic growth.	Projects Brazil's economic futures with and without a portfolio of fiscal policies using the Energy-Environment-Economy Model, highlighting the potential benefits of green stimulus in modernizing and decarbonizing manufacturing sectors.	Indicates that the correct mix of green stimulus policies can accelerate modernization and decarbonization of Brazilian manufacturing sectors, leading to faster economic growth and decreased carbon emissions.	The study emphasizes the potential benefits of implementing green stimulus policies in Brazil's manufacturing sectors, suggesting a pathway for economic growth aligned with climate mitigation goals.
Kumar, A. [2023]	The Transformation of The Indian Healthcare System.	Delves into the intricate issues confronting India's health care system, critically	Conducts a deep-dive analysis of Indian healthcare strategies, initiatives, and breakthroughs, evaluating their impact on the	Highlights challenges such as inadequate infrastructure and disparities in	The study underscores the progress and challenges in India's

		evaluating government endeavors, schemes, and groundbreaking initiatives designed to enhance the provision of healthcare services, bolster infrastructure, and ensure equitable access to medical care.	healthcare system, service provision, and accessibility.	healthcare access, while also discussing government programs like the National Health Mission and Ayushman Bharat scheme aimed at addressing these challenges.	healthcare system, emphasizing the importance of government initiatives in improving healthcare infrastructure and access to medical services.
Girase et al. [2022]	Policy review on promoting youth mental health in India.	Reviews policies, programs, and legislations across multiple Indian ministries to identify enablers and barriers for promoting youth mental health in India, providing insights into potential strategies for advancing mental healthcare in the country.	Undertakes a comprehensive review of policies and programs across Indian ministries, analyzing their approach to youth mental health promotion and identifying potential enablers and barriers.	Recognizes fragmented approaches to youth mental health promotion across Indian ministries and identifies opportunities for integration of preventive, promotive, and curative mental health interventions.	The study emphasizes the need for a comprehensive approach to youth mental health in India, advocating for strategic planning and intersectoral integration to improve access to mental healthcare services.
Overland, I. and Loginova, J. [2023]	The Russian coal industry in an uncertain world: Finally pivoting to Asia?	Examines internal and external pressures on the Russian coal industry and evaluates its capacity to adapt to rapidly changing socio-political and techno-economic environments, using the Triple Embeddedness Framework (TEF) to analyze potential strategies and risks.	Utilizes the Triple Embeddedness Framework (TEF) to assess internal and external pressures on the Russian coal industry and evaluate its adaptive capacity in a changing global context.	Concludes that the Russian coal industry is not adequately prepared for long-term changes in international coal markets, exacerbating risks for local communities and regional economies within Russia and global decarbonization efforts.	The study highlights the need for strategic adaptation in the Russian coal industry to mitigate risks and ensure alignment with global decarbonizatio n efforts.
Dey, S., Sreenivasulu , A., Veerendra, G.T.N., Rao, K.V. and	Renewable energy present status and future potentials in	This study examines the intricate interplay between renewable energy utilization, energy	Conducts an analysis of the utilization of renewable energy sources, energy efficiency measures, and their impact on economic growth and carbon	Identifies energy efficiency, renewable energy output, economic growth, and	The potential of renewable energy contributing to sustainable development in

Babu, P.S.S.A. [2022]	India: An overview.	productivity, economic expansion, and carbon emissions in India. The potential impact of renewable energy on fostering sustainable development is formulated.	emissions in India, employing econometric techniques to examine the intricate interdependencies between these variables.	carbon emissions as significant factors influencing renewable energy consumption in India.	India is investigated, emphasizing the need for higher investments in the sector of renewables and energy efficiency measures.
Kumar, C.R. and Majid, M.A. [2020]	The role of renewable energy in India's pursuit of sustainable development: an analysis of current state, future prospects, obstacles, job creation potential, and investment opportunities.	This report delves into the realm of India's vibrant renewable energy landscape, highlighting not only its remarkable accomplishments but also the intricate challenges it faces. It provides a comprehensive analysis of the prospects and projections for the future, offering a deep dive into investment opportunities and employment prospects. Moreover, it presents recommendations tailored for policy makers and stakeholders, aiming to foster sustainable development in this crucial sector.	This report critically analyses the current state of affairs in India's renewable energy industry, examining its progress, obstacles, future trajectories, and potential outcomes. The findings are then used to formulate recommendations for policy-makers and other stakeholders.	The paper delves into the intricacies of India's journey in the realm of renewable energy, highlighting both its remarkable accomplishments and the formidable challenges it faces. It underscores the critical importance of sustained investment and innovative thinking to fully unlock the potential of this sector for driving sustainable economic growth.	The study provides insights into the opportunities and challenges in India's renewable energy sector, emphasizing the importance of policy support and innovation to drive sustainable economic development.
Nguyen, D.H. and Khominich, I.P. [2023]	The evaluation of the environmental economic performance in the BRICS countries: should they prioritize funding for environmental conservation,	The study develops a Green Economy Index with the aim of assessing the quality of green economic systems in BRICS nations. The index evaluates these systems based on their	The Green Economy Index is a tool for evaluating the performance of green economies in BRICS (Brazil, Russia, India, China, and South Africa) countries. It is based on a set of environmental, economic, and social indicators, which are used to identify challenges and	Argues that the gradual shift towards green economies takes place among the BRICS nations, with Russia representing the best balance among the three pillars of sustainability,	Reveals that the BRICS nations should prioritize funding environmental protection, economic growth, and social objectives to balance these aspects and

	economic development, or social objectives?	environmental performance, economic metrics, and adherence to principles of sustainable living. Additionally, it identifies specific challenges and areas for improvement.	opportunities for improvement.	India and China making notable progress, while South Africa and Brazil face difficulties in developing their economies and increasing social welfare.	attain green economy goals.
Steenkamp [2018]	From Kyoto to Paris - a review of South Africa's climate change response with particular emphasis on the Clean Development Mechanism and envisaged transition to the Sustainable Development Mechanism	Examines the transition from the Clean Development Mechanism (CDM) to the Sustainable Development Mechanism (SDM) under the Paris Agreement, exploring past experiences and lessons learned to inform the future of carbon market mechanisms.	This paper traces the evolution of the Clean Development Mechanism (CDM) and delves into its prospective successor, the Sustainable Development Mechanism (SDM), examining how the SDM enhances and optimizes the CDM within the framework of South Africa's legislation and policies related to climate change.	Argues that transitioning from the CDM to the SDM is necessary to ensure effective mitigation of emissions and support for sustainable development, particularly in the context of South Africa's climate-related laws and policy frameworks.	The research underscores the significance of transitioning from CDM to SDM in order to effectively reduce emissions and promote sustainable development objectives, particularly in the context of South Africa and analogous situations.
Silva [2023]	Wastewater Treatment and Reuse for Sustainable Water Resources Management: A Systematic Literature Review.	Evaluates the economic and environmental sustainability of wastewater treatment, highlighting its role in minimizing water waste, pressure on natural resources, and energy production, and providing insights into its potential contributions to sustainable resource management.	Conducts a systematic literature review to evaluate evidence supporting wastewater treatment for economic and environmental sustainability, using the PRISMA framework to select relevant articles for inclusion.	Indicates that wastewater treatment enables sustainable resource management by improving clean water supply, minimizing pressure on natural resources, recovering energy, and supporting agricultural productivity.	The study underscores the importance of wastewater treatment for economic and environmental sustainability, highlighting its potential contributions to sustainable resource management.
Suhrab, Chen and Ullah [2024]	The interplay between digital financial inclusion and income disparity: Can technological advancements and	This research delves into the intricate connection between digital financial inclusion (DFI) and income disparity in the	The analysis makes use of Driscoll-Kraay (DK) tests and fixed effects techniques to evaluate the impact of DFI (direct foreign investment) on income inequality, as well as the moderating influences of TI (tax incentives) and ID (institutional development).	The research reveals that digital financial inclusion (DFI) significantly mitigates income disparity in the BRICS nations. Technological	The research underscores the transformative potential of digital financial inclusion in mitigating income disparities

	infrastructure development contribute to the attainment of sustainable development objectives?	BRICS nations, specifically examining how technological advancements (TI) and infrastructural development (ID) may serve as mediators in this dynamic.		advancements and infrastructure development amplify the positive impact of DFI, underscoring the critical role of these elements in leveraging financial inclusion as a tool for addressing income inequality. The implementation of technological innovation (TI) and infrastructure development (ID) expedites and secures transactions, expands market access, and provides crucial services, collectively contributing to a reduction in income inequality.	within BRICS nations. It underscores the significance of investing in technological advancements and infrastructure development, which are crucial for enhancing the efficacy of financial inclusion efforts. By implementing these strategies, policy makers can foster sustainable development objectives and foster more equitable economic expansion.
Wei [2016]	Strengthening the customs cooperation of the BRICS countries: enhancing people-centered capacity-building strategies to achieve mutual recognition of Accredited Operator programs.	This research undertakes a comparative analysis of Accredited Operator programs in the BRICS nations, examining their potential for establishing mechanisms of mutual recognition among customs authorities, and suggesting practical strategies for capacity-building efforts.	A comparative study of Accredited Operator programs across BRICS countries.	The study delves into a comparative analysis of Accredited Operator (AO) programs across the BRICS nations, unveiling both obstacles and prospects for their harmonization. The proposed strategies suggest delving into standardized human resource development strategies and	The study highlights the importance of mutual recognition arrangements among customs authorities in facilitating trade facilitation and economic competitiveness in BRICS countries, advocating for capacity building to support the implementation of Accredited Operator programs.

				professional training programs, aiming to foster the mutual recognition of AO schemes among customs authorities. The significance of this endeavor lies in its contribution to capacity building, which is crucial for enhancing trade facilitation and bolstering economic competitiveness within the BRICS bloc.	
Yadav et al. [2024]	Nexus between fintech, green finance and natural resources management: Transition of BRICS nation industries from resource curse to resource blessed sustainable economies.	Explores the potential of green investment and financing in alleviating the resource curse in BRICS countries, offering insights into strategies for sustainable economic development and social welfare.	Develops a decision-making framework for executives in resource and non-resource sectors, exploring the investment and real exchange rate channels through which green investment and financing can help alleviate the resource curse.	Proposes a decision-making framework for executives in BRICS countries to navigate green investment and financing opportunities, emphasizing the potential of green goods and practices to mitigate real exchange appreciation and promote sustainable economic development and social welfare.	The study underscores the potential of green investment and financing to alleviate the resource curse in BRICS countries, offering a decision-making framework for executives to promote sustainable economic development and social welfare through green initiatives

Source: compiled by the authors.

3. Data and Methodology

This research employs panel data drawn from the economic landscapes of the BRICS nations, spanning the period from 2010 to 2022. Some of the data on SDG indicators extends up to 2020/21. The analysis concentrates on five specific countries within the broader BRICS framework, namely Brazil, Russia, India, China, and South Africa. The study specifically focuses on five SDGs, namely Goal No. 02, which aims to eradicate hunger, Goal No. 04, which aims to provide quality education, Goal No. 07, which aims to ensure affordable and clean energy, Goal No. 08, which seeks to promote decent work and economic growth, and Goal No. 13, which aims to address climate change. Table 2 represents the indicators utilized for the investigation of various targets.

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.

Panel data analysis was employed in this study to evaluate the advancement of BRICS countries in attaining the SDGs, with a particular emphasis on economic dimensions, specifically the promotion of green growth. The research employed a set of five variables to represent each Sustainable Development Goal (SDG), namely REC, GDP, QEC, CO2EM, and ZERHUNG. These variables correspond to renewable energy consumption, gross domestic product, quality education, carbon dioxide emissions, and zero hunger, respectively. The data were obtained from a secondary source known as the World Development Indicator (WDI).

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.

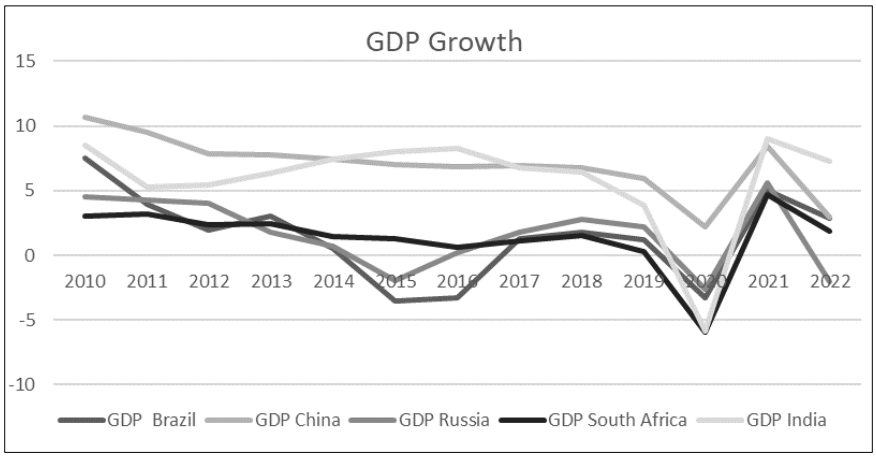

Figure 1 GDP Growth

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.

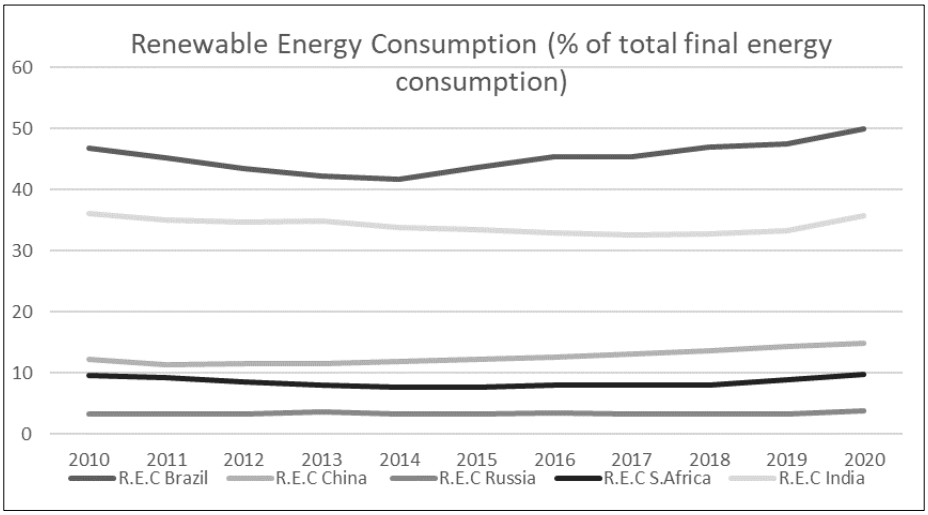

Figure 2 Renewable Energy Consumption (% of total final energy consumption)

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.

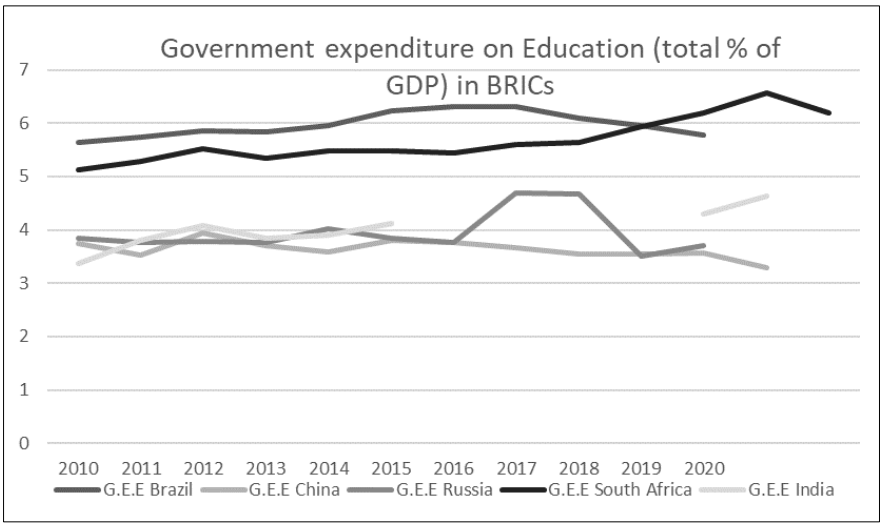

Figure 3 Government expenditure on Education (total % of GDP) in BRICs

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.

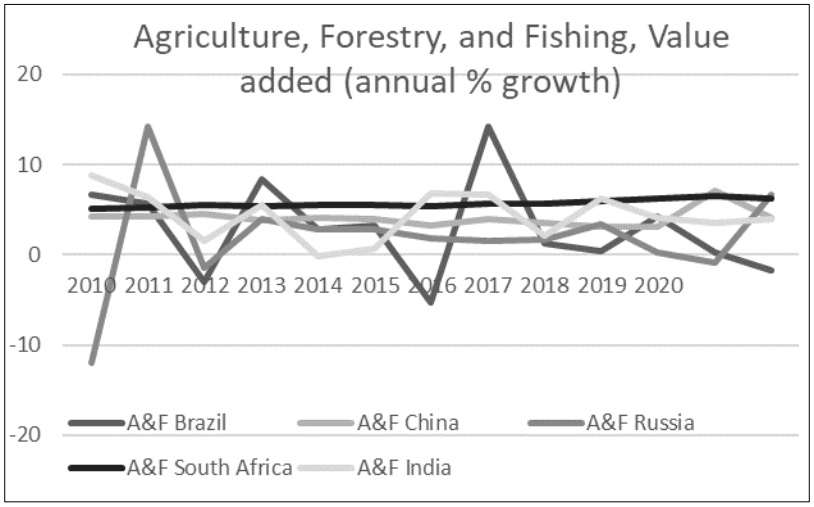

Figure 4 Agriculture, Forestry, and Fishing, Value added (annual % growth)

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

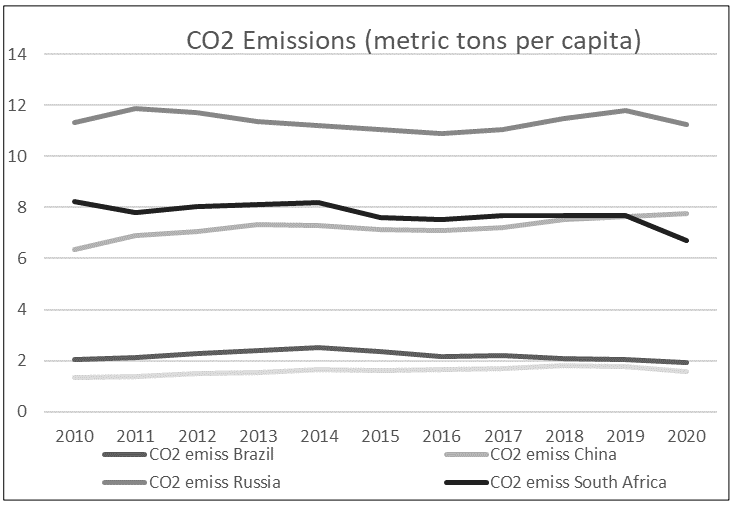

Figure 5 CO2 Emissions (metric tons per capita)

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 Auto Regressive Distributive Lag (PARDL) Model:

We analyzed the long-run impact of GDP, REC, QEC and ZERHUNG on CO2EM by using Panel Auto Regressive Distributive Lag Model (PARDL) approach. The result of PARDL are shows in Table 8. Table 8A represents the results of long run coefficients estimates, while Table 8B represents the long run coefficients results.

$$CO2EMit = f(GDPit, QECit, RECit, ZERHUNGit)$$

$$(CO2EM)it = \beta o - \beta 1(GDP)it + \beta 2(QEC)it - \beta 3(REC)it - \beta 4(ZERHUNG)it$$

$$\Delta CO2EMit = \beta o + \beta 1\left(D(GDPit)\right) - \beta 2\big(GDP(-1)\big)it + \beta 3\big(D(QECit)\big) + \beta 4(D(QEC(-1)it) + \beta 5\big(D(RECit)\big) - \beta 6(D(REC(-1)it) + \beta 7\big(D(ZERHUNGit)\big) + \beta 8(D(ZERHUNG(-1)it) + \varepsilon it \ldots$$

The above equation (1) represents the general function of the model while equation (2) represents the econometric model. This study will follow the equation (3) for the Panel ARDL analysis.

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

Variable	Coefficient	Std. Error	T-Statistic	Prob
GDP	-0.300	0.063	-4.742	0.0006
QEC	0.842	0.726	1.159	0.2707
REC	-0.537	0.147	-3.645	0.0039
ZERHUNG	-0.292	0.119	-2.453	0.0320

Source: Estimated by the authors.

4.5. 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 8B 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 research findings highlight the complex dynamics of sustainable economic development and green growth in the BRICS nations by providing insights through visual representations, relevant statistical models and various tests. In Trend Analysis a set of charts and visual aids display the trends in GDP growth rate, CO2 emissions, renewable energy consumption, agricultural & forestry productivity, and education expenditure in BRICS nations over the study period. The visual trends highlight the rapid industrialization in China and India and three other countries alongside their increasing efforts in renewable energy adoption and sustainable economic development. The descriptive statistics and correlation matrix reveal the interconnectedness of economic, environmental, and social indicators. The inverse relationship between CO2 emissions and the use of renewable energy sources underscores the efficacy of environmental policies aimed at reducing emissions. Meanwhile, the moderate positive correlation between educational spending and economic growth highlights the importance of human capital development in promoting sustainable economic growth among the BRICS countries. We applied panel unit root tests in order to determine the stationarity of the time series data. By Utilizing the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests all variables, namely GDP growth, CO2 emissions, renewable energy consumption, and education expenditure, appeared to be non-stationary at level but became stationary after first differencing. This stationarity is crucial for ensuring the reliability of further econometric analyses. Based on the results of unit root tests, further we employed the Pedroni and Johansen co-integration tests to investigate the long-term equilibrium relationships between the variables. The findings suggest a strong cointegration between GDP growth, CO2 emissions, consumption of renewable energy, agricultural, forestry and fishing productivity,

and educational expenditure. These variables tend to co-move in the long term, despite short-term fluctuations. This highlights the interdependence of economic development and environmental sustainability in the BRICS nations. The core analysis utilized Panel Autoregressive Distributed Lag (ARDL) model aims to find both short-term dynamics and long-term relationships among variables. The results of panel ARDL reveal that in the short run GDP growth is positively associated with CO2 emissions, indicating that economic activities still rely on carbon-intensive processes in BRICS, but in the long-term increased investments in renewable energy and education are found to significantly reduce CO2 emissions.

5.1. Interpretation of Key Findings

- Economic Growth and CO2 Emissions: The significant short-term positive relationship is revealed between GDP growth and CO2 emissions which highlights the challenge to achieve immediate reductions in emissions while pursuing economic growth or economic expansion. However, the long-term negative relationship identified through the co-integration analysis suggests that sustained investments in renewable energy and education can cover this impact.
- Renewable Energy Consumption: The disparity in renewable energy usage among the BRICS countries, with China at the forefront in terms of investment and adoption, illustrates the potential of renewable energy in reducing greenhouse gas emissions. This potential is further supported by the strong inverse relationship between renewable energy use and carbon emissions.
- Quality of Education: The positive impact of education expenditure and investment in education on economic growth and its indirect effect on reducing CO2 emissions reveals the importance of human capital development. Enhanced education quality promotes environmental awareness, motivation and innovation, driving the adoption of green technologies and sustainable practices in BRICS.
- Sustainable Agriculture: The mixed performance in agricultural productivity and its environmental impacts calls for targeted policies to support sustainable farming practices. Brazil's success in implementing agroecological practices provides a valuable model that other BRICS countries can learn from and implement

6. Conclusion

The study investigates the sustainable economic development and green growth progress and their impact on economic growth in BRICS nations by providing comprehensive insights into the relationships between GDP growth, agricultural & forestry productivity, CO2 emissions, renewable energy consumption, and government education expenditure. The results highlight the complexity and interconnectedness of economic, environmental, and social factors in shaping sustainable development trajectories in these countries. The trend analysis represents rapid industrialization in China and India, alongside increasing efforts in renewable energy adoption across all BRICS nations. Descriptive statistics and correlation matrices analysis reveal a significant negative and inverse correlation between CO2 emissions and renewable energy consumption, and demonstrate the effectiveness of green energy policies. Additionally, a moderate positive correlation between education expenditure and economic growth emphasizes the important role of human capital development in fostering sustainable economic progress. Panel unit root tests indicate that all variables are non-stationary at the level but after taking first differencing become stationary, which is crucial to ensure the reliability of further econometric analyses. The co-integration analysis employing Pedroni and Johansen tests reveals a significant long-term equilibrium relationship among GDP growth, CO2 emissions, renewable energy consumption, and education expenditure. These findings suggest that despite short-term fluctuations in variables, these variables tend to move jointly in the long run and underscore the interconnected nature of economic growth and environmental sustainability in the BRICS countries. The Panel ARDL model provides further insights into both short-term dynamics and long-term relationships. It reveals that in the short run GDP growth is positively associated with CO2 emissions, indicating that economic activities in BRICS still rely on carbon-intensive processes. However, in the long-term increased investments in renewable energy and education sector are found to significantly reduce CO2 emissions, highlighting the potential for these investments to foster sustainable development.

In summary, findings of the study emphasize the critical need for the BRICS nations to balance economic growth with environmental sustainability for sustainable economic development. The significant long-term benefits of investing in renewable energy and on education underscore their potential to drive green growth and sustainable development. As the BRICS countries continue to pursue the SDGs, it is imperative to adopt integrated policies which harmonize economic advancement with environmental preservation and social inclusiveness. The current research insights provide a valuable foundation for policymakers to design effective strategies for achieving sustainable economic development in the BRICS nations.

6.1. Policy Recommendations

Based on an analysis of the sustainable economic development and the pursuit of green growth in the BRICS nations, the following policy recommendations are put forward to promote sustainable development and advance green growth:

Strengthening investments in renewable energy: the BRICS member states should substantially augment their investments in renewable energy sources, such as solar, wind, and hydropower adapting to the global focus on sustainability. Developing robust infrastructure for renewable energy is crucial. This includes expanding grid capacity to accommodate renewable energy, enhancing energy storage solutions, and investing in smart grid technologies to improve energy efficiency and reliability This can be achieved by providing financial incentives, subsidies, and tax breaks to renewable energy projects. Countries like China and India have made considerable progress in this area, which should serve as a model for other BRICS nations.

- Advancing Education and Capacity Building: the escalation of governmental investment in education is imperative for the enhancement of human capital, which, in turn, fosters sustainable economic expansion. Educational initiatives should prioritize sustainability, eco-friendly technologies, and environmental responsibility to equip the workforce with the skills required for a sustainable economy. Provision of training and skill development programs in green technologies and sustainable practices will lead to the creation of a qualified workforce capable of driving green growth initiatives. This includes vocational training and higher education programs focused on renewable energy, energy efficiency, and environmental management.
- Strengthening Regulatory Frameworks: strengthening environmental regulations and ensuring their effective enforcement is vital. This includes updating and implementing laws related to air quality, water conservation, waste management, land use planning. improving corporate governance structures and building institutional capacity to manage and monitor sustainable development initiatives is essential. This includes enhancing transparency, accountability, and stakeholder engagement in policy-making processes.
- Encouraging Sustainable Agriculture and Land Use: the proposal is to promote sustainable agricultural practices that harmonize economic expansion with environmental conservation. This includes agroecology, conservation agriculture, and integrated pest management. Implementation of effective land use planning to prevent deforestation, protect biodiversity, and ensure sustainable use of natural resources is necessary. Policies should encourage reforestation, afforestation, and the preservation of critical ecosystems.
- Fostering Innovation and Technology Transfer: increasing investment in R&D for green technologies and sustainable practices is necessary for green growth. This includes funding for clean energy research, sustainable agriculture innovations, and green manufacturing processes. Facilitating the transfer of green technologies between BRICS countries can accelerate the adoption of sustainable practices. Establishing platforms for knowledge sharing and collaboration on green technology innovations is recommended.
- Addressing Socio-economic Disparities: formulating policies that address socio-economic disparities and promote inclusive growth is essential. This includes ensuring access to education, healthcare, and basic services for marginalized communities. Implementation of social protection programs to support vulnerable populations during the transition to a green economy can mitigate adverse impacts and promote social equity.
- International Cooperation and Partnerships: enhancing collaboration among BRICS countries on sustainable development projects can lead to shared benefits and collective progress. This includes joint research initiatives, policy dialogues, and collaborative investment in green infrastructure.

These policy recommendations aim to provide a comprehensive framework for the BRICS countries to achieve sustainable economic development and green growth, balancing economic advancement with environmental preservation and social inclusiveness. Implementing these policies will require coordinated efforts from governments, private sectors, and civil society to ensure a sustainable and prosperous future for all BRICS nations

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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