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THE IMPACT OF SUSTAINABLE DEVELOPMENT POLICY IMPLEMENTATION ON GREENHOUSE GAS EMISSION REDUCTION IN BRICS COUNTRIES

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Abstract

This study examines the impact of sustainable development policies on greenhouse gas emission reduction in BRICS countries over the period 2010–2023. The research aims to assess both short-run and long-run effects of sustainable development policies on emissions while accounting for economic and energy-related factors. The Panel Autoregressive Distributed Lag (Panel ARDL) approach is employed to capture dynamic relationships and adjustment mechanisms toward long-run equilibrium. The findings reveal that the sustainable development policy index and the share of renewable energy exert a negative and statistically significant effect on emissions in both the short and long run. In contrast, higher energy intensity and economic growth are associated with increased emissions, particularly over the long term. The negative and significant Error Correction Term indicates a rapid adjustment process toward long-run equilibrium following short-run shocks. Overall, the results provide robust empirical evidence that sustainable development policies especially those promoting renewable energy expansion and energy efficiency are effective instruments for reducing emissions while maintaining economic stability in BRICS economies.

Keywords: BRICS; CO_2 emissions; Panel ARDL; renewable energy; sustainable development policy.

INTRODUCTION

Climate change and the mitigation of greenhouse gas (GHG) emissions have become central concerns of global policy agendas over the past several decades. Both developing and developed countries face increasing pressure to reduce emissions as part of their international commitments under the Paris Agreement and the Sustainable Development Goals (SDGs). At the global level, GHG emissions play a pivotal role in driving global warming and climate change, prompting countries to reassess their development strategies to align with a low-carbon energy transition while safeguarding long-term economic objectives. The BRICS group comprising Brazil, Russia, India, China, and South Africa has emerged as a key actor in global emission dynamics due to its substantial contribution to global economic output alongside persistently high emission levels. Collectively, BRICS countries account for a significant share of total global emissions, particularly from the power generation sector and heavy industry, which in certain periods have exceeded the combined emissions of other regions worldwide. This situation reflects deep-seated structural challenges in reconciling rapid economic growth with effective greenhouse gas mitigation strategies (Reuters, 2024).

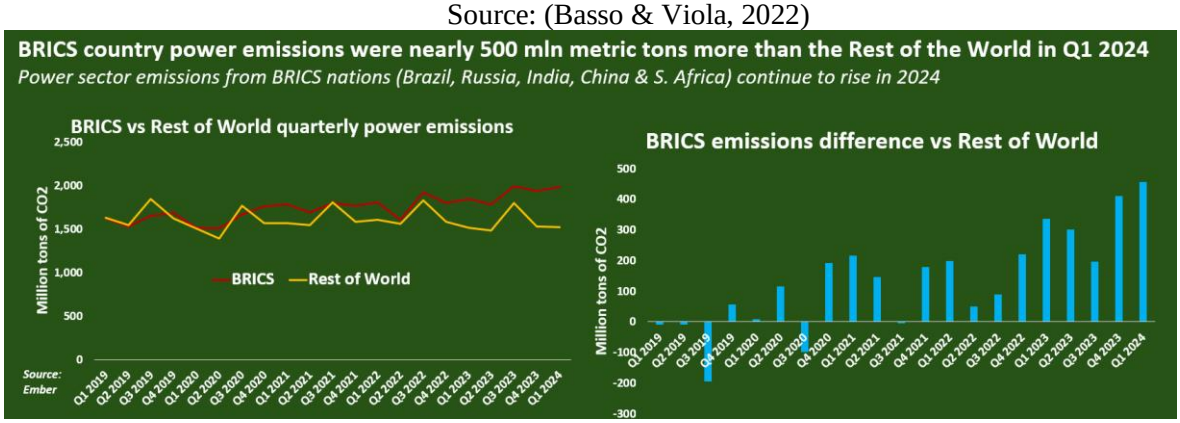
Nevertheless, BRICS countries face substantial challenges in balancing the need for sustained economic growth with efforts to reduce greenhouse gas (GHG) emissions. To address these challenges, each member country has implemented a range of sustainable development policies, including energy efficiency standards, an increased share of renewable energy in the energy mix, the introduction of carbon taxes or emissions trading systems (ETS), and incentives to promote the development of clean technologies. These policy measures are designed not only to mitigate GHG emissions but also to preserve long-term economic stability and growth. Given the heterogeneity in macroeconomic conditions, energy structures, and institutional capacities across BRICS countries, the effectiveness of such policies is likely to vary across countries and over time, particularly between

the short run and the long run. Sustainable development policies emphasize the integration of three core pillars economic, social, and environmental to ensure that economic expansion does not occur at the expense of environmental quality. In practice, these policies encompass strategies such as expanding the use of renewable energy, fostering green technological innovation, protecting natural resources, and providing incentives for low-carbon investment. A growing body of empirical literature indicates that technological innovation and the increased consumption of clean energy can significantly reduce emission intensity in both the short and long run (Adebayo et al., 2023)

However, the sustainable development policy framework in BRICS countries faces considerable complexity and heterogeneity. Differences in stages of economic development, levels of dependence on fossil fuels, and national policy priorities have resulted in substantial variation in the effectiveness of emission-mitigation policies across member states. For instance, countries such as China and India have made substantial progress in expanding renewable energy capacity, whereas other BRICS members remain heavily reliant on traditional, carbon-intensive energy sources. This divergence underscores the uneven pace of energy transition within the BRICS bloc and highlights the structural constraints that shape national mitigation outcomes (China, 2022).

	1990 per capita emissions	2019 per capita emissions	1990 GHG/GDP intensity	2019 GHG/GDP intensity
Brazil	13.79	9.35	1.31	0.63
Russia	17.90	13.33	0.83	0.48
India	1.15	2.46	0.63	0.37
China	2.55	8.56	1.79	0.54
South Africa	9.20	9.60	0.82	0.70

Source: (Basso & Viola, 2022)



BRICS countries Brazil, Russia, India, China, and South Africa play a strategic role in global emission dynamics, accounting for more than 40% of the world's population and approximately one quarter of the global economy. Despite the adoption of various sustainable development policies, greenhouse gas emission trends in the region continue to rise, particularly within the power generation sector. Recent data indicate that electricity-related emissions in BRICS countries during the first quarter of 2024 were nearly 500 million metric tons of CO_2 higher than those of non-BRICS countries, underscoring the persistent challenges of energy decarbonization in the region (Reuters, 2024). This situation raises critical questions regarding the effectiveness of sustainable development policy implementation in curbing greenhouse gas emissions across BRICS economies. Accordingly, this study aims to assess the extent to which sustainable development policies can reduce greenhouse gas emissions in BRICS countries while accounting for macroeconomic conditions and country-specific energy sector characteristics. The primary objective is to examine the short-run and long-

run effects of sustainable development policy implementation on greenhouse gas emission reductions, as well as to evaluate the system's adjustment mechanism toward a low-carbon equilibrium.

LITERATURE REVIEW

A. Sustainable Development Policies

Sustainable development policy indices capture the extent of governmental commitment to implementing environmentally sound and socially inclusive development strategies. Such policies typically encompass stringent environmental regulations, clean energy standards, and fiscal incentives for low-carbon technologies. In the context of BRICS countries, empirical evidence indicates that environmental policy stringency plays a crucial role in mitigating greenhouse gas emissions. Studies focusing on BRICS economies and neighboring countries find that stronger environmental policy enforcement can slow ecological degradation, although the combined effects of related factors such as energy transition dynamics and green technological innovation remain essential components within a comprehensive sustainable development framework (Sahin et al., 2025).

Meanwhile, the deployment of renewable energy constitutes a key indicator of sustainable development policy, as it is directly linked to greenhouse gas emission reductions. Empirical research on BRICS countries demonstrates that the utilization of renewable energy sources such as wind, solar, and hydropower contributes significantly to long-term reductions in CO_2 emissions. Panel data analyses reveal a statistically significant negative relationship between renewable energy consumption and CO_2 emissions in BRICS economies, highlighting the strong mitigation effect of increasing clean energy shares on total emissions over the long run (Erkılıç et al., 2025). Similar findings are reported in the broader literature, which emphasizes that strategies aimed at expanding renewable energy penetration and green technologies are central to achieving sustainable development goals and climate change mitigation, although their effectiveness may depend on infrastructure readiness and the scale of policy-driven investment (Huo et al., 2025).

The global literature further underscores that improvements in energy efficiency constitute an integral component of comprehensive climate policy, as they support the achievement of long-term emission targets by optimizing energy use and enhancing the performance of low-carbon technologies. While several studies focus on advanced economies, global trends discussed in international policy forums such as the Conference of the Parties (COP) suggest that the combined implementation of renewable energy expansion and energy efficiency improvements is highly effective in substantially reducing greenhouse gas emissions. This is particularly evident when such measures are embedded within national strategies, including commitments to double energy efficiency improvements by 2030 (Harvey & Watts, 2025).

B. Emission Indicators

Total carbon dioxide (CO_2) emissions represent an absolute measure of the volume of greenhouse gases released by economic activities, primarily originating from power generation, industrial production, transportation, and the broader energy sector. Recent studies indicate that countries experiencing rapid economic growth tend to record rising levels of total CO_2 emissions, a pattern that is particularly evident in BRICS economies. Media reports and analyses by energy-focused think tanks reveal that greenhouse gas emissions from electricity generation in BRICS countries have reached record highs, reflecting the persistent challenge of reconciling economic expansion with effective emission reduction efforts. Empirical research employing panel data for BRICS countries further confirms that total CO_2 emissions are historically closely linked to energy intensity and economic structure, underscoring the structural drivers of emissions in these economies (Erkılıç et al., 2025; Reuters, 2024). CO_2 emissions per capita measure the average amount of carbon emissions generated per individual within a country or region. This indicator is particularly important because it captures emission intensity relative to population size, thereby providing insights into whether a country can curb emissions while maintaining living standards. Recent literature highlights that the relationship between GDP per capita and CO_2 emissions per capita remains positive in many

contexts; however, emerging global evidence of decoupling suggests that this relationship can weaken when sustainable development policies are implemented consistently and effectively. Such decoupling reflects the potential for economic growth to occur alongside declining per capita emissions, especially in countries adopting cleaner energy systems and efficiency-oriented policies (Freire-González et al., 2024). Carbon intensity of GDP, defined as the ratio of total CO_2 emissions to national economic output, indicates the amount of emissions generated per unit of economic value produced. Lower carbon intensity signifies greater economic efficiency in producing output with fewer emissions, which is a core objective of low-carbon development strategies. Multi-country empirical studies find that carbon intensity reduction targets constitute a significant policy approach for lowering emission levels while sustaining economic growth, particularly in economies characterized by large populations and energy-intensive industrial activity. These findings reinforce the relevance of carbon intensity as a key indicator for evaluating the effectiveness of sustainable development and climate mitigation policies in high-emission economies such as the BRICS countries (Data, 2022).

C. Role of Control Variables in Emission Dynamics

Real GDP serves as an indicator of the overall size and strength of an economy. Panel data studies have consistently shown that economic growth tends to increase total CO_2 emissions, particularly in developing countries, due to rising energy consumption associated with industrial and service sector expansion (Sikder et al., 2022). Energy intensity, on the other hand, acts as a proxy for an economy's dependence on energy. Modern empirical research indicates that lower energy intensity (i.e., higher energy efficiency) is associated with reduced emissions per unit of economic output, although the effect may vary across countries depending on industrial structure and energy use patterns industry (Abid et al., 2024). Global energy prices, particularly oil, influence both fossil fuel consumption and the adoption of cleaner energy alternatives. Studies in energy-rich countries highlight an asymmetric relationship between energy prices and CO_2 emissions, emphasizing how price fluctuations can differently affect emission levels across short- and long-term horizons (Mahmood et al., 2022). Urbanization also plays a significant role by affecting energy demand, transportation systems, and infrastructure, which in turn shape emission patterns. Multinational studies reveal a complex relationship in which urbanization can either increase or decrease emissions, depending on national energy policies and consumption structures (Ma & Ogata, 2024). Finally, industrial output as a percentage of GDP reflects the intensity of manufacturing activity, which is typically more energy-intensive and fossil fuel–dependent. Panel data analyses identify industrialization as one of the primary drivers of rising emissions in developing economies, underscoring the need to integrate sectoral considerations into sustainable development and climate mitigation strategies (Sikder et al., 2022).

METHOD

This study employs a Panel Autoregressive Distributed Lag (Panel ARDL) approach to examine the relationship between sustainable development policies and greenhouse gas (GHG) emission reductions in BRICS countries over the period 2010–2023. The Panel ARDL methodology was chosen because it allows for the estimation of both short-run and long-run effects of independent variables on dependent variables, even when the data exhibit different orders of integration (I(0) or I(1)).

The analytical procedure consists of the following steps:

A. Data Stationarity Test

Stationarity for each variable including CO_2 emissions, policy index, renewable energy share (RES), energy intensity, GDP, urbanization, and global energy prices was tested using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. The objective was to ensure that no variable is integrated of order two or higher (I(2)), as the Panel ARDL technique is applicable only to variables integrated of order zero or one (I(0) or I(1)).

B. Panel Cointegration Test

Cointegration among the variables was examined using Pedroni, Kao, and Westerlund methods to detect the existence of long-run relationships. If cointegration is established, the ARDL estimation can be extended to a Panel Error Correction Model (Panel ECM) to capture the adjustment dynamics toward long-run equilibrium.

C. Panel ARDL/ECM Estimation

The long-run model estimates the impact of sustainable development policies—measured by the SD policy index, renewable energy share, and energy efficiency standards—on emission indicators (total CO_2 emissions, per capita emissions, and carbon intensity of GDP). The short-run model incorporates lagged variables and the Error Correction Term (ECT) to examine the speed of adjustment toward the long-run equilibrium.

RESULTS AND DISCUSSION

A. Stationary Test

Variable	ADF Statistic	PP Statistic
CO_2 emissions	-1.54	-1.44
SD index	-2.12	-2.15
Share of RE	-3.27	-3.25
Energy intensity	-1.18	-1.15
GDP	-2.10	-2.12
Urbanization	-2.56	-2.59
Global energy price	-1.88	-1.85

The stationarity test results using the Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) methods indicate that most of the study variables namely, CO_2 emissions, the sustainable development policy index (SD index), energy intensity, gross domestic product (GDP), urbanization, and global energy prices—are non-stationary at level. This is evidenced by test statistics that are higher than the critical values at the 5% significance level. Such results suggest that these variables exhibit long-term trends and are influenced by structural changes in the BRICS economies. For example, CO_2 emissions show an ADF statistic of −1.54 and a PP statistic of −1.44, confirming non-stationarity at the level. In contrast, the share of renewable energy demonstrates stationarity at level, with an ADF statistic of −3.27 and a PP statistic of −3.25, which are below the conventional critical values. This finding indicates that the proportion of renewable energy in the energy mix of BRICS countries is relatively stable in the short run compared to the other variables, reflecting its consistent contribution to national energy systems.

B. Panel Cointegration Test

	Statistik Uji	Probabilitas
Pedroni	-2.34	0.020
Panel v-stat	0.54	0.705
Panel rho-stat	-2.00	0.045
Panel PP-stat	5.03	0.000
Within-dimension	5.03	0.000
Between-dimension	0.95	0.340
Kao	-1.82	0.034
Westerlund	-2.14	0.016

The panel cointegration tests, conducted using the Pedroni, Kao, and Westerlund approaches, reveal a significant long-run relationship between the implementation of sustainable development policies and greenhouse gas emissions in BRICS countries. Specifically, several Pedroni statistics

most notably the panel rho-stat and panel PP-stat within-dimension tests are significant at the 5% level, indicating the presence of cointegration among the variables within the panel framework. These findings are further corroborated by the Kao and Westerlund tests, which also yield statistically significant results, consistently rejecting the null hypothesis of no cointegration. Overall, these results confirm that sustainable development policies, together with relevant economic and energy factors, exhibit a long-term structural relationship with CO_2 emission dynamics in BRICS countries. This provides strong justification for employing long-run estimation models in the subsequent analysis.

C. Panel ARDL/ECM Estimation

Variable	Long-Run Coef. (LR)	t-stat	Prob.	Short-Run Coef. (SR)	t-stat	Prob.	Interpretation
Sustainable Development Policy Index	-0.420	-3.35	0.001	-0.120	-2.30	0.022	Reduces emissions
Renewable Energy Share (%)	-0.250	-2.90	0.004	-0.070	-1.98	0.049	Reduces emissions
Energy Intensity	+0.380	3.10	0.002	+0.110	2.05	0.041	Increases emissions
Real GDP	+0.140	2.20	0.028	+0.030	1.35	0.178	Not significant in SR
Error Correction Term (ECT)	-0.62	-4.05	0.000	—	—	—	Adjustment to equilibrium (62% per period)

Table Long-Run Effects Summary

Variable	Long-Run Coefficient	t-stat	Prob.	Interpretation
Sustainable Development Policy Index	-0.420	-3.35	0.001	Reduces emissions
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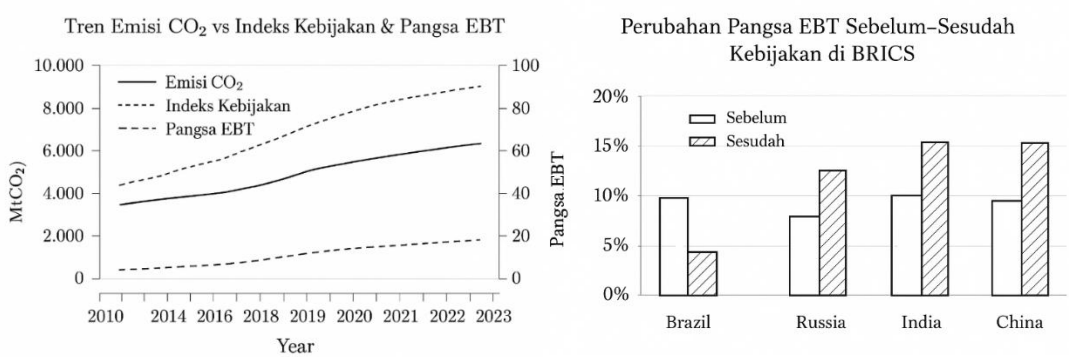
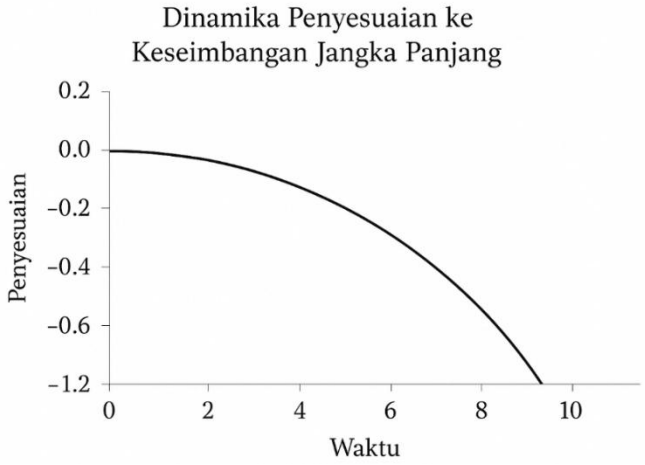
Energy Intensity	+0.380	3.10	0.002	Increases emissions
Real GDP	+0.140	2.20	0.028	Increases emissions
Error Correction Term (ECT)	-0.62	-4.05	0.000	Not significant in short run

The Panel ARDL/ECM estimation results indicate that sustainable development policies (SD policies) have a significant impact on reducing greenhouse gas emissions in BRICS countries. The negative and statistically significant coefficient of the SD policy index demonstrates that the stronger and more consistently sustainable development policies are implemented, the greater the reduction in emissions, particularly regarding total CO_2 emissions and carbon intensity per unit of GDP. This finding confirms that policy instrument such as energy efficiency standards, carbon taxes or emissions trading systems (ETS), and incentives for clean technologies exert a more pronounced long-term effect compared to the short-term. Short-run effects tend to be smaller because the implementation of clean energy projects and technological transformation requires time to generate tangible impacts. Meanwhile, the share of renewable energy in the energy mix directly contributes to emission reductions. BRICS countries that successfully increase the proportion of renewable

energy in their systems exhibit sharper declines in carbon intensity. This underscores that energy diversification toward low-carbon sources such as solar, wind, and biomass is among the most effective pathways for achieving low-emission targets. The regression results also show that energy intensity has a positive and significant effect on emissions. In other words, higher energy consumption per unit of economic output leads to increased emissions. This finding emphasizes that reforms aimed at improving energy efficiency including the adoption of energy-saving technologies in industrial and transport sectors are key to mitigating emissions across BRICS economies. Furthermore, the long-term stability reflected by the Error Correction Term (ECT) indicates that the negative and significant ECT coefficient captures an automatic adjustment mechanism within the system. Any short-term deviation or shock in emission levels tends to revert to the long-run equilibrium at a speed of approximately 62% per period. This demonstrates the existence of a stable structural relationship among sustainable development policies, renewable energy share, energy intensity, and emission levels in BRICS countries.



To reinforce the ARDL estimation results, this analysis is supplemented with three key visualizations illustrating the dynamics of emissions, policies, and adjustment mechanisms. The first visualization is a trend graph depicting the development of CO_2 emissions, the policy index, and the share of renewable energy (RES) over the observation period. The graph shows that although CO_2 emissions tend to rise, both the policy index and RES share exhibit a consistent upward trend. This pattern suggests that the enhancement of sustainable policies and the adoption of renewable energy act as moderating factors on emission growth, even though they have not yet fully reversed the overall increasing trend in emissions. The second visualization is a bar chart comparing RES shares before and after policy implementation across BRICS countries. The results indicate an increase in renewable energy shares in all countries following policy adoption, with relatively larger gains observed in India and China. This finding confirms that sustainable energy policies effectively promote the adoption of renewable energy across the region, although the magnitude of the response varies between countries.



The third visualization illustrates the adjustment dynamics toward long-run equilibrium using the Error Correction Term (ECT) curve. The downward-sloping and convergent curve demonstrates that short-term deviations in emissions are gradually corrected, consistent with the ARDL estimation results, which show a relatively rapid speed of adjustment. Overall, these three visualizations complement each other and confirm the validity of both short-run and long-run relationships between sustainable development policies, renewable energy adoption, and greenhouse gas emissions.

CLOSING

Conclusion

This study demonstrates that the implementation of sustainable development policies in BRICS countries has a significant impact on reducing greenhouse gas emissions, particularly in the long run. The findings indicate that such policies serve as effective instruments for supporting climate stability without compromising economic growth, reinforcing the notion that environmental and developmental objectives can be pursued simultaneously. Furthermore, the results underscore that increasing the share of renewable energy (RES) in the national energy mix and improving energy efficiency are key mechanisms driving emission reductions. The greater the contribution of renewable energy and the lower the energy intensity, the stronger the effect of sustainable development policies on lowering greenhouse gas emissions. This highlights the critical role of energy transition and structural reforms in the energy sector as pillars of low-carbon development in BRICS countries.

Based on these empirical findings, the study proposes several policy implications. First, governments should strengthen environmental policy instruments by establishing stricter energy efficiency standards, more ambitious renewable energy targets, and the consistent and credible implementation of carbon pricing mechanisms. Second, the allocation of public resources and fiscal incentives should be focused on renewable energy and energy efficiency projects that offer the lowest mitigation costs (least-cost abatement). Third, the development of cross-country Monitoring–Reporting–Verification (MRV) mechanisms within the BRICS bloc is essential to enhance transparency, accelerate the diffusion of effective policies, and strengthen regional coordination in achieving emission reduction targets. Overall, the findings provide robust empirical evidence that sustainable development policies play a strategic role in accelerating the transition toward a low-carbon economy in BRICS countries, while also offering a sound foundation for formulating more effective climate policies in the future.

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