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Abstract

In the context of sustainable development, this study investigates the intricate dynamics among good governance, renewable energy investment, and green finance in BRICS nations. The aim of the study is to assess how green finance and governance effectiveness moderate the impact of renewable energy investment on CO_2 emissions. Utilizing the Cross-Sectional Autoregressive Distributed Lag (CS-ARDL) model, a meticulous analysis spanning two decades was conducted to unravel the relationships among key variables and CO_2 emissions. The findings underscore a nuanced interplay where renewable energy investments, synergized with robust governance and strategic green finance, significantly mitigate CO_2 emissions, contributing to sustainable economic development. However, the study reveals non-linear relationships, highlighting the necessity for optimal allocation and strategic planning to maximize environmental benefits. In the short-run, a government effectiveness policy threshold that should be attained in order for renewable energy investment to reduce CO_2 emissions is provided. In the long-run, the negative responsiveness of CO_2 emissions to renewable energy investment is further consolidated by green finance. Moreover, enhancing renewable energy investment in the long run is positive for environmental sustainability. It follows that policy makers should tailor policies aimed at enhancing renewable energy investment in the long-run as well as complementing renewable energy investment with green finance in the long-run in order to ensure environmental sustainability by means of reducing CO_2 emissions. Policymakers in BRICS nations are urged to strengthen governance structures, promote renewable energy investments, leverage green finance, foster public-private partnerships, adopt a holistic approach, and address non-linear effects to accelerate the transition to a low-carbon economy.

Keywords: Sustainable Development, Governance, Renewable Energy Investment, BRICS and CS-ARDL

1. Introduction

In an era where the delicate balance between economic growth and environmental sustainability is increasingly scrutinized, the BRICS nations — Brazil, Russia, India, China, and South Africa — stand at a pivotal crossroad (Sadik-Zada & Gatto, 2023). These emerging economies, characterized by rapid industrialization and burgeoning populations, are facing a unique paradox: how to sustain their economic development while mitigating the environmental costs traditionally associated with it (Tian et al., 2020). Central to this challenge is the transformative potential of renewable energy investments, which emerge as a beacon of hope for a greener future (Saud et al., 2024; Zhu et al., 2024). The true effectiveness of these investments in reducing carbon emissions hinges not just on capital but also on the complex interplay of robust governance and strategic green finance. By unravelling these dynamics, the study aims to provide a nuanced understanding of the multifaceted approach needed for a successful energy transition in emerging economies.

The pursuit of economic expansion, long considered the hallmark of national progress, is now inextricably linked with the pressing need for environmental stewardship (Halkos & Gkampoura, 2021). This intersection has ushered in an era where sustainable development is imperative, particularly for the rapidly emerging BRICS economies that are key players in global economic change (Jakovljevic, 2015; Tian et al., 2020). The selection of the BRICS nations—Brazil, Russia, India, China, and South Africa—for our study is underpinned by their substantial collective impact on the global economy and environment. These nations, with their robust economic trajectories, contribute approximately 32% to the world's GDP. Notably, China and India are significant, ranking second and fifth respectively in the list of the world's largest economies. This growth trajectory is accompanied by an increasing energy demand, projected to surge annually by 2.5%[1] (Ren, 2022). The share of renewable energy in their overall energy mix varies significantly, with China at the lower end with a 4.5% share and Brazil leading at 17.7%[2] (World Economic Outlook, 2022). This disparity reflects various factors, including different levels of economic development, energy policies, and resource endowments.

Furthermore, the BRICS nations are responsible for a significant share of global CO_2 emissions, contributing approximately 40% of worldwide emissions. This is indicative of their central position in efforts to combat climate change and transition towards renewable energy sources (Wei et al., 2023; Zakari et al., 2023). Notably, China and India alone are among the top emitters globally,

[1] International Energy Agency (IEA), World Energy Outlook 2022, p.16
[2] REN21, Renewables 2022 Global Status Report, p.10

emphasizing the critical importance of their transition to renewable energy in achieving global carbon reduction targets. Given their significant and growing influence on the global economy and environment, the BRICS economies present an essential and timely focus for examining the dynamics of renewable energy investments, the interplay of governance and green finance, and the broader implications for sustainable development and carbon emissions reduction (Chandio et al., 2024).

Renewable energy investment emerges as a cornerstone in this endeavor (Chu & Majumdar, 2012). Moving away from fossil fuels to renewable sources like solar and wind energy offers a pathway to reduce carbon emissions and foster sustainable economic growth (Khan et al., 2022; Santosh et al., 2024). Numerous studies (Fant et al., 2016; Nunes et al., 2023) have underscored the effectiveness of renewable energy investments in mitigating climate impact, marking them a crucial strategy in the global sustainability agenda. The shift from conventional to renewable energy consumption holds significant promise for attaining carbon neutrality targets (Yuan et al., 2022) . Embracing energy-efficient and clean resources is imperative for mitigating greenhouse gas emissions, as it plays a crucial role in reducing CO_2 output (Akram et al., 2020). By fostering a clean and sustainable energy landscape, renewable investments directly reduce dependence on carbon-intensive energy sources, playing a pivotal role in steering our global trajectory towards a lower-carbon future (Hassan et al., 2022). As the world strives for carbon neutrality, investing in renewable energy emerges not only as a conscientious choice for the planet but also as a strategic move for a sustainable and prosperous future (A. Chen et al., 2023; Huang & Zhai, 2021).

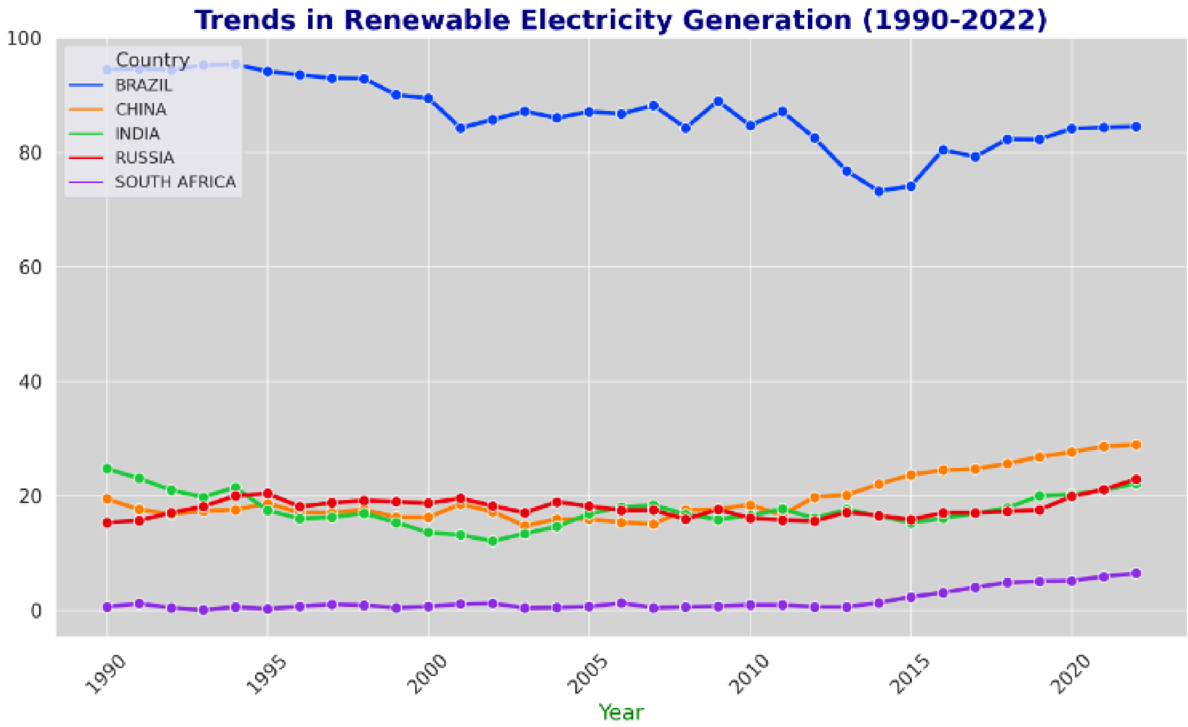

Fig. 1. Renewable energy generation over the years

Source: https://climateactiontracker.org/

Moreover, the importance of sustained and adequate climate finance is steadily considered as a cornerstone for achieving substantial reductions in carbon emissions. Sachs et al. (2019) and Taghizadeh-Hesary (2022) observe that government effectiveness, when bolstered by persistent green finance, can significantly amplify the impact on sustainable development, especially in alignment with Sustainable Development Goal 7 and 13. This synergy between good governance and green finance forms the bedrock upon which successful and environmentally impactful renewable energy investments are built. However, the success of renewable energy investments is not solely contingent on financial resources; it equally depends on the interplay of effective governance in facilitating the implementation of policies and regulations tailored to sustainable energy projects (Butt et al., 2023). This is due the fact that, the underlying economic context – characterized by robust economic growth, low-interest rates, and high fuel prices – creates a favorable backdrop for transitioning from fossil fuels to renewable energy sources (Eyraud et al., 2013). This intricate relationship is critical to ensuring that these investments not only thrive but also yield the anticipated environmental benefits. Zheng and Jin (2023) emphasize the centrality of good governance in the effective implementation of policies and regulations tailored to sustainable energy projects. Concurrently, Tiawon and Miar (2023) highlight the indispensable role of green finance in channelling essential capital towards these sustainable endeavors. Delving deeper, the significance of good governance emerges in its capacity to foster a conducive environment for renewable energy projects. This involves not just policy-making but also ensuring compliance and facilitating innovations in the renewable sector.

Recent studies have begun to uncover the nuanced dynamics between renewable energy investments and carbon emissions, pointing towards both linear and complex non-linear relationships. For instance, research focusing on the BRICS countries from 2000 to 2013 highlights the heterogeneous impacts of renewable energy on CO_2 emissions, revealing that renewable investments significantly reduce emissions, especially at higher quantiles of emission levels (Cheng et al., 2019). Similarly, analysis within the G20 countries underscores a significant long-term linear relationship between renewable energy consumption, stock market growth, foreign direct investment, and both CO_2 emissions and economic output, advocating for renewable energy as a critical component for sustainable economic development (Paramati et al., 2017). These findings underline the importance of exploring beyond linear relationships to fully grasp the potential of renewable energy investments in mitigating carbon emissions. Consequently, this study seeks to delve into the non-linear interplays, proposing that the impact of renewable energy investment on CO_2 emissions may exhibit diminishing returns or threshold effects at higher investment levels, thereby necessitating a nuanced analysis to inform effective policy formulations.

While existing research (Chandio, Nasereldin, et al., 2023; Kwilinski et al., 2023; Sachs et al., 2019; Tiawon & Miar, 2023) has explored these elements in isolation, the impact of climate finance in achieving the target of carbon neutrality has been sparsely analysed by various studies. Similarly, previous studies (G. C. Chen & Lees, 2016; Hashemizadeh et al., 2023; Kennedy & Qayyum, 2023; Zheng & Jin, 2023) have also talked about the impact of government effectiveness in reducing carbon emissions; a comprehensive analysis focusing on their interplay within the BRICS context remains uncharted territory. This study addresses this gap, offering novel insights into how the quality of governance and the availability of green finance in BRICS nations influence the effectiveness of renewable energy investments in reducing carbon emissions. By unraveling these dynamics, the research provides a nuanced understanding of the multifaceted approach needed for a successful energy transition in emerging economies.

In doing so, this research illuminates the intricacies of this dual interaction, offering a comprehensive and nuanced perspective essential for a successful energy transition in the BRICS nations. The study is underpinned by two principal objectives: the first is an in-depth examination of the length and breadth to which the effectiveness of renewable energy investments in curbing carbon emissions is influenced by the robustness of governance structures in these nations. The second objective delves into the role of green finance, investigating how its availability can amplify the positive impacts of these renewable energy investments under the moderating effect of good governance.

This dual-pronged approach is not only academically innovative but also of immense practical significance. It seeks to equip policymakers and key stakeholders in the sustainable development arena with a deeper, more actionable understanding of the factors that drive successful renewable energy initiatives in the BRICS context. Ultimately, this study aspires to contribute substantially to the discourse on sustainable development, particularly in emerging economies, by bridging identified gaps and illuminating pathways towards more effective and environmentally responsible energy policies. Additionally, the study also recognizes the potential for non-linear relationships by introducing a squared term for renewable energy investment. This allows us to assess whether the impact of renewable energy investment on CO_2 emissions intensifies or diminishes at higher investment levels, potentially revealing diminishing returns or threshold effects.

Recognizing the critical role of this research within the broader discourse on sustainable development, our study uniquely combines the analytical lenses of governance quality and the availability of green finance to dissect their influence on the efficacy of renewable energy investments in the BRICS context. By exploring the synergistic effects of these two pivotal factors, this research not only fills a significant gap in the existing literature but also offers practical insights for policymakers, investors, and stakeholders aiming to accelerate the transition towards a sustainable energy future. The findings underscore the imperative of integrating robust governance frameworks with strategic green financing mechanisms to optimize the environmental outcomes of renewable energy projects. This integrated approach is vital for BRICS nations and similarly positioned emerging economies seeking to balance economic growth with ecological sustainability. The significance of this study lies in its potential to inform policy formulation, encourage sustainable investment practices, and ultimately contribute to the global effort to mitigate climate change. Through this exploration, we aim to catalyze a paradigm shift in how renewable energy investments are approached, underlining the necessity for a collaborative effort between governance structures and financial strategies to achieve sustainable development goals.

The rest of the sections of this paper are structured as follows: Section 2 provides a brief overview of the relevant theoretical background, Section 3 describes the data and its sources, model formulation and methodology employed in the study, Section 4 presents the empirical findings, Section 5 concludes the paper with a conclusion and policy implications derived from the findings, respectively.

2. Literature Review

To appreciate the current landscape of renewable energy investments in the BRICS nations, it is essential to trace the historical evolution of their energy policies and economic growth. The trajectory of the BRICS countries towards renewable energy is a reflection of their economic and policy transformations(Azam, 2019; Chandio, Gokmenoglu, et al., 2023). Initially focused on industrial growth powered by fossil fuels, these nations contributed significantly to greenhouse gas emissions, leading to a re-evaluation of their energy strategies at the turn of the century (W. Chen et al., 2024). Influenced by global environmental agreements and domestic pressures, the BRICS nations began integrating renewable energy into their national agendas (Ali et al., 2023). The shift varied among these countries, shaped by their unique economic, geographical, and political circumstances. Brazil advanced in the energy transition at a much faster pace (Figure 1), especially in bioenergy and hydropower; Russia moved slowly but started exploring its renewable potential; India and China aggressively invested in solar and wind to combat air pollution; and South Africa diversified its energy mix for better energy security (Podoba & Kryshneva, 2018).

In examining the impact of renewable energy investments on carbon emissions, the BRICS nations present a diverse picture. Chapungu et al. (2022) conducted a study revealing how India's investment in solar energy significantly reduced its carbon footprint, yet faced challenges in storage technology and grid integration. This finding resonates with the Song et al. (2022) analysis of China's renewable sector, which emphasizes rapid expansion but also points to issues in policy inconsistency and renewable infrastructure management. The situation in Brazil, as explored by van der Hilst et al. (2018), differs notably, where investment in bioenergy and hydropower has been effective in reducing emissions but raised concerns regarding biodiversity and water usage. In contrast, the examination by Bratanova et al. (2016) of Russia's energy transition indicates a slower adoption of renewable energy, highlighting the country's reliance on its vast natural gas and oil reserves. Quacoe et al. (2023) further analyze this interplay through the Quintuple Helix Innovation Model, employing Ordinary Least Squares (OLS) and Generalized Linear Models (GLM) to prioritize entrepreneurship and green growth for sustainable development. Their findings echo the critical challenges in the pace and effectiveness of the transition to renewable energy, highlighting the need for focused efforts on overcoming these barriers.

Governance theory, particularly its application in environmental policy, provides a lens to examine how BRICS nations manage and regulate renewable energy investments (Partelow et al., 2020). Governance plays a pivotal role in shaping renewable energy policies and investments, a fact well-documented in recent studies. For instance, Chebotareva et al. (2020) highlight how governance structures in Russia influence the implementation and efficacy of renewable energy initiatives, pointing to a need for more robust policy frameworks and transparent regulatory processes. Similarly, in China, Xu et al. (2022) extend the investigation to the practical application within the renewable energy industry, selecting samples of geothermal, wind, and solar energy companies to examine if government initiatives and regulatory mechanisms can enhance company innovation and assess their action pathways. The results underscore the impact of government incentives and regulatory mechanisms on the growth of the renewable energy sector, revealing a complex interplay between state control and market forces.

In the case of India, the analysis by Shaktawat and Vadhera (2021) reveals that while there are ambitious renewable energy targets, inconsistent governance at various administrative levels often hinders their realization. This contrasts with Brazil, where, as per the findings of Dutra and Menezes (2022), a more integrated approach to governance has facilitated significant advancements in renewable energy, particularly in the bioenergy and hydropower sectors. South Africa's governance challenges in renewable energy investments are uniquely highlighted by Mehta et al. (2023), who point out that despite having favorable policies, there are gaps in implementation, largely due to bureaucratic inefficiencies and a lack of coordination among various stakeholders.

An insightful exploration by Cheng et al. (2019) into the dynamics of renewable energy investments and their impact on CO_2 emissions within the BRICS countries is presented in a pivotal study covering the years 2000 to 2013. Employing both panel Ordinary Least Squares (OLS) method and panel quantile regression, this research uncovers the heterogeneous effects of renewable energy, economic growth, and other variables on CO_2 emissions per capita. Crucially, it reveals that renewable energy significantly reduces CO_2 emissions, most notably at higher emission levels (95th quantile), underscoring the critical role of renewable investments in mitigating carbon output. Conversely, the development of environmental patents was found to inadvertently accelerate carbon emissions, particularly at the upper tail of the distribution. This suggests that governance structures facilitating renewable energy investments can have a heterogeneous impact on emissions reduction. Significantly, the methodological rigor and findings of this study offer a profound understanding of the multifaceted impacts of renewable energy investments, echoing our first objective's emphasis on the necessity of robust governance structures to enhance these investments' effectiveness in reducing carbon emissions. The results provide a compelling argument for policy recommendations aimed at bolstering renewable energy's contribution to sustainable development within emerging economies.

The importance of sustainable finance in fostering renewable energy initiatives in BRICS nations has been increasingly recognized in recent research. Yuan, Murshed et al. (2022), in their study, employed econometric tests that accommodated structural break concerns in the data to check how the Chinese financial market facilitates greening the economy. The study illustrates how state-backed green bonds and loans have catalyzed investments in renewable energy sectors, though they note challenges in terms of transparency and risk assessment. Similarly, in India, Nepal et al. (2021) highlight the growing involvement of private and international finance in renewable energy, underscoring the need for stronger regulatory frameworks to ensure sustainable financing.

Brazil's experience, as explored by de Deus et al. (2022), showcases a successful integration of green finance in renewable projects, particularly in solar and wind energy, facilitated by supportive government policies and international collaborations. In contrast, Makarov and Petrov's (2024) analysis of Russia indicates a nascent but growing interest in green finance, with a focus on developing new financing mechanisms to support its emerging renewable sector. South Africa's approach to green finance, examined by Rasoulinezhad and Taghizadeh-Hesary (2022), reveals a unique model where public-private partnerships are increasingly leveraged to fund renewable energy projects, although they point out challenges related to economic stability and investor confidence.

A study by Jiang et al. (2023) employs the STIRPAT framework and a comprehensive econometric approach to explore the impacts of governance and green finance on renewable energy generation in BRICS from 2000 to 2020. The methodology uncovers that ICT trade positively influences renewable energy production, with effective governance acting as a crucial link in this dynamic. Contrarily, financial development is found to negatively impact renewable energy production, highlighting the critical need for specifically targeted green finance mechanisms. These findings suggest the complexity of financial development's role and the indispensability of robust governance in leveraging green finance for sustainable energy. This pivotal study, aligning with our second objective, underscores the significance of targeted green finance and effective governance in amplifying the positive impacts of renewable energy investments, advocating for green ICT strategies to bolster renewable initiatives in emerging economies

Recent research has increasingly focused on how governance and green finance interact to shape renewable energy landscapes. For instance, studies by Song et al. (2022), Sadiq et al. (2023) and Xu et al. (2022) on China provides an intriguing analysis of how government policies and financial support mechanisms work in tandem to accelerate renewable energy projects, emphasizing the need for policy consistency to enhance investor confidence. In the context of India, Jena and Meattle (2020) explore the dynamic relationship between regulatory governance and green financing, highlighting how bureaucratic hurdles can impede the flow of green capital into renewable projects. The situation in Brazil, as meticulously examined by D. Xu et al. (2022) in their comprehensive study published in 2022, sheds light on the prospects of addressing environmental challenges and achieving sustainable development goals within the country. Their analysis, employing the Autoregressive Distributed Lag (ARDL) method, illuminates a significant synergy between government policies and financial incentives. This collaborative approach has proven instrumental in propelling the growth of Brazil's renewable energy sector, with a particular emphasis on solar energy. On the flip side, the research conducted by Vukovic and Nekhorosheva (2022), which utilized cluster analysis within the Russian context, brings to light a noteworthy finding. It highlights that the absence of cohesive governance and financial strategies has been a hindrance to the advancement of renewable energy in the region. This underscores a substantial area where policy enhancements are urgently needed. This theoretical exploration of governance and finance synergy underscores the research gap in the BRICS context, guiding the focus of this study.

While existing literature provides foundational theories, a noticeable gap persists in comprehensive analyses of the governance and green finance interplay within the BRICS economies. Addressing this gap, the current study aims to contribute novel theoretical and empirical insights into the sustainable development discourse.

3. Data Methodology

3.1. Data and its source

The present study employs a panel dataset spanning 21 years, from 2000 to 2021[3], focusing on the BRICS economies, encompassing Brazil, Russia, India, China, and South Africa. The study

[3] However, it should be noted that complete data availability was limited for the renewable energy investment (RI) variable up to 2020, and for gross domestic product (GDP) up to 2021. To address this data limitation, ARIMA-based

compiles data from diverse secondary sources, as indicated in Table 1. Notably, BRICS economies have experienced remarkable economic growth in recent decades. Their combined Gross Domestic Product (GDPPC) has surged from $2 trillion in 2000 to an impressive $24.9 trillion in 2022. Correspondingly, their share of the global GDPPC has risen from 4.3% in 2000 to 21.7% in 2022. This robust economic growth potential raises important environmental concerns, thus motivating our analysis of environmental impacts. To evaluate these impacts, we have selected carbon dioxide (CO_2) emissions as our primary dependent variable. CO_2 is a primary contributor to greenhouse gas emissions and a major driver of environmental degradation. Figure 1 provides an overview of the trends observed in the BRICS nations over the past two decades.

It is evident from Figure 2 that CO_2 emissions exhibit a consistent upward trend in BRICS nations, with the notable exception of the year 2020, a period significantly affected by the global COVID-19 pandemic. Notably, China stands out as the largest contributor to CO_2 emissions (see Fig. 2), followed closely by India. In contrast, South Africa consistently maintains the lowest levels of CO_2 emissions among the BRICS countries.

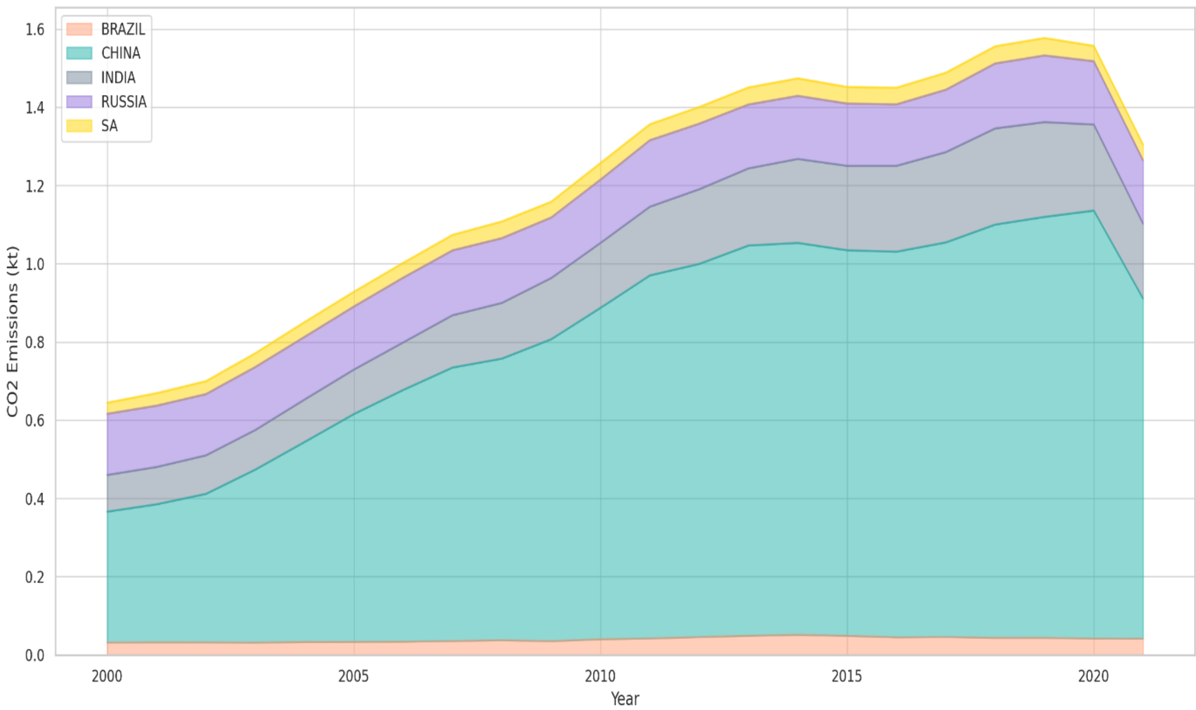

Fig. 2. Trend of CO_2 emissions in BRICS nations.

predictions were employed to estimate values for RI, and GDP beyond their available data points. The ARIMA model was utilized to generate predicted values, enabling a more comprehensive analysis of the relationships between these variables and other factors within the specified timeframe. These predicted values were integrated into the dataset to ensure a more complete representation of the variables of interest throughout the study period.

Source: WDI

In addition to CO_2 emissions, this research considers a set of key independent variables, including renewable energy consumption (RENE), green finance (GF), government effectiveness (GG), GDP growth (GDP), Renewable energy investments (RI) and energy intensity (EI). Each of these variables plays a critical role in understanding the broader context of environmental and sustainable development dynamics. The growth in renewable energy consumption holds significant promise, not only in mitigating climate change but also in improving public health. Realising this potential, however, requires substantial investments in sustainable, green technologies. Here, green financing plays a pivotal role by facilitating investments in low-carbon technologies. Similarly, investments in technical innovation through research and development contribute to sustainable environmental practices. The effectiveness and efficiency of government policies, as measured by the Government Effectiveness (GG) variable, are crucial factors in addressing global warming and climate change, making them an integral part of this analysis. Furthermore, the study explores how

Table 1:

Variable description.

Variables	Abbreviation	Source
CO_2 emission (kt)	CO_2	WDI, 2023*
Renewable energy consumption (% of total final energy consumption)	RENE	WDI, 2023*
Green finance (overseas fund received for clean energy in millions of constant US$)	GF	Our World in Data, 2022**
Government Effectiveness: Estimate (It measures public service quality, civil service independence from political constraints, policy formulation and implementation, and the government's commitment to such policies.) It is a proxy of Good Governance.	GG	WDI, 2023*
GDP (annual growth rate)	GDP	WDI, 2023*
Share of renewable electricity over the years	RI	Climate Action Tracker

Energy intensity level of primary energy (MJ/$2017 PPP GDPPC) (Lower ratio indicates that less energy is used to produce one unit of output.). It is used as proxy for Energy efficiency.	EI	WDI, 2023*

Authors' compilation

Data Source: *1. https://data.worldbank.org/

**2. https://ourworldindata.org/

***3. https://climateactiontracker.org/

efficiently energy resources are utilised and how economic growth impacts the sustainable development of a nation. Consequently, energy intensity (EI) and GDP growth are important variables in our analysis.

To verify the reliability and comprehensibility of the data and variables used in this study, we have adhered to a well-defined data collection and analysis methodology. Table 1 further displays the specific information regarding the variables and their respective sources.

3.2. Model Formulation

This study delves into the intricate relationship between renewable energy investment (RI) and government effectiveness (GG), striving to unveil their potential in decoupling economic growth from environmental impact. We employ advanced econometric techniques, particularly the Cross-Sectional Augmented Dickey-Fuller (CADF) and Common Stochastic Trends (CST) tests, to analyse dynamic interactions within the BRICS economies. Our investigation unfolds through four distinct model specifications, each shedding light on different facets of this complex interplay.

The equation 1 serves as the foundation of the analysis, capturing the individual effects of renewable energy investment $\ln(RI_{(-2)it})$ and government effectiveness $\ln(GG_{(-2)it})$ on CO_2 emissions. It also incorporates green finance (GF_{it}), energy intensity (EI_{it}), GDP growth (GDP_{it}), and renewable energy consumption $(RENE_{it})$ as additional explanatory variables. This model provides a baseline understanding of how these key factors influence environmental outcomes.

$$\ln(CO_{2it}) = \alpha_0 + \beta_1 * \ln(RI_{(-2)it}) + \beta_2 * \ln(GG_{(-2)it}) + \beta_3 * \ln(EI_{it}) + \beta_4 * \ln(GDP_{it}) + \beta_5 * \ln(RENE_{it}) + \beta_6 * \ln(GF_{it}) + \varepsilon_{it} \quad (1)$$

Furthermore, equation 2 recognizes the potential for non-linear relationships; this equation introduces a squared term for RI $(RI^2{}_{(-2)it})$. This allows us to assess whether the impact of renewable energy investment on CO_2 emissions intensifies or diminishes at higher investment levels, potentially revealing diminishing returns or threshold effects.

$$\ln(CO_{2it}) = \alpha_0 + \beta_1 * \ln(RI_{(-2)it}) + \beta_2 * \ln(RI^2{}_{(-2)it}) + \beta_3 * \ln(GG_{(-2)it}) + \beta_4 * \ln(EI_{it}) + \beta_5 * \ln(GDP_{it}) + \beta_6 * \ln(RENE_{it}) + \beta_7 * \ln(GF_{it}) + \varepsilon_{it} \quad (2)$$

Moreover, building upon the base model, the equation 3 investigates the potential moderating role of government effectiveness $(GG_{(-2)it})$ in the relationship between renewable energy investment $\ln(RI_{(-2)it})$ and CO_2 emissions. This model explores whether robust governance structures can amplify the positive environmental impact of renewable energy investments, offering valuable insights into the interplay between policy and technological innovation.

$$\ln(CO_{2it}) = \alpha_0 + \beta_1 * \ln(RI_{(-2)it}) + \beta_2 * \ln(GG_{(-2)it}) + \beta_3 * \ln(GG_{(-2)it}) * \ln(RI_{(-2)it}) + \beta_4 * \ln(EI_{it}) + \beta_5 * \ln(GDP_{it}) + \beta_6 * \ln(RENE_{it}) + \beta_7 * \ln(GF_{it}) + \varepsilon_{it} \quad (3)$$

This equation delves further into the intricate interplay between $(RI_{(-2)it})$ and $(GG_{(-2)it})$. Recognizing the potential for complex interactions, it incorporates a cross-interaction term between RI and GF. This term allows us to investigate whether the effectiveness of renewable energy investments in reducing CO_2 emissions depends on the level of green finance available. We explore the possibility of synergistic or dampening effects, providing valuable insights into the interplay between financial support and technological innovation in environmental mitigation.

$$\ln(CO_{2it}) = \alpha_0 + \beta_1 * \ln(RI_{(-2)it}) + \beta_2 * \ln(GG_{(-2)it}) + \beta_3 * \ln(EI_{it}) + \beta_4 * \ln(GDP_{it}) + \beta_5 * \ln(RENE_{it}) + \beta_6 * \ln(GF_{it}) * \ln(RI_{(-2)it}) + \beta_7 * \ln(GF_{it}) + \varepsilon_{it} \quad (4)$$

3.3. Methodology

The current empirical investigation utilizes a series of diagnostic assessments to aid in the selection of suitable estimators, ensuring the attainment of dependable and resilient outcomes. To address potential multicollinearity concerns, this study employs the variance inflation factor (VIF) method subsequent to examining the correlation matrix and descriptive statistics. The study uses VIF to quantify the extent of multicollinearity in a regression model by measuring how much the variance of the estimated regression coefficients is inflated due to correlations among predictor variables. To make the results reliable, the study uses Pesaran (2007) Cross-Sectional Dependency (CSD) as it is useful to determine whether there is cross-sectional dependence between the error terms of different cross-sectional units. Moreover, it is also imperative to run CSD test to deal with the biasness in the results before moving ahead with further empirical analysis. Given the potential for misleading results from first-generation unit root tests, this study adopts second-generation unit root tests, namely the Cross-Sectionally Augmented Im-Pesaran (CIPS) and Covariate-Augmented Dickey Fuller (CADF) tests, to determine the stationarity of the variables (Haldar et al., 2023). To assess for potential serial autocorrelation, long-run relationships, and heteroskedasticity among the variables, the study employs the autocorrelation test developed by WooldridGG (2010), the cointegration test devised by Westerlund, and the heteroskedasticity test proposed by Breusch and Pagan (1979). The result of the tests shows the absence of muti-collinearity however, it does point to CSD, heteroskedasticity and autocorrelation problems in the modelling.

Further, the Hausman (1978) test directs to option for the Fixed Effect versus the Random Effect model for empirical analysis. Considering the dimensions of the study, which encompass 22 time periods and 5 cross-sections, we determine that the Cross-Section Augmented Autoregressive Distributed Lag (CS-ARDL) estimator, initially proposed by Pesaran and Smith (1995) and further developed by Chudik and Pesaran (2015), is well-suited for our analytical approach. The applicability of the CS-ARDL estimator is particularly notable in instances of an extended time period (T) and small cross-sections (N), demonstrating robust performance even in the presence of cross-sectional dependency (CSD), heteroskedasticity, and endogeneity challenges within the model, as underscored by studies such as Chudik et al. (2016), Akadiri et al. (2022) and Mir et al. (2023).

Moreover, the CS-ARDL model allows for the inclusion of both I(0) and I(1) series in the analysis without the need for pretesting for unit roots, thus avoiding potential biases associated with such preliminary tests, especially in the presence of cross-sectional dependencies. Additionally, the model accounts for endogeneity and heteroskedasticity, ensuring that the coefficient estimates are both consistent and efficient.

To differentiate between short-term and long-term effects within the CS-ARDL framework, we focus on the coefficients of the lagged differences of the variables to capture short-term dynamics. These coefficients reflect the immediate impact of changes in the independent variables.

Conversely, long-term relationships are modeled through the coefficients of the lagged levels of the variables, which indicate the equilibrium relationship expected to prevail in the long run, after short-term fluctuations have subsided.

By incorporating both short-term and long-term effects, our analysis provides valuable insights into the temporal dynamics of the economic and environmental interplay within the BRICS nations. It enables us to assess the efficacy of immediate policy actions—captured through the short-term effects—and the sustainability of these policies over time—reflected in the long-term effects—thereby offering a more nuanced understanding of the policy implications in the context of renewable energy investment and government effectiveness.

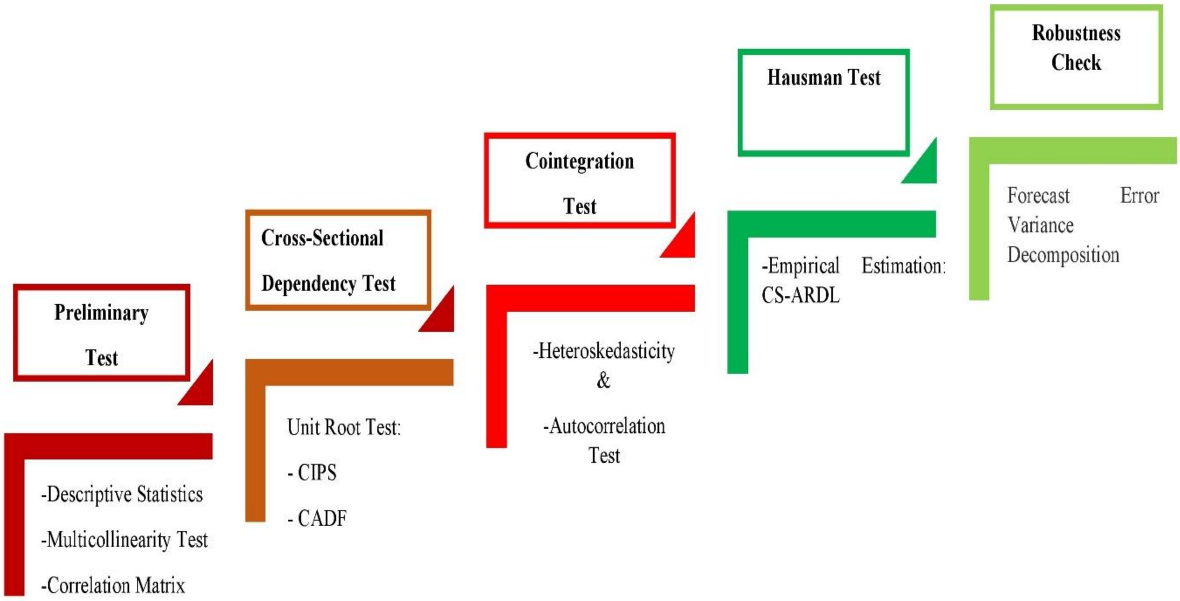

Fig. 3. Flowchart of the Methodology.

Mathematically, the representation of the CS-ARDL estimator is articulated as follows:

$$\mathrm{CO}_{2it} = \sum_{1=0}^{qx} \alpha_{l,i}\mathrm{CO}_{2it-1} + \sum_{1=0}^{qy} \beta_{1,i}V_{i,t-1} + v_{it} \tag{5}$$

Where CO_{2it} is the dependent variable, CO_{2it-1} denotes the lag specification, $\beta_{1,i}$ represents the coefficients for the independent variables at time $t-1$, reflecting the, $V_{i,t-1}$ reflects the lag of the predictor variables and v_{it} represents the error term for country i at time t, capturing unobserved factors that may affect CO2 emissions. Furthermore, to account for the mean values of independent variables across different cross-sections, Equation (6) is modified by introducing an additional term as follows:

$$CO_{2it} = \sum_{1-0}^{qx} \alpha_{l,i} CO_{2i,t-1} + \sum_{1=0}^{qy} \beta_{1,i} V_{i,t-1} + \sum_{1=0}^{qz} \delta_{1,i} \bar{X}_{i,t-1} + \mu_{it} \tag{6}$$

Where $\bar{X}_{i,t-1} = \overline{CO}_{2i,t-1} V_{i,t-1}$ refers to the lagged form of cross-sectional average, qx, qy and qz denotes the lagged form of predictor variables and μ_{it} represents the country-specific error term that accounts for individual effects not captured by the independent variables in the model. Moreover, the short-term and long-term model estimates derived from the CS-ARDL estimator are depicted in Equations (7) and (8), correspondingly.

$$\psi_i = \frac{\sum_{l=0}^{qy} \alpha_{l,i}}{\hat{\delta}_i} \text{ and } \hat{\theta}_{MG} = \frac{1}{N} \sum_{l=1}^{N} \hat{\varphi} \tag{7}$$

$\delta = -1\left(1 - \sum_{I=1}^{qx} \hat{\beta}_{l,i}\right)$ and $-1\left(1 - \sum_{I=1}^{qx} \hat{\beta}_{l,i}\right)$ refers to the negative error correction term (ECT) that points to the stability of the model.

$$\hat{\varphi}_{CS-ARDL} = \frac{\sum_{1=0}^{qx} \hat{\beta}_{l,i}}{1 - \sum_{1=0}^{qy} \hat{\gamma}_{l,i}} \text{ and } \hat{\varphi}_{MG} = \frac{1}{N \sum_{i=1}^{N} \hat{\varphi}_i} \tag{8}$$

Where, φ refers to the estimation of individual cross-section. In addition, Equation (9) demonstrates the error-correction component associated with CS-ARDL, which is as follows:

$$\begin{aligned} \Delta CO_{2it} = {} & \psi_i \left[CO_{2i,t-l} - \hat{\varphi} V_{i,t} \right] - \alpha_i + \sum_{I=1}^{qx-1} \lambda_{1,i} \Delta_l CO_{2i,t-1} \\ & + \sum_{I=0}^{qy} \beta_{1,i} \Delta_l V_{i,t} + \sum_{1=0}^{qz} \dot{\gamma}_{l,i} \Delta_l \bar{X}_{i,t-1} + \varepsilon_{it} \end{aligned} \tag{9}$$

Where ψ_i signifies the rate at which the Error Correction Term (ECT) adjusts, and Δ_l is equal to t multiplied by (t -1).

3.3. Robustness Check

To ensure the robustness of our findings, we employed Forecast Error Variance Decomposition (FEVD) within the Vector Autoregression (VAR) framework for additional analysis. FEVD is chosen for its proven effectiveness in breaking down forecast error variance across variables, offering insights into their impact on CO_2 emissions over various time horizons. This method complements the CS-ARDL model by providing a deeper analysis of the dynamic relationships among economic growth, environmental impact, renewable energy investment, and governance. It addresses the complexities of our multi-faceted model, accounting for potential variations over time and cross-sectional dependencies. The application of FEVD enhances the credibility and generalizability of our results, aligning with best econometric practices to affirm the reliability of our conclusions. This robustness check strengthens our study's insights into the economic and environmental dynamics within BRICS nations.

4. RESULTS AND DISCUSSION

4.1. Result

Table 2 and Table 3 show the descriptive statistics and correlation matrix of our study, respectively. It is evident from mean values from the table 1 that most of the variables are highly dispersed as the standard deviations are considerably high. Additionally, the Jarque-Bera test points to the fact that data is not normally distributed.

The correlation matrix, presented in Table 3, underscores notable associations among the variables. With the exception of renewable energy (RENE) and renewable investment (RI), all other variables, encompassing both dependent and control variables, exhibit varying degrees of positive correlations with CO_2 emissions. Specifically, CO_2 demonstrates a strong negative correlation with renewable energy investment (RD) at -0.59, a moderate positive correlation with GDP at 0.53, and a moderate positive correlation with energy intensity (EI) at 0.42. While these correlations provide valuable insights into potential relationships, it is essential to address the possibility of multicollinearity within the model.

Table 2

Descriptive Statistics

Authors' calculation

Variables	CO_2	RI	GG	GF	GDP	RENE	EI
Mean	6.09	0.47	-0.01	8.12	4.57	22.73	22.73
Median	6.19	0.21	-0.02	8.32	4.86	14.84	7.10
Maximum	7.03	2.75	0.84	10.13	14.23	50.05	12.14
Minimum	5.45	0.13	-0.67	4.60	-7.79	3.18	3.74
Std. Dev.	0.48	0.45	0.31	0.98	3.95	16.84	2.24
Skewness	0.47	2.07	0.30	-1.03	-0.54	0.29	0.16
Kurtosis	2.10	7.99	2.77	4.39	3.60	1.41	2.04
Jarque-Bera	7.82	1.89	1.97	28.53	7.21	13.10	4.66
Probability	0.01	0.01	0.37	0.00	0.02	0.00	0.00
Observations	110	110	110	110	110	110	110

Table 3

Correlation

Variables	CO_2	RI	GG	GF	GDP	RENE	EI
CO_2	1.00	-0.59	0.09	0.33	0.53	-0.29	0.42
RENE	-0.29	-0.16	-0.23	-0.06	-0.01	1.00	-0.75
GF	0.33	0.06	-0.13	1.00	0.02	-0.06	-0.03
GE	0.13	0.13	1.00	-0.23	0.06	-0.12	0.04
GDP	0.53	0.22	0.11	0.02	1.00	-0.01	0.33
RD	0.66	1.00	0.21	0.06	0.22	-0.16	0.19
EI	0.42	0.19	0.07	-0.03	0.33	-0.75	1.00

Authors' calculation

Consequently, we conducted variance inflation factor (VIF) tests, the results of which are detailed in Table 4. These tests serve to assess and mitigate potential multicollinearity concerns, ensuring the reliability of the model's explanatory power. The VIF analysis reveals acceptable levels of multicollinearity, with a mean VIF of 1.798333. While Renewable Energy (RENE) and Energy Intensity (EI) show moderate VIF values (2.93 and 3.12, respectively), none exceed critical thresholds, ensuring the reliability of the model. The presence of some correlation among predictors is acknowledged, but it does not unduly compromise the integrity of the regression analysis.

Table 4

Correlation Matrix

Variable	VIF	1/VIF
RI	1.34	0.74
GG	1.47	0.88
GF	1.12	0.89
GDP	1.41	0.71
RENE	2.93	0.34
EI	3.12	0.32
Mean VIF	1.79	

Authors' calculation

Additionally, we perform a CSD examination to assess the existence of cross-sectional dependency. The outcomes of the CSD test are presented in Table 5. We use second-generation unit root tests, specifically CIPS and CADF, introduced by Pesaran (2007), after the CSD evaluation to determine the degree of stationarity. The panel unit root test results are shown in Table 6. They show that the variables are stationary either at the "level (I-0)" or at the first-order difference "(I-1)".

Table 5

Cross-sectional Dependency Test

Variables	CO_2	RI	GG	GF	GDP	RENE	EI
Pesaran CD	9.742	3.472	-1.456	4.082	9.001	3.914	4.988
p-value	0.000	0.000	0.003	0.000	0.000	0.000	0.000

Authors' calculation

Table 6

Unit Root Testing Using CADF and CIPS Methods

	Covariate Augmented Dickey -Fuller (CADF)		Cross sectional augmented lm- Pesaran (CIPS)	
Variables	I (0)	I (1)	I (0)	I (1)
CO_2	2.013***	-8.428***	-2.038	-5.725***
RI	5.112	-5.924***	-1.621	-4.524***
GG	-3.147***	-16.343***	-4.712***	-7.157***
GF	-7.231***	-19.021***	-4.974***	-6.862***
GDP	-3.717***	-7.035***	-3.387***	7.446***
RENE	-2.115	-9.175***	-1.813	-4.216***
EI	-1.927***	-6.981***	-4.157***	-7.218***

Authors' calculation. ***is the significance level at 1%

To examine the long-run relationship among the variables, we performed the co-integration test by Westerlund (2007), as illustrated in Table 8. The outcomes of the co-integration tests, featuring notable p-values in Table 8, signify the existence of a sustained association among the variables. Subsequently, Table 7 presents the results of additional diagnostic assessments, encompassing tests for heteroskedasticity, autocorrelation, and the Hausman test.

Table 7

Diagnostic Tests

Test Statistics	Value
Breusch-Pagan Heteroskedasticity Test	14.365 (0.008) **
Wooldridge Autocorrelation Test	57.374(0.000) ***
Hausman Test	21.720(0.013) ***

Authors' calculation. ***,** are significance levels at 1% and 5%, respectively

Table 8

Cointegration Test

Test Statistics	Value
Augmented Dickey–Fuller	-1.716(0.071) *
Phillips–Perron	-1.392(0.067) *
Westerlund	3.937(0.000) ***

Authors' calculation. ***,* are significance levels at 1% and 10%, respectively

The CS-ARDL analysis unveiled intricate and often non-linear relationships between key variables and CO_2 emissions in BRICS nations, offering valuable insights for policy formulation and sustainable development efforts in the region**.** These findings are detailed in Table 9.

Short-Run Dynamics

A 1% increase in renewable energy investment (RI) two periods ago is associated with a statistically significant ($p < 0.001$) 0.013% decrease in CO_2 emissions (see Table 9). This suggests an immediate inverse relationship (Zeraibi et al., 2023), but the introduction of the squared term (RI^2) reveals a non-linearity, indicating diminishing returns or a potential threshold effect at higher investment levels. This warrants further investigation into the optimal allocation of resources for maximizing emission reductions.

Surprisingly, a 1% increase in government effectiveness (GG) two periods ago is associated with a statistically significant ($p < 0.01$) 0.019% increase in CO_2 emissions in the short run. The result aligns with the findings of Voumik et al. (2023) and Nahrin et al. (2023). This unexpected positive coefficient challenges conventional expectations and necessitates further exploration of potential underlying mechanisms, such as temporary infrastructure disruptions during policy implementation or unintended consequences of certain governance initiatives.

As expected, a 1% increase in energy intensity (EI) is associated with a statistically significant ($p < 0.001$) 0.021% increase in CO_2 emissions. This positive relationship persists in the long run, highlighting the crucial need for energy efficiency improvements across BRICS nations.

A 1% increase in renewable energy consumption (RENE) is associated with a statistically significant ($p < 0.001$) 0.005% decrease in CO_2 emissions, confirming the anticipated inverse relationship. This trend continues in the long run, underscoring the immediate effectiveness of higher renewable energy consumption in mitigating emissions.

Interestingly, a 1% increase in green finance (GF) is unexpectedly associated with a statistically significant ($p < 0.05$) 0.009% increase in CO_2 emissions in the short run. This counterintuitive result might be due to factors like transitional investment costs or infrastructure adjustments associated with green finance initiatives. However, it is mitigated in the long run, revealing a more substantial 0.041% decrease in CO_2 emissions. This underscores the importance of a long-term perspective when evaluating the environmental benefits of green finance, particularly in developing economies.

Long-Run Dynamics

The long-run results for RI, RENE, and EI align with the short-run dynamics and further emphasize their potential for CO_2 reduction in BRICS nations. Notably, the interaction between GG and RI exhibits a negative effect on CO_2 emissions (statistically significant at $p < 0.05$), suggesting that the combination of effective governance and higher renewable energy investment leads to more pronounced emission reductions. This underlines the importance of fostering enabling governance frameworks for maximizing the effectiveness of renewable energy investments.

Similarly, the interaction between GF and RI also shows a negative impact on CO_2 emissions (statistically significant at $p < 0.1$), reinforcing the potential synergies between financial support and renewable energy investments. This highlights the need for coordinated policies that combine green finance initiatives with targeted renewable energy deployment strategies.

Table 9

Cross-Sectional ARDL Estimator Results

	Short - Run				Long-Run			
Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
$RI_{(-2)}$	-0.013 *	0.007	0.091***	0.067	-0.047***	-0.069***	-0.095	-0.049**
	(0.001)	(0.003)	(0.049)	(0.519)	(0.018)	(0.016)	(0.019)	(0.016)
$GG_{(-2)}$	0.019***	0.034***	0.000	0.029	-1.201***	-0003***	-0.071***	0.013***
	(0.016)	(0.016)	(0.001)	(0.017)	(0.041)	(0.001)	(0.021)	(0.059)
EI	0.021*	0.019*	0.031*	0.023*	0.014*	0.038*	0.003	-0.009
	(0.005)	(0.001)	(0.003)	(0.004)	(0.003)	(0.013)	(0.008)	(0.005)
GDP	0.639***	0.301***	0.818***	0.836***	0.539***	0.401***	0.714***	0.356***
	(0.097)	(0.091)	(0.134)	(0.117)	(0.067)	(0.101)	(0.124)	(0.57)
RENE	-0.005*	-0.023***	-0.096*	0.593	-0.021***	-0.015*	0.343	-0.096*
	(0.000)	(0.033)	(0.163)	(0.329)	(0.001)	(0.000)	(0.419)	(0.163)
GF	0.009**	0.007**	-0.005	-0.015**	-0.017**	-0.023***	-0.041**	-0.002
	(0.005)	(0.004)	(0.000)	(0.005)	(0.005)	(0.07)	(0.01)	(0.000)
RI^2		-0.163***				-0.087***		
		(0.016)				(0.042)		
*GG * RI*			-0.172***				-0.213**	
			(0.029)				(0.043)	
*GF * RI*				-0.007**				-0.014***
				(0.000)				(0.012)
ECT (-1)	-0.36*	-0.262***	-0.253**	-0.324***				
	(0.091)	(0.100)	(0.076)	(0.002)				
Countries	5	5	5	5	5	5	5	5

Note: Parenthesis () shows Standard Error. ***,**,* are significance levels at 1%, 5% and 10% respectively

Authors' calculation

From Table 9, it is also worthwhile to mitigate the pitfalls of interactive and quadratic regressions by computing the thresholds associated with the corresponding regressions. In the short-run (i.e., short-run Model 3), government effectiveness (i.e., GG) should exceed a threshold of 0.529 (0.091/0.172) in order to renewable energy investment (RI) to no longer have a positive effect on

CO_2 emissions. This is essentially because at a government effectiveness threshold of 0.529, the net effect of RI on CO_2 is zero and above the attendant GG threshold, the net effect of RI on CO_2 emissions becomes negative. To put this in more perspective, at a GG threshold of 0.529, the corresponding net effect is 0.000 or (0.529*-0.172) + 0.091. In the corresponding computation, -0.172 is the interactive or conditional effect of RI while 0.091 is the corresponding unconditional effect. Moreover, in order for the government effectiveness threshold to make economic sense and have policy relevance, it should be situated within statistical range (i.e., min to max) of the corresponding policy or moderating variable (i.e., GG). This is the case because the computed governance threshold is situated between the minimum (-0.673) and maximum (0.840) values of GG apparent in the summary statistics. Moreover, for the sampled countries, more policy effort is needed to reach the policy threshold, not least, because the actionable policy threshold is substantially above the average of GG (i.e., -0.018). The narrative on policy thresholds and conditions for their economic relevance is consistent with contemporary interactive regressions literature (Asongu & le Roux, 2023; Tchamyou et al., 2023).

In the long-run, green finance and RI engender a negative synergy on CO_2 emissions (i.e., long-run Model 4). This is essentially because both the conditional or interactive and associated unconditional effects of RI are negative. It implies RI and green finance policies can be complemented to reduce CO_2 emissions. Thresholds can therefore not be computed in the presence of the same sign for the unconditional and interactive or conditional effects. Moreover, in terms of policy chronology, RI should be complemented with green finance and not the contrary. This is essentially because the unconditional effect of green finance in the corresponding model is not significant.

Moreover, in the attendant quadratic regressions (i.e., in long-run Model 2), the unconditional effect of RI is negative while the corresponding marginal effect is also negative. This is also evidence of a negative synergy from the perspective of enhancing RI for the reduction of CO_2 emissions. It follows that RI can be enhanced without complementary policies in the long-run in view of reducing CO_2 emissions. The related policy of RI enhancement is not robust in the short-run because the corresponding unconditional effect of RI in the quadratic regression (i.e., short-run Model 2) is not significant. It is worthwhile to note that consistent with the extant literature on interactive and quadratic regressions, net effects and thresholds are only computed when both the conditional and unconditional effects of the channel (i.e., RI) are significant (Tchamyou et al., 2019; Asongu & Odhiambo, 2022). Moreover, the notion of synergy is also in line with the relevant contemporary literature of positive and negative synergies within the remit of interactive and quadratic regressions (Asongu & Odhiambo, 2020; Nchofoung et al., 2022).

Robustness Check

This study's primary analysis, conducted through the Cross-Sectional Autoregressive Distributed Lag (CS-ARDL) model, uncovers significant insights into the short-run and long-run dynamics of key variables influencing economic and environmental sectors. For instance, in the CS-ARDL model, Renewable Energy Investment (RI) exhibits a negative coefficient in the short-run (Model 1: -0.013) and a fluctuating impact across other models, indicating a complex and variable influence on the dependent variables. Similarly, Government Effectiveness (GG) and Energy Intensity (EI) demonstrate significant positive impacts across most models (GG in Model 1: 0.019; EI in Model 1: 0.021), suggesting their strong influence on the studied variables.

To validate these findings, the Forecast Error Variance Decomposition (FEVD) analysis was employed as a robustness check in Table 10. The FEVD results for CO_2 emissions show a total effect of 1.05, with a notable between effect of 57.14%, aligning with the CS-ARDL's long-run significance. This suggests that inter-entity differences, rather than temporal changes within entities, predominantly drive CO_2 emissions.

Renewable Energy Investment (RI) in the FEVD analysis shows a total effect of 1.22, with a larger within effect (60.66%) than between effect (39.34%) as apparent in Figure 4. This complements the CS-ARDL findings where RI displays varying impacts across models, indicating the importance of internal dynamics within entities over time, such as policy changes or economic shifts.

Table 10

FEVD estimator result

Variable	Total Effect	Between Effect	Within Effect	Between Effect %	Within Effect %
CO_2	1.05	0.60	0.45	57.14%	42.86%
Renewable Energy Investment (RI)	1.22	0.48	0.74	39.34%	60.66%
Government Governess (GG)	1.10	0.77	0.33	70.00%	30.00%
Green Finance (GF)	1.04	0.35	0.69	33.65%	66.35%
GDP	0.92	0.46	0.46	50.00%	50.00%
Renewable Energy (RENE)	1.15	0.68	0.47	59.13%	40.87%
Energy Intensity (EI)	0.94	0.28	0.66	29.79%	70.21%

Authors' Calculation

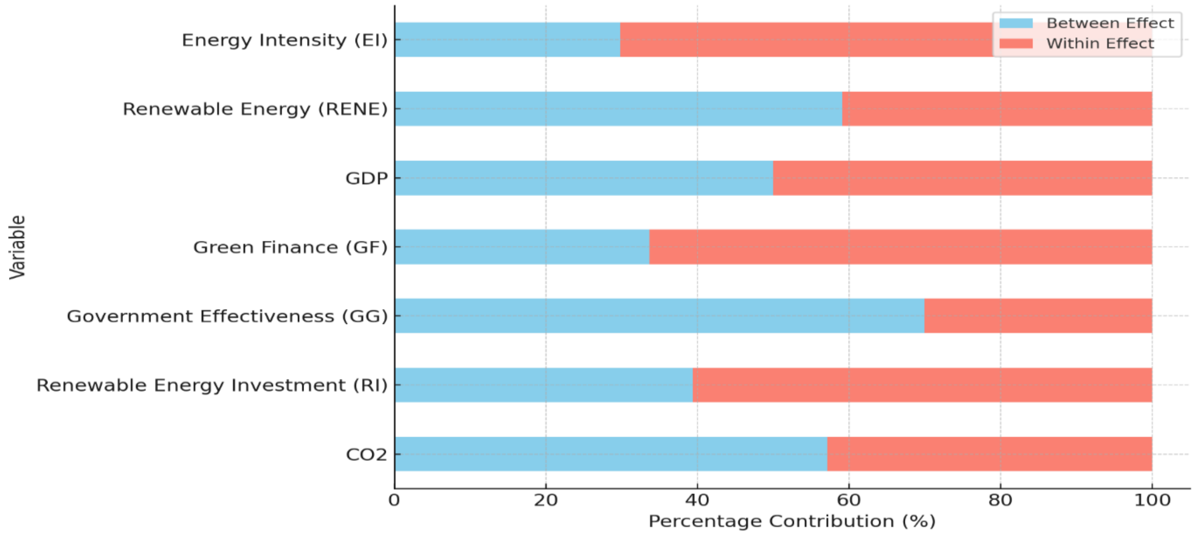

Fig. 4. FEVD result visualization

Similarly, the FEVD analysis for Government Effectiveness (GG) exhibits a strong between effect (70.00%), which corresponds with the consistent and significant positive impacts observed for GG in the CS-ARDL models. This highlights the crucial role of inter-entity differences in government effectiveness.

For Green Finance (GF), the FEVD reveals a total effect of 1.04 with a predominant within effect of 66.35%. This finding is in line with the CS-ARDL results where GF shows a mixed influence, further emphasizing the role of temporal internal dynamics in influencing green finance initiatives.

Moreover, the FEVD results for GDP demonstrate an even split between and within effects (50% each), paralleling the CS-ARDL findings where GDP shows significant impacts in both short-run and long-run models, indicating its balanced and comprehensive influence.

4.2. Discussion

The empirical results obtained from the Cross-Sectional Autoregressive Distributed Lag (CS-ARDL) model provide valuable insights into the short-run and long-run dynamics of key variables influencing economic and environmental sectors, particularly regarding the impacts of Renewable Energy Investment (RI) and Green Finance (GF) on CO_2 emissions reduction.

Renewable Energy Investment (RI) exhibits a consistently negative impact across various models, suggesting a potential mitigating effect on carbon dioxide emissions. This observation holds true in both the short-run and long-run analyses (Naseem & Guang Ji, 2021; Naz et al., 2019; Ponkratov et al., 2022; Younis et al., 2021). Contrary to earlier studies by Murshed et al. (2022) and Nguyen & Kakinaka (2019), indicating limited advantages for low-income countries in embracing renewable energy, this study asserts a more positive relationship. The disparities may arise from extensive investments, advanced technologies, and infrastructure prerequisites for renewable energy generation. While earlier studies (such as Barbier & Burgess, 2020; Sher et al., 2021) suggest a potentially higher economic burden on low-income nations, hampering their progress toward sustainable goals, the current study underscores the overall favorable impact of renewable energy investments on mitigating CO_2 emissions.

Expanding the analysis to incorporate the non-linear relationship, as captured by the squared term RI^2, the results indicate a significant negative coefficient of -0.163* in the long run. This implies that the effect of renewable energy investment on reducing carbon emissions diminishes at an increasing rate. In practical terms, this suggests that while higher levels of renewable energy investment contribute to emission reduction, the marginal impact diminishes as investment levels rise.

However, a nuanced understanding emerges when considering the interaction term GG * RI. The results in Table 9 reveal a significant negative coefficient of -0.172* in the long run. This implies that the combined effect of good governance and renewable energy investment yields a diminishing negative impact on CO_2 emissions. In practical terms, as both good governance and renewable energy investment increase, the reduction in CO_2 emissions becomes less pronounced, indicating potential diminishing marginal returns.

The interaction term's outcome supports the idea that while good governance independently contributes to emission reduction, the interaction with renewable energy investment introduces a level of complexity, suggesting that the simultaneous pursuit of both factors may have diminishing returns. This aligns with the intricate relationship discussed in the broader GG interpretation, emphasizing the multifaceted nature of the interplay between governance, economic factors, and environmental outcomes.

In examining the short-run and long-run dynamics, the results in Table 9 provide valuable insights into the role of Green Finance (GF) and its interaction with Renewable Energy Investment (RI). Notably, GF demonstrates a statistically significant impact on CO_2 emissions reduction in both Model 1 and Model 2, with coefficients of 0.009** and 0.007**, respectively. This underscores the potential of Green Finance as a mitigating factor in environmental outcomes(Xue et al., 2023).

The interaction term GF * RI also warrants attention as it reveals an intriguing pattern. In the long run, the coefficient of -0.007** suggests that the combined effect of Green Finance and Renewable Energy Investment leads to a diminishing negative impact on CO_2 emissions (C. Li et al., 2023; X. Wang et al., 2021). This implies that while Green Finance independently contributes to emission reduction, its interaction with Renewable Energy Investment introduces a level of complexity, resulting in diminishing returns. The significance level highlights the robustness of this finding.

Moreover, the results indicate that the simultaneous pursuit of Green Finance and Renewable Energy Investment may encounter diminishing marginal returns. This observation has practical implications for policymakers and stakeholders involved in sustainable development, suggesting the need for a nuanced approach when considering the joint implementation of these factors. It is worth noting that the results pertaining to the interaction term GF * RI contribute valuable insights to the ongoing discourse on environmental policies. These findings emphasize the importance of carefully evaluating the synergies and potential trade-offs between Green Finance and Renewable Energy Investment to optimize their combined impact on reducing CO_2 emissions (Gibon et al., 2020). This approach aligns with recent research that highlights the intricate relationships between financial mechanisms and environmental outcomes, calling for a holistic understanding in policy formulation (Tiawon & Miar, 2023).

The individual effect of good governance (GG) consistently demonstrates significant influences across various models, highlighting their impacts on CO_2 emissions. Empirical evidence suggests that, over the long term, good governance acts as a mitigating factor, limiting CO_2 emissions(Danish et al., 2019; R. Li et al., 2023; K. Wang et al., 2022). However, a nuanced understanding arises from empirical results, indicating that, in the short run, government effectiveness has a positive effect on carbon emissions. This observation aligns with the Environmental Kuznets Curve hypothesis, which proposes that environmental degradation initially intensifies with economic development before decreasing at higher income levels. This observed pattern supports the findings of Fan et al (2020), affirming that policy lag, coupled with political and economic pressures, can contribute to increased carbon emissions. This intricate relationship underscores the multifaceted nature of the interplay between governance, economic factors, and environmental outcomes. The positive influence of Energy Intensity (EI) across diverse models underscores the significance of energy efficiency in instigating positive transformations. The noticeable pattern in the results presented in Table 9 aligns with the conceptualization of EI as a lower ratio signifying superior energy efficiency, thus intimating those enhancements in energy efficiency correlate with a decrease in CO_2 emissions (Pang et al., 2023). Nevertheless, the outcome also illuminates that solely transitioning towards alternative energy sources is insufficient for mitigating carbon dioxide emissions; rather, it necessitates concurrent attention to and support from energy intensity measures (Babatunde et al., 2023). This dual emphasis on both energy transition and energy intensity becomes imperative for devising comprehensive strategies to address environmental concerns and curtail the carbon footprint.

A nuanced understanding further emerges when considering the interaction term GG * RI. The results in Table 9 reveal a significant negative coefficient of -0.172* in the long run. This implies that the combined effect of good governance and renewable energy investment leads to a diminishing negative impact on CO_2 emissions. In practical terms, as both good governance and renewable energy investment increase, the reduction in CO_2 emissions becomes less pronounced, indicating potential diminishing marginal returns.

The robustness check using Forecast Error Variance Decomposition (FEVD) analysis validates these findings and provides additional insights into the total, between, and within effects of key variables. The FEVD results for CO_2 emissions indicate a total effect of 1.05, with a significant between effect of 57.14%, emphasizing the role of inter-entity differences in driving CO_2 emissions. The FEVD results for RI, on the other hand, show a larger within effect (60.66%) than between effect (39.34%), suggesting the importance of internal dynamics within entities over time.

Government Effectiveness (GG) exhibits a strong between effect (70.00%) in the FEVD analysis, aligning with its consistent positive impacts observed in the CS-ARDL models. This underscores the crucial role of inter-entity differences in government effectiveness. Green Finance (GF) displays a total effect of 1.04 in the FEVD, with a predominant within effect of 66.35%, corresponding with its mixed influence observed in the CS-ARDL results. This emphasizes the role of temporal internal dynamics in influencing green finance initiatives.

The FEVD results for GDP demonstrate an even split between and within effects (50% each), reflecting the balanced and comprehensive influence of GDP observed in the CS-ARDL findings. These results collectively emphasize the importance of considering both short-run and long-run dynamics and internal and external factors when assessing the impact of variables on economic and environmental outcomes.

5. Conclusion and Policy Implications

This study delved into the intricate dynamics between good governance, renewable energy investment, and green finance within the BRICS nations, aiming to discern their collective impact on decoupling economic growth from environmental degradation. Through meticulous CS-ARDL analysis spanning two decades, we unveiled that renewable energy investments, when synergized with robust governance and strategic green finance, play a pivotal role in mitigating CO_2 emissions, thereby contributing to sustainable economic development. Our findings underscore a nuanced interplay where the effectiveness of renewable energy investments in reducing environmental impact is significantly amplified by the presence of strong governance structures and supportive green finance mechanisms. However, the non-linear nature of this relationship suggests the necessity for optimal allocation and strategic planning to avoid diminishing returns at higher investment levels.

In light of these findings, policymakers in BRICS countries are urged to focus on strengthening governance structures to effectively support environmental policies. This entails not only the creation of comprehensive renewable energy policies but also ensuring their effective implementation, monitoring, and enforcement. Additionally, promoting renewable energy investments through incentives like subsidies and tax credits, alongside the development of clear policy guidelines, can attract more private investments into the sector, accelerating the transition to a low-carbon economy. Leveraging green finance markets, such as through initiatives like green bonds and green banks, supported by government policies, can channel resources towards sustainable investments. Encouraging public-private partnerships can further accelerate the deployment of renewable energy technologies by mobilizing capital, technology, and expertise.

Recognizing the interconnected nature of economic, environmental, and social goals, policymakers must adopt a holistic approach by integrating renewable energy investments with broader strategies for sustainable development. This includes improving energy efficiency and investing in energy infrastructure. Moreover, addressing the observed diminishing returns of renewable energy investments underscores the importance of strategic planning and avoiding over-investment in specific sectors.

The established governance effectiveness policy threshold is an actionable critical mass that policy makers should take into account so that renewable energy investment reduces CO_2 emissions. The corresponding governance effectiveness threshold in the short-run for governance effectiveness to moderate renewable energy investment in order to reduce CO_2 emissions is 0.529. The government effectiveness threshold is within statistical range and thus, is worthwhile for policy makers. In the long run, green finance moderates' renewable energy investment for negative synergies on CO_2 emissions and by implication, the negative responsiveness of CO_2 emissions to renewable energy investment is further consolidated by green finance in the long run. Moreover, enhancing renewable energy investment in the long run is positive for environmental sustainability. It follows that policy makers should tailor policies aimed at enhancing renewable energy investment in the long-run as well as complementing renewable energy investment with green finance in the long-run in order to ensure environmental sustainability by means of reducing CO_2 emissions.

Future research could expand beyond the BRICS nations to conduct a comparative analysis of renewable energy policies' effectiveness in other emerging economies. By examining countries with similar economic profiles but different governance structures and levels of green finance availability, deeper insights can be gained into the factors influencing the success of renewable energy transitions on a global scale, informing more tailored policy recommendations for sustainable development.

Data availability statement: The data that supports the findings of this study are publicly available, and there are no restrictions on their accessibility. The source of the data is provided in Table 1.

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