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Unraveling the nexus of economic growth, clean energy, and carbon emissions: An environmental Kuznets Curve-based econometric analysis

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ABSTRACT

BACKGROUND AND OBJECTIVES: This study explored the complex relationships among economic growth, environmental policies, renewable energy adoption, and carbon emissions in various economic environments, specifically focusing on Brazil, Russia, India, China, and South Africa. These factors are investigated through the lens of the Environmental Kuznets Curve framework to discover if these emerging economies adhere to, vary from, or demonstrate distinctive variants. This study has established a framework for analyzing how development phases impact environmental degradation and evaluates the sustainability initiatives, particularly focusing on renewable energy adoption and policy change, to help lessen carbon emissions in different economic contexts.
METHODS: The study employed a range of statistical and econometric techniques to examine the relationship among economic growth, environmental policies, renewable energy adoption, and carbon emissions in Brazil, Russia, India, China, and South Africa from 1990 to 2022. This study used statistical analysis through descriptive statistics and correlation analysis. Furthermore, stationarity of the data is tested by using the Augmented Dickey-Fuller and Phillips-Perron tests. Moreover, the bounds testing is utilized to examine the cointegration among the estimated variables, whereas the Autoregressive Distributed Lag method is applied to investigate both short and long-run elasticities. By utilizing these methods collectively, a detailed investigation of whether panels of these economies align with, deviate from, or exhibit variations in the Environmental Kuznets Curve framework.
FINDINGS: The findings revealed that an inverted U-shaped trajectory between economic development and environmental pollution is evident in Russia, South Africa, Brazil, and China, suggesting that as economic development increases in these countries, environmental degradation worsens because of escalating carbon emissions. Four key points of particular interest from energy, environmental, and economic perspectives are: (1) realigning panel of these countries' industrialization and economic development policies with environment management initiatives, acknowledging that (2) an all-size-fits-all renewable energy consumption policy may not be equally effective in abating carbon emissions across all economies, (3) the incomplete coverage of consumptions sources and a subset of industries limiting a higher carbon tax's effective reduction in carbon emissions (4) financial regulations and incentives related to carbon taxes, green financing, or sustainable investments and emission reductions providing an impactful and novel avenue for enhancing financial development's carbon emissions inhibiting role.
CONCLUSION: These findings may offer policy-makers or organizations key information for sustainable development policies, which help address the conflict between economic growth and environmental quality, and may be applicable in all selected countries as well as other developing countries.

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47	3	6

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INTRODUCTION

Certainly, climate change mitigation strategies involving the reduction of Carbon Dioxide (CO_2) emissions have brought economies at loggerheads and heightened policy inconsistency and incompatibility issues around the world. Due to the potential hazards of climate change, numerous studies have been conducted to classify the factors that might help reduce carbon emissions. Similarly, in practical terms, numerous key developments have been advanced to reduce surging CO_2 emissions levels and address climate change. To highlight a few, energy expansion (like hydroelectric power, wind, and solar), technological innovations (e.g., electric vehicles, carbon capture and storage, and energy-efficient machinery), the industrial and transportation sectors, and global collaboration. Despite their enactment, reducing CO_2 emissions still seems like a far-reaching initiative, especially across Brazil, Russia, India, China, and South Africa (BRICS) economies, where rapid growth and industrialisation policies are not matched with environmental preservation initiatives (Samour *et al.,* 2023). This grouping offers an intriguing context due to its rapid economic growth, diverse policy approaches, and substantial contributions to global emissions (Iqbal *et al.,* 2023). Examining these nations provides valuable insights into the dynamics of sustainability initiatives in economies at different stages of development, reflecting diverse policy landscapes and varied levels of environmental consciousness. In an attempt to better design effective environmental preservation strategies, several policy options have been advanced. Especially, from environmental, economic, and energy perspectives, there are four particular propositions of interest as follows. Firstly, realigning BRICS' industrialization and economic development policies with environmental management initiatives proves to be a far-reaching endeavour. Amongst the contributing factors is the unending quest to satisfy inquiries about how the Environmental Kuznets Curve (EKC) hypothesis's dynamics shape the BRICS' policies and intricate relationships with economic and environmental policies. The EKC hypothesis assumes that there is a pollution level and per capita income tends to follow an inverted U-pattern, where pollution initially rises with income and then declines after a certain threshold (López-Menéndez *et al.,* 2014). With various EKC hypothesis shapes like the inverted U shape (Culas, 2007), U shape (Dinda *et al.,* 2000), inverted N shape (Harbaugh *et al.,* 2002), monotonically increasing (Permann and Stern, 2003) and monotonically decreasing (Egli, 2004) being in existence, it remains an interesting inquiry as to whether BRICS economies comply with, deviate from, or display variations in the EKC hypothesis. To add traction to this matter, the EKC may not appear in developing countries, despite the general belief that it occurs in developed countries. Secondly, a further investigation is required to determine whether a blanket policy (a one-size-fits-all) of renewable energy consumption policy across BRICS economies is effective in abating CO_2 emissions in light of factors specific to each country, like economic structures, policy implementation, and energy infrastructure. As it stands, attempts to explore these notions within the context of BRICS economies are a new phenomenon that has been continuously sidelined in long-standing academic debates (Ayhan *et al.,* 2023; Charfeddine and Kahia, 2019; Steckel *et al.,* 2021). Historical environmental policy trajectories have substantially affected the carbon emissions patterns of BRICS countries. To make this distinction, we identified early reforms (China) and renewable energy incentives (Brazil) as examples of early engagement and contrast them with Russia, India, and South Africa, which show late impacts or uneven enforcement. Differences in policy histories may have direct relations to the order and timing of each country's EKC and indicate the value of policy variables in the empirical model. Thirdly, though Li *et al.,* (2022) acknowledged carbon pricing policy's role in alleviating CO_2 emissions concerns, notions regarding a carbon pricing policy's potency to yield the highly coveted CO_2 emissions reduction outcomes continue to be the subject of long-standing CO_2 emissions debates. Unlike previous related studies (Li *et al.,* 2022; Steckel *et al.,* 2021), this study adds to the existing literature by further determining factors that significantly influence carbon pricing policies' ability to yield such outcomes. Contemporary attempts aimed at assessing such effects in BRICS economies are gathering momentum and are in their infancy. Lastly, although the United Nations Framework Convention on Climate Change (UNFCCC) strongly advocates for climate finance in mitigating such challenges (UNFCCC Standing Committee on Finance, 2023), the financial ability to familiarize themselves with climate change and pursue sustainable development remains a key issue BRICS economies have to endure. With Charfeddine and Kahia (2019) indicating that the UNFCCC and the Kyoto Protocol remain insufficient to respond to climate change difficulties, turning to alternative avenues like financial development remains highly attractive. Despite financial development's role in such matters having been significantly emphasized and well documented academically (Charfeddine and Kahia, 2019; Lahiani, 2020; Khan and Ozturk, 2021), it possesses an intricate relationship with CO_2 emissions, consumption of renewable energy, and carbon pricing policy that demands further examination. In light of the above, while the existing body of literature around the EKC is increasingly overwhelming, there has been comparatively limited attention given to how renewable energy uptake, carbon pricing regimes, and financial development simultaneously impact carbon emissions across BRICS nations' varied economic contexts. This research aims to fill this void by combining these three areas into one EKC-based econometric model, representing a novel multi-country approach to the literature while taking into account both short- and long-run dynamics (using ARDL). The novel contribution of this study is to focus on country-specific heterogeneity, the effectiveness of policy, and a financial mechanism to inform environmental outcomes. Therefore, the study aims to find out how BRICS countries' industrialisation rate influences CO_2 emissions within the EKC model, assess whether a common renewable energy policy will be as effective in all BRICS countries, and finally examine the potential of financial development and whether it can help reduce emissions. Thus, these aims should position the study to provide both theory and policy-relevant contributions pertinent to sustainable development in newly industrializing countries.

Literature review

Renewable energy consumption's impact on the environment (CO_2 emissions)

It is no longer sufficient simply to impose environmental regulations and strict environmental policies to combat environmental degradation. Therefore, renewable energy is increasingly becoming one of the most effective ways to improve environmental and economic sustainability. In addition, according to Charfeddine and Kahia (2019), renewable energy is one of the environmental policy issues encompassed in the environmental policy strict index, which is a composite relative policy stringency measure. According to Gielen *et al.,* (2019), Renewable energy can contribute to supplying two-thirds of total global energy demand and create potentially significant reductions in the greenhouse gas emissions required to keep average global surface temperature increases below 2°C from now until 2050. Renewable energy's CO_2 emissions mitigating effects were confirmed in Turkey (Acaroğlu and Güllü, 2022), Vietnam (Le, 2022), Chile (Kirikkaleli *et al.,* 2022), and Malaysia (Raihan and Tuspekova, 2022). On a panel level, López-Menéndez *et al.,* (2014) Ordinary Least Squares (OLS) fixed effects and random effects findings on 27 European Union (EU) countries, Al-Mulali and Ozturk's (2016) Fully Modified Ordinary Least Squares (FMOLS) and Vector Error Correction Model's (VECM) results on 27 advanced economies, and Charfeddine and Kahia's (2019) Panel Vector Autoregression (PVAR) findings on 24 Middle East and North Africa (MENA) region countries confirmed that clean energy reduces CO_2 emission. The same was validated by Wolde-Rufael and Weldemeskel's (2020) Pool Mean Group-Autoregressive Distributed Lag (PMG-ARDL) model results within the context of BRIICTS (Brazil, Russia, India, Indonesia, China, Turkey, and South Africa). Nonetheless, Cai *et al.,* (2023) found using quantile regression for BRICS countries from 1990-2020 that resource rents lead to increased CO2 emissions, whereas Pata (2018) could not support, mitigating effects of REC on CO_2 emissions. Danish *et al.,* (2019) found a positive and insignificant relationship between REC and CO_2 emissions in South Africa but a negative and significant relationship with CO_2 emissions in Brazil, China, Russia, and India. Of all empirical work, there appears to be no agreement among researchers about the relationship between REC and CO_2 emissions because single-country and panel data analysis studies are generally mixed overall. This study is limited to presenting and discussing only single-country results in the context of the economies of BRICS, as mentioned in the previous paragraph.

Carbon pricing policy's impact on the environment (CO_2 emissions)

Green (2021) presents carbon pricing as an efficient, flexible, and low-cost pathway to GHG reductions.

Because of this belief in the efficacy of carbon pricing, it is widespread and growing. Already, 22% of global emissions are subject to carbon pricing through 30 carbon taxes and 31 emissions trading schemes (World Bank, 2020). A carbon tax adds a charge on fuel or energy use; if someone emits more than their allowance, they can purchase more; if they emit less, they can sell their allowances or bank them. While it is an important policy tool for lowering CO_2 emissions, the literature on carbon pricing policy is still in its infancy. Apart from being limited to specific nations, carbon pricing policies in mitigating CO_2 emissions are another area subject to debate. For instance, Haites (2018) discovered that carbon taxes in European countries resulted in small reductions of 'up to 6.5% over several years' and that countries without a carbon tax reduced emissions faster than those with a carbon tax. On the other hand, Green (2021) established that the aggregate reductions from carbon pricing on emissions are generally limited between 0% and 2% per year. Li *et al.,* (2022) economic dispatch model results on five provinces comprising China's Southern Power Grid unearthed that carbon pricing raises overall power system costs considerably, irrespective of low carbon prices. Another meta-review investigates several studies of the British Columbia carbon tax, indicating that drops between 2008 and 2014 vary between 5% and 15% below a counterfactual reference level (Green, 2021). They do, however, point out that no studies have been conducted to investigate leakage to neighbouring jurisdictions. Aside from responding to these empirical voids, the current study weighs and validates such examinations on a yet-to-be-modelled platform involving BRICS economies. Overall, a carbon pricing policy's effectiveness in mitigating CO_2 emissions remains vital for creating a Sustainable Development Mechanism and achieving the 2015 Paris Agreement goals on climate change. Amid such observations, it, therefore, remains an interesting inquiry as to whether carbon pricing policies yield the highly coveted CO_2 emissions reduction outcomes across BRICS economies with distinct economic, social, and structural characteristics. Unlike previous studies, this study extends further to determine how this aligns or hampers their rapid industrialisation and growth initiatives.

Financial development's impact on the environment (CO_2 emissions)

Undoubtedly, financial development is an instrumental factor in economic growth today since it facilitates capital accumulation through the accumulation and management of reserves, enhances essential knowledge about investment operations, and allocates money wisely. In light of the EKC hypothesis' inverted U-shape that suggests higher levels of economic growth increase CO_2 emissions (López-Menéndez *et al.,* 2014), the indirect effects of financial development on greenhouse gas emissions are evident in this case, especially when manufacturing activities are increased (Aye and Edoja, 2017). According to Charfeddine and Kahia (2019), in terms of environmental quality, the financial sector can have a catalytic function in the reduction of emissions through innovations in technology in the energy supply sector. Furthermore, financial development has the potential to boost the fight against environmental deterioration through CO_2 reduction. It can do this by being a funding channel for projects by stock markets and banks, and providing financial resources for productive activities (Charfeddine and Kahia, 2019). In this view, environmental degradation declines as financial progress is made. Additionally, by transforming the energy sector into a more efficient one, a well-developed financial sector can promote investment activities, reduce borrowing costs, and restrain the spread of energy emissions (Charfeddine, 2017; Tamazian *et al.,* 2009). Financial development helps not only to attract foreign direct investment, support research and development initiatives, and increase the level of economic activity, but also has an impact on the quality of the environment through green-related investments (Charfeddine and Al-Malk 2018; Hayat *et al.,* 2018). Expanding on this idea further, Awosusi *et al.,* (2022) applied a quantile regression approach to data from Uruguay (1990-2018), and Usman *et al.,* (2022) utilized an ARDL study with Pakistan data from 1990-2017, to find that financial development and renewable energy hurt CO2 emissions. Khan and Ozturk (2021) applied several different Generalized Method of Moments (GMM) and system GMM techniques to a sample of 88 developing countries (2000-2014) and confirmed that the Lawrence curve is inequitably shaped concerning the EKC, while also substantiating the pollution-abating nature of financial development. Nevertheless, financial development can yield negative effects on the environment caused by manufacturing activities that lead to pollution levels to increase (Charfeddine and Kahia, 2019). In their panel data model using a partially linear functional-coefficient, Xu *et al.,* (2021) found further evidence that the effect of financial development on CO2 emissions transitioned from negative to positive as energy consumption and industrialization also increased. Although there was evidence of an inverted U-shape EKC in both Khan and Ozturk (2021) and Xu *et al.,* (2021). Xu *et al.,* (2021) revealed that an increase in financial development was associated with increasing CO2 emissions only when per-capita income was less than $1100 or greater than $8100. While there is a consensus in the literature regarding the theoretical effects of renewable energy consumption, carbon pricing policy, and financial development on environmental quality, previous empirical work has found it difficult to concur on the same conclusion. Validating the EKC hypothesis across countries like BRICS has been a far-reaching objective for several time series data studies. To contribute to this literature, this study used 5 ARDL econometric models for BRICS economies. The adopted ARDL model form is discussed in detail in the next section.

MATERIAL AND METHODS

The model

The current study was theoretically underpinned by the EKC hypothesis to determine whether BRICS economies' environmental impacts follow similar or divergent patterns. A further contribution of the EKC hypothesis is that it will enable us to identify Income Turning Points (ITPs) where increasing income results in a decrease in CO_2 emissions, which may be a reflection of environmental awareness, technology adoption, or policy changes. As suggested by Grossman and Kruger (1995), an important component of this model is that pollution increases at the beginning of economic progress, whereas the trend reverses following a certain income level (ITP). This means that at levels of high-income levels, economic progress results in an enhancement in environmental quality. With contrasting outcomes like the inverted U shaped (Culas, 2007), the U shaped (Dinda *et al.,* 2000) and inverted N shaped (Harbaugh *et al.,* 2002), and scant empirical examinations within the context of BRICS economies characterising such propositions, this studytheoretically commence by acknowledging BRICS rapid industrialisation and economic growth's adverse impact on environmental quality as suggested by Grossman and Kruger (1995). According to López-Menéndez *et al.,* (2014), the Kuznets Curve is a polynomial type of function as follows in Eq. 1 and Eq. 2:

$$Y = \beta_0 + \beta_1 X + \beta_2 X^2 + \mu \quad (1)$$

$$Y = \beta_0 + \beta_1 X + \beta_2 X + \beta_3 X^3 + \mu \quad (2)$$

In this scenario, X signifies the economic development levels, usually assessed using Growrh Domestic Product (GDP) per head of population. In addition to water pollution, fine smoke, municipal waste, deforestation, and air pollution, Y is also an indicator of environmental degradation. However, emphasis is usually placed on CO_2 emissions. Despite the EKC hypothesis serving as an instrumental framework for assessing economic growth's impact on the environment, its theoretical propositions always spark debates in various fields. In the environmental management and energy policy context, the EKC hypothesis is not confined to following environmental regulations and foreign direct investments (Orubu and Omotor, 2011) nor foreign trade (Lee and Roland-Holst, 1997) as suggested. With numerous variables at play in this context, a nuanced understanding of environmental quality management is provided by acknowledging Renewable Energy Consumption's (REC) role in such matters in abating pollution (Charfeddine and Kahia, 2019). Furthermore, by integrating financial development's increasingly important role and the significance of sustainability initiatives involving carbon pricing policies into such examinations, a realistic picture of BRICS' environmental management and energy policy is projected based on the EKC framework. Due to the possibility of obtaining several quadratic functions and cubic form EKC hypotheses, as well as the lack of consistency in terms of the association between environmental quality and economic growth, these propositions have significant implications for the BRICS economies' rapid industrialization and economic growth policies. This study applied a multi-country ARDL approach to analyse the dynamics of short and long-term effects. The simultaneous examination of multiple BRICS nations using an ARDL approach provides valuable insights into common trends and variances in the intricate relationships between CO_2 emissions and key variables for policymakers. Unlike studies limiting focus to the environment-output-energy relationship under the basic EKC context (Arouri *et al.,* 2012; Yavuz, 2014), this study recognises policy decisions and the financial sector's role in such matters. Ultimately, this study provided a comparative approach by integrating the EKC hypothesis propositions with Renewable Energy Consumption (REC), Carbon Pricing Policy (CPP), and Financial Development (FD) across BRICS economies. This was instrumental in providing a nuanced understanding of the diverse policy landscapes within the group. Thus, to formulate the multi-country ARDL model, Carbon Emissions (CE) were regressed on Y, quadratic income (Y^2), REC, CPP, and FD. The adapted form of this model employed in this paper is as follows in Eq. 3:

$$\mathrm{CE} = \left(Y, Y^2, REC, CPP, FD\right) \quad (3)$$

According to Bilgili *et al.,* (2016), log-linear models produce more efficient results than linear models. As a result, Eq. 4 is developed following improvements made to related models by Orubu and Omotor (2011) and Saboori *et al.,* (2012) as follows:

$$LnCE = \alpha + \beta_1 LnY + \beta_2\, LnY^2 + \beta_3 LnREC + \beta_4 LnCPP + \beta_5 LnFD + \varepsilon_{it} \quad 4 \quad (5)$$

Where α = constant, β_1 to β_5 are parameters and ε_{it} is the error term. Assuming that the inverted U-shaped EKC relationship between CO_2 and income (Y) holds, β_1<0 and β_2>0. β_3 and β_4 are expected to adversely impact CO_2 emissions. While financial development may lack the propensity to directly impact CO_2 emissions, it is expected to contribute towards abating CO_2 emissions and its coefficient (β_5) can be greater or smaller than zero. Apart from dealing with outliers, the variables were converted to logarithms to determine the CO_2 emissions' elasticity responses to changes in Y, REC, CPP, and FD. Keeping these caveats in mind, this study shall apply 5 ARDL (Auto-Regressive Distributive Lag) models of order p for the dependent variable, and order q for the explanatory variable, as follows in Eq. 5:

$$ce_{tt} = \sum_{j=1}^{p} \beta_{ij} ce_{i,t-j} + \sum_{j=0}^{q} Y_{ij} X_{i,t-j} + \mu_i + \varepsilon_{it}$$

Where X_{it} the vector of explanatory variables is defined in Eqs. 3 and 4 can be re-parameterized as an error-correction form as follows in Eq. 6:

$$ce_{tt} = \mu_i + \varphi_i \left(cc_{i,t-1} - X_{it}\right) + \sum_{j=1}^{p-1} ijce_{i,t-j} + \sum_{j=0}^{q-1} ijX_{i,t-j} + \mu_i + \varepsilon_{it} \quad 6 \quad (6)$$

X_{it} represents the vector of independent variables defined above, where Δceit is the annual growth per capita of CO_2 emissions for country *i* at time *t*. The parameters *λ* and *δ* rank the short-run coefficients on each lag of the dependent and independent variables, respectively. *Ψ* represents the long-run coefficient, and φ_i represents the coefficient on the error-correction term, which measures the pace at which CO_2 emissions adjust to return towards their long-run equilibrium after the changes in the independent variables (X_{it}). That is, following Aksoy (2019), the criterion $\varphi_i < 0$ is important evidence of a long-run relationship. Thus, a negative and statistically significant value of ϕi suggests there is evidence of cointegration between ceit emissions and its determinants. In advance of this, this study tested the variables for unit roots, using both the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) stationarity tests to avoid the possibility of spurious outcomes.

Data

This paper employs World Bank country indicator time series data for 5 BRICS economies (Brazil, Russia, India, China, and South Africa) for the period 1990-2022. The variables are carbon emissions (percentage change in CO_2 emissions), economic growth (% GDP growth), Renewable Energy Consumption (REC) (% of total final energy consumption), Carbon Pricing Policy (CPP) (greenhouse gas emissions as a percentage of GDP) and Financial Development (FD) (domestic credit to the private sector (%)). According to the economic growth and CO2 emissions scores presented in Table 1. Renewable Energy Consumption is defined as the percentage of total final energy consumption that came from renewable sources, from World Bank indicators, and used as a proxy for both the quantity of clean energy investments and the effectiveness of renewable energy policies in BRICS economies.

Table 1: Descriptive analysis

Country	Variable	Descriptive stats.	
		MN	SD
Brazil	CE	-1.80	0.14
	EG(Y)	1.84	0.54
	REC	4.44	0.09
	CPP	1.73	0.09
	FD	3.89	0.37
		MN	SD
Russia	CO_2E	2.77	0.09
	EG(Y)	2.60	0.69
	REC	1.26	0.06
	CPP	-0.16	0.65
	FD	3.42	0.51
		MN	SD
India	CO_2E	-1.13	0.10
	EG(Y)	1.78	0.36
	REC	3.72	0.17
	CPP	0.74	0.18
	FD	3.60	0.33
		MN	SD
China	CO_2E	1.47	0.51
	EG(Y)	2.15	0.33
	REC	2.93	0.43
	CPP	1.85	0.41
	FD	4.78	0.23
		MN	SD
South Africa	CO_2E	-0.57	0.06
	EG(Y)	2.16	0.35
	REC	2.45	0.32
	CPP	2.36	0.06
	FD	4.72	0.13

MN=Mean and SD=Standard Deviation

Policy-specific instruments are not part of the model directly; however, cross-country heterogeneity in terms of the design, implementation, and enforcement of renewable energy policies was partially captured. Therefore, the analysis of added impacts of policy enables some differentiation of policies across countries, based on varying levels of development and institutional context. Cai *et al.,* (2023) discoursed that about 38% of the global CO_2 emissions are accounted for by BRICS economies. Countries, comprising Brazil, Russia, India, China, and South Africa, comprise a mix of rapidly growing economies from different regions with considerable economic weight and varying developmental stages. The findings of the BRICS group show varying levels of development. For instance, unlike India and Brazil, with low mean scores of 1.78 and 1.84, respectively, Russia, South Africa, and China recorded high economic growth mean scores of 2.60, 2.16, and 2.15. An increase in economic growth is often accompanied by an increase in transportation, industrial activities, and energy consumption, thereby resulting in an increase in CO2 emissions in Russia, South Africa, and China, which follows the EKC hypothesis. There are, however, negative CO_2 emissions, mean scores of -1.80, -1.13, and -0.57 observed in Brazil, India, and South Africa, respectively, which signifies that these countries emit lower amounts of CO_2 than Russia and China. However, the key is to manage the growth sustainably to mitigate the effects of carbon emissions and ensure environmental protection worldwide. The scholarship's proposition to integrate environmental management initiatives with economic and financial sector activities and an energy policy gains further traction when observations of Fig. 1 are considered.

Though Russia observed a decline in per capita consumption-based CO_2 emissions from 13.8t/person in 1990 to 5.2t/person in 1992, 9.4t/person,

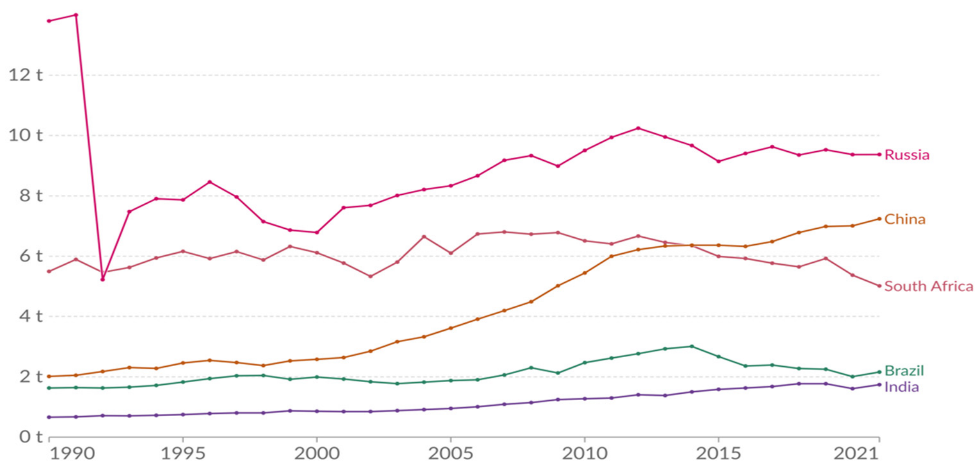


Fig. 1: Per capita consumption-based CO_2 emissions (Source: World In Data, 2023)

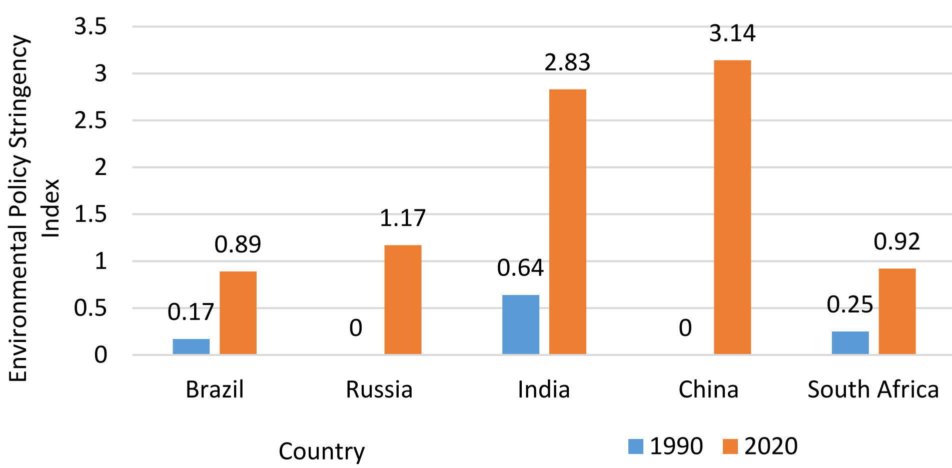


Fig. 2: Environmental Policy Stringency Index (Source: Authors)

the demand for such novel initiatives has been highly coveted as China, South Africa, Brazil, and India registered high per capita consumption-based CO_2 emissions in 2021. In light of the statistically significant changes recorded in China, South Africa, Brazil, and India, respectively, in terms of percentage changes of 263.64%, -14.1%, 46.67%, and 65%, this study expresses concern over the impact of CO_2 emissions on their environment. This study also highlights empirically sidelined yet important influences of country-specific factors on environmental management across the BRICS economies. To support the scholarship's objectives, Fig. 2 shows that the Environmental Policy Stringency Index (EPSI) has increased among BRICS economies, indicating a more demanding regulatory environment regarding environmental protection and sustainability. This indicates that, despite existing policies, CO_2 emissions may not be reduced or mitigated effectively. Despite higher stringency indexes suggesting stricter regulations and standards, CO2 emissions continue to increase, as illustrated in Fig. 2. EPSI are scored on a 0–6 scale increasing in stringency (0 is assigned when the instrument is not present in a country), and 6

Table 2: Unit root tests

Country	Variable	ADF		PP		Decision
		t. stat.	Prob.	t. stat.	Prob.	
Brazil	$LC0_2e$	-4.5620	0.0000	-4.617	0.0000	I(I)
	LCPP	-4.1281	0.0000	-4.4807	0.0000	I(I)
	LREC	-4.1215	0.0000	-4.4283	0.0000	I(I)
	LFD	-4.0921	0.0000	-3.7020	0.0000	I(0)
	LEG	-4.4000	0.0000	-4.6183	0.0000	I(I)
Russia	$LC0_2e$	-3.8246	0.0000	-4.1257	0.0000	I(I)
	LCPP	-4.5783	0.0000	-4.5783	0.0000	I(I)
	LREC	-4.6202	0.0000	-4.7354	0.0000	I(I)
	LFD	-4.4586	0.0000	4.8095	0.0000	I(0)
	LEG	-5.097	0.0000	-4.7764	0.0000	I(0)
India	$LC0_2e$	-3.7425	0.0000	-3.7425	0.0000	I(I)
	LCPP	-3.9344	0.0000	-3.9344	0.0000	I(I)
	LREC	-5.4817	0.0000	-4.8451	0.0000	I(I)
	LFD	-4.1897	0.0000	-4.0670	0.0000	I(0)
	LEG	-7.4205	0.0000	-7.4205	0.0000	I(0)
China	$LC0_2e$	-4.2426	0.0000	-4.2426	0.0000	I(I)
	LCPP	-4.9375	0.0000	-4.1087	0.0000	I(I)
	LREC	4.5660	0.0000	4.5660	0.0000	I(I)
	LFD	-4.359	0.0000	-3.769	0.0000	I(0)
	LEG	-7.720	0.0000	-4.3167	0.0000	I(0)
South Africa	$LC0_2e$	-4.167	0.0010	-4.724	0.0010	I(I)
	LCPP	-46.744	0.0000	-24.095	0.0000	I(I)
	LREC	-10.874	0.0000	-10.075	0.0000	I(I)
	LFD	-4.282	0.0040	-4.262	0.0040	I(0)
	LEG	-6.560	0.0000	-10.322	0.0000	I(0)

denotes the most stringent policies. Accordingly, this raises questions about the adequacy, enforcement, or effectiveness of the current policies.

In light of these observations, this study proposed that addressing rising CO_2 emissions crucially demands a shift towards renewable energy sources and implementing a carbon pricing policy by introducing economic incentives to reduce carbon emissions. Promoting financial development is pivotal in supporting the transition to a low-carbon economy to enhance effectiveness in abating CO2 emissions. However, without adequate empirical validation, such propositions can lose huge practical grounds. Hence, following the modelling of the purported interactions, the study findings are presented in the next section.

RESULTS AND DISCUSSIONS

Unit root tests

By computing the ADF and PP unit root tests, the results of Table 2 show that all five estimated variables are integrated at I(O) and I(I) across the BRICS as projected by both tests, which proves that there were no unit roots. Apart from being an essential condition of avoiding an ARDL crash (Nkoro and Uko, 2016), this is vital for reducing spurious relationships and ensuring that more robust and valid statistical inferences are drawn from the ARDL model.

Panel data estimations are a growing norm in contemporary related examinations. Hence, motivated by the sidelining of multi-country level ARDL analyses by related studies, this study proceeded to ascertain CO_2 emissions, carbon pricing policy, renewable energy consumption, financial development, and economic growth’s short-run ARDL dynamics across BRICS economies.

Short-run ARDL estimation

In the short run, lagged variables pose distinct effects on the main variables across BRICS economies, as shown in Table 3. This indicates that historical or past factors affecting CO_2 emissions (such as economic growth, renewable energy consumption patterns, carbon pricing policy implementations, and financial development) have varying impacts on present emissions levels across BRICS nations. As a result, a one-size-fits-all policy approach for mitigating CO_2 emissions across BRICS countries might be ineffective. Policymakers should consider country-specific strategies. In that regard, policymakers should

Table 3: Short-run ARDL estimation

	Brazil	Russia	India	China	South Africa
LCPP	1.855(11.128)*	0.124(2.740)	0.5146 (15.671)*	1.164(34.888)*	-2.469(-2.455)**
LCPP(-1)	-3.232(-9.724)*	-0.197(-2.280)**	1.3193 (15.671)*	-1.846(-9.351)*	-2.469(0.016)**
LCPP(-2)	1.374(6.643)*	0.069(1.483)	-0.3539 (15.671)*	0.748(9.330)*	-
LCO^{2}E (-1)	1.793(31.931)*	1.789(30.990)*	-0.7029 (15.671)*	1.544(21.302)*	1.627(0.000)
LCO^{2}E (-2)	-0.805(-14.093)*	-0.806(-13.673)*	0.1748 (15.671)*	-0.604(-9.351)*	-0.736(0.000)
LEG	-0.003(-1.719)	0.013(5.075)*	0.0142 (15.671)*	0.004(2.179)**	0.008(0.009)
LEG(-1)	-	-0.021(-5.463)*	-0.0123 (15.671)*	-0.010(-2.684)**	-0.008(0.027)**
LEG(-2)	-	0.010(4.429)*	0.0013 (15.671)*	0.005(2.008)**	0.003(0.500)
LEG(-3)	-	-	0.0002 (15.671)*	0.002(1.553)	0.0002(0.953)
LEG(-4)	-	-	(15.671)*	-	0.0058(0.127)
LFD	-0.0004(-0.248)	-0.25(-2.055)**	(15.671)*	0.060(5.528)*	-2.020(0.068)
LFD(-1)	-	0.048(2.171)**	(15.671)*	-0.091(-4.684)*	-
LFD(-2)	-	-0.026(-2.163)**	(15.671)*	0.037(3.433)*	-
LFD(-3)	-	-	(15.671)*	-	-
LFD(-4)	-	-	0.046 (15.671)*	-	-
LREC	0.005(0.365)	-0.237(-7.599)*	-0.029(15.671)*	-0.144-9.741)*	-0.035(0.012)**
LREC(-1)	-	0.422(8.138)*	1.121(1.861)	0.198(6.920)*	-
LREC(-2)	-	-0.192(-6.129)*	-0.361(-0.624)	-0.059(-3.249)**	-
LREC(-3)	-	-	-0.008(-0.014)	-	-
LREC(-4)	-	-	0.738(1.176)	-	-
LREC(-5)	-	-	-0.970(-2.860)*	-	-
C	-0.035(-0.392)	0.066(2.364)*	0.107 (15.671)*	-0.055(-3.597)*	-0.004(0.922)
CointEq(-1)	-0.012(-3.066)*	-0.017(-4.448)*	-0.009 (-7.510)*	-0.060(-5.586)*	-0.111(-5.142)*
R^2	0.8011	0.9985	0.8042	0.9922	0.9907
Adj. R^2	0.7962	0.9983	0.7661	0.9915	0.9898
F-stat.	467.812	532.157	463.304	128.493	109.89
DW stat.	1.992	2.008	2.025	1.822	2.024

Values in parentheses show t-statistics while * and ** indicate statistical significance at 0.01 and 0.05 levels, respectively.

develop flexible and dynamic policy frameworks that can adapt to the changing impacts of lagged variables.

Table 3 further shows that South Africa has a higher speed of adjustment of 11.1% compared to China (6%), Russia (1.7%), Brazil (1.2%), and India (0.9%) as denoted by the ECTs. Though lower, this denotes a higher level of economic resilience. Thus, South Africa takes a longer period to recover from disturbances or shocks compared to China, Russia, Brazil, and India, respectively. In contrast to panel regression analysis, these findings direct attention to policy and structural factors demanding targeted and proactive policy interventions across BRICS economies. With predictive accuracies of 80.11%, 99.85%, 80.42%, 99.22%, and 99.07%, evidence of the relationships under investigation is convincing and credible. This carries huge weight in renewable energy policy and decision-making initiatives.

Bounds test

Table 4 shows the findings of the bound tests. In a quest to establish the long-term dynamics between CO_2 emissions, carbon pricing policies, renewable energy consumption, financial development, and economic growth in BRICS economies, long-run cointegration was confirmed across Russia, India, China, and South Africa, but not in Brazil. Unlike Wolde-Rufael and Weldemeskel's (2020) 1993-2014 PMG-ARDL estimator results on BRIICTS, revealing cross-sectional dependencies, our findings suggest country-specific effects or heterogeneity across BRICS. This entails that a one-size-fits-all policy approach to CO_2 emissions is, to some extent, not appropriate for the entire BRICS economies. In that context, highly coveted focused interventions addressing the specific needs of individual BRICS economies can be more effective than generic CO_2 emissions policies. Therefore, it is pivotal to implement tailored CO_2 emission strategies that consider the specific environmental, social, and economic characteristics of each BRICS economy.

Long-run ARDL estimation results

This section provides the long-run multi-country ARDL results reported in Table 5. According to the long-run ARDL estimation results, mixed inferences

Table 4: Bounds test

Country	Significance	I(0) Bound	I(1) Bound	F-statistic	Long-run exist
Brazil	5%	2.56	3.49	1.503	No
Russia				3.571	Yes
India				11.568	Yes
China				4.975	Yes
South Africa				3.973	Yes

Table 5: Long-run ARDL estimation

	Brazil	Russia	India	China	SA.	Net effect
C	1.49[0.54]	3.97[(3.69]*	3.08[5.14]*	-0.92[-5.08]*	-0.04[-0.10]	-
LY-->LCO_2E	-0.01[4.26]*	-0.72[6.71]*	0.42[-5.38]*	-0.18[5.52]*	-0.89[3.91]*	-1.38
LY^2-->LCO_2E	0.04[0.30]	0.09[1.03]	-0.39[-4.26]*	-0.04[2.69]*	0.06[2.15]**	0.159
LREC-->LCO_2E	-0.06[0.90]	-0.47[0.59]	0.13[3.75]*	-0.08[-2.64]*	-0.32[2.76]*	-0.512
LCPP-->LCO_2E	-0.35[0.15]	-0.22[-2.88]*	0.07[1.47]	1.10[29.25]*	0.79[-1.69]	1.387
LFD-->LCO2E	-0.05[0.36]	-0.25[-2.93]*	0.10[-8.52]*	0.11[3.79]*	-0.19[2.05]**	-0.273

Values in parentheses show t-statistics while * and ** indicate statistical significance at 0.01 and 0.05 levels, respectively.

can be drawn from each other in terms of the projected different EKC relationship types. Unlike findings drawn from India (β_{23}=-0.39*) and Naradda Gamage *et al.*, (2017) rejecting a negative scenario for the EKC hypothesis, an inverse U-shaped path can be observed between economic development and environmental pollution in Russia, South Africa, Brazil, and China. A declining pattern of economic growth's effects on CO2 emissions spanning from Russia (β_{22}=0.09), South Africa (β_{25}=0.06**), Brazil (β_{21}=0.04) to China (β_{24}=0.04*), confirms differences in economic and institutional dynamics' effects on the environment across BRICS economies. The EKC patterns contrast across BRICS nations, as Russia, South Africa, Brazil, and China display a classic inverted U-shaped pattern, India displays a slight bit of a heterogeneous deviation. This, to some extent, is suggestive of the differences in timing of each economy achieving the turning point of decreasing emissions with economic growth. For example, India's EKC turning point seems to occur earlier/later (usual format would have you specify it) in time, suggesting that structural economic factors and stages of industrialization can impact the environmental consequences of growth quite differently.

According to Table 5, promoting renewable energy consumption highly mitigates CO_2 emissions in Russia by 47%, followed by South Africa, China, and Brazil with reduction levels of 32%, 8%, and 6%, respectively. A significant inelastic increase in CO_2 emissions of 0.13t is observed in India following an increase in renewable energy consumption, as depicted in Table 5. With an observed net elastic carbon pricing policy effect of 1.387, CO_2 emission increments observed in China, South Africa, and India outweigh CO_2 emission reductions observed in Brazil and Russia for each marginal price increase of $1/t$CO_2$. Table 5 reports that a 1-unit improvement in financial development levels increases CO_2 emissions in India and China by 10% and 11%, respectively, but lowers CO_2 emissions in Brazil, Russia, and South Africa by 5%, 25%, and 19%, respectively.

Sensitivity analysis

Concerning the model diagnostics tests, the redundancy test was applied to ascertain whether carbon pricing policy, renewable energy consumption, financial development, and economic growth were jointly insignificant. Table 6 shows that the variables were jointly significant across Brazil (χ^{2RT} =0.946*), Russia (χ^{2RT} =2.223*), India (χ^{2RT} =6.238*), China (0.366*), and South Africa (0.333*) in influencing carbon emissions. Thus, taking into consideration carbon pricing policy, renewable energy consumption, financial development, and economic growth, this study offers reliable, valid, and robust explanations of variations in BRICS economies' CO_2 emissions levels.

Stability tests

The provided Fig. 3 stability tests prove that the

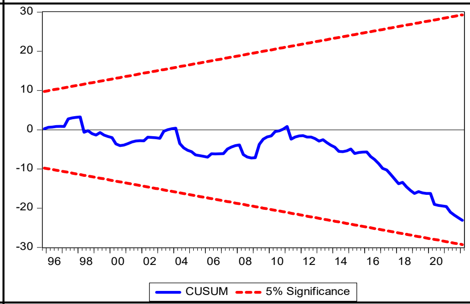
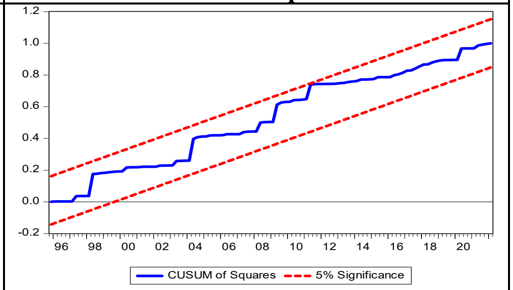
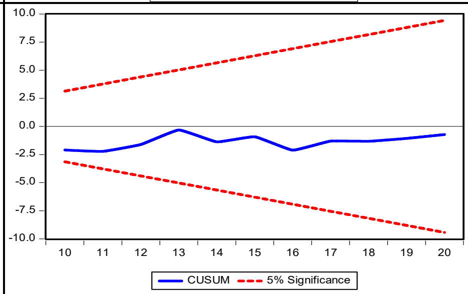
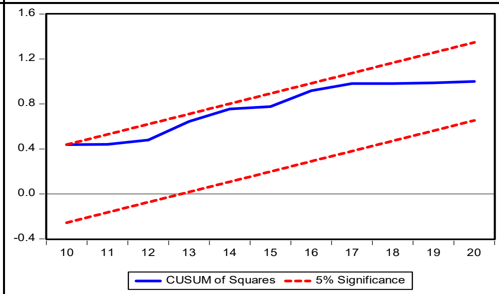
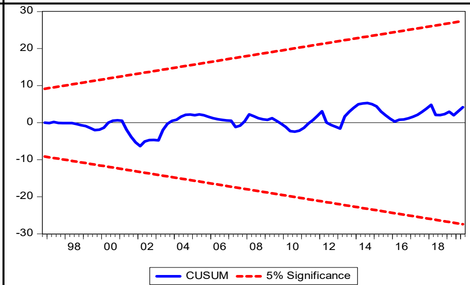
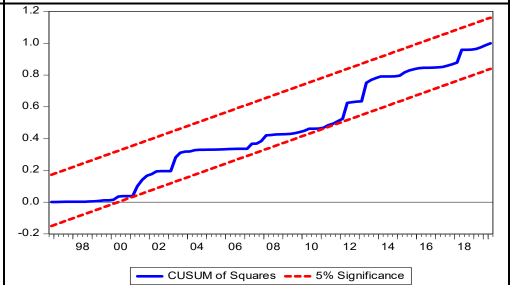
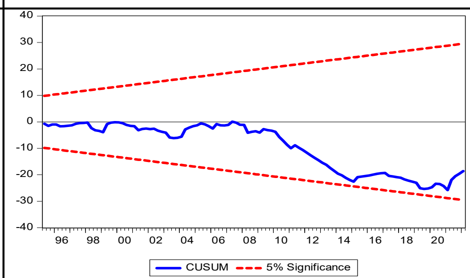
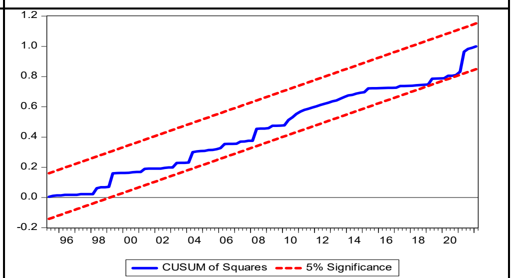
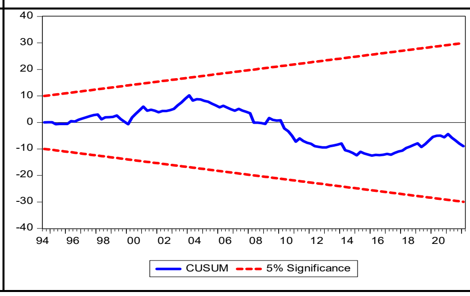
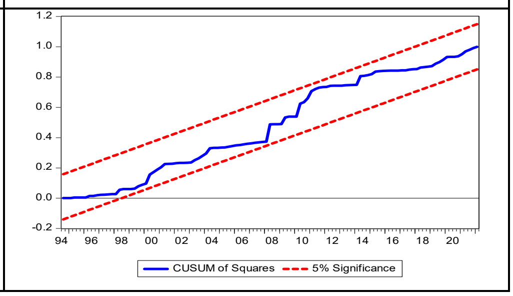
Country	Cusum test	Cusum of squares
Brazil		
Russia		
India		
China		
South Africa		

Fig. 3: Stability tests

Table 6: Sensitivity analysis

Country	χ^{RT}	χ^{2RR}	χ^{2BR}	χ^{2AR}	χ^{2SC}	χ^{2N}
Brazil	0.946 (0.325)	32.801 (0.000)	1.608 (0.413)	0.068 (0.793)	0.669 (0.485)	499.58 (0.000)
Russia	2.223 (0.139)	25.459 (0.000)	4.663 (0.120)	0.465 (0.493)	0.025 (0.971)	107.915 (0.000)
India	6.238 (0.000)	6.238 (0.000)	0.0000 (0.0000)	6.238 (0.000)	6.238 (0.000)	6.238 (0.000)
China	0.366 (0.694)	821.539 (0.000)	1.551 (0.1078)	0.006 (0.937)	6.238 (0.000)	1.791 (0.132)
South Africa	0.333 (0.740)	6.238 (0.000)	6.238 (0.000)	0.045 (0.830)	0.092 (0.9019)	48.285 (0.000)

p-values in ( ).

Table 7: Robustness through alternative estimation method (FMOLS)

	Brazil	Russia	India	China	SA.
C	1.73[2.14]**	2.88[4.08]*	2.67[2.23]**	-3.49[-7.02]*	-2.65[-2.24]**
LY-->LCO_2E	-0.02[2.43]**	-0.69[4.48]*	0.38[-3.89]*	-0.16[8.87]**	-0.78[4.65]**
LY^2-->LCO_2E	0.07[0.78]	0.12[1.78]***	-0.44[-5.34]*	-0.06[3.38]*	0.06[2.29]**
LREC-->LCO_2E	-0.09[1.83]***	-0.89[0.98]	0.17[2.31]**	-0.09[-2.58]*	-0.29[3.09]*
LCPP-->LCO_2E	-0.19[0.33]	-0.31[-2.33]**	0.28[1.08]	0.10[2.25]**	-0.81[-1.79]*
LFD-->LCO2E	-0.10[0.45]	-0.31[-3.15]*	0.14[-6.97]*	0.09[3.91]*	-0.21[1.89]***

Values in parentheses show t-statistics while *, **, and *** indicate statistical significance at 0.01, 0.05, and 0.10 levels, respectively.

interactive connections linking CO_2 emissions with renewable energy consumption, carbon pricing policy, financial development, and economic growth are stable during the period 1990 to 2022 across BRICS economies. As a result, the estimated ARDL models provide valuable insights for decision-making, process monitoring, and model diagnostics across various fields.

Robustness Analysis

The Fully Modified Ordinary Least Squares (FMOLS) method is used for robustness testing to validate the long-run relationship discovered from the ARDL framework. FMOLS deals with serial correlation and endogeneity in cointegrated regressions, making it a valid alternative estimation technique, which increases the reliability of the findings by providing a comparison for possible biases induced by ARDL's estimation. In this study, the FMOLS is shown in Table 7, and it can be seen that nearly all the coefficients and their respective signs are in agreement with those found in the ARDL model for all countries, demonstrating the robustness and stability of the finding initially asserted. Therefore, we are confident in the long-run associations.

Post-estimation validation tests

The results from the diagnostic tests are shown in Table 8, which indicate that the ARDL models are well specified and have been bootstrapped in terms of the requirements of the ARDL assumptions for all BRICS countries. The Breusch-Godfrey LM test concluded that there is no evidence of serial correlation since the p-values were all above the 0.05 significance level. Similar results were achieved using the Breusch-Pagan-Godfrey test, which confirmed that there is no heteroskedasticity for all BRICS countries and that the residuals are homoscedastic for the fitted values. The Jarque-Bera test results indicated that the residuals are normally distributed for all BRICS countries, and the p-value was significantly above the 0.05 level of significance for all BRICS countries. Models also successfully passed the Ramsey RESET test, indicating that by and large the models were correctly specified and there were no serious misspecification issues. Finally, the Durbin-Watson statistics were all found to be close to 2, implying that there were no serious problems of autocorrelation. Overall, the econometric properties of the models appear to be satisfactory.

Table 8: Diagnostic tests outcomes

	Brazil	Russia	India	China	SA.
Tests	F-statistic	F-statistic	F-statistic	F-statistic	F-statistic
Breusch-Godfrey LM test for serial correlation	0.404 [0.806]	0.724 [0.937]	0.387 [0.114]	0.449 [0.564]	0.198 [0.103]
Breusch-Pagan-Godfrey test for heteroskedasticity	1.392 [0.249]	0.882 [0.243]	2.117 [0.198]	1.267 [0.165]	2.076 [0.876]
Jarque-Bera test for normality	1.503 [0.511]	2.034 [0.944]	1.164 [0.768]	1.687 [0.257]	0.985 [0.496]
Model Specification test: Ramsey RESET	2.101 [0.158]	1.734 [0.223]	2.284 [0.185]	1.850 [0.878]	0.910 [0.145]
Durbin-Watson stat.	1.992	2.008	2.025	1.822	2.024

Values in parentheses show p-values

DISCUSSION

Firstly, while an inverted U-shaped trajectory between economic development and environmental pollution is evident in Russia, South Africa, Brazil, and China, an inverted U-shaped relation exists in India. Contrary to India and Gamage *et al.,'s* (2017) findings, this suggests that as economic development increases in Russia, South Africa, Brazil, and China, environmental degradation worsens because of escalating CO_2 emissions. In contrast to the other BRICS countries, India is not clearly showing an inverted-U-shaped EKC. This is due to its unique economic structure that still transitions from agriculture backward to industry and services. In addition, India's energy mix continues to be dominated by coal because it is still making the transition to renewables. The slower transition to clean energies, along with rapid urban growth and population increase, may delay the EKC turning point and consistently affect what the normal income-emissions trajectory is. Apart from the inverted U-shaped trajectory traces being evident in Ayhan *et al.,'s* (2023) study, findings on Russia, South Africa, Brazil, and China are congruent with Aye and Edoja's (2017) highly concentrated manufacturing companies. Besides, CO_2 emission variations in Brazil, Russia, China, and South Africa are likely to result from the presence of energy-intensive industries (e.g., mining and manufacturing) relying heavily on fossil fuels. In the presence of increasing GDP, these industries increase their output, resulting in higher energy consumption and, consequently, an increase in carbon emissions. An increase in economic activity in these countries may increase CO_2 emissions if the energy mix is dominated by coal and other carbon-intensive sources. Most importantly, rapid economic growth often necessitates increased infrastructure development, which may involve energy-intensive construction projects. With a GDP cumulative effect on CO_2 emissions of 0.159, aligning BRICS economies' rapid industrialization and economic growth initiatives with environmental management policies targeted at reducing CO_2 emissions is highly coveted in BRICS economies. Essentially, this confirms Aye and Edoja's (2017) notion that GDP growth levels over 0.156 always result in higher CO_2 emissions. Consequently, this raises an environmental alarm as it signals that the BRCIS's initiatives to boost economic performance will adversely impact the environment through a surge in CO_2 emissions. Therefore, the need for BRICS economies to adopt renewable energy, energy efficiency, and sustainable development policies cannot be refuted in this context. Such findings also signal the importance of increasing cleaner technologies and shifting toward cleaner energy sources, reducing the economic activities' carbon intensity. Since traces of ITP evidence have been lacking, our findings add traction to the long-standing energy consumption and CO_2 emissions debate by establishing a GDP-related ITP of -0.40 for BRICS economies. Amid such discoveries, there is a policy case for early investments in renewable energy sources involving the promotion of energy efficiency measures, implementation of carbon pricing mechanisms, and incentivizing renewable energy projects. Secondly, the study findings project that an all-size-fits-all renewable energy consumption policy across BRICS economies is effective in abating CO_2 emissions in Russia, South Africa, China, and Brazil by 47%, 32%, 8%, and 6%, respectively, as opposed to a 13% increase in CO_2 emissions observed in India. Hence, this study obtained good results and agreed with the empirical investigation of Al-Mulali and Ozturk (2016), which found a reduction in CO_2 emissions of 12% and 4%, respectively. As a result of the implementation of renewable energy consumption policies, these results are not surprising. Therefore, this study's insights can also prove to be an effective solution to low- and middle-income countries and the MENA region's long-standing environmental issues. Meanwhile, this reduction can, therefore, be attributed to the successful integration and adoption of renewable energy sources in Russia, possibly driven by favourable policy shifts in technological advances or energy production. Although South Africa may have developed effective renewable energy policies aimed at transitioning from carbon-intensive energy sources, China's reduction, even though relatively small, may reflect a shift towards cleaner energy sources and significant investments in renewable energy infrastructure. By successfully implementing policies related to renewable energy, Brazil, with its emphasis on hydropower and bioenergy, may have experienced a reduction in emissions. In the case of India, rapid population growth and urbanization may have outpaced renewable energy policies positive effects. In light of the disparity in outcomes, it is crucial to understand and address the factors that influence CO_2 emissions. Thus, to achieve policy success, it is imperative to consider factors specific to each country, such as economic structures, policy implementation, and energy infrastructure. BRICS countries may require policymakers to tailor policies on renewable energy consumption in response to their specific needs and challenges. Thirdly, with an observed net elastic carbon pricing policy effect of 1.387, CO_2 emission increments observed in China (β_{44}=1.10*), South Africa (β_{45}=0.79), and India (β_{43}=0.07) outweigh CO_2 emission reductions observed in Brazil (β_{41}=-0.35) and Russia (β_{42}=-0.22*) for each marginal price increase of \$1/tCO_2. Consequently, this not only suggests ineffectiveness in BRICS economies' adoption of carbon pricing policies but also highlights the importance of exploring the potential transferability and adaptability of successful policies across BRICS nations. Despite China's keen pursuit of various strategies to reduce CO_2 emissions from its coal-dominated electric power system (Li *et al.,* 2022), its carbon pricing and power market reforms are in their infancy and point to ineffectiveness and potentially unintended effects in reducing its coal-dominated electric power system. Accordingly, a higher carbon tax may not cause significant reductions in CO_2 emissions due to incomplete coverage of emissions sources and a subset of industries, especially in sectors with elastic demand. In low and middle-income countries like South Africa and India, equity concerns loom large (Steckel *et al.,* 2021). Consequently, public support of domestic climate and energy policies is severely undermined. It is often the case that policies that increase the price of fossil fuels, which in turn increase the price of essential energy services, are met with fierce resistance from the public. On the contrary, Brazil and Russia have economies that are heavily reliant on natural resources, particularly in the form of fossil fuels (oil and gas in Russia, and agriculture and deforestation-related activities in Brazil). Hence, the implementation of carbon pricing policies could encourage the adoption of cleaner technologies and practices, leading to emissions reductions. On a sectoral level, vulnerable sectors should be supported to move towards carbon-friendly production processes and materials. Policymakers should carefully consider a complex interplay of global market dynamics, technological considerations, political factors, policy design and economic structures when designing and implementing carbon pricing policies to ensure positive environmental outcomes while fostering economic development. Lastly, although financial development inelastically curbs CO_2 emissions in BRICS economies by -0.273, the findings show that a 1-unit improvement in India and China's financial development levels dampens environment preservation initiatives by increasing CO_2 emissions by 0.10t and 0.11t, respectively. Xu *et al.,* (2021) echoed similar sentiments by postulating that financial development's impact on CO_2 emissions changes from negative to positive as industrialization and energy consumption increase. The findings also support financial development's role in abating CO_2 emissions in Brazil, Russia, and South Africa by 5%, 25%, and 19%, respectively. Such findings mirror Khan and Ozturk's (2021) findings that support the pollution-inhibiting role of financial development in 88 developing countries during the 2000-2014 period. Interestingly, this study suggests that varying financial regulations and incentives related to carbon taxes, green financing, or sustainable investments can affect how financial development impacts emissions. On a policy level, Brazil, Russia, and South Africa's financial development policies can be utilized to incentivize and stimulate green innovation and emission reductions, and influence sustainable development. Besides, South Africa, Russia, and Brazil have diverse industrial structures and energy profiles compared to India and China. They might have less energy-intensive industries or greater reliance on renewable energy sources, which could be less carbon-intensive. This study analyzes total CO_2 emissions across the BRICS economies, and it does not break CO_2 emissions down by sector (e.g. transport, industry, residential). This study allows us to see the overall trends in the environment, but it loses the sector specific EKC relationships which probably differ by sector depending on the sector structure and energy use. Future studies could disaggregate emissions, to illuminate the fact that EKC relationships are often heterogeneous across and within sectors. Moreover, the effectiveness of environmental policies within the EKC perspective may be substantially moderated by differences in institutional capacities and governance structures unique to each country. In BRICS countries, differences in regulatory compliance, transparency, and the processes of policy action may impact the trajectory and timing of achieving emissions reductions. Countries with more robust institutional frameworks may have a clearer path in developing and executing effective renewable energy and carbon pricing policies leading to an earlier EKC turning point. Future work should continue to unpack the institutional dimensions of environmental policy outcomes, identified in our scope, across emerging economies.

CONCLUSION

The manuscript disentangled and shed light on the intricate dynamics of carbon pricing policies, renewable energy consumption, economic growth, and financial development's effect on CO_2 emissions and their implications for sustainable development in BRICS countries. A multi-country ARDL approach was conducted using 1990 to 2022 data to validate claims that panel data estimations rely on an unsubstantiated similar characteristics. Several important policy options have been advanced to design an environmental strategy that can reduce the level of CO_2 emissions. The research provides theoretical foundations for understanding whether BRICS economies follow the suggested inverted U-shaped curve or diverge from it by examining the trajectory of CO_2 emissions concerning economic growth. Apart from providing theoretical insights into designing long-term sustainable development policies in BRICS economies concerning CO_2 emissions, the EKC hypothesis enables cross-country comparisons and offers regional policy implications. The study provides policymakers with valuable insights to enhance renewable energy adoption and reduce carbon emissions. Further research and policy measures should build upon these findings to ensure sustainable and environmentally responsible development within the BRICS initiative. The study is not void of limitations, and the major limitation is the lack of comparative analysis, as a multi-country ARDL analysis overlooks shared regional dynamics and restricts the ability to compare interactions, patterns, and trends among BRICS nations. In addition, by not capturing cross-country effects, the study may overlook influences of economic and policy changes or spill-over effects in one BRICS country on others. As a result, this can hamper efforts to enhance understanding of how policy interventions interact across countries. Therefore, future studies should integrate cross-country comparisons with country-level analysis to gain a more comprehensive understanding of differences, similarities, and regional dynamics among BRICS countries. To chart the course of financial development, economic growth, and policy interventions in BRICS countries, panel longitudinal studies and time-series analyses can be conducted. As this study discusses renewable energy use, carbon pricing, and financial development as the primary influences behind emissions trajectories, this still does not account for trade openness, foreign direct investment (FDI), and overall global economic integration as potential contributors. These other factors could all potentially alter emissions trends, and BRICS countries are particularly reliant on international trade and investment flows. Follow-up studies could expand the model in this research to include some of these variables to investigate their behavior when interacting with renewable energy use and emissions reductions. Although this study has focused on macroeconomic and policy-driven determinants of CO_2 emissions, it is recognised that aspects of socio-demography, including urbanization, population growth or decline, and income inequality, may serve significant mediating effects on the growth-emission relationship. These narratives of urbanization, population growth, population decline, and income inequality will shape consumption patterns, energy demands, and the ability to access sustainable infrastructure, and hence they to also be predictors of emissions in future analyses. Additionally, political stability, institutional quality, and governance structures can shape the efficacy and timing of environmental policy implementations. In some contexts, these issues can affect when and where the Environmental Kuznets Curve turning point occurs for BRICS countries. While these institutional and demographic aspects of sustainability are beyond the capability of the present model, they represent the important aspects of future potential research to investigate the complex and country-level specific pathways towards sustainable development. Furthermore, this study does not use a regional clustering method with BRICS. However, comparing groupings such as Russia–China or India–South Africa may yield different EKC trends resulting from geographic, economic, or policy similarities. Future research may wish to investigate clustering to yield more directed policy implications.

AUTHOR CONTRIBUTIONS

M. Kamal: Conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, visualization. The author has read and agreed to the published version of the manuscript.

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CONFLICT OF INTEREST

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PUBLISHER NOTE

ABBREVIATIONS

$	United States Doller
ADF	Augmented Dickey-Fuller
ARDL	Autoregressive Distributed Lag
BRICS	Brazil, Russia, India, China, and South Africa
CE	Carbon Emissions
CO_2	Carbon Dioxide
CPP	Carbon Pricing Policy
DOLS	Dynamic Ordinary Least Squares
EKC	Environmental Kuznets Curve
EPSI	Environmental Policy Stringency Index
EU	European Union

FD	Financial Development
FMOLS	Fully Modified Ordinary Least Squares
GDP	Gross Domestic Product
GMM	Generalized Methods of Moments
ITPs	Income Turning Points
MENA	Middle East and North Africa
OLS	Ordinary Least Squares
PMG-ARDL	Pool Mean Group-Autoregressive Distributed Lag
PP	Phillips Perron
PVAR	Panel Vector Autoregression
REC	Renewable Energy Consumption
UNFCCC	United Nations Framework Convention on Climate Change
VECM	Vector Error Correction Model

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