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Policy uncertainty, renewable energy, corruption and CO_2 emissions nexus in BRICS-1 countries: a panel CS-ARDL approach

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Abstract

Due to the ecological impacts of fossil energy, renewable energy has become crucial for inclusion in the energy supply to realize a sustainable environment, enhance public welfare, and combat global climate change. However, the transition to renewable energy and eco-sustainability is hampered by certain factors, such as uncertainties in economic policies and corruption. To this end, this study delves into the effects of renewable energy, policy uncertainty, and corruption on CO_2 emissions for a panel comprising Brazil, Russia, India, and China (BRICS-1) regulating the environment Kuznets growth curve (EKGC) hypothesis for a period 1990–2020. The unique panel cross-sectional augmented ARDL (CS-ARDL) approach was used in the study, which addresses the constraints of standard procedures by integrating cross-sectional dependence heterogeneity and endogeneity. The findings demonstrated that renewable energy consumption and corruption control contribute to long-term emissions reductions; however, policy uncertainty threatens environmental sustainability. In addition, BRICS-1 nations can benefit from the EKGC theory. The study offers significant ramifications for reducing pollution and suggests that policymakers establish sustainable measures to reduce policy uncertainties, control corruption, and enact environmental regulations that foster a safer environment for all citizens.

Keywords Economic policy uncertainty · Control of corruption · Renewable energy · Environmental quality · BRICS-1 countries

1 Introduction

Although CO_2 emissions and other greenhouse gases (GHG) dropped by 4.6% in 2020 because of COVID-19-related lockdowns that restricted global mobility and reduced economic activities, these emissions rebounded by 6.4% in 2021, which is a new record, demonstrating the pre-pandemic peak (IMF, 2022). The rebound effects are shown in Fig. 1, presenting the annual global GHG emission since 1900.[1] Compared to any previous

[1] For more detail see: "CO_2 and Greenhouse Gas Emissions". Retrieved from: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions.

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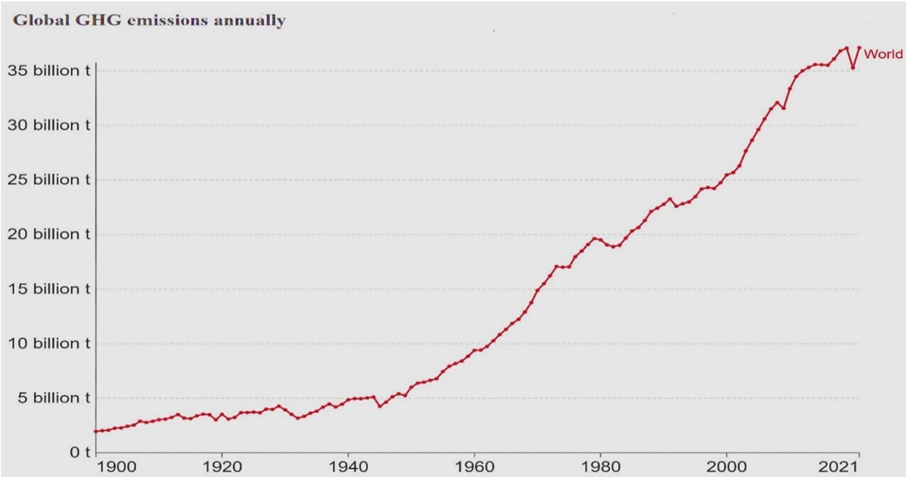

Fig. 1 Global CO_2 emissions in billion tones 1900–2021 (Global Carbon Budget 2021. Retrieved from: https://doi.org/10.5194/essd-14-4811-2022)

decade, average annual GHG emissions were higher during 2010–2019 (IPCC, 2022). Hence, the issue of growing greenhouse gas emissions is still one of the most international problems, which is connected to the accelerating process of climate change and global warming, resulting in various devastating environmental problems such as air pollution, bushfire, floods, drought, and cyclones, which in turn adversely affect the economy and society as a whole (Rahman & Alam, 2022). Realizing the depth of the problem, researchers worldwide have strived to identify the factors responsible for CO_2 emissions (Balcilar et al., 2020; Sadiq et al., 2022; Weimin et al., 2022) but their findings are inconclusive in formulating and executing a unique policy. Among the contributory factors, energy use, economic growth, population density, urbanization, foreign direct investment, globalization, industrial growth, financial development, informal economy, tourism activities, and biowaste recycling are notable (Kashem & Rahman, 2020; Khanal et al., 2022; Saidi & Rahman, 2021; Sasmoko et al., 2022; Shahbaz et al., 2020; Sultana et al., 2022b). However, some important potential factors, including policy uncertainty and corruption control in the energy-environment nexus, are still under-researched, and the motivation of this study is to explore the roles of these factors in reducing CO_2 emissions.

Renewable energy usage and production is the most critical component for a sustainable environment and have increased in emerging and developed economies since the 1980s. The emergence of renewable energy can be categorized into four aspects. First, due to technological advancements, renewable energy installations have become more affordable (Li et al., 2021), and such advancements have reduced the financial constraints in the energy transition pathways (Shaheen et al., 2022). The second aspect of renewable energy is government regulation that supports green energy investments (Dong et al., 2017). As a result of initiatives such as tax deductions and credit easing, investment standards for renewable energy have been raised. Thirdly, climate change is a concern, and renewable energy can mitigate the impact of climate change through reduced CO_2 emissions due to the increased use of green energy resources (Sadiq et al. 2022; Wang et al. 2022). Finally, fossil fuel prices have increased, encouraging the use of renewable energy (Owusu &

Asumadu-Sarkodie, 2016). Thus, renewable energy can sustain long-term economic growth and environmental sustainability if these four factors are considered.

Although the shift to renewable energy and eco-sustainability is desirable, it is being impeded by issues including economic policy uncertainty and corruption. Recently, policy uncertainties and volatilities in the global economy have challenged the global ability of energy transition to bring long-term eco-sustainable growth. Due to emergent economic policy uncertainty, expenditures and investments in green development tend to be delayed, which has environmental consequences (Perić & Sorić, 2018). Many countries have experienced economic and political instability over the past decades due to global uncertainties and vice versa, such as the impact of the second Gulf War in 2003, the financial crisis in 2007, and the recent global COVID-19 pandemic on international markets (Khan et al., 2022). Economic growth and development policy is impacted mainly by the uncertainty of fiscal and monetary policies, which also affects energy transition and the environment. Policy uncertainty can negatively influence the environment by encouraging industries to exercise ecologically unfriendly production practices, leading to environmental pollution (Hussain et al., 2022). Moreover, an increase in uncertainty due to economic policies may lead to reduced investment in renewable energy sources and environmental technologies, and consequently, there will be a negative impression on the environment (Xue et al., 2022).

The maintenance of ecological quality and the sustainable use of resources need effective environmental governance (Hassan et al., 2020). The environment quality is affected differently by different facets of governance and the quality of regional institutions. Corruption, directly and indirectly, impacts CO_2 emissions because it hinders the efficient execution of ecological legislation, undermines the functioning of institutions, and encourages rent-seeking behavior; overcoming corruption improves environmental quality (Hussain et al., 2021). Corruption may make it more difficult to allocate money, labor, and other resources efficiently, lowering energy efficiency and increasing carbon dioxide emissions into the atmosphere (Pei et al., 2021). Corruption impacts a country's production efficiency, government priorities, and environmental quality through trade policies by reducing the stringency of environmental laws and is the leading cause of embezzled natural resources impacted by wrong government policies backed by particular interest consortia (Ganda, 2020). Businesses break emission reduction protocols in weak intuitional frameworks, which are the prime impediment to environmental legislation, green technology adoption, and the advancement of the energy system; thus, stable governance with adequate control of corruption is necessary for a successful environmental policy to be implemented.

Against this backdrop, this empirical work aims to observe the impact of policy uncertainty, corruption control, and renewable energy on the CO_2 emissions nexus in BRICS-1[2] economies. The rationale for selecting the BRICS countries is that these are some of the world's most important emerging markets. The BRICS countries individually have remarkably risen the economic ladder. For instance, China achieved second place in the world's economic rankings in 2010 (BRICS, 2017). With a current gross domestic product (GDP) of around US$400 billion, India is the 10th-largest economy in nominal terms and the fourth-largest in purchasing power parity (World Bank, 2010). Brazil became the sixth-largest economy in the world in 2011. Currently, Russia and South Africa are ranked ninth and 26th in terms of economic size. These nations account for around 42% of the world's renewable energy investment and are amongst the ten largest energy consumers

[2] BRICS consist of five countries Brazil, Russia, India, China and South Africa. The data on policy uncertainty for South Africa is not available; hence, it is excluded from the panel study, and we named it as BRICS-1 Panel.

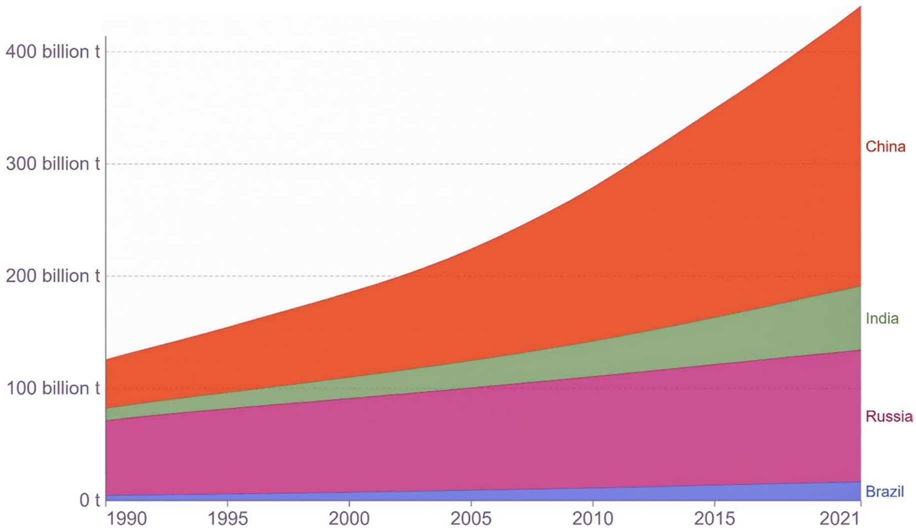

Fig. 2 Cumulative CO_2 emissions in BRICS -1 countries (Global Carbon Project)

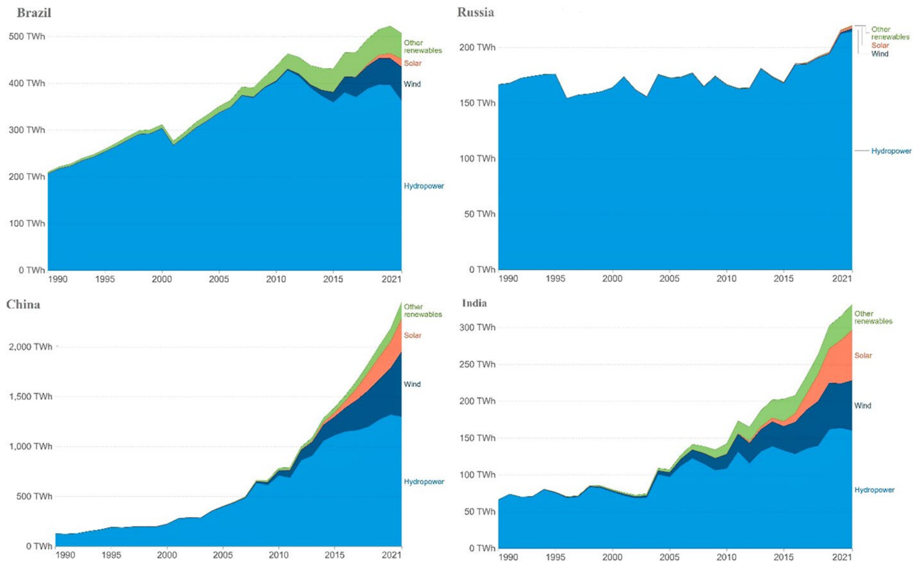

Fig. 3 Renewable energy generation in BRICS-1 countries (British Petroleum, Statistical Review of World Energy 2022. Retrieved from: https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html))

and producers of greenhouse gases (World Bank, 2021). Figure 2 shows the cumulative CO_2 emissions, and Fig. 3 presents the renewable energy generation in BRICS-1 countries. In addition, BRICS has positively impacted the global economic system due to their coordinated actions within international institutions and has emerged as the driving force for global economic recovery and governance by providing momentum to worldwide market collaboration (Iqbal, 2022).

Given the above assertions, examining the enduring connection among policy uncertainty, corruption, renewable energy and CO_2 emissions is pertinent. The rationale for conducting this study is rooted in the observation that policy uncertainty and corruption have had a detrimental impact on ecological systems, posing significant challenges to the advancement of sustainable growth. Notwithstanding the significance of the relationship between policy uncertainty, corruption and environmental quality, the existing body of literature on this subject is limited in scope. The predominant dwell of the earlier research is on analyzing a one of these factors considering the energy-emissions nexus. For example, Amin and Dogan (2021), Adedoyin and Zakari (2020), and Xue et al. (2022) analyzed country-specific data of China, UK, and France, respectively, whereas Khan et al. (2022) and Syed et al. (2022) considered Asian countries and BRICST to investigate the impacts of uncertainties in economic policies on the environment. Similarly, the linkages of corruption with environmental quality is studied by Zhao et al. (2023) for China, Ganda (2020) and Leal and Marques (2021) for African countries, and Sinha et al. (2019) for BRICS and N-11 states. However, none of these studies considered both the regulatory and intuitional factors in a single framework particularly for BRICS economies. Thus, this study is novel in its contribution by considering the role of both, policy uncertainty and corruption control, as regulatory and intuitional elements in combatting the global climate change issues considering the BRICS-1 panel that is a prominent consortium of developing nations in the world.

This study contributes to the extant literature on the environment and energy in the following ways. First, to our knowledge, this is the maiden study investigating the pooled effects of renewable energy, government regulatory factor (policy uncertainty), and the institutional element (corruption control) on eco-sustainability, confirming their environmental consequences, particularly in BRICS-1 countries. Second, there has been an uptick in advocates for innovation and investment in renewable energy since COP26 and COP27 ended, calling for more empirical evidence to support these claims. Therefore, this research adds to the discussions on the BRICS-1 embracing renewable energy toward green energy transition and ecological sustainability. Third, there is a contradiction between the studies on how policy uncertainty affects CO_2 emissions, and no research has explicitly identified corruption as a possible factor in such conflicting conclusions. The current analysis is, therefore, the first step toward a quantitative evaluation of the influence of corruption in policy uncertainty and CO_2 emissions linkages. Moreover, it is unclear from earlier studies whether refining corruption control measures lead to improved environmental quality in BRICS-1. To combat climate change, policymakers would be guided to adopt new methods for enforcing environmental regulations concerning the degrees of corruption and affluence. The existence of such effects and their significance and scope are practical problems that must be addressed. Fourth, the current study employs sophisticated econometric tools such as cross-sectionally augmented autoregressive distributed lag (CS-ARDL), cross-sectionally augmented distributed lag (CS-DL), common correlated effects mean group (CCEMG), augmented mean group (AMG) regression, and Dumitrescu and Hurlin (D-H) causality approaches. These approaches can manage the integrated analytical framework of the study and resolve some statistical and econometric problems, in contrast to the majority of statistical approaches, such as accounting for the issue of cross-sectional dependence, endogeneity, and heterogeneity in the model to capture the actual effects.

This research examined yearly panel data of BRICS-1 nations from 1990 to 2020, analyzed it using the CS-ARDL approach, and proposed several intriguing and intuitive conclusions that add to the current literature. The findings indicate that policy uncertainty discourages long-term efforts to reduce environmental emissions, which is consistent with the prevailing literature. This impact is attributed to the hindrance of environmental laws, the reduction in renewable energy and new technologies, and the decrease in energy and environmental research and development initiatives that ultimately contribute to increased environmental pollution. The research additionally discovered that implementing corruption control measures plays a role in mitigating atmospheric emissions ascribed to the government's policy execution approach and enforcing stringent regulatory frameworks. This could be attributed to the potential of anti-corruption efforts to prevent the wasting of resources. In tandem with expectations, results show that switching to renewable energy sources assists in reducing emissions in the long run. Finally, the inverted U-shaped EKGC hypothesis, which states that the environmental costs associated with economic expansion are enormous at initial stages but decrease as a country's GDP rises, is supported by panel regression, lending credence to the EKGC theory and reassuring policymakers in these countries. Moreover, the causal analysis illustrates bidirectional causation among CO_2 emissions, economic growth, and control of corruption, while unidirectional causation is observed from CO_2 emissions to renewable energy and from policy uncertainty toward carbon emissions.

The rest of this research is organized as follows: Section 2 provides an overview of the literature review, whereas Sect. 3 describes the theoretical framework, model, data, and econometric techniques. The results and discussions are demonstrated in Sect. 4, while Sect. 5 outlines the conclusion and policy recommendations.

2 Literature review

2.1 Renewable energy and carbon emissions

More than two decades of studies have shown that energy usage causes CO_2 emissions and climate change issues in several countries, and many of these nations have tried alleviating these issues by pushing renewable energy sources to meet their power demands while protecting the planet. The importance of renewable energy in reducing emissions and resource depletion and promoting environmental and economic sustainability is widely recognized in the literature (Musah et al., 2021; Rahman et al., 2022; Sadiq et al., 2023; Usman & Radulescu, 2022) Renewable energy may reduce resource extraction, contaminated waste, and environmental degradation while preserving natural resources and improving circular commodity supply in transitioning to a circular and sustainable economy (Pukšec et al., 2019). Nathaniel et al. (2020) discovered that renewable energy has insignificant reducing effects on CO_2 emissions in African countries; however, country-specific results suggested varying impacts on emissions depending on the renewables level. Lanre Ibrahim et al. (2022) also examined the current scenario in African nations and determined that prioritizing investment in renewable energy is a crucial policy recommendation for mitigating environmental pollution. Similarly, Usman and Makhdum (2021) hypothesized that expanding renewable energy usage would reduce the ecological impact and greatly enhance atmospheric quality over time in BRICS-T nations. Sun et al. (2022) and Ehigiamusoe and Dogan (2022) studied the association between renewable energy and related emissions in the MENA and low-income nations, respectively, arguing that renewable energy decreases energy-related environmental effects and is the optimal solution for reducing environmental degradation. Recently, Wang et al. (2023) analyzed panel data from 14 developing European Union nations from 1995 to 2020. Their findings suggest that renewable energy sources favorably impact mitigating environmental degradation, while nonrenewable energy sources have adverse effects resulting in increased environmental deterioration. Likewise, Jahanger et al. (2023) conducted empirical studies which found that nonrenewable energy usage had a significant impact on hastening environmental harm, whereas renewable energy had a mitigating effect on ecological damage in Pakistan economies. However, Farhani and Shahbaz (2014) indicated that more renewables usage increases CO_2 emissions in MENA nations, while Xue et al. (2022) discovered that renewable and clean energies did not contribute to lowering environmental impact significantly.

2.2 Policy uncertainty and carbon emissions

Economic policy uncertainty potentially affects environmental regulations, economic production, and corporate business operations regarding investment and consumption choices intimately connected to climate change and CO_2 emissions (Adams et al., 2020). Additionally, the unpredictable regulatory framework and increased investments in traditional energy that result from an uncertain economic policy diminish the usage and investment in renewable energy sources, a crucial factor in environmental sustainability (Yi et al., 2023). Amin and Dogan (2021) theorized that increased policy uncertainty reduced the government's focus on implementing environmental protection regulations and climate initiatives, which induced a carbon emissions spike in China. Prior research by Adedoyin and Zakari (2020) using country-specific data from 1985 to 2017 for the United Kingdom revealed that economic policy uncertainty moderated the energy usage impacts on the environment and significantly reduced harmful emissions in the short but upsurges in the long term. Utilizing the augmented ARDL approach, Xue et al. (2022) inspected the impacts of economic policy uncertainty on ecology in France from 1987 to 2019 and uncovered that it presents a danger to ecological sustainability by increasing CO_2 emissions over the long term. Danish et al. (2020) acknowledged that policy uncertainty undermined energy conservation measures owing to lax regulation and disclosed that it impaired atmospheric quality by driving up energy consumption and amplifying the deleterious energy intensity effect on CO_2 pollution in the USA. Khan et al. (2022) hypothesized that policy uncertainty influences the environment with increased carbon emissions in East Asian nations directly via policy modification and indirectly via market demand impact. Syed et al. (2022) assessed the role of policy uncertainty on environmental quality in BRICST nations, and their findings showed that uncertainty related to economic policies harms environmental quality and increases CO_2 emissions. Similarly, the CS-ARDL results of Zhou et al. (2022) confirmed the deteriorating effects of policy uncertainty on the ecological quality of the top five carbon-emitting countries. In contrast, Ahmed et al. (2021) studied the nonlinear impacts of renewable technologies and policy uncertainty in the USA. They clinched that both positive and negative shocks in policy uncertainty are beneficial in reducing carbon emissions, with the negative changes playing a more pervasive and dominating effect. Similarly, the bootstrap ARDL analysis of Syed and Bouri (2021) showed that policy uncertainty led to emissions reduction in the US over time; hence, reducing PU would not decrease CO_2 emissions.

2.3 Corruption and carbon emissions

Strong institutions can formulate and revise tactics and financial allocations that promote environmentally conscious advancements, fundamental low-carbon components, and adaptable climate practices. Enhanced institutional quality has been found to alleviate environmental stress and is a crucial factor in bolstering economic, governance, and social preparedness to mitigate the impacts of global warming (Makhdum et al., 2022). Corruption is frequently seen as a destabilizing institutional factor with adverse environmental effects. Previous studies asserted that corruption impacts eco-legislative stringency; for instance, bribery alters policy in corruptible cultures and impedes law enforcement, enabling polluters to dodge accountability for their actions or promoting the depletion of natural resources (Haseeb & Azam, 2021). Azam et al. (2021) and Jahanger et al. (2022) contended that the quality of institutions is crucial to environmental sustainability, and tight institutional rules and effective methods may compel enterprises to adhere to emission reduction laws. Zhang et al. (2016) studied the consequence of corrupt practices on the environment in the Asia–Pacific Economic Cooperation (APEC) region from 1992 to 2012. The authors concluded that corruption negatively affected low-emissions countries but had an insignificant influence on high-emissions nations. Muhammad and Long (2021) highlighted that corruption control is crucial for reducing carbon emissions and enhancing ecological integrity regardless of economic level. Likewise, Ganda (2020) demonstrated the damaging effects of corruptible activities on the local habitat and highlighted that corruption worsened sustainability practices which are among the fundamental causes producing considerable environmental harm in Southern African nations. Sinha et al. (2019) observed that corruption exacerbated carbon pollution by diminishing the benefits of renewable energy usage on ecological quality and magnifying the adverse influence of nonrenewable energy usage in the BRICS and N-11 nations. Wang et al. (2018) concluded that corruption control decreased CO_2 emissions in BRICS nations and moderated and inhibited the detrimental impacts of growth on the environment, indirectly reducing CO_2 emissions. Sahli and Rejeb (2015) asserted that the growth of corruption intensity damaged the country's GDP and productivity, leading to poor living conditions and the government's ability to govern the environment's overall quality. Rehman et al. (2012) signified that corruption impacts the environment adversely by postponing the EKGC threshold point for ASEAN nations. Zhao et al. (2023) found that corruption positively triggers atmospheric emissions directly and indirectly via market division in China and suggested institutional mechanisms to reduce haze pollutants by bolstering performance evaluations and cracking down on corrupt practices. Moreover, Xie et al. (2023) expounded upon the mechanism by which corruption impacts environmental pollution in provinces of China through the lens of resource distribution. Their results revealed that corruption is a significant but overlooked factor in carbon emissions, with its positive effects stemming from the misallocation of resources, which is especially prevalent in regions with lax environmental legislation and limited marketization processes. However, Leal and Marques (2021) reported no evidence of the direct effects of corruption on environmental deterioration and proposed that strict controls might limit corruption and prevent the transfer of polluting businesses.

To sum up, the relationship among renewable energy, policy uncertainty, control of corruption, and CO_2 emissions is a central topic of debate in the existing literature. The mechanism for policy uncertainty and control of corruption functions in the renewable energy-emissions nexus is complicated, regardless of whether or not pollution is reduced. Few investigations on such evidence are now accessible, and the outcomes of existing studies concentrating on these interconnections are ambiguous and sparse due to considering one of the two critical factors. In addition, in the context of BRICS-1, such evidence was neglected. Due to limited inquiry between underlying factors, inconclusive results, shortcomings in methodology, and insufficient evidence in a particular group of nations, this study probed the impacts of policy uncertainty, control of corruption, and economic growth on carbon emissions considering renewable energy for BRICS-1 countries.

3 Methodology

3.1 Theoretical framework and empirical model

The global sustainable development initiative aspires to advance the lives of the citizens by demoting emissions to the bare minimum in the context of present awareness of the catastrophic effects of climate change on human life as a consequence of a continual rise in CO_2 emissions (Usman & Balsalobre-Lorente, 2022). Similarly, a conscious effort to provide affordable and sustainable power to a rising population is a critical global objective that promotes economic expansion and environmental sustainability (Akadiri et al., 2020). Due to mounting apprehensions about the ecological and health hazards of fossil energy sources, fuel price volatility, and climate change, nations worldwide have set goals to increase renewable energy usage as a critical remedial tool for emissions reduction that has the potential to provide cost-effective and environmentally friendly energy (Awan et al., 2022; Rahman & Vu, 2020). Adopting renewable energy sources may improve air quality, adequate energy security, and more lasting and viable community development projects (Zheng et al., 2021). In addition, using renewable energy for manufacturing operations and residential usage may accomplish industrial efficiency and sustainable economic development with reduced CO_2 emissions (Bashir et al., 2022).

However, several elements make it challenging to adopt a green energy portfolio and decrease CO_2 emissions, such as corruption and uncertainty in economic policy, which are counterproductive to enforcing environmental legislation. Corruption raises socioeconomic and environmental costs due to weak institutions and rent-seeking attitudes toward administrative procedures (Wang et al., 2018). Institutional corruption and lousy governance permit foreign investment to introduce and transfer obsolete and polluting technologies that lead to environmental degradation (Liu et al., 2021). Moreover, corruption leads to poor environmental law enforcement, reduced eco-stringency policies, and weak environmental authority accountability, all resulting in increased carbon pollution (Yao et al., 2021). On the other hand, corruption control can strengthen the country's environmental protection laws. Similarly, economic growth and, by extension, energy usage and the environment are greatly impacted by economic policy uncertainty since economic activity is typically assumed to follow the course of power usage, especially when a country is dependent on energy (Adams et al., 2020). This uncertainty refers to changes in monetary policy, fiscal policy, and tax regulations that impact the course of government policy (Baker et al., 2016). Research and innovation in renewable energy can be stymied by such policy uncertainty, which over time, accelerates environmental degradation (Zhou et al., 2022). Additionally, a rise in PU may cause the government to halt addressing ecological threats, impacting the implementation of environmental regulations and climatic quality (Amin & Dogan, 2021).

Moreover, income has an active role in the environmental quality of any country. Although economic expansion leads to using nonrenewable energy that threatens the environment, with increased earnings, people spend more on environmental protection and reducing pollution's detrimental impacts (Sultana et al., 2022a). In addition, the EKGC theory predicts that with incomes rising, nations prefer transitioning to renewable energy and boosting technological advancements that might lead to increased productivity and industrial efficiency while reducing carbon pollutants (Balsalobre-Lorente et al., 2018). Thus, economically integrated environmental modeling may improve awareness of alternatives emerging from environmental actions and explain how economic structural changes affect ecological systems and natural resource preservation (Shinwari et al. 2023).

The theoretical framework and literature gap lead this research to investigate the connection between CO_2 emissions, RE, PU, CORR, and GDPPC. The baseline model for the variables in the study may be noted as follows:

$$CO_2 = f(GDPPC, RE, PU, CORR) \quad (1)$$

The data series is normalized by transforming all variables into natural logarithms and regression coefficients to be interpreted as elasticities to avoid heteroskedasticity and outliers' effects. In addition, this research utilized $GDPPC^2$ (the square term for economic growth) to determine whether or not the EKGC theory is pertinent for the BRICS-1 nations. Therefore, the log-converted empirical form of Eq. (1) is presented in Eq. (2):

$$Ln(CO_2)_{it} = \beta_0 + \beta_1 LnGDPPC_{it} + \beta_2 LnGDPPC_{it}^2 + \beta_3 LnRE_{it} + \beta_4 LnPU_{it} + \beta_5 LnCORR_{it} + \mu_{it} \quad (2)$$

where CO_2, GDPPC, $GDPPC^2$, RE, PU, and CORR are the symbolizations of carbon emissions, economic growth, the square of economic growth, renewable energy, policy uncertainty, and the control of corruption. β_1–β_5 are the corresponding slope coefficients of parameters. The subscripts t is the analysis period (1990–2020), i signifies the cross-sections (1–4), β_0 is the intercept, and μ is the stochastic disturbance term.

3.2 Data and descriptive statistics

The primary purpose of this empirical work is to estimate the effect of renewable energy (RE), policy uncertainty (PU), control of corruption (CORR), and economic growth (GDPPC) on the CO_2 emissions of BRICS-1 economies (Brazil, Russia, India, and China) between 1990 and 2020.[3] Due to data nonavailability for PU variable, South Africa is excluded from the BRICS panel study. Table 1 provides information on variables, data sources, and units of measurement. Table 2 includes the descriptive summary of the series in logarithmic form. The probability of Jarque–Bera statistics illustrates that the data series poses normal distribution, leading the study to follow linear regression estimation. A graphical description of the variables is presented in Fig. 4.

[3] The period is based on data availability. All variables' data are annually except for PU, which is monthly. Therefore, the monthly PU data are transformed to annual frequencies using the average observation technique in EViews.

Table 1 Description of variables and sources of data

Variable	Acronym	Measurement unit	Sources of data
Carbon emissions	CO_2	Metric tons per capita	World Development Indicator World Bank[a]
Economic growth	GDPPC	Gross domestic product per capita (constant 2015 US$)	World Development Indicator World Bank
Renewable Energy Consumption	RE	Percentage of total primary energy	World Development Indicator World Bank
Policy Uncertainty	PU	Economic policy uncertainty index	Economic Policy Uncertainty Database[b]
Corruption	CORR	Control of corruption index	World Governance Indicator World Bank[c]

[a]See for data: https://databank.worldbank.org/source/world-development-indicators

[b]See for data: https://www.policyuncertainty.com/

[c]See for data: https://databank.worldbank.org/source/worldwide-governance-indicators#

Table 2 Results of descriptive statistics

	$LnCO_2$	LnGDPPC	LnRE	LnPU	LnCORR
Mean	1.124688	8.206804	2.962377	4.588680	− 0.472618
SD	0.938759	0.946260	1.075630	0.582627	0.356640
Skewness	0.211127	− 0.687438	− 0.742494	0.233702	− 0.496455
Kurtosis	1.654399	1.958306	1.872206	3.030008	2.317028
Jarque–Bera	10.27618	15.37295	17.96505	1.133393	7.503652
Probability	0.105869	0.291459	0.126760	0.567397	0.234751
Observations	124	124	124	124	124

3.3 Econometric approaches and techniques

The model in this study is estimated using a panel econometric approach. The steps in the methodological approach are presented in Fig. 5. The following section details the step-by-step process for the various techniques, including cross-sectional dependence (CSD) and slope coefficient heterogeneity (SCH) tests, unit root tests, cointegration techniques, regression estimators, and causality between these variables.

3.3.1 CSD and SCH testing

In panel data econometrics, examining panel CSD and SCH is critical since the investigated panel (BRICS-1) may share similar characteristics while being distinctive in other dimensions, assuring unbiased results and selecting a suitable estimation strategy. The rise of globalization resulted in a more interconnected and interdependent global economy, creating certain economic complexities and social assimilation among countries. This initiates common factors and spillover effects among countries caused by policy and events shocks, such as the current COVID-19 pandemic and the Russia–Ukraine conflicts, due to which the panel data variables and residuals are more likely to be correlated across cross-sectional

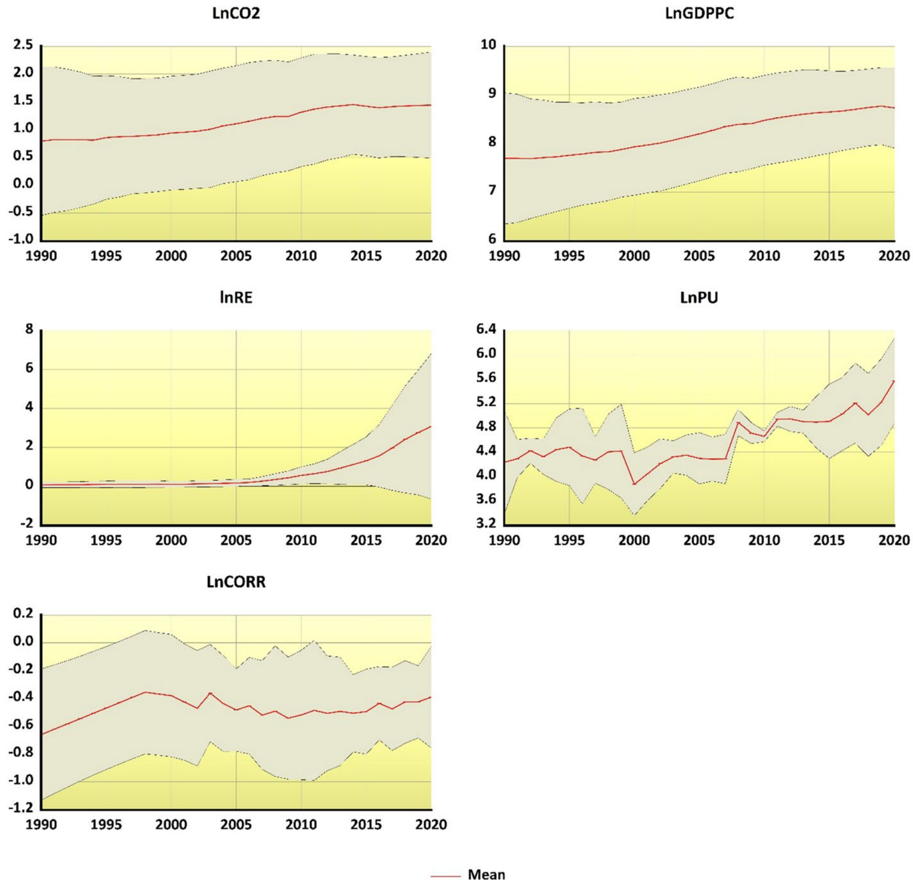

Fig. 4 Graphical demonstration of variables

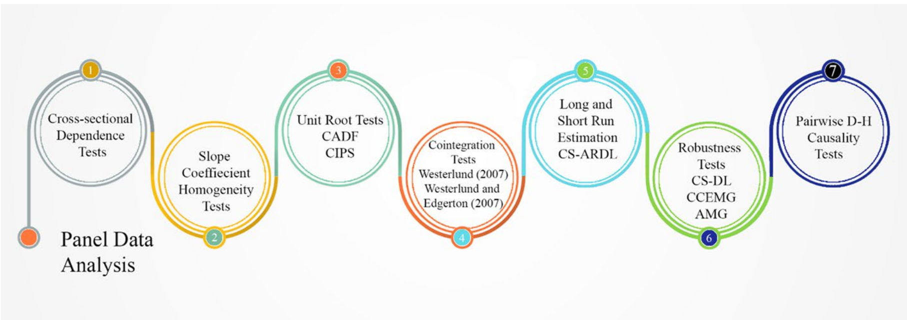

Fig. 5 Steps in econometric approach

elements. Hence, this study utilized the Breusch and Pagan (1980) Lagrange multiplier (LM_{BP}) and the Baltagi et al. (2012) bias-corrected scaled LM (SLM_{BC}) tests to corroborate

CSD in variables, considering $T > N$ in the studied panel. The LM_{BP} and SLM_{BC} test statistics under the H_0 of no cross-sectional dependence are ascertained as:

$$LM_{BP} = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^2 \tag{3}$$

$$SLM_{BC} = \sqrt{\frac{1}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \left(T\hat{\rho}_{ij}^2 - 1 \right) \right) - \frac{N}{2(T-1)} \tag{4}$$

where $\hat{\rho}_{ij}^2$ denotes the cross-countries correlation components. The Pesaran (2004), Frees (1995), and Friedman (1937) tests were employed to determine the existence of CSD in model residuals. Besides, the studied panel may have heterogeneous characteristics relating to their economies, energy supplies, population growth, and corruption control. The SCH that reflects country-specific variations in the cross-sectional units is endorsed by using the Pesaran and Yamagata (2008) slope homogeneity procedure estimating two test statistics ($\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$) under the H_0 of homogenous slope coefficients and are generally expressed as:

$$\tilde{\Delta} = (N)^{\frac{1}{2}} (2k)^{-\frac{1}{2}} \left(\frac{1}{N} \tilde{S} - k \right) \tag{5}$$

$$\tilde{\Delta}_{adj} = (N)^{\frac{1}{2}} \left(\frac{2k(T-K-1)}{T+1} \right)^{-\frac{1}{2}} \left(\frac{1}{N} \tilde{S} - 2k \right) \tag{6}$$

where $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$ represent the slope homogeneity and biased-adjusted slope homogeneity statistics, respectively. Proving CSD and SCH leads to applying second-generation econometric procedures in subsequent steps.

3.3.2 Testing for stationarity

This study applied the cross-sectional augmented IPS (CIPS) and Cross-sectional ADF (CADF) tests designed by Pesaran (2007) to assess the stationarity of the data series since the standard unit root tests do not account for CSD and are prone to size bias. In the CADF test, the ADF regression is extended using cross-section means of lagged and first differences of the observed variable across panel units to account for CSD and SCH. The CADF statistics under the H_0 of homogeneous non-stationarity can be formulated in the following econometric form:

$$\Delta v_{it} = \alpha_i + \beta_i v_{i,t-1} + \delta_i \overline{v}_{it-1} + \lambda_i \Delta \overline{v}_{it} + \varepsilon_{it} \tag{7}$$

where $\overline{v}_{it-1}$ is the lagged variable cross-sectional average, and $\Delta \overline{v}_{it}$ is the variable first difference cross-sectional average. The CIPS test is represented as the cross-sectional mean of each CADF test:

$$CIPS = \frac{1}{N} \sum_{i=1}^{N} t_i(N, T), \text{ where, } t_i(N, T) = CADF. \tag{8}$$

3.3.3 Panel cointegration test

After evaluating the variables' stationarity properties, the Westerlund (2007) error correction and Westerlund and Edgerton (2007) LM bootstrap panel cointegration tests were used. The primary advantages of these approaches are that they consider CSD and slope heterogeneity and provide consistent conclusions in small samples. The Westerlund (2007) test is created on the error correction concept and includes the leads and lags in the cointegration equation, to which often the results are sensitive within a short time frame and can be expressed under the H_0 of no cointegration in the following form:

$$\Delta(CO_2)_{it} = \delta_i' d_t + \partial_i (CO_2)_{i,t-1} + \lambda_i' (CO_2)_{i,t-1} + \sum_{j=1}^{pi} \partial_{ij} \Delta(CO_2)_{i,t-1} + \sum_{j=-qi}^{pi} \gamma_{ij} \Delta x_{i,t-1} + \varepsilon_{it} \tag{9}$$

where d_t is the deterministic factor, δ' is the vector parameter, and ∂_i labels error correction term. pi and qi are the lags and leads. Westerlund and Edgerton (2007) allow for autocorrelation and heteroscedasticity in the equation based on bootstrap methods and can be computed under the H_0 of cointegration as follows:

$$LM_N^+ = \frac{1}{NT^2} \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{\omega}_i^{-2} S_{it}^2 \tag{10}$$

where S_{it}^2 signifies the partial sum process and $\hat{\omega}_i^{-2}$ estimates the residual long-run variance.

3.3.4 Panel regression estimation and causality testing

The potential long- and short-run impacts of economic growth, renewable energy, policy uncertainty, and corruption on CO_2 emissions were investigated using CS-ARDL econometric method pioneered by Chudik and Pesaran (2015). The CS-ARDL is an augmented edition of the standard ARDL method, integrating cross-section means of variables and their lagged values. Below is the generic CS-ARDL model:

$$(CO_2)_{i,t} = \alpha_i + \sum_{j=1}^{p} \lambda_{ij} (CO_2)_{i,t-j} + \sum_{j=0}^{q} \delta_{ij}' x_{i,t-j} + \sum_{j=0}^{K} \varphi_{ij}' (\overline{Z_{i,t-j}}) + \varepsilon_{it} \tag{11}$$

The execution of the CS-ARDL framework was motivated by its many benefits over standard regression analysis in supervision cross-sectional dependence, slope heterogeneity, and endogeneity in the chorus (Chudik et al., 2017). The CS-ARDL method controls the effects of unobserved mutual components by adopting the panel ARDL modeling of the Pesaran (2006) technique by taking the lagged dependent parameter as a weakly exogenous variable. Similarly, this algorithm substitutes cross-section averages of the observed indicators and their lags for unobserved factors, effectively capturing the CSD under slope heterogeneity and parameter endogeneity assumptions. Moreover, it can produce robust estimates in $T > N$ panels, regardless of whether the variables are integrated with different orders, and account for sample selection bias. The error correction pattern of CS-ARDL, including error correction term (ECT), long- and short-run dynamics, and the cross-sectional means of the long and short run for each variable of interest can be written as:

Table 3 Results of CSD and SCH tests

CSD tests in panel variables					
Tests	$LnCO_2$	LnGDPPC	LnRE	LnPU	LnCORR
LM_{BP}	80.08283*	146.1084*	64.62145*	27.67296*	24.09135*
SLM_{BC}	21.31920*	40.37914*	16.85589*	6.189777*	5.155856*

CSD tests in panel data residual			
Model	Pesaran (2004)	Frees (1995)	Friedman (1937)
$CO_2 = f$ (GDPPC, GDPPC^2, RE, PU, CORR)	− 3.473*	1.834*	11.665*

SCH tests		
Model	Delta (Δ)	Adjusted delta (Adj Δ)
$CO_2 = f$ (GDPPC, GDPPC^2, RE, PU, CORR)	10.573*	12.016*

CSD H_0 is cross-sectional independence; SCH H_0 is homogenous slope coefficients; * indicates $P < 0.01$

$$\Delta(CO_2)_{i,t} = \alpha_i + \xi_i\left((CO_2)_{i,t-1} - \varpi_i' x_{i,t-1}\right) + \sum_{j=1}^{p-1} \lambda_{ij}^{*}\Delta(CO_2)_{i,t-j} + \sum_{j=0}^{q-1} \delta_{ij}'^{*}\Delta x_{i,t-j} + \sum_{j=0}^{K} \varphi_{ij}'(\overline{Z_{i,t-j}}) + \sum_{j=1}^{p-1} \psi_j \overline{\Delta(CO_2)_{t-j}} + \sum_{j=0}^{q-1} \zeta_j \overline{\Delta x_{t-j}} + \varepsilon_{it} \tag{12}$$

where $\xi_i\left((CO_2)_{i,t-1} - \varpi_i' x_{i,t-1}\right)$ denotes the long-term link between CO_2 emissions and explanatory variables and ϖ' signifies long-term scalar elasticities. ξ_i is the error correction element. The short-run dynamic of the dependent variable is represented by $\Delta(CO_2)_{i,t-j}$ and regressors by $\Delta x_{i,t-j}$. $\overline{Z} = (\overline{(CO_2)_{t-j}}, \overline{x_{t-j}})$ is the long-run the cross-sectional means of the dependent factor $(\overline{(CO_2)_{t-j}})$ and model covariates $(\overline{x_{t-j}})$. $(\overline{(CO_2)_{t-j}})$ and $(\overline{x_{t-j}})$ are the short-run cross-sectional means of dependent and regressors factors, respectively.

The CS-ARDL estimation was validated using the proposed CS-DL model (Chudik et al., 2016), the CCEMG model (Pesaran, 2006), and the AMG model (Eberhardt & Bond, 2009) as robustness tests considered resilient in panel CSD, endogeneity, and parameter slope heterogeneity. Finally, this research exercised the Dumitrescu and Hurlin (2012) panel causality check under the H_0 of homogenous non-causality to evaluate the causal relationship between observed factors, providing policymakers with more information to draft regulatory frameworks.

4 Results analysis and discussions

The empirical analysis examines the CSD and SCH first; the corresponding outcomes are displayed in Table 3. The H_0 assuming cross-country independence is rejected based on the significance of the p-values at 1% for these tests. The significance of the LM_{BP} and SLM_{BC} tests confirms the cross-sectional dependency of the underlying indicators, and the significance of the Pesaran, Frees, and Friedman tests validate the CSD for the model residual, revealing interdependence and spillover effects from any shocks among the BRICS-1

Table 4 Results of CIPS and CADF

Variables	CIPS		CADF	
	Level	Difference	Level	Difference
$LnCO_2$	− 1.209	− 3.009*	− 1.893	− 3.492*
LnGDPPC	− 2.066	− 3.460*	− 2.196	− 3.761*
LnRE	− 1.438	− 3.090*	− 2.093	− 2.945*
LnPU	− 2.130	− 4.826*	− 2.124	− 4.237*
LnCORR	− 1.578	− 3.859*	− 1.735	− 2.697*

Table 5 Results of cointegration tests

Westerlund (2007)			
Statistics	Value	Z-value	Robust *P*-value
Gτ	-3.125*	−0.239	0.000
Gα	-5.378	3.013	0.500
Pτ	-6.936*	−1.370	0.000
Pα	-8.578*	1.575	0.000
Westerlund and Edgerton (2007)			
Constant		Constant & trend	
LM-statistic	Bootstrap *p*-value	LM-statistic	Bootstrap *p*-value
4.61309	1.000	7.50563	1.000

H_0 for Westerlund (2007) is No cointegration, and for Westerlund and Edgerton (2007) is cointegration; * indicates $P < 0.01$

countries. Similarly, the SCH findings demonstrate the existence of slope heterogeneity, negating the proposed model's H_0 of slope coefficient homogeneity based on the significance of delta and adjusted delta at a 1% level, indicating that the slope coefficients of GDP, RE, PU, and CORR are heterogeneous among BRICS-1 nations.

Following the CSD and SCH tests, the outcomes of CIPS and CADF unit root applications at the $I(0)$ and $I(1)$ publicized in Table 4 are utilized to confirm the series' stationarity. The data series at $I(0)$ is insignificant, establishing the non-stationarity of all variables. However, the results demonstrate that the H_0 of homogeneous nonstationary variables is rejected at the 1% significance in the $I(1)$. Therefore, these findings conclude that the observed parameters are stationary with homogeneous variance at the first difference having order one integration.

After confirming the first-order integration for all variables, the cointegration analysis was executed to seek long-run linkages among the underlying factors. The testified results in Table 5 divulge that all indicators support the long-term cointegration between variables, with the rejection of H_0 of no cointegration at the 1% significance (Gt, Pt, Pa) in Westerlund (2007) tests. Similarly, the H_0 of cointegration could not be rejected using the Westerlund and Edgerton (2007) tests with insignificant bootstrap *p*-values. Hence, the analysis has conclusively shown the long-run linkages between CO_2 emissions and independent variables (GDPPC, $GDPPC^2$ RE, PU, and CORR).

Table 6 CS-ARDL regression results

Variables	Long-run			Short-run		
	Coefficient	Std. Err	*p*-value	Coefficient	Std. Err	*p*-value
LnGDPPC	1.207*	0.274	0.000	1.984*	0.668	0.003
$LnGDPPC^2$	− 0.783*	0.215	0.000	− 1.029	0.834	0.217
LnRE	− 0.227*	0.052	0.000	− 0.425*	0.124	0.001
LnPU	0.030*	0.007	0.000	0.058**	0.025	0.019
LnCORR	− 0.053*	0.020	0.008	− 0.080**	0.038	0.034
ECT (− 1)				− 0.793*	0.142	0.000

* & ** indicate $P < 0.01$, 0.05, respectively

After validating the existence of cointegration between parameters, the CS-ARDL regression measures the degree of the long- and short-term association of CO_2 emissions with its drivers. The empirical findings and pragmatic implications of the CS-ARDL estimation are summarized in Table 6. The results demonstrate that economic growth (LnGDPPC) positively and statistically significantly influences CO_2 emissions, but the squared GDP ($LnGDPPC^2$) has a negative and statistically significant effect. Initially, a 1% increase in economic growth leads to a 1.25% upsurge in CO_2 emissions per capita, and after a threshold point, it decreases CO_2 emissions per capita by 0.73%; thus, the panel regression sustains the inverted U-shaped EKGC theory for BRICS-1 countries. This conclusion, akin to (Saqib et al., 2022), Liu et al. (2021), and Rahman et al., (2022a), shows that during the initial stages of economic expansion, CO_2 emissions increase steadily, but after income reaches a certain level, CO_2 emissions decrease in BRICS-1 nations. This means that with the rise in growth level, individuals tend to purchase more eco-sustainable commodities, and using more advanced equipment raises fuel efficiency. Additionally, the structural changes brought about by rising incomes make people more conscious of the environment and necessitate the government to enforce eco-friendly policies, culminating in the execution of environmental laws and regulations (Balsalobre-Lorente et al., 2018). Although the BRICS-1 nations have seen structural changes and fast industrialization led by increased economic growth, these countries are yet to achieve carbon neutrality targets and thus must concentrate on reducing CO_2 intensity via increased wealth.

The long-run finding for LnRE reveals that it significantly influences CO_2 emissions, with a 1% expansion in LnRE would decrease CO_2 emissions by 0.22%. This outcome is harmonious with the previous literature (Nathaniel et al., 2020; Rahman & Vu, 2020; Sun et al., 2022; Usman et al., 2021). This finding suggests that a major shift toward energy systems with a high proportion of renewable energy is required to reduce CO_2 emissions and mitigate climate change hazards in BRICS-1 countries. Additionally, enabling effective renewable power use promotes energy conservation and reduces energy poverty by offering new, competitive energy and minimizing the bad bearings of fossil fuels on air sustainability and human wellbeing (Zheng et al., 2021). Using renewable energy may pave the way for net-zero societies, spur economic development, and generate employment.

The positive elasticity of LnPU demonstrates that policy uncertainty has a discouraging impact on environmental emissions reduction in the long term. A 1% intensification of LnPU creates 0.030% atmospheric CO_2 emissions. This result is consistent with the verdicts of Hassan et al. (2022), Amin and Dogan (2021), and Danish et al. (2020),

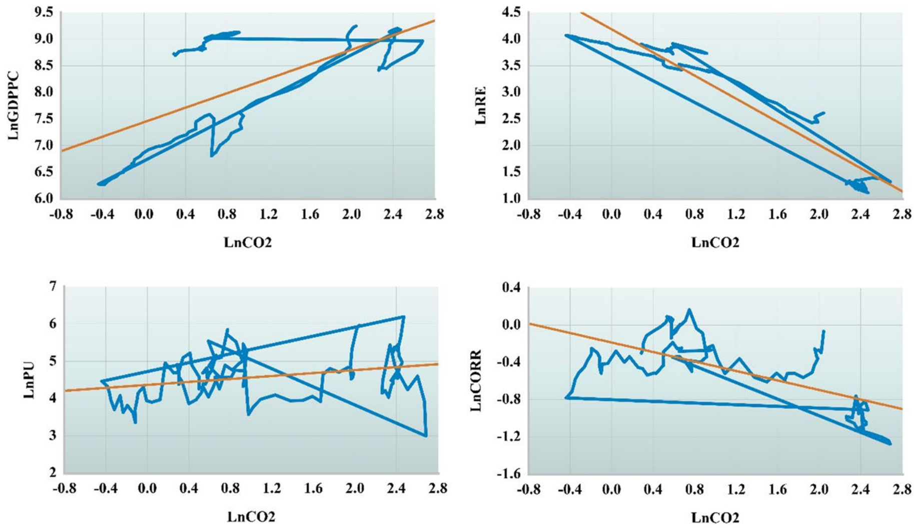

Fig. 6 Association of study variables with CO_2

who found that uncertainties in economic policies and CO_2 emissions had a strong positive association. One reason for growing CO_2 emissions driven by greater economic policy uncertainty in BRICS-1 is that it affects environmental regulations, and unstable environmental rules naturally lead to rising environmental pollution in an economy. Similarly, decreasing renewable energy, new technologies, and R&D may increase CO_2 emissions because of increasing LnPU. Another plausible cause for the damaging effects of the LnPU on the ecosystem is that it promotes firms and manufacturers to use environmentally risky production processes that employ inexpensive and dirty forms of energy, resulting in increased CO_2 emissions. This argument demonstrates that since the climate is tied to corporate strategy and economic situations, a spike in LnPU may result in economic crises and a rise in CO_2 emissions (Adams et al., 2020). However, when EPU falls, the government's focus on implementing environmental protection measures grows, and these environmental-related initiatives will favor the ecosystem.

Finally, the CS-ARDL coefficient of LnCORR in BRICS-1 nations is negative against CO_2 emissions, indicating that corruption control contributes to reducing atmospheric emissions. An increase of 1% control in corruption leads to a decrease in CO_2 emissions by 0.053%. Alternatively, this result infers that corruption accelerates environmental deterioration. This effect may be accredited to the government's attitude to policy execution and the adoption of strict rules and regulations, which successfully controls environmental pollution, maybe because curbing corruption aids in preventing resource waste. Corruption generally accelerates economic activities through increased energy consumption and public spending; however, control of corruption moderates and lowers the positive influence of growth on CO_2 emissions (Wang et al., 2018). Moreover, a high degree of corruption increases fossil energy consumption and affects green energy initiatives due to weak energy policy stringency, resulting in a rise in CO_2 emissions. Furthermore, this illegal behavior reduces the quality and efficiency of different projects due to authorities' involvement in economically and environmentally unviable or intentionally low-quality infrastructure projects. The BRICS-1 economies are steadily expanding due to robust regional

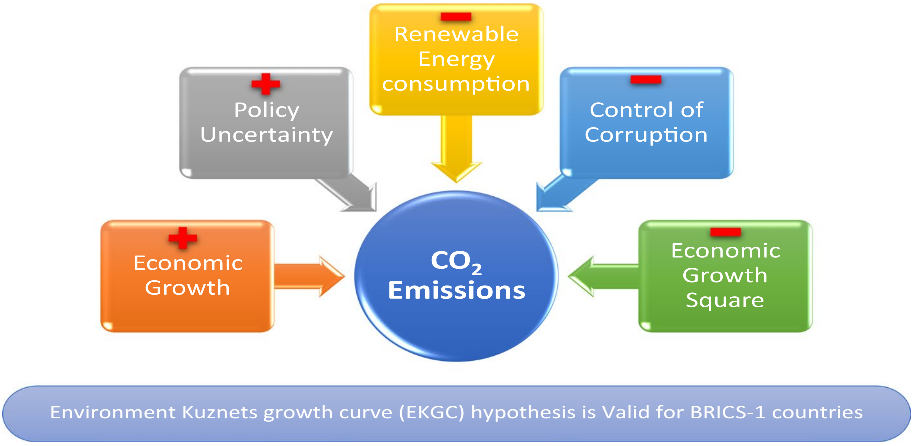

Fig. 7 Graphical presentation of empirical findings

Table 7 Results of CS-DL, CCEMG, and AMG

Regressors	CS-DL		CCEMG		AMG	
	Coefficient	*p*-value	Coefficient	*p*-value	Coefficient	*p*-value
LnGDPPC	1.256**	0.032	1.069***	0.064	1.051**	0.029
$LnGDPPC^2$	− 0.321***	0.084	− 0.361**	0.042	− 0.307***	0.061
LnRE	− 0.423*	0.000	− 0.498*	0.000	− 0.546*	0.004
LnPU	0.074*	0.005	0.039***	0.052	0.051*	0.006
LnCORR	− 0.127*	0.004	− 0.046**	0.048	− 0.070*	0.008

*, **, &*** indicate $P < 0.01$, 0.05, 0.1, respectively

anti-corruption initiatives, and their mature economic systems may regulate illegal activities that harm the environment. Governments enact the proper regulations as the economy grows in response to public awareness of environmental deterioration and to prevent any market distortion that would increase pollution. The result of the study is congruent with earlier scientific literature (Liu et al., 2021; Muhammad & Long, 2021). Figure 6 presents the association of the studied variables with CO_2 emissions. The red line in the figure shows the regression line, and the blue line shows the interaction between the variables. As can be seen in the figure, carbon emissions increase with the increase in the GDPPC and PU and vice versa. In contrast, any increase in RE and CORR lowers carbon emissions in BRICS-1 countries and vice versa.

The short-run findings in Table 6 are identical to the long-run CS-ARDL results. With the positive coefficient of LnGDPPC and the negative coefficient of $LnGPPC^2$, the findings indicate the existence of EKGC. LnRE exhibits the same behavior in the short term as in the long run, demonstrating an inverse relation with CO_2 emissions. Similarly, the LnPU illustrates a statistically significant positive connection with per capita emissions, whereas the LnCORR is significantly negatively associated. In addition, Table 6 displays the negative and very significant ECT_{t-1} coefficients at 1%, which implies model robustness and a long-run stability connection between the modeled indicators. The significant

Table 8 Results of pairwise D-H panel causality

	$LnCO_2$	LnGDPPC	LnRE	LnPU	LnCORR
$LnCO_2$	–	7.4339 4.3949 0.0000*	2.3570 0.1466 0.8834	5.7998 3.0275 0.0025*	4.0570 1.5691 0.0166**
LnGDPPC	4.1800 1.6721 0.0945***	–	2.5031 0.2688 0.7880	5.8757 3.0910 0.0020*	2.5347 0.2953 0.7677
LnRE	2.8846 0.5881 0.0564***	5.8954 3.1075 0.0019*	–	2.8059 0.5223 0.6015	3.7668 1.3263 0.1847
LnPU	2.3931 0.1768 0.8596	3.4717 1.0794 0.2804	3.2331 0.8797 0.0379**	–	6.1784 3.3444 0.0008*
LnCORR	2.9382 0.6329 0.0268**	5.2685 2.5830 0.0098*	2.9463 0.6397 0.0223**	2.4637 0.2359 0.8135	–

H_0 is No Causality; first and second are W-stat and Z-stat and third is the *P*-value; *, **, &*** indicate $P<0.01$, 0.05, and 0.1, respectively

ECT_{t-1} values revealed the swift short transition tendency for $LnCO_2$ to its long-run equilibrium position, with a 79% adjustment speed in one year in reaction to any changes in the underlying components for BRICS-1 nations. The anticipated findings of this study are graphically represented in Fig. 7.

The outcomes of the CS-DL, CCEMG, and AMG estimations, which were utilized to test the robustness of the CS-ARDL estimations, are shown in Table 7. The forecasts for the CS-DL, CCEMG, and AMG models are analogous to the CS-ARDL projections, with the equivalent indications at varying degrees of significance. According to the analysis, GDPPC has a positive and $GDPPC^2$ has a negative coefficient, confirming the inverted U-shaped conventional EKC theory presented in the CS-ARDL results for BRICS-1 countries. Similarly, the CS-DL, CCEMG, and AMG findings for RE, PU, and CORR confirmed the CS-ARDL inferences; RE and CORR resulted in improved environmental quality, and PU is the source of degrading the environment.

Although the CS-ARDL, CS-DL, CCEMG, and AMG estimators have shown the long-run linkage between the regression model, it is still vital to understand the causal relationships between these components to establish appropriate policies. Table 8 illustrates the findings of the paired D-H heterogeneous panel causality test undertaken for this purpose. The findings demonstrate two-way feedback causation between CO_2 emissions, economic growth, and control of the corruption index. In other words, fluctuation in any of these factors will result in variation in the others, i.e., any new legislation related to the environment will affect economic growth and corruption level, and any policy shift related to economic growth and control of corruption will affect environmental quality in this region of the world. In addition, CO_2 emissions have a unidirectional causal relationship with renewable energy, and this result suggests that any changes to environmental laws in BRICS-1 countries would impact renewable energy initiatives.

Similarly, one-way causation runs from policy uncertainty toward carbon emissions, indicating that uncertainties in economic policies directly impact the environmental regulations and quality in these countries. Table 8 also demonstrates that unidirectional causalities run from policy uncertainty and corruption control toward renewable energy. These statistics confirmed that increased policy uncertainty and corruption affect renewable energy projects, which harms economic and environmental sustainability. Discovering the two-way causal relationship between GDPPC- CO_2 and CORR- CO_2 has important implications for legislators to establish appropriate CO_2 emissions reduction strategies. These results, together with the conclusions of the long-term estimations, are helpful for policymakers to effectively reduce carbon pollution by controlling policy uncertainties and corruption and augmenting the energy system with more renewables.

5 Conclusion and policy recommendations

This empirical study probed the linkages of renewable energy, policy uncertainty, and corruption with CO_2 emissions for BRICS-1 countries. The results of this analysis fill the research gap by including the government regulatory factor of policy uncertainty and the institutional element of corruption control in energy-growth-emissions literature for the proposed panel data from 1990 to 2020. The study employs novel panel CS-ARDL and D-H causality approaches for regression estimates and to achieve the empirical objectives. The findings concluded that renewable energy consumption and corruption control support climate change reduction endeavors, whereas policy uncertainty hampered the efforts to reduce CO_2 emissions in BRICS-1 countries. Additionally, CO_2 pollution steadily declines with increasing long-term economic growth, validating the EKGC theory for these nations. Finally, control of corruption and economic growth have a bidirectional causal bond and renewable energy, and policy uncertainty has unidirectional causation with CO_2 emissions.

Based on the inferences, this study puts forward imperious policy implications to support the governments of BRICS-1 countries in scheming ecologically sustainable initiatives and accomplishing sustainable energy targets. First, investments in renewable energy should be reinforced, and policies toward preventing and responding to energy-related climate catastrophes should be bolstered. The policymakers should execute a set of energy policies geared toward short- and long-term development and undertake innovative and targeted renewable energy initiatives to raise the percentage of renewable production. For this purpose, policymakers should boost spending on renewable energy facilities and technologies, expand financing for energy research and development, give subsidies and tax breaks for innovative investments in energy efficiency, and offer institutional support to the corporate sector. Moreover, governments should investigate the people's perspective on energy consumption, give loans to companies and families to encourage renewable usage, and educate the public about the significance of renewable energy via media campaigns and educational curricula.

Second, enhancing corruption control and raising transparency within local governments is crucial to CO_2 emissions reduction and better enforcing environmental laws. Corruption jeopardizes the governance impact of environmental laws and has negative repercussions; hence it must be investigated and prosecuted to improve governance. To enhance the efficiency of diverse institutions, the government must decrease corruption by providing enough institutional support, transparent management, and autonomous judicial authority. Governments must also emphasize the availability of transparent, ethically guided mechanisms that facilitate the transfer of green financing at the national, regional, and worldwide levels. Furthermore, business coalitions aid in the fight against corruption that threatens environmental sustainability. Adopting green economy standards may be aided by corporations actively engaging in sustainable economic activities and increasing environmental information disclosure.

Third, policy uncertainty in the BRICS-1 economies must be reduced to decrease CO_2 emissions. Since the unpredictability of economic policy makes companies hesitant to invest in cutting-edge innovations with the potential to lower their carbon footprint significantly, these nations should endorse growth policies that foster innovations and support investment in renewables and energy-efficient equipment to cut CO_2 emissions. Similarly, policymakers in these nations should be prepared for the environmental implications of exogenous shocks like pandemics and financial turmoil, which increase policy uncertainty. In addition, to control the effects of policy uncertainties on clean energy initiatives, governments should pledge feasible and consistent policies connected to economic and environmental circumstances that encourage investment and use of clean energy, which would mitigate pollution simultaneously.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Consent to publish All authors reviewed and approved the manuscript for publication.

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