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Achieving green environment in Brazil, Russia, India, China, and South Africa economies: Do composite risk index, green innovation, and environmental policy stringency matter?

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Abstract

The Paris Accord has brought the world's governments together to begin implementing plans for their individual economies to become carbon-free. The goal of attaining low-carbon growth is not, however, as simple as it would appear since the world economies, which are dependent on fossil fuels and are fast expanding, are concentrated on accelerating economic expansion at the price of worse environmental effects. In light of this, the study aims to investigate the combined effects of the composite risk index (CRI), green innovation (GINOV), and environmental policy stringency (EPS) on carbon dioxide (CO_2) emissions in the context of Brazil, Russia, India, China, and South Africa (BRICS) countries while controlling for gross domestic product (GDP) and renewable energy research and development (RERD) over the period from 1960 to 2020. The research addresses the problems of cross-sectional dependence and slope heterogeneity in the data set used for analysis by using the second-generation cross-sectionally augmented autoregressive distributed lags framework to evaluate long- and short-run models. The corresponding findings show cointegrating relationships between the research variables. Additionally, the results of the regression demonstrate that EPS, GINOV, and RERD contribute to a long-term decrease in CO_2 emissions. CRI and GDP, however, increase CO_2 emissions. It is suggested that environmental policies be tightened, GINOV and RERD expenditures be promoted, political stability and institutional quality be maintained, and clean economic growth strategies be adopted in order to help the BRICS countries reduce sectoral risks, create a sustainable environment, and decarbonize their respective economies.

KEYWORDS
BRICS economies, carbon neutrality, composite risk index, environmental policy, green innovation, renewable energy research and development

1 | INTRODUCTION

Environmental deterioration is seen as a difficult issue that the contemporary world is now addressing (Udeagha & Breitenbach, 2023a,

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2023c; Udemba, Emir, & Philip, 2022). The earth's environment and way of life are negatively impacted by rising carbon dioxide (CO_2) emissions and temperatures. Extreme weather events are a result of increasing air pollution and worrying CO_2 emissions (Sharif et al., 2023; Udemba, Philip, & Emir, 2022). Because of this, it is believed that climate change poses a major threat to human existence. This is because pollution is continuously added to the atmosphere without consideration for its adverse effects. In addition, the environment has been gravely impacted by increased energy use, population expansion that is happening quickly, and global productivity that is still rising. The Kyoto Protocol in 1997 and the Conference of the Paris (COP21) in 2015 are only a couple of the agreements that have been achieved in recent years to address environmental concerns, identify practical solutions to global warming, and protect the environment (Udeagha & Breitenbach, 2023b, 2023c; Udemba & Alola, 2022). Many countries throughout the world are taking a range of measures to achieve their aim of carbon neutrality. To ensure the transition to post-carbon emissions, countries are making various attempts to offset carbon emissions. Despite these agreements, however, global CO_2 emissions increased at a concerning 2.7% rate in 2018 (Deng et al., 2023).

Due to modern society's constant dependence on fossil fuels, the earth is warming at a rate that has not been seen in the last 2000 years, and its effects are already being felt as record-breaking droughts, wildfires, and floods obliterate towns all over the world (Udemba & Tosun, 2022a). Environmental degradation is a global concern since it affects every country. Countries like Brazil, Russia, India, China, and South Africa (BRICS), Germany, Japan, and the United States are accountable for protecting the environment as significant greenhouse gas (GHG) emitters. Their dedication is vital for lowering global CO_2 emissions. However, lowering CO_2 emissions would lead to decreased output, which would obstruct economic expansion because doing so is linked to energy usage, which is required for it (Udemba & Tosun, 2022b; Zhu et al., 2023). Due to this circumstance, it is extremely difficult for these countries to accept or implement initiatives that are meant to reduce global CO_2 emissions. It is consequently necessary to develop new methods for producing green economic growth and improved environmental circumstances. In this endeavor, several governments from all over the world have employed a variety of tactics to address environmental degradation and global warming (Udeagha & Breitenbach, 2023d). Some of these initiatives—paying close attention to composite risk index (CRI), promoting green innovation (GINOV), and enforcing environmental policy stringency (EPS)—are viewed as helpful strategies to enhance environmental quality.

In order to attain environmental sustainability, an economy's policies must take into account CRI, which is made up of total political risk, total financial risk, and total economic risk (Qin et al., 2021). Each risk consists of many elements listed in Table 1. Economic risk first identifies an economy's strengths and weaknesses. In any situation (economic, political, and financial), the risk is inversely correlated with the total risk point: the higher the point, the lower the risk; the lower the point, the higher the risk. Economic activities that provide possibilities and raise income levels increase with the development of economic growth (Udeagha & Breitenbach, 2023e). As a result of this expansion, economies use more energy to power their domestic industries during a period of transition. Economic development or an increase in income is linked to environmental degradation, according to environmental economists, who also claim that such extreme surges increase carbon emissions and further impair environmental quality. As a result, we anticipate that economic risk and carbon emissions will be positively correlated. The second component of political risk is law and order, as well as the corruption index, government stability, investment profile, and democratic accountability. Policies for carbon neutrality would not be properly implemented if political risk was significant in an economy (Khan et al., 2021). Degradation of the environment results from this. A 12 component economy's political system stability is evaluated using the political risk index. Higher political risk entails more corrupt politicians and weak institutions, as well as weak or unstable institutions of government, low or low rates of education, poverty, and unequal access to resources (Wang et al., 2022). Generally speaking, emerging nations with high political risk face a variety of challenges. For instance, more corrupt authorities may make it possible for unlawful manufacturing to flourish and emissions to increase (Wang et al., 2023). Strong institutions are essential for protecting environmental quality because they impose strict regulations and penalties for any activity involving illegal emissions, even though anti-corruption campaigns are helpful in reducing corruption and subsequently reducing environmental pollution (Amin et al., 2023). Therefore, we anticipate that an economy's political power will be crucial in regulating CO_2 emissions. Third, financial risk gauges a nation's ability to pay for its government's operations, including its obligations under official, commercial, and trade debt (Fu & Zhu, 2023). In conclusion, an economy's productivity and ability to service its debt increase with decreasing financial risk. Furthermore, due to lower financial risk, nations with stable currency rates draw money from abroad. Therefore, we anticipate that increased financial risk may cause CO_2 emissions. The International Country Risk Guide (ICRG) calculates the total of political, financial, and economic risk, or CRI, and it is thought that paying close attention to CRI can assist to enhance environmental quality. Since there is controversy among scholars on the impact of CRI on CO_2 emissions, we decided to undertake this study.

In accordance with Zou et al. (2023), GINOV is an effective instrument for mitigating the environmental harm caused by increased economic activity. The basis for the effectiveness of GINOV is the "creative destruction" theory put forward by Schumpeter in 1942, which contends that established businesses replace unproductive ones through the course of evolution. With the aid of GINOV, countries may employ carbon-free technology, produce commodities that are energy-efficient, and restructure their economic models to focus on cleaner energy sources (Ali et al., 2021; Alola & Adebayo, 2022; Ibrahim, Huang, et al., 2022; Ji et al., 2021; Udeagha & Muchapondwa, 2023a). Reduced environmental harm from increased economic activity is also made possible through environmental innovation. Over the past several years, nations all over the world have been searching for ecologically friendly technology to slow down environmental deterioration (Ibrahim, Ajide, et al., 2022). GINOV, which relates to investments in innovative products, research and development (R&D), and affordable technologies that

TABLE 1 Sub-components of composite risks.

Risk	Political risk	Economic risk	Financial risk
Risk components	Government stability	GDP per-capital	Foreign debt % of GDP
	Socioeconomic conditions	Real GDP growth	Foreign debt as % of export of goods and services
	Investment profile	Annual inflation rate	Current account as % of exports of goods and services
	Internal conflict	Budget balance % of GDP	Net international liquidity as months of import cover
	External conflict	Current account % of GDP	Exchange rate stability
	Corruption		
	Military in politics		
	Religious tensions		
	Law and order		
	Ethnic Tensions		
	Democratic Accountability		
	Bureaucracy quality		

Source: International Country Risk Guide (ICRG).

improve energy efficiency, reduce the use of fossil fuels, increase production capacity, and support economic progress without sacrificing the sustainability of the environment since it provides efficient energy sources, is another effective method of reducing CO_2 emissions that is frequently suggested. However, depending on a country's affluence and pollution levels, GINOV's relevance might vary. By reducing CO_2 emissions, GINOV benefits the environment and the host country's economy. It has been demonstrated that industrial technology employed by multinational businesses is more protective than those utilized by less developed nations. GINOV is now the most efficient strategy for assuring economic growth while lowering emissions and resource depletion because of how effectively it can address environmental issues (Hao & Chen, 2023; Khan, Ali, et al., 2020; Khan, Yu, et al., 2020; Koseoglu et al., 2022; Ma et al., 2022). However, the results of the endogenous growth model demonstrate that environmental innovation is the outcome of continual R&D expenditure. As a result, GINOV and energy investment have a lot in common in terms of CO_2 emissions. In order to foster innovation and alleviate the market failure problem brought on by knowledge spillovers, public assistance for R&D is a very effective strategy. Technical innovation will be required to change the industrial structure from using non-renewable to renewable energy sources, hence public funding for R&D is essential. As Udeagha and Muchapondwa (2023b) pointed out, investing in the energy industry also helps to create a stable climate market and a strong energy infrastructure. Eco-friendly goods and services include water and waste management, recycling, testing, and consulting the environment. Eco-friendly products include eco-homes and climate change mortgages. Improving logistics, increasing resource efficiency, and saving money are a few of the direct operational benefits of GINOV. Examples of indirect gains include advantages for health and safety, improved relationships with authorities and the general public, and a better reputation. GINOV, which is defined as any technique that accomplishes resource conservation and environmental benefit, has been developed in recent years as a crucial concept to promote the creation of a green economy (Onifade et al., 2022; Ramzan et al., 2022; Sharif et al., 2022; Temesgen Hordofa et al., 2023). GINOV supports the transition away from fossil fuel energy and toward renewable energy sources, which can spur economic expansion and mitigate unfavorable environmental impacts. According to the environmental Kuznets curve (EKC) in economic growth, the usage of fossil fuels can lead to environmental pollution, which can produce an inverted U-shape curve (Fang, 2023; Sun & Razzaq, 2022; Zhang & Zheng, 2022). Udeagha and Ngepah (2023a, 2023b) report that prior research suggests that economic expansion spurred on by technology improvements may actually lead to a reduction in CO_2 emissions. Additionally, studies have shown that innovation may lead to increased CO_2 emissions (Onifade et al., 2022). Another source of inspiration for our study in this work is the extensive body of research on the relationship between GINOV and CO_2 emissions.

Capturing the effect of stringency on environmental quality can both help countries quickly reach the EKC income turning point and the early stages of economic development (Ibrahim, 2022a; Li et al., 2023) and inform us of the effectiveness of environmental rules and regulations in reducing carbon emissions. The justifications given above are adequate to show the importance of EPS and its function in lowering CO_2 emissions in the most polluted countries. EPS is one of the most important tools for environmental policy (EP) that has been implemented to address the urgent threat to environmental sustainability and quality. Environmental stringency strives to drive GINOV by seeking to reduce unnecessary externalities like pollution (Shah et al., 2023). Without the stringent application of environmental rules and regulations, it is difficult to promote sustainable growth and green technology. The numerous CO_2 emissions reduction objectives, such as environmental levies and renewable energy, cannot be reached without the implementation of strict environmental laws and regulations as well as tighter GHG policy regimes (Udeagha & Ngepah, 2022a). The availability of the EPS index enables tracking of progress achieved in lowering CO_2 emissions, promoting green energy, and maintaining an environmentally sustainable environment. In order to change consumer and producer attitudes toward eco-friendly products, EPS aims to raise the cost of pollution and climatic services (Udeagha & Ngepah, 2022b). This makes EPS another instrument at a nation's disposal to battle environmental deterioration. To achieve this, regulations on substances that cause pollution can be put in place, which will raise the cost of activities that cause pollution and lessen their appeal. Porter and Linde (1995) started the discussion on the connection between environmental outcomes and environmental regulation. A well-planned EP encourages the industrial sector to use ecologically friendly technology that tend to reduce carbon emissions. By supporting environmentally clean technology and discouraging ecologically “dirty” ones, EPS can minimize the harmful consequences of CO_2 emissions (Udeagha & Ngepah, 2022c). In order to encourage energy usage and production that is more ecologically friendly, EPS thus has the capacity to change consumer and producer behavior. For the aforementioned reasonable reasons, it is important to consider how EPS aids the BRICS countries in lowering their CO_2 emissions. This study's main objective is to narrow this gap by accounting for EPS when calculating CO_2 emissions in the BRICS countries. By assessing the effectiveness of the stringency of environmental rules and regulations, we think we can test the idea that a nation's environmental performance can be linked to the evolution of the severity of its environmental laws and policies.

Our analysis in this paper is motivated by all the aforementioned factors, including the lack of scientific consensus on the relationship between CRI, GINOV, EPS, and CO_2 emissions. The following is a summary of this paper's significant contributions. First, the choice of the BRICS countries is based on their prominence in international discussions and agreements on carbon neutrality target and environmental sustainability (Udeagha & Ngepah, 2022d). Due to rigorous environmental regulations in advanced economies and cheap production costs in developing markets, many companies in developed economies have migrated and transferred their manufacturing units and technology to BRICS economies, which is one of the main reasons for this expanding impact (Udeagha & Muchapondwa, 2022a). These five economies' levels of CO_2 emissions have multiplied as a result of this industrial migration, making the BRICS nations' CO_2 emissions higher than those of other growing economies. Due to these factors, this study intends to give useful policy implications to the region's carbon reduction goals and provides a crucial lesson for the future of the world. The relationship between some factors, such as CRI, GINOV, EPS, and environmental quality has drawn a lot of attention from academics all around the world, which brings us to our second point. Previous studies looked at the relationship between CRI and environmental quality (Khan et al., 2021). A number of research also looked into how GINOV affected environmental quality (Yuan et al., 2022). However, the combined effect of GINOV, EPS, and CRI on environmental quality has typically been disregarded. By examining the impact of CRI, GINOV, and EPS on environmental quality from 1960 to 2020 in the BRICS countries while controlling for economic growth (gross domestic product [GDP]) and renewable energy research and development (RERD), our study seeks to address this gap. Our understanding of how CRI, GINOV, and EPS interact with environmental quality is improved when we model them all at once, and this is a crucial topic for industrialized nations like the BRICS nations dealing with environmental challenges. By concurrently examining the environmental impacts of CRI, GINOV, and EPS, this research specifically contributes to the body of knowledge and advances our understanding of the subject. Third, by adopting the recently constructed Organization for Economic Co-operation and Development (OECD) EPS index as a surrogate for our measure of environmental regulation, we feel that the research offers few contributions to the literature on the link between CO_2 emissions and EPS. The EPS index, which ranges from 0 (not strict) to 6 (very rigorous), is a country-specific and globally comparable indicator of the severity of EP. Fourth, previous empirical research produced inconsistent estimate findings because it failed to address the crucial problems of slope heterogeneity and cross-sectional dependence in panel data. This study employs recently developed econometric methods that can manage both problems, taking into account advanced panel data techniques that are resistant to the aforementioned econometric obstacles and filling in important knowledge gaps. Last but not least, the study aims to provide helpful policy recommendations on the significance of CRI, GINOV, and EPS in promoting environmental quality. The BRICS countries are working hard to find a sustainable solution to improve the quality of their environment, and they have made significant progress toward achieving ecological sustainability in the region. Additionally, the area has committed to halving CO_2 emissions by 2030 and achieving net-zero emissions by 2050. To achieve such ambitious objectives, the area has been consistently investing in R&D. The BRICS countries' R&D intensity increased from 2016 to 2017 from 2.34% to 2.37%, showing that they are boosting their R&D spending. Additionally, their actual R&D investment rose by 3.8%. In a similar vein, public R&D spending was 1.3%, whereas private R&D spending was over 28% (Udeagha & Muchapondwa, 2022a, 2022b). Therefore, this study is crucial for the BRICS nations under examination.

The rest of the research is structured as Section 2 reviews the existing literature; Section 3 features the methodological techniques utilized in this research; Section 4 offers the findings and discussions; and Section 5 concludes with policy recommendations.

2 | LITERATURE REVIEW

This section is divided into four subsections: (i) relationship between CRI and CO_2 emissions; (ii) relationship between GINOV and CO_2 emissions; (iii) relationship between EPS and CO_2 emissions; and (iv) summary of the gaps in the literature.

2.1 | Relationship between CRI and CO_2 emissions

CRI, which consists of political, financial, and economic risks, is essential to the success of environmental sustainability and the economic policies of an economy. The influence of political, financial, and economic risks on CO_2 emissions have all been studied in-depth by numerous scholars, but the impact of CRI on environmental quality is less well understood. The relationship between CRI and CO_2

emissions has barely been explored in empirical investigations. For example, Khan et al. (2021), who examined the effects of export diversification and CRI on CO_2 emissions for the Regional Comprehensive Economic Partnership (RCEP) countries between 1987 and 2017, discovered that lowering CRI, transitioning to renewable energy, and advancing environmentally-related technological innovations all assist in reducing CO_2 emissions in the RCEP countries. Diversifying exports, on the other hand, is proven to steadily increase CO_2 emissions. The rest of the literature review for this portion covers the available research concentrating on the environmental implications of political risk, economic risk, and financial risk because there are few studies on the relationship between CRI and CO_2 emissions.

Recently, several studies have focused on how risks—particularly political, financial, and economic risks—affect CO_2 emissions. For instance, several researchers have looked into how financial risk affects CO_2 emissions, but their results are mixed. Using a panel dataset of 111 countries, including all members of RCEP with the exception of Cambodia and Laos, Zhang and Chiu (2020) investigated the nonlinear effects of countries' comprehensive risks (i.e., political risk, financial risk, and economic risk) on CO_2 emissions. They found that financial risk can have an impact on CO_2 emissions that is monotonically increasing. On the other hand, Shahbaz et al. (2016) agreed with Zhang's (2011) assertion that financial stability is a key factor that enables Chinese policymakers to reduce CO_2 emissions. This viewpoint has been supported by Ngepah and Udeagha (2019), who found similar evidence in the case of African countries.

For the past three decades, a great deal of research has looked at the relationship between political risk and CO_2 emissions, but its conclusions have been mixed. For instance, using the autoregressive distributed lag (ARDL) approach, Ashraf (2023) discovered that a more favorable political climate (lower political risk) encourages economic development and reduces carbon emissions in Pakistan over the period 2000–2020. Using the ARDL method, van Vu and Huang (2020) studied the effect of political risk on CO_2 emissions in Vietnam. According to their findings, there is an association between political risk and CO_2 emissions that is statistically significant and positive. Su et al. (2021) and Zhang and Chiu (2020) research on the impact of political risk on CO_2 emissions in 111 countries between 1985 and 2014 supports this theory by demonstrating a statistically significant negative relationship between political risk and CO_2 emissions and refuting van Vu and Huang's (2020) conclusion. This suggests that in the countries under study, environmental degradation is lessened by a stable environment. Political quality (reducing political risk), according to Ashraf (2022a, 2022b), improves environmental protection by reducing environmental deterioration. Similar to this, Mehmood (2023) used panel data from Pakistan, India, Bangladesh, and Sri Lanka to estimate the effects of political risk on carbon emissions while taking into account the importance of technical advancements, financial development, economic growth, and trade. In doing so, they used the cross-sectionally augmented autoregressive distribution lag (CS-ARDL) approach, an advanced econometric method, to analyze the annual data from 1984 to 2017. Their findings showed that developing South Asian nations need a stable political environment in order to achieve carbon neutrality. Moreover, Kartal et al. (2023) discovered that political stability (reduced political risk) had a statistically significant negative impact on production-based CO_2 emissions in UK utilizing quarterly data from 1995/Q1 to 2018/Q4 in a nonlinear autoregressive distributed lag (NARDL) framework. By using dynamic ARDL and Breitung and Candelon (BC) frequency domain causality techniques, Adebayo (2022) investigated Canada from 1990 to 2018 and concluded that political stability (lower political risk) reduces CO_2 emissions. Moreover, Adebayo et al. (2022) used the moments of quantile regression technique to investigate the BRICS nations for the years 1990–2018 and discovered a negative effect between political risk and environmental degradation. A considerably better political climate (lower political risk) improves environmental quality, according to Ashraf (2022b), who used the generalized technique of moments to analyze 75 Belt and Road Initiative (BRI) nations over the years 1984–2019. Moreover, Kirikkaleli et al. (2022) used cointegrating regression and BC frequency domain causality techniques to study China between 1990/Q1 and 2018/Q4 and discovered that political stability has a substantial impact. As a result, these research reach the conclusion that political stability (reduced political risk) is a key predictor of CO_2 emissions and has a decreasing influence. Political stability (reduced political risk) is incorporated into CRI in accordance with the body of research, and it is anticipated that political stability will have a negative impact on environmental quality.

2.2 | Relationship between GINOV and CO_2 emissions

GINOV is thought to have a tight connection to CO_2 emissions. On how GINOV contributes to carbon neutrality and the reduction of global carbon emissions, there are several disagreements. According to some scholars, there is a negative association between the two. According to Yue et al. (2021), who used the CS-ARDL approach, GINOV is helpful for lowering carbon emissions and enhancing environmental quality in Thailand. In the analysis of the G7 nations, Qin et al. (2021) also discovered the beneficial effect of GINOV on carbon emission control and highlighted the two-way causal link between them. According to Paramati et al. (2021), GINOV is the primary factor assisting OECD economies in reducing carbon emissions. According to the research conducted in Turkey by Shan et al. (2021), GINOV lowers carbon emissions. Suki et al. (2022) revealed that GINOV is negatively connected with carbon emissions over the short-term and long-term using the novel approach of bootstrap ARDL with Malaysia as the research context. Studies have discovered conflicting results on the link between GINOV and CO_2 emissions. Xu et al. (2021) used 218 prefecture-level Chinese cities as their research subject and discovered, using a two-way fixed effect model, instrumental variable method, spatial econometric model, and causal intermediary effect model, that GINOV and its subcategories have a positive impact on China's carbon emission performance. Furthermore, it is made clear that GINOV greatly lowers and enhances carbon emission performance via the effects of industrial structure and foreign direct investment, respectively. In the long-run, GINOV has a considerable negative influence on carbon emissions, according to Shao et al. (2021), but there is no statistically significant association between the two in the short-run in N-11 nations. Khattak et al. (2022) examined the asymmetric and periodic link between green and sustainable technology innovation and carbon emissions using panel data of G7 nations from the first quarter of 1990 to the fourth quarter of 2018. It has been determined that while the beneficial effects of green and sustainable technology innovation will lower carbon emissions in economic success, the negative effects will result in carbon emissions during an economic downturn.

Also, Ahmad, Muslija, and Satrovic (2021) found that for OECD economies, positive innovation shocks had the opposite effect of negative innovation shocks in terms of CO_2 emissions. By examining innovation shocks—both positive and negative—and figuring out how these shocks affected pollution in OECD nations, the authors significantly advanced the field of study. The authors concentrated on the CO_2 emissions and overall innovation positive and negative shocks. By focusing on the cyclical and asymmetric impacts of innovation in environmentally friendly technology, Ahmad and Zheng (2021) also significantly contributed to the research. They identified a significant and sustained positive association between CO_2 emissions during the recession and adverse shocks to innovation in environmentally friendly technology. In their study of the top 10 carbon emitting countries, Ali et al. (2021) concentrated on the relationship between innovative activity, trade, and the use of renewable energy. They discovered that over the long-term, trade, GINOV, and the use of renewable energy are important factors that predict both consumption-based and territory-based carbon emissions. The authors focused on the examination of variables that affect CO_2 emissions and the part that GINOV played in encouraging ecological responsibility for the top 10 carbon emitter nations. Using panel data on 264 Chinese cities at the prefecture-level from 2006 to 2017, Lin and Ma (2022) looked at how the urban innovation environment impacted the impact of green technology advancements on CO_2 emissions. According to the empirical results, different types of cities are affected by developments in green technology in a variety of ways. Similar to this, Abid et al. (2022) used data from 1990 to 2019 to analyze the effects of GINOV on carbon emission in G8 member nations and discovered that GINOV contributes to CO_2 emission reduction. On the other hand, Khan et al. (2022) looked at how GINOV affected environmental sustainability across 176 nations. Khan et al.'s (2022) main objective are to investigate the effects of GINOV, good institutions, trade openness, the use of renewable energy sources, and foreign direct investment on environmental quality. For the OECD nations between 1990 and 2017, Huang et al. (2022) investigated the impacts of GINOV, human capital, and trade openness on energy consumption at the aggregate (total) and disaggregate levels (renewable and non-renewable). The study found that increasing the use of renewable energy in the OECD area was a result of GINOV, human capital, and energy pricing.

In conclusion, previous research ignored a number of crucial issues and only looked at the relationships between trade openness, the adoption of renewable energy, and CO_2 in pieces. The varied and ambiguous findings of empirical research demand additional investigation. Unlike other studies, this study examines the combined impacts of CRI, GINOV, and EPS on environmental quality using data from 1960 to 2020. To fully appreciate the connected problems and comprehend the processes via which this connection occurs in the BRICS region, a close examination of the relationship between CO_2 emissions and these factors is required.

2.3 | Relationship between EPS and CO_2 emissions

EPS shows the potential and successes in the implementation of environmental rules, and explains how economies are motivated by ecological goals in relation to the average standards of nations when implementing such regulations (Udeagha & Muchapondwa, 2022b). Kongbuamai et al. (2021) demonstrated that EPS plays a major role in accomplishing sustainable development goals (SDGs) while preserving ecological quality. Out of several administrative consequences, the regulation of EPS maintains the leading relevance in sanctioning certain behavior that leads to worsening environmental pollution via navigating and putting into practice purposeful environmental policies and regulations (Yirong, 2022). Among the recent works, Chu and Tran (2022) examined the nexus between EPS and CO_2 emissions utilizing the innovative Method of Moments Quantile Regression in 27 member countries of the OECD. The statistical investigation revealed that EPS has a significant influence in the eighth quantile to lessen the negative effects of environmental deterioration. Also, the policies recommended establishing stricter, more suitable rules on manufacturers to prevent the overuse of natural resources and reduce the ecological footprint deficit ratio. These results are comparable to those of studies by Murshed (2021), Ngepah and Udeagha (2018), and Sohag et al. (2021), which assessed the positive effects of normalizing the EPS in the industrial sectors because these units are closely linked to energy-consuming products and have an adverse effect on the global ecological footprint.

Galeotti et al. (2020) used a variety of ecological regulation metrics to examine the significance of policy indicators on environmental quality from 1995 to 2009 for 19 OECD economies. The results pointed to the critical part that environmental policies play in reducing ecological deterioration. The results showed that there is a larger consensus for using the composite environmental index and emanations-based policy measures when it comes to within-nation and between-nation disparities. Nevertheless, the empirical results varied depending on the indicators for strategic pollution reduction. The study concluded that various policy indicators provide varied results about their impact on the environment. Moreover, Kongbuamai et al. (2021) discovered that the stringency of environmental policies reduces ecological burden in the five developing BRICS countries. Their findings demonstrated that the use of renewable or non-renewable energy, industry, and the stringency of environmental regulations all had a favorable impact on ecological footprints. Rafique et al. (2022) also showed the short-term advantage of using stringent environmental regulations in enhancing ecological conditions. The study by Nathaniel et al. (2021), which examined the relationship between international trade, economic growth, and the role of environmental regulation in the N-11 nations during the time periods of 1990 and 2016, clarifies the conflicting viewpoint in their findings showing that EPS has no effect on reducing the ecological footprint in the N11 countries. A similar stance was also stated by Kampas et al. (2021).

Without a doubt, environmental contamination is a negative externality. It is inevitable that authorities will create appropriate environmental laws and regulations to deal with externality and the reduction of carbon emissions from governments, businesses, and individuals (Zhang & Wen, 2008). No matter what, groups, companies, and individuals work to maintain clean water sources, conserve arable land, and restrict pollutant discharge. Government involvement is essential to the success of such initiatives that improve environmental quality (Feng et al., 2019). Governments throughout the world may support environmental governance by implementing environmental policies (Zhang et al., 2019). EPS and regulations are strategy that may be used to combat environmental deterioration. The goal of stringent EP is to increase the cost of climate services and pollution in order to change consumer and producer attitudes toward environmentally friendly products (Neves et al., 2020). Limiting the contaminating agents of pollution can accomplish this by increasing the expense of activities that cause pollution and deterring people from engaging in them (Neves et al., 2020). The overall literary work identified the important investigations of applying stringent EP in various economies. But, developing nations must carefully consider how to put the EPS system into practice because doing so demands a highly mechanized industrial structure, which emerging nations do not yet have in full operation (Udeagha & Ngepah, 2019). Moreover, it is believed that using existing environmental policies would not fully take advantage of how emerging nations' political, technological, and financial systems are changing (Udeagha & Ngepah, 2020). Due to their failure to enact ecological policies, many emerging economies are thus seen as being at fault for raising the ratio of the ecological deficit by using conventional means of attaining economic advancement. In order to achieve environmental and economic sustainability, the present study emphasizes the significance of EPS at the governmental level and its potential role in decreasing environmental deterioration.

2.4 | Summary of the gaps in the literature

Several important areas of knowledge were left out due to the extensive relevance of earlier investigations. In order to address these shortcomings in our analysis, we paid close attention to it. The gaps that were identified are as follows: First, there has not been any research done to analyze the complex connections between CRI, GINOV, EPS, and environmental quality in the BRICS nations, or to pinpoint the particular processes by which these links could function. Moreover, many past investigations have shown inconsistent results about the relationships between these components. This is mostly due to the fact that very few scholars have explored the links using the methodology that is most suitable for this relationship, such as the endogenous growth model, and have instead employed a range of models. Finally, several investigations have been made to ascertain the major causes of the BRICS countries' environmental deterioration. The precise relationships and combined consequences of CRI, GINOV, and EPS on environmental sustainability in the BRICS area have not received significant attention. The current discussion has shown that depending on the perspective from which it is seen, the influence of CRI, GINOV, and EPS differs on environmental quality. Effective steps should be put in place to improve conditions because the BRICS countries are now confronting increasing environmental difficulties. The results of the current study may thus help the governments, institutions, officials, and organizations of the BRICS countries pursue more reasonable, appropriate, and useful efforts relating to environmental safety generally and specifically in the BRICS nations. As a result, this work has produced the following noteworthy contributions: First, this study offers the environmental literature yet another novel perspective by taking into account the model's implications of CRI, GINOV, and EPS. As far as we are aware, no study has looked at how much the combined impacts of CRI, GINOV, and EPS may account for variances in the carbon emissions of the BRICS economies. Second, this study adds to the body of literature by concentrating on developing nations with economies like the BRICS, which are the main sources of global environmental pollution. By doing this, we provide academics the opportunity to concentrate on the main economies that cause significant environmental catastrophes. Lastly, the research offers recommendations for both developed and emerging nations on how to enhance environmental sustainability by considering the BRICS economies in the theoretical framework. The current study broadens the scope of past environmental studies by looking at the complex relationships between these variables in the top economies in the world. Fourth, the study provides results that are essential for the policymakers in the BRICS countries to reflect on the progress toward environmental sustainability goals by using EPS and GINOV as threshold variables to determine the individual heterogeneous effects of the parameters. This study also helps to consolidate the findings of other earlier studies that emphasize the importance of EPS and GINOV in reaching the region's goals for carbon neutrality and a green environment. Fifth, to the best of our knowledge, this is the first research to look at the dynamic link between CRI, GINOV, EPS, and CO_2 emissions in the context of the BRICS nations while taking the EKC hypothesis into account. A panel of BRIC nations (excluding South Africa) and a first-generation test were used in earlier research by Tamazian et al. (2009) and Pao and Tsai (2011), and they neglected the combined impacts of CRI, GINOV, EPS. But in this study, we included these variables in the BRICS (South Africa included) panel and used reliable estimation techniques like the CS-ARDL framework, which generates precise estimates for projecting the short-term and long-term effects of the explanatory variables on the sustainability of the BRICS environment. The findings of this study will provide policymakers in the BRICS nations with a more detailed view to help them create more extended policies to reach carbon neutrality goals.

3 | METHODOLOGY

3.1 | Theoretical framework

The EKC hypothesis argues that regional environmental pollution rises in step with regional GDP growth (Udeagha & Breitenbach, 2021). The usage of both renewable and non-renewable energy sources is anticipated to rise along with GDP. Increased economic production in nations with significant non-renewable energy usage further increases the strain on energy supply. A significant percentage of the energy required by expanding economic activity is provided by fossil fuels. Demand for fossil fuels is increasing, which is unfriendly to the environment and opens the door to a high rate of carbon emissions into the atmosphere (Udeagha & Ngepah, 2021a). Consequently, based on this supposition, we anticipate that GDP will have a positive influence on CO_2 emissions in the chosen nations, that is, $\left(\beta_1 = \frac{\alpha CO_2}{\alpha GDP} > 0\right)$.

To check for the existence of the EKC hypothesis for the BRICS countries, the GDP-squared factor is introduced to the model. Therefore, it is anticipated that the GDP-squared element will have a negative impact on CO_2 emissions if the EKC hypothesis is true, that is, $\left(\beta_2 = \frac{\alpha CO_2}{\alpha GDPS} < 0\right)$.

Porter (1996) and Porter and Linde (1995) make the assertion that environmental policies may be advantageous to industries and that well formulated environmental policies encourage innovation, which improves enterprises' private benefits by raising productivity. Environmental regulations would therefore benefit enterprises as well as society as a whole. A supportive audience for this perspective has emerged among decision-makers and the broader public. It makes sense that stringent environmental restrictions deter CO_2 emissions, which ultimately results in a decrease in environmental pollution. Environmental policies and regulations that are strict are being put into place to fight environmental deterioration. These policies increase the cost of pollution and other environmental services in an effort to shift consumer and producer behavior toward more environmentally friendly goods. In order to achieve this, limits are placed on polluting agents to raise the cost and reduce the allure of polluting operations. The argument between environmental regulation and environmental outcomes has been at the forefront of the regulation-environmental-outcome nexus since the pioneering work of Porter and Linde (1995), which stresses that an EP that is correctly crafted can assist firms in adopting environmentally friendly practices that can reduce emissions. By encouraging ecologically beneficial technologies and inhibiting environmentally "dirty" ones, stringent environmental policies can reduce the deleterious impacts of pollution. Therefore, like environmental taxes, strict environmental laws and regulations have the capacity to influence producers' and consumers' behavior to promote the production and use of energy products in an environmentally sustainable manner. EPS is therefore anticipated to result in a reduction in CO_2 emissions, that is, $\left(\beta_3 = \frac{\alpha CO_2}{\alpha EPS} < 0\right)$.

In order to achieve environmental sustainability, economic strategies must take into account the CRI, which combines all political, financial, and economic risks. First, an economy's strengths and weaknesses are determined by economic risk. The risk decreases with increasing total risk point and increases with decreasing total risk point in every instance (economic, political, and financial). Economic activities that provide possibilities and raise income levels increase with the expansion of economic growth. In order to support their domestic sector throughout the transitory stage, economies with such expansions use more energy. In addition, environmental economists assert that such sweeping expansions increase carbon emissions and worsen environmental quality, which is likewise described by the EKC hypothesis in the first stage; economic growth or an increase in income is linked to environmental degradation. Consequently, we anticipate that economic risk will be positively correlated with carbon emissions. Second, political risk encompasses factors like the corruption index, the stability of the government, the investment profile, democratic accountability, and law and order. Political risk makes it difficult to adopt carbon neutrality rules in an economy. Deterioration of the environment results from this. The political risk index evaluates the political system's stability in an economy through 12 different components. Higher political risk is associated with weaker or more unstable governments, lower or less educated populations, poverty, unequal access to resources, riskier investment history, more corrupt officials, and weaker institutions. Developing nations with significant political risk typically face a number of challenges. For instance, more dishonest government representatives can undermine environmental laws, allowing for unlawful manufacturing and increasing emissions (Chen et al., 2018). Strong institutions are crucial for protecting environmental quality because they impose strict regulations and penalties for any activity involving illegal emissions, while an anti-corruption campaign is helpful to reduce corruption and subsequently mitigate environmental pollution (Zhou et al., 2020). Therefore, we anticipate that political stability in an economy will be crucial in regulating CO_2 emissions. Third, financial risk gauges a nation's ability to finance its government's operations, including obligations under official, commercial, and trade debt. An economy is more productive and better able to repay its debt if its financial risk is lower. Additionally, because there is less financial risk in nations with stable currency rates, international investment flows there. An economy's ability to be productive and repay its debt depends on how high the financial risk is for that economy. Furthermore, because they pose less of a risk to investors, nations with stable exchange rates attract foreign capital. So, we anticipate that more financial risk may cause carbon emissions. In conclusion, ICRG uses the formula "A" to determine the composite risk index, which is the sum of political, financial, and economic risks. It is therefore predicted that CRI is positively related to carbon emissions, that is, $\left(\beta_4 = \frac{\alpha CO_2}{\alpha CRI} > 0\right)$.

The most important element influencing sustainable development and environmental sustainability is thought to be technological innovation (Udeagha & Ngepah, 2021a, 2021b). Dietz and Rosa (1994) developed the STIRPAT model in the theoretical research and included technology as one of the three key elements that affect environmental sustainability. Numerous studies based on various nations or areas have concluded in the empirical investigation that technological innovation encourages sustainable development. The conflict between carbon emissions and economic growth can be more immediately resolved by green technological innovation that prioritizes clean production and energy-efficient utilization. There are two different ways that GINOV affects carbon emissions: directly and indirectly. First, through increasing green productivity, having diverse spillover effects, reducing costs, specialization, and other factors, GINOV may directly reduce carbon emissions. Second, the primary source of carbon emissions in high carbon sectors is the combustion of fossil fuels. By improving the industrial structure of the pollution industry, GINOV can indirectly raise energy consumption rate and accomplish energy conservation aim. The two ways clearly divide the work, which has a double impact on carbon emissions. Therefore, encouraging GINOV has turned into a crucial tool for attaining green development goals and is crucial to cutting emissions. Furthermore, the ecological modernization theory suggests that increasing resource efficiency (renewable energy) through technological innovation might aid in reducing the environmental risks brought on by economic expansion. We establish relationships between the development of technology and CO_2 emissions in light of the aforementioned ideas. Through technological advancement, energy usage can be reduced, energy efficiency can be raised, and the environment can be enhanced. Advanced technologies would be used in order to promote sustainable manufacturing and enhance environmental sustainability. This study looks at how green technological innovation affects environmental quality since it has the potential to make renewable energy sources like solar and wind less wasteful and more ecologically friendly. Modern energy-intensive industrial equipment is being replaced with greener, more efficient alternatives, which eases the burden on the environment and the economy. As a result, GINOV is anticipated to reduce CO_2 emissions, that is, $\left(\beta_5 = \frac{\alpha CO_2}{\alpha GINOV} < 0\right)$.

One of the key factors in a nation's ability to fulfill its SDGs and grow its economy is the use of renewable energy. By minimizing the burning of fossil fuels, renewable energy deployment can help ensure the energy supply and be a potential solution in addressing the climate change challenges. Theoretically, RERD is one of the strategies for addressing excessive carbon emissions to achieve carbon neutrality or a low-carbon economy (Udeagha & Ngepah, 2021b). RERD can be viewed as one of the game changers for the economic development and achievement of SDGs in a country. It is crucial to switch from conventionally non-renewable energy sources to renewable ones in order to attain carbon neutrality, and R&D cannot be disregarded in this process. Investment in RERD substantially promotes environmentally friendly innovation and technology, contributes to economic growth, and reduces CO_2 emissions in the atmosphere, leading to achieving carbon neutrality. Therefore, to achieve carbon neutrality target, it is important to increase investment in RERD to avoid future adverse effects of CO_2 emissions. Consequently, it is projected that RERD will decrease CO_2 emissions, that is, $\left(\beta_6 = \frac{\alpha CO_2}{\alpha RERD} < 0\right)$.

3.2 | Model specification

In order to assess the combined impacts of EPS, CRI, and GINOV on CO_2 emissions for BRICS nations, this study adopts the standard EKC hypothesis framework, which is in line with the robust empirical methodology that has been extensively employed in past works. According to the EKC hypothesis, economic growth has a significant negative impact on environmental quality because throughout the initial stages of social development, obtaining greater income levels received more attention than preventing environmental deterioration to a minimum. Therefore, more economic growth—which unavoidably led to the deterioration of the environment—was energetically pursued at the price of decreased carbon emissions. Thus, this explanation provides an easy explanation for the logic underlying the positive correlation between the scale effect (a proxy for economic expansion) and environmental quality. People grew increasingly ecologically sensitive as society developed, particularly during the advanced industrial era, and governments passed environmental regulations intended to boost environmental quality. As a result, throughout this stage of development, as income rose, the environment got better due to people's propensity for a clean environment and the implementation of stricter environmental norms. The reasoning behind the negative association between the technique effect (square of economic growth) and environmental quality is thus intuitively explained by this argument. The typical EKC hypothesis is thus expressed as follows, following Udeagha and Breitenbach (2021) and Udeagha and Ngepah (2019).

$$\log CO_{2it} = \alpha_{it} + \beta_1 \log GDP_{it} + \beta_2 \log GDPS_{it}, \tag{1}$$

where CO_2 represents CO_2 emissions as a proxy for environmental quality; GDP denotes gross domestic product as a measure of economic growth (scale effect); GDPS is the square of GDP as a measure of technique effect. Scale effect (GDP representing economic growth) deteriorates environmental quality as income increases; however, technique effect (GDPS) improves the environment due to the implementation of environmental laws and people's predisposition for the carbon-free environment. Given this background, for the EKC hypothesis to be present, the theoretical expectations require that: $\beta_1 > 0$ and $\beta_2 < 0$. Following literature, as a control variable in the model, we use research and development in renewable energy. Accounting for this variable in the EKC framework and capturing our three main variables of interest, Equation (1) is thus augmented as follows:

$$\begin{aligned} \log CO_{2it} = {} & \alpha_{it} + \beta_1 \log GDP_{it} + \beta_2 \log GDPS_{it} + \beta_3 \log EPS_{it} + \beta_4 \log CRI_{it} \\ & + \beta_5 \log GINOV_{it} + \beta_6 \log RERD_{it} + \mu_{it}, \end{aligned} \tag{2}$$

where CO_2, GDP, and GDPS are as defined above; EPS stands for environmental policy stringency; CRI represents composite risk index; GINOV captures green innovation; and RERD denotes research and development in renewable energy. The letters "*i*" and "*t*" in the subscript stand for the cross-section and the time or year, respectively. All the variables are expressed in their logarithmic terms. Regarding estimates, the study uses the particular to general strategy to progressively examine every explanatory variable's impact on the CO_2 emissions.

3.3 | Variables and data sources

We use panel data spanning the years 1960–2020 in our analysis. The dependent variable in this study, CO_2 emissions (kg per 2015 US$ of GDP), is employed as a proxy for environmental quality. World Bank World Development Indicators provided data on CO_2 emissions (kg per 2015 US$ of GDP) from 1960 to 2020. To confirm the validity of the EKC hypothesis, we use GDP to represent economic growth and its square to express the square of economic growth. The World Bank World Development Indicators are used to gather relevant data for GDP and its square from 1960 to 2020. We have taken the environmental-related/green patents counts as a proxy for GINOV. Green patents refer to the patenting of green or environmentally friendly technology. In other words, green patents are granted for the technology that has no negative impact on the environment. Therefore, green patents lessen environmental degradation. The data for environmental-related patents were taken from the OECD database, 2021. The EPS index is an internationally comparable and country-specific determinant of the environmental stringency strategy. The term stringency is described as the measures at which ecological planes put an implicit or may be explicit monetary value on defiling or ecological destructive actions. The data for the EPS index were taken from the OECD database (https://stats.oecd.org/Index.aspx?DataSetCode=EPS). R&D relevant to the field of renewable energy is measured by percentage of total energy R&D. The data were sourced from the World Bank World Development Indicators. Table 2 therefore provides the summary of the sources of data and definitions of the variables.

3.4 | Econometric techniques

3.4.1 | Slope heterogeneity and cross-section dependence of the panel

We check the panel data's cross-section dependence (CD) and slope heterogeneity as the first steps in our research. Nations on the panel may mirror one another in certain ways while differing in others. In contrast, homogeneous attributes in empirical model may result in skewed estimates, especially for panel estimates. As a result, the group of nations in question has to be homogenized (i.e., BRICS economies). In this context, we used the slope coefficient homogeneity (SCH) test proposed by Pesaran and Yamagata (2008) while taking into account coefficients parallel to the null hypothesis. Equation (3) and Equation (4) are general equations for the earlier tests.

$$\tilde{\Delta}_{SCH} = (N)^{\frac{1}{2}}(2k)^{-\frac{1}{2}}\left(\frac{1}{N}\tilde{S} - k\right), \tag{3}$$

$$\tilde{\Delta}_{ASCH} = (N)^{\frac{1}{2}}\left(\frac{2k(T-k-1)}{T+1}\right)^{-\frac{1}{2}}\left(\frac{1}{N}\tilde{S} - 2k\right), \tag{4}$$

where $\tilde{\Delta}_{SCH}$ denotes slope coefficient homogeneity from Equation (3); $\tilde{\Delta}_{ASCH}$ represents slope coefficient homogeneity after adjustment in Equation (4); N is the cross-section dimension; T denotes time series dimension; $\tilde{S}$ represents Swamy's test statistic; and k is the mean bias.

The second-generation procedures is used in place of the first-generation testing methods if the data exhibits homogeneity features. The worldwide village we live in makes it possible for a nation to become more and more dependent on other nations. However, if the CD problem is disregarded, this might result in erratic and false estimations (Campello et al., 2019). In order to examine cross-section reliance among the BRICS nations, we used the Pesaran (2004) CD test. The relevant test is presented in its general form as Equation (4), with the independence of the cross-sections serving as the null hypothesis.

$$CD_{Test} = \sqrt{\frac{2T}{N(N-1)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{\rho}_{ij}}, \tag{5}$$

where CD_{Test} is the cross-section dependence test; T denotes time dimension of the panel; N represents cross-section dimension; $\widehat{\rho}_{ij}$ is the sample estimate of the pair-wise correlation of the residuals. According to a specific "connection or spatial matrix" that describes the pattern of spatial dependence in accordance with a pre-established set of principles, the degree of CD is quantified in the literature on spatial statistics. A connection matrix's (i, j) elements, for instance, might be set to 1 if the ith and jth regions are connected and to zero otherwise.

3.4.2 | Unit root

We proceeded on to look for the unit root or stationarity in the chosen panel after the findings for CD and heterogeneity were obtained. Dealing with data that includes both cross-sections and time series at once requires constant attention. In order to address the problem of the heterogeneous panel and resolve the CD dilemma between the components, we employed the panel unit root test, such as IPS (2003) provided by Im et al. (2003) and CIPS (2007) established by Pesaran (2007). The null hypothesis for these tests is that the unit root exists in the data.

3.4.3 | Panel cointegration test

We use the Westerlund (2007) error correction model (ECM) to determine the cointegration among the heterogeneous variables after the stationarity or unit root is checked. The issue of CD and heterogeneous slope parameters are both addressed by Westerlund (2007). In order to determine the long-term connection between variables, we also used the Kao-residual cointegration test advanced by Kao et al. (1999).

3.4.4 | Cross-sectionally augmented autoregressive distributed lags

Prominent events associated with the cross-section-dependence problem include the oil price shocks of 1997–1999 and the global

TABLE 2 Variable definition and sources.

Variable	Definition	Unit	Source
CO_2	CO_2 emissions	kg per 2010 US$ of GDP	WDI
GDP	Gross domestic product: the sum of the economies all final goods and services	Constant US 2010	WDI
GDPS	Gross domestic product squared	Constant US 2010	WDI
CRI	Composite risk index: consists of total political, financial, and economic risk indicators	Index	Political risk services (PRS)
GINOV	We have taken the environmental-related/green patents counts as a proxy for green innovation. Green patents refer to the patenting of green or environmentally friendly technology. In other words, green patents are granted for the technology that has no negative impact on the environment	Environmental innovations	WDI/OECD
EPS	The environmental policy stringency index is an internationally comparable and country-specific determinant of the environmental stringency strategy. The term stringency is described as the measures at which ecological planes put an implicit or may be explicit monetary value on defiling or ecological destructive actions	Index	OECD[a]
RERD	Research and development relevant to the field of renewable energy	Percentage of total energy R&D	WDI

[a]https://stats.oecd.org/Index.aspx?DataSetCode=EPS.
Abbreviations: EPS, environmental policy stringency; GDP, gross domestic product; GINOV, green innovation; OECD, Organization for Economic Co-operation and Development; RERD, renewable energy research and development; WDI, World Development Indicator.

financial crises of 2008–2009. It can result in inaccurate estimations if these elements were not recognized in association to the regression. The CS-ARDL is a practical choice to utilize since it makes use of a dynamic common correlated effects estimator to get beyond the CD problem, slope heterogeneity, non-stationarity, and endogeneity (Khan, Ali, et al., 2020; Khan, Yu, et al., 2020; Yao et al., 2019). In comparison to common correlated effect mean group, augmented mean group, pooled mean group, and mean group (MG), Chudik and Pesaran (2015) introduced the CS-ARDL, that is regarded as effective for better result analysis and accurate control (Danish., 2020; Li et al., 2020). The CS-ARDL is typically presented as Equation (5) in the following format as below:

$$Y_{it} = \sum_{l=0}^{P_w} \alpha_{l,t}, Y_{i,t-l} + \sum_{l=0}^{P_z} \beta_{l,i} Z_{i,t-l} + \sum_{l=0}^{P_x} \gamma_i, l\overline{X}_{t-l} + \varepsilon_{i,t}. \tag{6}$$

The extended version of CS-ARDL is given by the Equation (6) above, where $\overline{X}_{t-l} = \overline{Y}_{i,t-l}, \overline{Z}_{i,t-l}$ reflects the means of the variables under consideration for both the dependent and independent variables. The $P_w, P_z,$ and P_w, on the other hand, denote the lags of every element. Additionally, Y_{it} denotes the response variable in this instance, which is CO_2 emission. Z_{it} simultaneously lists all the considered factors being taken into account, including the research and development of renewable energy sources, environmental taxes, GINOV, the CRI, and GDP.

3.4.5 | Robustness and causality tests

When using the conventional methodologies, a number of panel data concerns, such as CD and slope heterogeneity, may result in erroneous results (Çoban & Topcu, 2013). This work used the dynamic ordinary least square (DOLS) method to address the problems of non-stationarity, CD, and slope heterogeneity. By taking into account all of these factors, the estimation approach offers thorough evaluation and better results. Lastly, we used the Granger causality heterogeneous panel test proposed by Dumitrescu and Hurlin (2012) to determine if there could be a causal relationship among these variables involved. If the cross-sections and time series are not comparable, the technique is effective (i.e., $T \neq N$). Additionally, the technique simultaneously handles the panel data's CD and heterogeneity. The following part includes the findings, interpretations, and discussions (Section 4).

4 | EMPIRICAL RESULTS AND DISCUSSIONS

The calculated results, interpretations, and discussions of the findings are presented in this part. The SCH and CD test results from Pesaran and Yamagata (2008) are presented in Table 3. To cope with biased cointegration and unit root estimates, the CD must be addressed (Salim et al., 2017; Westerlund, 2007). In terms of practical assessments, the findings for RERD, GINOV, CRI, EP, GDPS, and GDP, respectively, support the diverse character of the slope coefficients at various significance levels. The alternative hypothesis is therefore acceptable, and the null hypothesis of slope homogeneity is discarded as a result. This demonstrates the diverse properties of every research variable in our analysis. Additionally, the Pesaran (2004) estimated findings, which do not include cross-sectional dependence as a null hypothesis, are disproved and the alternative acknowledged as the potential substitute. Our findings suggest that each country's dependence on the other is confirmed by the fact that all relevant variables are determined to be significant at 1%, 5%, and 10%, respectively. This further explains why the augmentation or decrease of CO_2 emissions could not be managed entirely. Instead, other nations would have an impact on the goals of a particular nation.

Im, Pesaran, and Shin (IPS's, 2003) and Pesaran (CIPS's, 2007) unit root test estimations are shown in Table 4. The data, at level I(0) and the first difference I(1) are processed using these two procedures. According to the previous report (IPS, 2003), all of the variables' data are insignificant at I(0) but significant at I(1). This confirms stationarity at first difference, according to the variables. The variables, however, are significant at the 10%, 5%, and 1%, according to the CIPS (2007) estimates, with the exception of GDP and EP, which are very significant at I(1). Moreover, this supports the data's stationarity at I(0) and I(1), respectively. As a result, the null hypothesis of the unit root existence is rejected for the variables RERD, GINOV, CRI, and CO_2 while being confirmed for GDP and EPS at level. GDP and EPS at I(1), however, were among the variables for which the null was rejected.

Table 5 provides statistical findings for cointegration using the residual cointegration test developed by Kao et al. (1999) and Westerlund (2007). In a conditional panel ECM, Westerlund (2007) evaluated the test's hypothesis of whether the error correction term is zero (i.e., ECT = 0). For each of the five models, the numbers from the table strongly indicate a significant outcome at the 1%, 5%, and 10% levels. These figures reveal the error correction for the MG as well as the panel, or $G_\tau \& G_\alpha$ and $P_\tau \& P_\alpha$, respectively. The long-run relationship between RERD, GINOV, CRI, EPS, GDPS, GDP, and CO_2 is also shown by the Kao-residual cointegration test, which shows a significant value at 5% level of significance. The null hypothesis that there is no cointegration between the variables was thus rejected. As an alternative, it is possible to adopt the long-run cointegration presence hypothesis. Consequently, it is demonstrated that all factors have an impact on CO_2 emissions rather than just one. Since all of the variables and nations have long-run associations or cointegrations that are proven, we now investigate the link between CO_2 emission and other related indicators over the short-term and long-term.

Table 6 presents the outcomes of the CS-ARDL framework. Our findings indicate that economic growth (GDP) and economic growth

TABLE 4 Panel unit root tests.

Im, Pesaran and Shin (IPS, 2003)		
Variables	**Trend and intercept level**	**First difference**
CO_2	1.057	−6.731***
CRI	0.481	−7.184***
EPS	1.520	−4.177***
GDP	−0.301	−4.739***
GINOV	1.103	−4.831***
RERD	−0.318	−7.453***
Pesaran (2007) CIPS		
CO_2	−4.173***	-
CRI	−6.510***	-
EPS	−1.394	−5.403***
GDP	−3.041	−5.836***
GINOV	−2.863***	-
RERD	−3.057***	-

Note: *, **, and *** is for the significance level of 10%, 5%, and 1%.

TABLE 3 Cross-section dependence and heterogeneous slope coefficient.

Slope heterogeneity		
Models	$\bar{\Delta}$	$\bar{\Delta}_{Adjusted}$
$CO_{2it} = f(GDP_{it}, GDPS_{it})$	21.731***	23.841***
$CO_{2it} = f(GDP_{it}, GDPS_{it}, EPS_{it})$	20.646***	22.610***
$CO_{2it} = f(GDP_{it}, GDPS_{it}, EPS_{Sit}, CRI_{it})$	18.052***	20.831***
$CO_{2it} = f(GDP_{it}, GDPS_{it}, EPS_{it}, CRI_{it}, GINOV_{it})$	15.137***	17.426***
$CO_{2it} = f(GDP_{it}, GDPS_{it}, EPS_{it}, CRI_{it}, GINOV_{it}, RERD_{it})$	13.215***	15.218***
Cross-section dependence		
CO_2	GDP	GDPS
9.830***	24.741***	24.853***
EPS	CRI	RERD
13.963***	14.741***	11.053***
GINOV		
24.041***		

Note: *, **, and *** is for the significance level of 10%, 5%, and 1%.

TABLE 5 Cointegration tests.

Westerlund (2007)				
Models	G_t	G_α	P_t	P_α
$CO_{2it} = f(GDP_{it}, GDPS_{it})$	−9.430***	−48.618***	−22.315***	−49.715***
$CO_{2it} = f(GDP_{it}, GDPS_{it}, EPS_{it})$	−9.562***	−41.841***	−23.530***	−48.840***
$CO_{2it} = f(GDP_{it}, GDPS_{it}, EPS_{it}, CRI_{it})$	−6.710***	−39.015***	−20.061***	−44.142***
$CO_{2it} = f(GDP_{it}, GDPS_{it}, EPS_{it}, CRI_{it}, GINOV_{it})$	−8.425***	−41.430***	−23.946***	−46.416***
$CO_{2it} = f(GDP_{it}, GDPS_{it}, EPS_{it}, CRI_{it}, GINOV_{it}, RERD_{it})$	−8.534***	−39.133***	−21.621***	−40.313***
Kao-residual cointegration test				
ADF	***t*-statistics**			**Prob.**
	−1.604**			0.0301

Note: *, **, and *** is for the significance level of 10%, 5%, and 1%.

TABLE 6 CS-ARDL estimation results.

Variables	Short-run Model-1 Coefficients [Std Error]	Model-2 Coefficients [Std Error]	Model-3 Coefficients [Std Error]	Model-4 Coefficients [Std Error]	Model-5 Coefficients [Std Error]
ΔGDP	0.135*** [0.248]	0.106*** [0.153]	0.140** [0.058]	0.151* [0.093]	0.158*** [0.015]
ΔGDPS	−0.259*** [0.037]	−0.271*** [0.068]	−0.204** [0.039]	−0.211 [0.098]	−0.208** [0.047]
ΔEPS	-	−0.150** [0.031]	−0.170*** [0.016]	−0.148*** [0.027]	−0.136 [0.099]
ΔCRI	-	-	0.163* [0.086]	0.140*** [0.015]	0.139 [0.098]
ΔGINOV	-	-	-	−0.018*** [0.027]	−0.017*** [0.025]
ΔRERD	-	-	-	-	−0.021*** [0.016]
ECM (−1)	−0.831*** [0.028]	−0.805*** [0.017]	−0.813*** [0.024]	−0.892*** [0.019]	−0.807*** [0.013]
Long-run					
GDP	0.203** [0.423]	0.214*** [0.038]	0.205 [0.961]	0.281*** [0.028]	0.253*** [0.016]
GDPS	−0.142** [0.301]	−0.133*** [0.028]	0.105*** [0.025]	−0.131*** [0.019]	−0.129*** [0.028]
EPS	-	−0.205** [0.049]	−0.218*** [0.014]	−0.253* [0.138]	−0.281** [0.126]
CRI	-	-	0.204*** [0.018]	0.218*** [0.025]	0.240** [0.031]
GINOV	-	-	-	−0.183*** [0.014]	−0.175*** [0.026]
RERD	-	-	-	-	−0.057*** [0.017]

Note: *, **, and *** is for the significance level of 10%, 5%, and 1%.

squared (GDPS) have, respectively, positive and negative effects on environmental quality. While GDP degrades environmental quality, GDPS helps the BRICS economies' environmental sustainability. The empirical finding thus supports the EKC theory's applicability to the BRICS nations. The results are relevant to the region's fundamental transformation and technological development. When environmental awareness increases, environmental rules are put into place to encourage the adoption of eco-friendly technology and reduce emissions. These findings corroborate Udeagha and Breitenbach (2021), which show the EKC theory's applicability to the Southern African Development Community (SADC) from 1960 to 2014. Alharthi et al. (2021) for the Middle East and North Africa (MENA) region validate the EKC hypothesis in this region. Our findings support Ahmed et al.'s (2022) observation that Pakistan has an EKC since the income coefficient is positive but its quadratic component is negative from 1984 to 2017. The analysis conducted for South Africa by Udeagha and Ngepah (2019) further supported our finding. Similar to this, Ahmad, Jiang, et al. (2021b) showed that EKC occurred in 11 emerging economies from 1992 to 2014 using balanced yearly panel data. In contrast, EKC was not valid in the US, UK, Japan, Italy, Germany, and Canada, according to Işık et al. (2019), who verified these findings for France in their examination of G7 nations from 1995 to 2015. Udeagha and Muchapondwa (2022b) also claim that between 1960 and 2020, EKC was uncovered in South Africa. Our findings add to Murshed's (2021) findings for six South Asian economies. The findings, however, contradict those of Minlah and Zhang (2021), who found that the EKC hypothesis was not true for Ghana. Similar results from Ozturk (2015), Sohag et al. (2019), Tedino (2017), and Mensah et al. (2018) demonstrate the invalidity of the EKC hypothesis.

The estimated long-run coefficient on the CRI, which is found to be positive and statistically significant at 1% and 10% levels, suggests that the CRI has a detrimental impact on carbon emission in both the short-term and long-term in the BRICS countries. Political risk makes up the majority of the CRI (50%) while the remaining portions (25%) and (25%) are made up of financial risk and economic risk, respectively. As a result, both short-term and long-term carbon emissions increase with increasing CRI. However, if a varied range of political figures unite together to address the issue of climate change, this might reduce the risk of instability and ultimately result in the creation of a carbon-neutral world (Karhunmaa, 2019). Our findings are in line with those of Khan et al. (2021), who looked at how export diversification and CRI influenced CO_2 emissions for the RCEP nations and found that a greater CRI adversely affects the environment. Ashraf (2022a, 2022b), who noted that growing CRI deteriorates environmental protection through increasing environmental degradation, also lends credence to our conclusion. Mehmood (2023), who estimated the impacts of CRI on carbon emissions using panel data from Pakistan, India, Bangladesh, and Sri Lanka, made similar findings. In addition, greater CRI results in a large rise in production-based CO_2 emissions in the UK, according to Kartal et al. (2023). Our results, however, do not support Adebayo (2022) that CRI lowers CO_2 emissions in Canada. Ashraf (2022b), who noted that in 75 countries participating in the BRI, a much lower CRI enhances environmental quality found similar results. Additionally, Kirikkaleli et al. (2022) discovered same outcomes in the case of China. Furthermore, Khan et al. (2021), who studied the effects of export diversification and CRI on CO_2 emissions for the RCEP countries, found that lowering CRI, switching to renewable energy, and advancing environmentally conscious technological advancements all help to lower CO_2 emissions in the RCEP countries.

The calculated coefficient on EPS is found to be statistically significant, indicating that an increase in EPS of 1% results in a reduction in CO_2 emissions of 0.205%. This result implies that stringent EP aids the BRICS region in reducing CO_2 emissions, and it demonstrates the viability and success of putting environmental regulations into practice. It also explains how the BRICS economies are driven by ecological goals relative to the average standards of nations when putting environmental regulations into practice. Our result is in line with those of Kongbuamai et al. (2021), who showed that EPS is essential for achieving sustainable development objectives while maintaining ecological quality. Chu and Tran (2022), who investigated the relationship between EPS and CO_2 emissions, revealed comparable findings in the cases of 27 OECD member nations. Ngepah and Udeagha (2018), who found that EPS significantly influences the eighth quantile to minimize the harmful impacts of environmental degradation, provide more support for our finding. In order to avoid the exploitation of natural resources and lower the ecological footprint deficit ratio, the policies also suggested imposing stronger, more appropriate regulations on industries. The findings of research by Murshed (2021) and Sohag et al. (2021), which evaluated the advantages of normalizing the EPS in the industrial sectors and found that these units have a negative impact on the ecological footprint of the earth's surface, are similarly equivalent to the findings of this study. Galeotti et al. (2020), which examined the relevance of policy indicators on environmental quality for 19 OECD economies using a number of ecological regulation variables, found a similar conclusion. The findings demonstrated how important environmental regulations are in preventing ecological decline. The findings indicated that, when it comes to within-nation and between-nation differences, there is a greater agreement in favor of utilizing the composite environmental index and emanations-based policy approaches. Furthermore, Kongbuamai et al.'s (2021) observation that the five BRICS emerging nations' strict environmental regulations lessen environmental burden supports our finding. Additionally, Rafique et al. (2022) have demonstrated the immediate benefit of implementing stringent environmental regulations in improving ecological circumstances. Similar findings were made in the investigation conducted by Nathaniel et al. (2021) regarding the N-11 countries. However, our finding contradicts those of Shah et al. (2023), who found that EPS degrades environmental quality in BRICS economies.

The estimated coefficient for research and development in renewable energy (RERD) is statistically significant and negative in the long-run. In the BRICS countries, a 1% rise in RERD is strongly correlated with a 0.057% decrease in CO_2 emissions at a 1% level of significance. This empirical evidence suggests that the R&D in the use of renewable energy improves environmental sustainability in the region. The significant expenditures made in RERD by the BRICS nations are beginning to yield results. They are therefore presently moving toward completing the SDGs by 2030. The region employs a variety of strategies to reduce emissions and combat climate change, including a transportation sector that is environmentally friendly, a varied energy mix, and a dependable energy infrastructure. The best approach to the issues of electricity production and global warming is to encourage the development of renewable resources. It is significant that regulations for renewable energy are created and implemented because the BRICS region is one of the top producers and users of energy in the world. The zone places a high emphasis on the development of green sources because they are the biggest producers and consumers of energy in the world. They have devised a variety of long-term, intensive major projects to achieve this. Our findings support Udeagha and Ngepah (2021a), Udeagha and Ngepah (2021b) that the use of green energy, including hydroelectric power, super capacitors, solar energy, biogas, wave power, and other sources, has the potential to greatly reduce global CO_2 emissions. Additionally, our finding is consistent with Ponce and Khan (2021), who revealed that RERD improves the quality of the environment in nine developed European and non-European countries are in line with the findings from our study. In a similar vein, RERD, according to Udeagha and Ngepah (2022c), aids in raising environmental standards in South Africa. The results, however, disagree with those of Boluk and Mert (2014), who uncovered that RERD lowers environmental quality in 16 EU member states. Pata and Caglar (2021), who discovered evidence to back the assertion that RERD has no impact on China's carbon footprint, came to similar findings.

Over the long-term, it is demonstrated that the computed coefficient on GINOV, which shows that a 1% rise in GINOV causes a

TABLE 7 Dynamic ordinary least square for robustness.

Variables	Model-1 Coefficients [Std Error]	Model-2 Coefficients [Std Error]	Model-3 Coefficients [Std Error]	Model-4 Coefficients [Std Error]	Model-5 Coefficients [Std Error]
GDP	0.259** [0.110]	0.232*** [0.034]	0.243 [0.973]	0.280*** [0.023]	0.251*** [0.018]
GDPS	−0.130*** [0.019]	−0.121*** [0.023]	0.121*** [0.028]	−0.132*** [0.018]	−0.124*** [0.020]
EPS	-	−0.234** [0.048]	−0.237*** [0.015]	−0.279* [0.134]	−0.284** [0.120]
CRI	-	-	0.216*** [0.019]	0.214*** [0.020]	0.244** [0.032]
GINOV	-	-	-	−0.186*** [0.014]	−0.173*** [0.027]
RERD	-	-	-	-	−0.053*** [0.011]

Note: *, **, and *** is for the significance level of 10%, 5%, and 1%.

0.183% reduction in CO_2 emissions at a 1% level of significance, is statistically significant and negative. This empirical evidence reveals that green technological innovation has benefited the BRICS region, which has passed many legislative measures intended to boost GINOV in support of environmental sustainability. Among the BRICS countries, GINOV promotes energy efficiency, lowers the cost of access to renewable energy sources, and improves the environment. By improving energy efficiency through a variety of techniques, such as changing the fuel mix, adopting energy-efficient industrial processes, and utilizing end-of-pipe technology, GINOV aids in reducing CO_2 emissions in the BRICS countries. More importantly, the high levels of R&D expenditure and technological innovation are the fundamental components in the environmental stewardship of the zone, which has put in place a number of programs to increase government R&D involvement, enabling it to gradually shift its industrial activities from very energy-intensive coal-powered technologies to processes driven by technological advancements that use less energy. The BRICS region's capacity to decrease environmental pollution has been significantly boosted by some of these institutional initiatives that support green technological innovation. Our results are in agreement with those of Erdogan (2021) and Guo et al. (2021), who found that GINOV promotes an environment that encourages a reduction in energy consumption, an increase in energy efficiency, and ultimately a reduction in GHG emissions for China and the BRICS countries, respectively. Anser et al. (2021) for EU nations provide additional support for these findings. Nevertheless, our results do not support the claims made by Dauda et al. (2021) that GINOV in Sub-Saharan African countries undermines environmental health. For Asian nations, Usman and Hammar (2021) discovered comparable findings. The results of Udeagha and Ngepah (2022d) for South Africa and Ngepah and Udeagha (2018, 2019) for Sub-Saharan Africa provide more evidence for this assertion.

For robustness check, the DOLS method is used and its results are presented in Table 7. The DOLS estimations have verified that GDP and CRI have adverse effects on ecological quality. The other factors, such as RERD, GINOV, EPS, and GDPS are indicated to have contributed to improve ecological quality and achieve carbon neutrality target in the BRICS nations. We found evidence of little to no change in the estimated coefficients when the findings of the two approaches (CS-ARDL and DOLS) are compared, notably with regard to their signs and magnitudes. While keeping their signs, the majority of the variables are statistically significant, though in some cases, their magnitudes change slightly from one another.

TABLE 8 Dumitrescu–Hurlin causality testing method for heterogeneous panel.

Causality direction	*W*-statistics	$\bar{Z}$ − statistics	*p*-value
GDP→CO_2	3.481***	4.015	.000
GDPS→CO_2	4.104***	3.618	.000
EPS→CO_2	2.610***	2.413	.005
CRI→CO_2	4.120***	3.483	.000
GINOV→CO_2	4.429***	5.714	.000
RERD→CO_2	4.821***	5.260	.000

Note: 1%, 5%, and 10% significance levels are captured by the asterisks ***, **, and *, respectively. The right-pointing arrow denotes unidirectional causation between independent and dependent variables. There is no bidirectional causation, or the flow of information from dependent to independent factors.

Finally, it is crucial to identify the factors that are causal as well as how they affect the outcome of policies intended to promote economic growth and environmental preservation. The Dumitrescu and Hurlin (2012) approach is used to evaluate the suggested causal relationships between the variables in this study. Table 8 depicts a one-way causal link between CO_2 emissions and GDP, GDPS, EPS, CRI, GINOV, and RERD demonstrating that any short-term policy change in the aforementioned variables will have a long-term effect on the pollution levels in the BRICS countries.

5 | CONCLUSION AND POLICY IMPLICATIONS

5.1 | Conclusion

Innovation in technology has significantly increased economic participation and global output, which has significantly increased the consumption of fossil fuels and raised significant environmental concerns. Due to recent developments in environmentally friendly technologies, the economic structure has changed away from non-renewable energy sources and toward sustainable energy sources like renewable energy. Environmentally friendly practices have greatly increased the sustainability of the environment in developed nations since the start of the fourth industrial revolution. As a result, this study used the BRICS region as an example to examine the joint effects of GINOV, CRI, and EPS on CO_2 emissions over the period from 1960 to 2020 in the context of economic growth (GDP) and RERD. For solutions to be developed that maintain environmental sustainability, understanding the relationship between these factors is essential. The following are the main conclusions drawn from the research findings: (i) in the long-term, GINOV, CRI, EPS, RERD, GDP, and CO_2 emissions are cointegrating; (ii) EPS, GINOV, and RERD contribute to improve environmental sustainability; (iii) CRI degrades environmental quality; and (iv) GDP heightens environmental degradation while its square aids in preventing it, showing evidence of EKC hypothesis.

5.2 | Policy implications for sustainability

This part discusses not only the specific BRICS nations' context but also considers implications for sustainability (more broadly) and for the SDGs. This section also focuses on the significance of the study (in terms of its implications for policy) and what can be learned in the context of sustainable development. The United Nations' SDGs provide a helpful framework for addressing developmental difficulties in order to achieve a low-carbon economy free of societal, economic, and ecological imbalances and therefore guarantee a healthy and sustainable quality of the environment. The BRICS countries have thrived in all five of the goals—advancement of climate action, justice and social institutions, life on land and peace, industry, innovation and infrastructure, and access to affordable and clean energy—and have made considerable progress toward all of them. The findings of this research are extremely pertinent to the thirteenth UN Goal (climate action). First, the BRICS countries should vigorously promote and put into practice GINOV techniques in order to ensure environmental sustainability. On the one hand, it is critical to continue developing the industry's green standard system, find additional green factories, processes, products, parks, and supply chains, and create a green manufacturing system during the course of the sector's existence. On the other hand, it is critical to uphold intellectual property rules, focus on urgent problems like energy conservation, carbon emission reduction, environmental pollution control and governance, and provide targeted financial and tax help to encourage GINOV. The BRICS states should use top-level planning to create a list of prospective smart technological solutions for carbon reduction while also establishing technical value criteria. Furthermore, it is crucial to assist companies in selecting technologies and formulating business strategies based on the characteristics and application of certain technologies, as well as the potential for emission reduction and potential profit margins of smart carbon reduction solutions. In partnership with governmental agencies, energy providers, and other stakeholders, platforms are being developed for monitoring carbon emissions at the industrial level. The platform can analyze data on the impact of smart carbon reduction technology and monitor the carbon emissions of energy-intensive companies in real time, giving evidence in favor of technological adoption and the development of appropriate international regulations. It is crucial to create a green supply chain with significant companies at its core. Leading companies in the green manufacturing sector should get assistance and encouragement in order to actively create a green supply chain, take the lead, and motivate firms upstream and downstream to implement energy-saving and environmental initiatives. The implementation of ecological design, the development of green goods, the promotion of green manufacturing, and the provision of green consumption advice should all be promoted by major businesses. Also, businesses should be encouraged to adopt long-term low-carbon development strategies and roadmaps toward carbon neutrality. The BRICS governments should enhance aid and advice, industry promotion, and the depth of enterprise collaboration in order to fully capitalize on the leading position of big companies. Moreover, given that GINOV is environmentally benign in the BRICS nations, BRICS authorities should urgently concentrate on optimizing the ecological effect of green technologies in their efforts to strengthen and promote sustainable economies. In order to promote environmental advancements and associated technology, the BRICS government should also subsidize programs like the adoption of green practices and make a deliberate effort to reform all pertinent legislation (Udeagha & Breitenbach, 2023b). Adopting technology-friendly regulations, putting green policies into practice, and improving the environment are all important to support sustainable growth, solve ecological and sustainability challenges, and improve the environment. As more responsible technical infrastructures and innovation are built with the inclusion of green solutions, it will be possible to control the risk factors linked with innovations and technological achievements. While selecting environmentally friendly standards for technology that might increase environmental sustainability, authorities must also have a set of criteria in place.

Second, policymakers should manage political unrest, economic crises, and financial instability to reduce CO_2 emissions since the CRI increases CO_2 emissions in the BRICS countries. Political stability should theoretically result in higher income levels, which will raise people's awareness of environmental contamination. Policymakers are often under more pressure to create a better atmosphere in this circumstance. It follows that reducing political risk in a nation can cut CO_2 emissions, suggesting that political risk is probably a significant component in the deterioration of ecosystems and the environment. Also, while formulating policies that promote development at the expense of environmental sustainability, the BRICS countries should exercise caution. Innovations in carbon capture and storage that can lower CO_2 emissions from the production of power and airborne processing processes utilizing fossil fuels should also be adopted by governments. In order to limit environmental harm, decision-makers should also take into account imposing a carbon price on polluters in the short-term to control CO_2 pollution.

Third, raising environmental taxes and tightening environmental rules and regulations can both be useful tools for lowering CO_2

emissions since EPS enhances environmental quality. These two tools, however, are not enough to completely offset the negative consequences of energy use and CO_2 emissions. The relevance of the conflict between fostering economic growth and protecting the environment has been further underscored by our findings. The fundamental tenet of sustainable development for BRICS nations should be lowering total emissions while maintaining high levels of economic development. The BRICS nations should strike a balance between fostering economic development and preserving their environmental quality. Their long-term objective of protecting the environment should be an effective strategy of tightening their environmental rules and regulations while also supporting renewable energy, changing the energy mix to a fossil fuel-free economy, and improving energy efficiency. Our research further reveals that the best method to minimize CO_2 emissions is to increase the use of renewable energy sources. Over time, increasing the use of renewable energy both lowers emissions and supports a sustainable energy supply for a zero-emission plan. The BRICS nations should provide incentives for their citizens to buy more environmentally friendly products and services. In their efforts to create sustainable energy sources and improve environmental quality, they should also benefit from attracting foreign direct investment that supports cutting-edge green technology and renewables. The BRICS nations should improve their capacity for imitating advanced nations' GINOVs and team up to promote clean technologies. Because CO_2 emissions are a global issue, there must be a global response. In order to reduce CO_2 emissions, the BRICS nations should actively participate in international collaboration. Future clean growth should follow a path involving increased energy efficiency and the development of renewable energy sources. In order to stop environmental damage, the BRICS area should also tighten environmental regulations. Environmental rules that are more stringent will encourage businesses and consumers to adopt environmentally favorable behavior. In this regard, it is important to effectively promote and execute recent commendable regulatory improvements in the area, such as the Revised Environmental Protection Law that went into effect in 2014 and the Environmental Protection Tax Law that went into effect in 2018. Also, the current level of emissions should be taken into account when determining how strict environmental rules should be in the BRICS nations.

Finally, there is no disputing the role that renewable energy sources play in environmental protection. It is advised to increase green investment in order to move away from traditional energy manufacturing methods and to modernize and better the processes used to produce green energy. More emphasis should be placed on the production of nuclear, biomass, and solar thermal energy. The BRICS countries should increase green funding scope and volume to help the generation of renewable energy. The BRICS countries' next move in terms of policy will be to focus on making a major adjustment to their entire energy mix by raising the share of renewable sources in the overall domain of energy consumption. Similar to this, it is critically important to plan well for technological advancements and improvements in the energy sector to boost carbon sequestration and storage in order to avert ecological harm. In order to promote a green environment, growing green investment is crucial. Another suggestion is to create different credit or green credit policies or procedures that would allow for varying interest rates for various firms depending on how big of an impact they have on environmental degradation and carbon emissions. More polluting companies might face higher interest rates on their debt. Businesses that generate more pollution might face greater borrowing costs, and vice versa. All sectors will be compelled to develop sustainable or renewable energy sources to the utmost degree practicable as a result. Similarly, industries that produce little or no CO_2 should be given incentives like tax cuts or lower tax rates. Importers should be given incentives to simultaneously bring in green energy products. These concepts show how three important SDGs—improving economic growth (SDG no. 8), taking into account environmental degradation and enhancing environmental sustainability (SDG no. 13), and ensuring widespread access to affordable green energy (SDG no. 7)—can cooperate.

5.3 | Limitations of the study

Although the current inquiry produced robust empirical findings in the instance of the BRICS countries, the research investigation had several drawbacks that might be taken into account in further investigative work. The inadequate availability of the data outside of the sample period, which limits the use of panel data, is one of the investigation's key limitations. Nevertheless, this study assessed the combined impact of CRI, EPS, and GINOV on environmental quality in BRICS nations using up-to-date panel data. Further research utilizing other econometric methods or micro-disaggregated pertinent data may focus on other emerging regions. Other growth-related elements that were not taken into account in this study, such as institutional quality and natural resources, can be examined in future research. Nonetheless, CO_2 was employed in this study as an indicator of the quality of the environment. Additional research is required to determine whether consumption-based carbon emissions or other metrics of carbon footprints, such as chlorofluorocarbons, volatile organic compounds, hydrocarbons, and other transient climatological shocks, are better indicators of environmental quality in the BRICS countries. The present research examines CO_2 emissions as a reflection of environmental quality even though they are not the only cause of ecological pollution. Future research should study this connection by taking into account additional ecological contamination factors, such as water pollution and hazardous contaminants. By combining time series data with panel estimation techniques, further research may compare country-specific results to generic panel outputs using far more advanced strategies. This can assist illuminate the existing evidence by providing a comparison analysis with the findings of this inquiry. Another significant weakness in the inquiry is its narrow analysis of a single region. Thus, future study should concentrate on examining the combined impact of CRI, EPS, and GINOV on environmental quality for a wider perspective in the African panel setting and other regions of the world. Furthermore, using aggregate-level data, this study has examined the combined effects of CRI, EPS, and GINOV on CO_2 emissions in the BRICS economies. This is also another drawback. By combining time series data with panel estimation techniques, further research may compare country-specific results to generic panel outputs using far more advanced strategies. This can assist illuminate the existing evidence by providing a comparison analysis with the findings of this inquiry. The inquiry ignored any potential national disparities within each country in doing this. In light of this, future research may look into analyzing the combined environmental effects of CRI, EPS, and GINOV using statistics at the national level (as opposed to state- or provincial-level). The combined impact of CRI, EPS, and GINOV on emissions in various industries within the BRICS economies was ignored by using aggregate-level data in this analysis. The sectoral variations in the analysis could thus be another direction for future research. Lastly, future studies might think about looking into how certain factors like economic development and renewable energy on the environment interact with CRI, EPS, and GINOV.

AUTHOR CONTRIBUTIONS

Maxwell Chukwudi Udeagha and Edwin Muchapondwa conceptualized the study idea, drafted the paper, collected data, analyzed data, wrote the introduction section, organized the literature review, drafted the methodology section, interpreted the results, and provided the discussions, concluded the study with policy implications and organized the reference list.

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The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data relevant to this research is publicly available from the World Development Indicators or obtained from the authors by making a reasonable request.

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