

ARTICLE

The dynamics of green technological innovation and environmental policy stringency for sustainable environment in BRICS economies

Nudrat Fatima^{1,2} | Zheng Yanting¹ | Ni Guohua¹ |
Muhammad Kamran Khan²

¹Beijing Technology & Business University, Beijing, China

²Management Studies Department, Bahria University, Islamabad, Pakistan

Correspondence

Zheng Yanting, Beijing Technology & Business University, Beijing, China.

Email: zhengyanting@th.btbu.edu.cn

Abstract

The continuous rise in global economic growth (EG) and human activities has contributed to the release of CO₂, emphasizing the crucial role of environmental policy stringency (EPS) in encouraging green innovation to lower CO₂ emissions levels and achieve environmental sustainability. This study aims to analyze the direct impacts of geopolitical risk (GPR), renewable energy consumption (RE), EPS, green technical innovation, and EG on CO₂ emissions in Brazil Russia, India, China, and South Africa (BRICS) economies on the dataset spanning from 1990 to 2020 using dynamic ordinary least square, fully modified ordinary least square, and method of moment quantile regression approach. The results demonstrate that stringent environmental regulations and the adoption of green technology are negatively associated with CO₂ emissions. Further, the interaction of INV*EPS also demonstrates a negative impact on CO₂ emission. In contrast, GPR and EG have a positive effect on CO₂ emissions. These findings suggest that it is imperative for the policymakers of BRICS economies to implement measures that effectively encourage the adoption of green innovative technologies through the adoption of robust policy initiatives. In general conclusion, the long-term viability depends on the implementation of green innovations by

enacting strict environmental regulations in the sample countries. Based on these findings study suggests that there is a need to prioritize the consumption of renewable energy sources, the adoption of rigorous environmental regulations, and the utilization of climate-friendly technology to attain extensive and sustainable economic development. Furthermore, this study urges the attention of government officials and policymakers in these economies to redesign more effective strategies to address these potential challenges and safeguard the environment.

KEYWORDS

BRICS, environmental policy stringency, geopolitical risk, green technological innovation, MMQR, renewable energy consumption

1 | INTRODUCTION

Energy is a fundamental element in the growth of any country. Globally energy demand is continuously increasing due to increased human activities and economic growth (EG). Further, carbon dioxide (CO₂) emissions were mainly caused by energy usage, industrial activities, combustion, and methane emissions (Wang et al., 2024). Therefore, in a rapidly growing global environment where CO₂ emissions and the resulting climate change pose a significant threat (Sharif et al., 2024), a country's energy framework has become a vital instrument for ensuring its long-term sustainability (Feng, Durani, et al., 2024; Feng, Sabir, et al., 2024). Countries have adopted relevant policies to promote the development of environmentally friendly energy structures, technologies, and applications, to provide support for the preservation of energy and a sustainable environment. Nations that put significant emphasis on green innovations foster technology that enables them to discover novel solutions to their energy challenges (Han et al., 2023), reduce their reliance on constrained energy resources, and enhance their sustainable development. Figure 1 depicts the distribution of green and sustainable technology adoption across different nation groupings worldwide. OECD and Brazil Russia, India, China, and South Africa (BRICS) nations have a larger proportion of green and sustainable

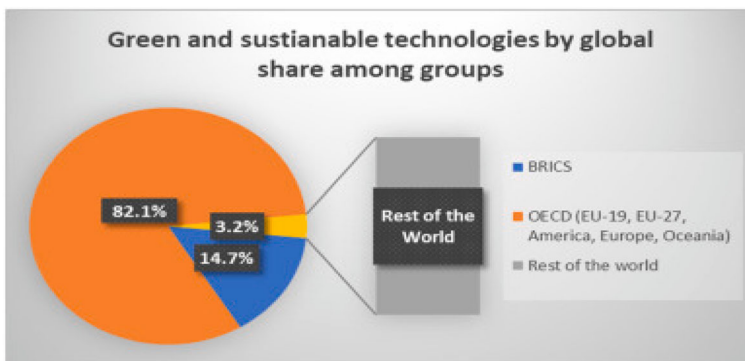


FIGURE 1 Global share sustainable and green technologies, Source OECD (2020) (OECD | Focus on green recovery).

technology investments compared to other regions globally. Strict environmental rules and policies are frequently being used as effective measures to manage energy consumption and promote environmental sustainability. For instance, environmental policies include providing financial incentives to green firms and imposing taxes on high CO₂ emission enterprises.

Multiple research substantiates the criteria that ascertain ecological sustainability as they enable decision-makers to implement practical measures to combat environmental deterioration (Akram et al., 2023; Pan, Adebayo, et al., 2023; Pan, Wang, et al., 2023; Zhang et al., 2024; Zhou et al., 2024). Therefore, employing green innovative technology is a very effective approach to enhancing environmental sustainability (Shen et al., 2024). These are mostly effective sources that are frequently encouraged to achieve carbon neutrality and transition toward ecologically friendly industrial practices. Since its integration into the manufacturing process, it enhances factors' performance, automates processes, enhances industrial competitiveness, reduces energy consumption, and allows the use of renewable energy, thus ultimately contributing to environmental sustainability.

Recently, countries have been adopting green policies to address environmental issues and attain objectives related to sustainable development (Leal Filho et al., 2023; Nazir, 2023). Environmental policy stringency (EPS) has the potential to address adverse consequences that affect the condition of environmental systems (Assamoi & Wang, 2023), while also fostering green technological innovation by promoting green growth (Alsagr, 2023). The existing body of empirical research analyzed the association of government policies and the environment, specifically the effectiveness of stringent environmental regulations, and is currently constrained in its exploration of the role of environmental regulation as a significant catalyst for the promotion of green technological innovation and sustainable environment. According to the OECD (2016), EPS is described as the cost, whether explicit or implicit, associated with activities that have a detrimental effect on environmental sustainability. One potential approach to shifting industrial structure toward more environmentally friendly goods is through the implementation of carbon taxes (Wan et al., 2022; Yue et al., 2022). This policy mechanism has the potential to encourage the replacement of energy-intensive items, therefore facilitating a shift toward the consumption of more sustainable alternatives (Liu et al., 2022; Talwar et al., 2023). By a review of the impact of EPS on the CO₂ emission level, this study aims to examine the association between environmental degradation and the growth of environmental policy strictness within BRICS economies. The examination of the energy policies specific to BRICS countries can also contribute to the development of a model for environmental policies (Ofori et al., 2023) that can be applied to other emerging economies.

Furthermore, several factors contribute to increased CO₂ levels thus degrading the environment. Geopolitical risk (GPR) refers to the potential consequences arising from both economic and political circumstances (Chu et al., 2023), with environmental catastrophes (Khan, Sun, et al., 2023), on world economies and diplomatic interactions (Ding et al., 2023). The concept incorporates an extensive number of elements, such as societal turmoil, armed hostilities (Khorram-Manesh & Burkle, 2023), acts of terrorism (Pan, Wang, et al., 2023), trade disagreements, and limitations in natural resource availability (Yuan et al., 2023). Over recent years, there has been an important extent of instability observed in the global political and economic landscape, resulting in the emergence of a more intricate global economic framework (Teece, 2022). The global economy has seen a decrease in growth as a result of recurring GPR, including the China–United States trade dispute, the COVID-19 pandemic, the Russo-Ukrainian confrontation, and the ongoing Israel–Palestine war. GPRs, including factors such as armed conflicts, terrorism, and regional disputes, are significant determinants that might elevate environmental pollution and also increase the financial burdens associated with investments in renewable energy (Liu et al., 2023). According to Caldara and Iacoviello (2022), the implementation of GPR results in a rise in investments by institutions and governments. In this study, we utilize the GPR index provided by Caldara and Iacoviello (2022) to assess the association between GPR and environmental quality in BRICS economies.

The selection of the BRICS countries for inclusion in this study is supported by the following rationales: The BRICS countries, contribute to approximately 32% of the global gross domestic product (GDP). Additionally, these countries represent nearly 42% of the global population. Furthermore, revealed that by the year 2050, the BRICS

countries will surpass the G7 nations in terms of GDP. In terms of CO₂ emissions, the BRICS countries contribute around 40% of the total emissions worldwide. According to statistical data, China, Brazil, India, and Russia are among the top 7 countries that contribute significantly to emissions, which are recognized as significant drivers of deteriorating the environment. Consequently, the economies of BRICS countries are currently facing challenges in their efforts to reduce emissions with the goal of achieving sustainable development. Moreover, the BRICS countries exert substantial political influence within the global energy and resources sector, along with the current global landscape. The statistical data depicted in Figure 2 indicates that the BRICS countries face GPRs that surpass the global average in most years. This implies that these economies encounter substantial geopolitical turmoil. Further, numerous factors pose a threat to the long-term sustainability of development and the formulation of energy and environmental policies. The transitional phase of economic development in the BRICS countries leads to an intensified interplay between geopolitical concerns, the shift toward RE sources, EPS, and the pursuit of environmental sustainability.

Consequently, this study aims to investigate the effects of GPR on CO₂ emissions within this group of growing economies, considering their economic, geopolitical, and demographic significance. In spite of this, the BRICS economies have intensified their efforts to reduce reliance on fossil fuels by actively advocating for the adoption and utilization of RE sources, allocation of investments toward green technologies, and coordination of political attempts that promote advancements in non-fossil resources (Chen et al., 2023; Yao et al., 2023). Extensive research has been performed on the association between GPR and the economy, but the association of GPR, RE, and EPS, with environmental concerns, specifically CO₂ emissions, remains ambiguous and lacks further investigation. Moreover, academia has not yet achieved a consensus on the combined effect of environmental regulation and technological innovation (INV*EPS) on environmental degradation, despite the recognition of green technology innovation as a crucial approach to mitigating ecological harm and achieving sustainable development specifically in the context of BRICS economies. Porter's hypothesis demonstrates varying effects between nations and territories, and the causal

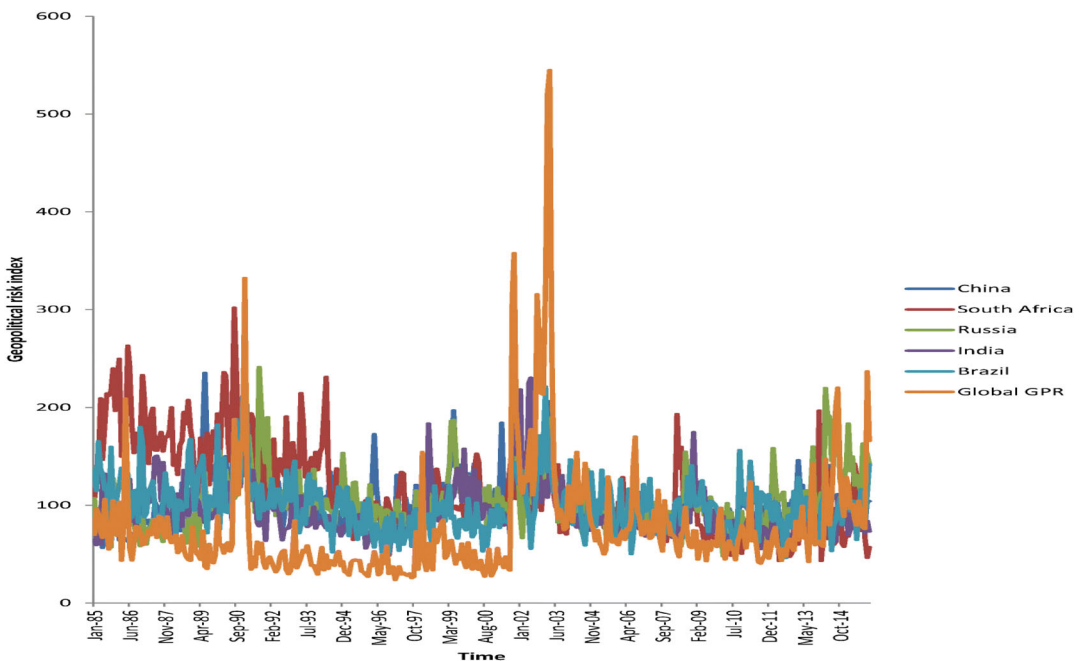


FIGURE 2 Source: Geopolitical risk index for Brazil Russia, India, China and South Africa economies.

process by which environmental regulations influence green technological innovation remains ambiguous. Based on this discussion the current study addresses the following research questions

1. Does GPR enhance the environmental degradation in the BRICS region?
2. Does the combined effect of EPS and green technological innovation contribute to increased environmental quality in BRICS countries?
3. Is the validity of the Porter hypothesis on the impact of strict environmental regulations on green technological innovation comparable to that of non-green technology innovation in BRICS nations?

The fundamental aim of developing and implementing environmental policy is to achieve sustainability. Porter's theory suggests that the effectiveness of environmental regulation in promoting innovative technologies for environmental sustainability depends on whether the regulated party is given the freedom to select their environmental protection technology and fully benefit from their initiatives. Hence, this study aims to fill the current gap in the academic literature with a thorough investigation that integrates the combination of GPR, RE, EPS, INV, and EG as well as the interaction of INV*EPS and CO₂ emissions in BRICS countries. Furthermore, with the development of industrialization, the economies of the BRICS nations are facing increasing pressure to implement measures aimed at diversifying their energy policy and reducing their environmental impact.

This study provides empirical and methodological contributions to the existing literature. It is motivated by the lack of empirical research on the subject and the requirement to establish an apparent association between political risk and environmental degradation, particularly in the BRICS economies. These economies are expected to play a significant role in global development in the coming decades. Hence, the objective of the research is to ascertain whether political risk influences the level of CO₂ emissions in the BRICS economies, considering the sustainable development goals. Therefore, the current study provides distinctiveness to the debate concerning the environment in various ways. *First*, the GPR index created by Caldara and Iacoviello (2022) is employed in assessing the negative consequences associated with the rapid economic transition in BRICS economies. Considering the significant prominence of prior academic studies and their findings, the proxies for GPR such as terrorism/terrorist incidents, warfare or militarism, and political volatility exhibit certain constraints. The constraints include the inability to capture data in real time, the presence of gaps in data gathering, and the failure to incorporate the spectrum of geopolitical events. Furthermore, it is crucial to emphasize that the proxies employed in this particular circumstance are inadequate in accurately representing GPR.

The primary explanation of this may be attributed to their lack of comprehensive consideration of many issues, such as economic downturns, geopolitical conflicts, and the impact of climate change (Bouoiyour et al., 2023). The GPR index serves as a metric for assessing the degree of risk associated with various factors such as acts of terrorism, military clashes, the likelihood of war, political instabilities, and uncertainty in geopolitical dynamics. The superiority of this index over other indicators derives from its capacity to consistently assess GPR across time, while comprehensively and accurately considering several components. Moreover, it is crucial to note that the GPR index considers both present risk and projected future risks (Qian et al., 2022). Additionally, this research incorporates the EPS index. The EPS index considers the various dimensions of environmental stringency, providing a comprehensive overview. This approach differs from previous indicators such as pollution reduction cost and expenditures, green technological innovation, and the growth of economic and industrial sectors in relation to environmental quality. The inclusion of these indicators enables us to broaden the discourse concerning environmental sustainability. Further, the inclusion of BRICS economies in this research will contribute to the current discussion on environmental issues in developing markets. *Second*, this study investigates the long-term impact of political risk, renewable energy consumption (RE), EPS, and green technological innovation on environmental degradation in the BRICS economies from 1990 to 2020. It employs an extensive range of statistical methods, including the dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS), and canonical cointegration regression (CCR) to analyze the long-term association among selected variables. Considering variations in distribution, the current study employs method of moments quantile regression (MMQR) recently proposed by Machado and Silva (2019) approaches for

assessing the long-term environmental performances of the economies of the BRICS nations. In contrast to previous research, this study used the quantile estimation approach to examine the various effects of explanatory factors on the varying levels of environmental degradation. This study also employs the feasible generalized least squares (FGLS) and bootstrapped quantile regression (BSQR) techniques to check the robustness of our empirical findings derived from primary techniques. This serves to validate the influence of various factors and ascertain their precise impact. *Third*, the comprehensive econometric methodology allows us to propose new policy recommendations to tackle environmental challenges resulting from geopolitics, economic development, and energy usage to achieve SDG 13 in BRICS economies. *Fourth*, this research has made a significant theoretical addition by employing the Porter hypothesis framework within the specific context of BRICS economies.

The empirical results of the research indicate a negative association between the execution of rigorous environmental regulations, developments in technology, and the promotion of sustainable development. Furthermore, there exists a positive correlation between environmental deterioration and both GPR and EG. These results contribute to the assessment of the effectiveness of environmental policies by encouraging the adoption of green innovative practices and the development of policy debates. The findings of this study would assist policymakers in developing accurate socioeconomic and environmental policy considerations on the negative impacts of rising political risk in a globalized economy on environmental quality. Policymakers should recognize the imperative of mitigating political risks that could potentially threaten both industry and the environment. This contends that increased political risk would impede the procedure and timeframe of addressing economic and commercial concerns that might affect both EG and the environment overall.

2 | LITERATURE REVIEW

The researcher has conducted extensive theoretical and empirical analysis on the determinants of CO₂ emissions in BRICS nations, contributing significantly to the assessment and mitigation of environmental risks. One prevalent viewpoint supported by researchers in the fields of sustainable environment and climate change contends that the natural environment is facing a growing peril for future generations (Dogan et al., 2023). Consequently, it is imperative to tackle this issue by implementing effective solutions. In these circumstances, various groups including scientists, policymakers, and environmental activists are advocating for a range of viable and sustainable strategies intended for mitigating the detrimental consequences of climate change in both the present and future timeframes. There exists a prevailing consensus that the energy transformation system confronts a significant challenge that is reliant on certain factors. It is important to prioritize the observation of sustainable solutions to enhance the standard of life while minimizing any adverse effects on the environment. Based on this rationale, the United Nations has embraced a sustainable development agenda for the year 2030, encompassing 17 distinct sustainable development goals. Among these objectives, SDG-13 assumes a central role by placing significant emphasis on climate action. In a more precise manner, these objectives were formulated with the aim of promoting sustainable development strategies across several domains, encompassing environmental, social, and economic components. To achieve sustainable outcomes, various measures have been implemented in both developed and developing economies. However, significant challenges remain in mitigating the threat to the natural environment, particularly in relation to increased levels of greenhouse gas emissions, haze pollution such as PM_{2.5}, and CO₂ emissions (Guan, Hossain, et al., 2023; Guan, Xiao, et al., 2023; Syed et al., 2023; Wu et al., 2023). Therefore, it is necessary to take decisive actions to address these issues.

2.1 | Green innovation and environmental sustainability

Sustainable technologies are commonly referred to as green technologies because of their considerable environmental ramifications. Green innovation (GI) implies a specific form of innovation in technology that has the capacity to

enhance environmental sustainability (Khan, Anwar, et al., 2024; Khan, Thang, et al., 2024; Shen et al., 2023). It is characterized by substantial investments, considerable pitfalls, and extensive research and development activities. According to these claims, economies have significant challenges when it pertains to executing green innovation activities (Dong et al., 2024). The recent exponential growth of green technologies has compelled enterprises, educational institutions, and governments to allocate resources toward enhancing the green energy infrastructure and productivity, while simultaneously tackling environmental issues (Zhang et al., 2023). Several studies have investigated the dynamic influence of these technologies in addressing sustainability challenges (Ibrahim, Al-Mulali, et al., 2023; Ibrahim, Huang, et al., 2023; Wang, Gu, et al., 2023; Wang, Ibrahim, et al., 2023). Technological innovation significantly contributes to improving environmental quality. BRICS countries are growing at an enormous pace in the last 3–5 decades. The rapid expansion of industrial activities has resulted in substantial infrastructural growth, necessitating increased fuel consumption and subsequently leading to elevated levels of carbon emissions (Dehdar et al., 2022; Hwang, 2023; Milindi & Inglesi-Lotz, 2022). The BRICS countries have experienced significant technical advancements in recent years. For instance, China has implemented an economic framework aimed at enhancing production levels. However, it is notable that this approach has resulted in certain implications for the standard of products produced during that period threshold (Bai et al., 2020; Du et al., 2019; Sadiq et al., 2023). The study of Behera et al. (2023) examined the significance of innovation in green technology for achieving carbon neutrality and promoting an environmentally friendly approach to the Turkish economy. Technological advancements have a crucial role in enhancing energy efficiency, mitigating energy consumption, and lowering CO₂ emissions. The study of Hou et al. (2023) demonstrated that innovations in technology provide significant prospects for achieving the energy demand by facilitating the transition from limited sources of energy to sustainable alternatives. Furthermore, these advancements enable the country to attain elevated production levels while minimizing energy consumption. Furthermore, technological innovation enhances entrepreneurial activities by improving market accessibility and fostering increased competition. One potential approach for stimulating EG and enhancing labor market outcomes is through the facilitation of technological advancements that promote the liberalization of global commodity markets. This approach has the potential to foster fresh investments, enhance productivity levels, and eventually lead to improvements in employment rates and real pay levels (Amin et al., 2023).

2.2 | Environmental policy stringency and environmental sustainability

The significance of the environment's quality has prompted numerous governments and policymakers to prioritize this issue. The impact of environmental policy on deteriorating the environment has been a subject of intense challenge in recent years. Researchers have shown considerable interest in examining the empirical outcomes of measures such as the EPS index in relation to climate change. For instance; (Abbasi et al., 2022; Bai et al., 2022; Dogan et al., 2023; Georgatzi et al., 2020; Khan et al., 2019; Li et al., 2022; Li et al., 2023; Lu et al., 2023; Niu et al., 2023; Yong et al., 2020). Similarly, many studies have expressed their interest in studying the effects of EPS on CO₂ emissions in the BRICS economies (Sezgin et al., 2021; Shah, Hao, et al., 2023; Shah, Usman, et al., 2023; Udeagha & Ngepah, 2023a, 2023b). They aim to investigate this relationship using panel cointegration analysis. However, empirical results show that initially, strict environmental regulations (EPS) do not produce positive results. However, it has been demonstrated that these policies help to improve the natural environment's overall quality. Therefore, it is advised that these policies be considered as successful tactics for implementing action to stop the environmental degradation.

According to Sachan et al. (2023), there is a continuing discussion regarding the potential of environmental regulations in achieving ambitious emissions reduction objectives stated in the Paris Agreement. Their findings indicate that the implementation of rigorous environmental policies aligns with the promotion of green innovation, consequently serving as a catalyst for the adoption of sustainable development practices. Afshan et al. (2023) performed a predictive analysis of EPS on CO₂ emission in China, utilizing the quantile-autoregressive distributed lag (ARDL)

approach. The study findings indicate that there is an anticipated increase in CO₂ emissions in China from 2000 to 2017. However, it has been observed that the implementation of strict environmental policies has led to a reduction in CO₂ emissions, particularly in cases where there is an increase in the intensity of emissions relative to GDP.

2.3 | GPR and environment

Geopolitical risk has been recognized as a significant element contributing to CO₂ emission (Bashir et al., 2023). Initially, analysis of geopolitics establishes a correlation between geography and global events, highlighting the significant factors of persistent competition, territoriality, and the influence of colonial armed forces (Jüni et al., 2020). According to the literature, these elements have been shown to exert influence on the natural environment, hence contributing to the exacerbation of environmental degradation (Feng et al., 2023; Kartal et al., 2023). As a consequence of this process, a limited number of environmentalists identify the influence of GPR on the exacerbation of CO₂ emissions. Rasoulinezhad et al. (2022) conducted a study on the strategies used in Russia's energy transition, with a specific focus on GPR by employing ARDL methodologies to analyze data spanning the years 1993–2018. Their findings demonstrated an association between GPR and the process of energy transition, as well as the impact of political disturbances on the development of climate change. According to Liu et al. (2023), there is evidence suggesting that geopolitical crises in China have a spillover impact on the renewable energy sector. Further, Wang et al. (2021) reveal that the disruption occurring on the border between China and India has resulted in significant implications, leading to the compromise of both social and economic stability. They used the GPR index and Granger rolling-window estimate technique to examine the relationship between the Chinese government's application of GPR and its ability to regulate CO₂ emissions. The findings suggest that the government may potentially utilize GPR in an attempt to mitigate CO₂ outflows by promoting the growth of green industries and maintaining a sustainable environment. However, the energy business serves as China's main source of GPR. Furthermore, Dong et al. (2023) conducted a study on the geopolitical issue in BRICS countries from 2000 to 2020, employing the CS-ARDL approach. The results of their study suggest a significant positive association between CO₂ emissions and GPR. Furthermore, it is observed that environmental externalities experience a significant increase over time.

Moreover, GPR demonstrates a robust association with the phenomenon of climate change. The imperative to reduce the potential effects of rising temperatures and mitigate a global climate catastrophe has elevated the significance of reducing CO₂ emissions (Anser et al., 2021; Du & Wang, 2023; Bordoff & O'Sullivan Meghan, 2022). Uddin et al. (2023) performed a research study with the objective of examining the influence of GPR, FDI, governance, energy consumption, and green technical innovation (GINV) on CO₂ emissions in BRICS economies. They employed the CS-ARDL, DOLS, and FMOLS methods to evaluate a dataset spanning the years 1990–2020. Their findings suggest that within the framework of climate change, GPR possessed the potential to exert a substantial influence on the environment. An illustration can be found in the persistent political tensions that exist between Iran and United States. These tensions have resulted in the implementation of economic sanctions, subsequently causing disruptions in global oil markets and a subsequent rise in oil prices. Consequently, economies with a significant dependence on imported oil, such as Korea and Japan, may exhibit a greater propensity to utilize more environmentally detrimental fossil fuels, such as coal. An additional illustration pertains to the ongoing conflict in Syria, which has given rise to a substantial humanitarian challenge in the form of a refugee crisis. The influx of refugees has caused considerable strain on the resources and infrastructure of adjacent nations, leading to increased demands for energy and subsequent escalation in CO₂ emissions. Similarly, the study of Pata et al. (2023) investigated the effects of GPR and economic policy uncertainty on sector-specific CO₂ emissions. The authors employed the wavelet transform coherence and time-varying wavelet causality test (TVWCT) methodologies to analyze a dataset spanning from 1997 to 2022. The study has provided evidence to support the claim that the implementation of GPR and EPU technologies has led to a notable decrease in CO₂ emissions across various sectors, including residential, commercial,

industrial, and electrical. Nevertheless, it is noteworthy that the transportation sector has witnessed a rise in CO₂ emissions due to the implementation of GPR measures. The TVWCT's findings indicate a significant relationship between the GPR and the EPU, and sector-specific CO₂ emissions, suggesting a causal effect. However, it is crucial to realize that the occurrence of these causal effects differs when examining both the unprocessed and broken-down data. The results demonstrate that EPU has a more significant influence on mitigating sector-specific CO₂ emissions in the context of the Ukraine–Russia crisis. Furthermore, it is apparent that the disruptions in production resulting from uncertainty have the most significant effect on reducing CO₂ emissions within the electric power and transportation sectors.

2.4 | Renewable energy consumption and environmental sustainability

According to the literature, the effect of renewable energy on the reduction of emissions is relatively basic in terms of energy transition. Considering that the consumption of fossil fuels is the primary contributor to emissions, RE is frequently suggested as an approach to alleviate the global increase in emissions (Ibrahim, Awosusi, et al., 2023; Yan, Ibrahim, et al., 2023; Yan, Qamruzzaman, & Kor, 2023; Zhou et al., 2023). According to Hund et al. (2023), the transition to renewable energy sources has the capacity to fulfill the need for sustainable energy while also addressing the requirement for various types of clean energy production which is free from greenhouse gas emissions. The empirical evidence has not yet generated absolute conclusions. Acheampong et al. (2019) conducted a study employing data from 46 sub-Saharan African countries spanning the years 1980–2015, a substantial decrease in CO₂ emissions has been observed as a result of the adoption of renewable energy sources. Husnain et al. (2022) used an augmented mean group approach to analyze data from multiple countries, including Turkey, Brazil, Russia, Indonesia, Mexico, and India. Their findings demonstrated that the transition to renewable energy sources greatly reduced CO₂ emissions. Yuan, Ma, et al. (2022); Yuan, Su, et al. (2022) conducted a study employing monthly data spanning from January 1973 to June 2021, employing a Granger causality methodology. They also suggested that renewable energy transition holds considerable promise in addressing the reduction of CO₂ emissions. Recently, Raihan and Tuspekova (2022) performed an analysis on data collected from Malaysia spanning the years 1990–2019. They employed the dynamic OLS methodology to examine the correlation between RE and CO₂ emissions. The findings of their study indicate that there is a significant impact of RE on CO₂ emissions. Pata and Caglar (2021) observed a comparable result through the utilization of augmented ARDL modeling on data spanning from 1980 to 2016, focusing specifically on China. According to the findings of Bekun (2022), there exists a correlation between the RE and a reduction in emissions. In another study, Bekun et al. (2021) noticed a correlation between non-RE consumption and the exacerbation of emissions within the E7 economies. According to Mohsin et al. (2023), within the European Union, there is evidence to suggest that energy consumption is positively correlated with the release of GHG emissions. To achieve net-zero emissions in the sub-Saharan African region, the transition toward sustainable energy sources is essential (Obobisa, 2022). Furthermore, Caglar and Ulug (2022) assert that the investment in energy through private–public partnerships has been found with a detrimental impact on the environment within the BRICS countries.

2.5 | Limitations in the literature and contributions

Although there is a significant amount of literature on the subjects of INV, EPS, RE, GPR, and CO₂, the combined effect of INV*EPS on CO₂ within the BRICS framework has not been thoroughly investigated. Numerous researches have been conducted to investigate the factors that contribute to environmental degradation, for instance; one significant limitation is the omission of considering the moderating role of environmental rules and policies, particularly aims to promote the development of green technology innovation for enhancing environmental sustainability.

Consequently, the objective of this study is to address this research void and enhance our comprehension of how stringent environmental regulations and green innovation jointly affect CO₂ emissions. This susceptibility enables the present research to be the first to offer full empirical insights on achieving a sustainable environment in BRICS economies by employing an extensive range of econometric techniques, that is, DOLS, FMOLS, CCR, and MMQR. This is intended to assist the development of comprehensive policy suggestions to achieve SDG 13 in BRICS economies. This study aims to address and overcome challenges related to green innovation, environmental policy, energy transition framework, rising GPR, and environmental sustainability to achieve carbon neutrality targets in sample countries. Further, it intends to contribute to the foundation of future research in this field.

3 | DATA AND MATERIAL

3.1 | Data

This study utilizes data from BRICS economies spanning from 1991 to 2020. The aim of this research is to investigate the interplay between GPR, RE, EPS, technical innovation (INV), and CO₂ emissions. The selection of BRICS countries for this study is based on their increasing contribution to the diversification of the global economy. These economies exhibit distinct political, economic, and social attributes, comprising variations in growing population rates, consumption of energy structures, manufacturing rates, metropolitan and infrastructure advancement, and industrial framework. This study intends to examine the impact of GPR on CO₂ emissions in BRICS economies, considering into account their economic, geopolitical, and demographic prominence. A detailed description of the variables is presented in Table 1.

The proxy used to measure environmental quality is CO₂ emission, which is selected as the dependent variable and is calculated as Metric Tons per Capita. Whereas independent variables, that is, GPR is measured as the GPR index (Caldara and Iacoviello, 2022), EPS is measured as the EPS index, RE is measured as %age of total RE, INV is measured with patent applications (development of environment-related technologies, % of all technologies), EG is measured using GDP per capita (Constant 2010 USD). The data for selected parameters is collected from the OECD database¹ (OECD, 2023), World development indicators² (WDI) database, and matteoiacoviello³ database (Caldara and Iacoviello, 2022).

The dynamic interplay between production and lifestyle exerts a significant influence on the composition of social, technological, and economic environments. In the current circumstances, the process of adapting to changing market conditions and meeting consumer demands carries the possibility of resulting in adverse implications for environmental sustainability. The study argues that the increasing consumer demand and the occurrence of climate change impose significant stress on the environment, resulting in the degradation of both economic and

TABLE 1 Variables description.

Variables	Description	Proxies	Sources
CO ₂ emission	Environmental degradation	Metric tons per capita	WDI
GPR	Geopolitical risk	GPR index	Matteo.iacoviello
EPS	Environmental policy stringency	EPS index	OECD statistics
RE	Renewable energy consumption	%age of total renewable energy consumption	WDI
INV	Green technological innovation	Green patents	OECD statistics
EG	Economic growth	GDP per capita (Constant 2010 USD)	WDI

Note: This Table illustrates the selected study variables and a description of these variables with suitable adopted proxies. It also demonstrates the sources of the data.

environmental conditions. The consumption of RE sources, along with advancements in advanced technology and the implementation of more rigorous policies for the environment, has a profound impact on environmental sustainability. The importance of implementing policies aimed at achieving sustainable development cannot be exaggerated in the pursuit of environmental sustainability. These policies provide accessibility to efficient technology, research, and development, as well as green funding. Therefore, GPR, RE, EPS, and INV have a substantial impact on enhancing environmental sustainability.

3.2 | Theoretical underpinning

To enhance sustainable environmental quality within BRICS countries, the purpose of this study is to evaluate the impact of GPR, EPS, RE, INV, EG, and the interaction of INV*EPS on CO₂ emissions.

Green technological innovation (INV) employs search methods specifically developed for identifying environmental technologies, this system collects innovative solutions that are focused on environmental management, global warming mitigation, adaptation, and sustainability (Hassan et al., 2024). Monitoring patents in this field provides valuable information about the technological innovations and advancements that contribute to environmental sustainability in the BRICS countries.

EPS measures the level of strictness of environmental constraints in each country. The EPS offers a thorough examination of the regulatory structure and the extent of dedication to tackling environmental issues (Kashif et al., 2024). This parameter allows for an evaluation of the impact of strict environmental regulations in the BRICS economies.

RE comprises renewable energy consumption derived from various renewable sources, such as hydro, solid biofuels such as; wind, sun, biogas, marine, thermal, and waste. A further benefit of improvements is the promotion of renewable energy utilization in countries (Shah, Hao, et al., 2023; Shah, Usman, et al., 2023). Obtaining a comprehensive overview of renewable energy (RE) is essential in evaluating the environmental consequences and the feasibility of shifting toward sustainable energy sources in BRICS economies.

Geopolitical risk (GPR), as stated by Caldara and Iacoviello (2022), encompasses potential hazards, conflicts, or actions, such as military conflicts, terrorism, and interstate disagreements, that significantly impact a nation's political and economic conditions. Increased GPR resulting from conflict and political turmoil can lead to a rise in CO₂ emissions. GPR associated with conflict or political unrest can impair energy infrastructure, including renewable energy sources, leading to a surge in CO₂ emissions (Chen et al., 2024).

Furthermore, employing interaction terms of *stringency of environmental regulation and the concept of green innovation (INV*EPS)* to analyze their influence on CO₂ emissions is a sophisticated and insightful method. This interaction term enables a more thorough investigation of how these variables collectively impact CO₂ emissions in the context of environmental policy strictness. Each of these variables is meticulously selected to provide a thorough comprehension of several aspects that are vital to the study's emphasis on energy transition, eco-policy strictness, green innovation, and energy consumption within the BRICS economies. Their inclusion provides an extensive investigation of the interaction of environmental policy, innovation, and energy dynamics in influencing the formation of sustainable development trajectories.

3.3 | Method and model specification

In the current study, an econometric analysis of panel data has been employed for numerous reasons. Firstly, by integrating the time series and cross-sectional measurements, panel data provide more observations, which improves the statistical accuracy and potential to draw conclusions (Hassan et al., 2020). Secondly, panel data analysis reveals effects that are not detectable in cross-sectional and time series analysis (Plümper et al., 2005). Furthermore, panel

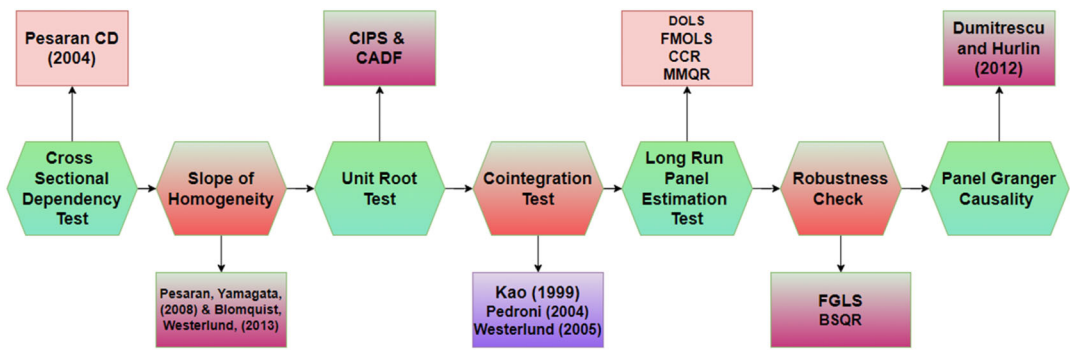


FIGURE 3 Estimation methods Roadmap.

data provide more meaningful statistics, greater variations, less collinearity across parameters, the greater degree of freedom, and more effectiveness (Baltagi, 2005). Therefore, the following econometric model has been employed to check the nexus of a selected series of variables.

$$CO_{2it} = \theta_0 + \theta_1 GPR_{it} + \theta_2 RE_{it} + \theta_3 EPS_{it} + \theta_4 INV_{it} + \theta_5 EG_{it} + \epsilon_{it} \quad (1)$$

$$CO_{2it} = \theta_0 + \theta_1 GPR_{it} + \theta_2 RE_{it} + \theta_3 EPS_{it} + \theta_4 INV_{it} + \theta_5 INV \times EPS_{it} + \theta_6 EG_{it} + \epsilon_{it} \dots \quad (2)$$

where i, t indicates countries and time period while ϵ_{it} represents the error term in the above equation. CO_2 emission is used as a dependent variable whereas GPR, RE, EPS, GINV, and EG are used as explanatory variables. The parameters are precisely considered to ensure a comprehensive explanation of several significant variables associated with the research's focus on the joint effect of the strictness of environmental policies and green innovative practices (Bright et al., 2024) in BRICS countries. Figure 3 visualizes the seven steps of empirical estimation methods which are explained in the subsequent section.

3.4 | Panel estimation technique

The present study employed a distinctive estimating MMQR approach, to examine the long-term connection between the considered parameters. The MMQR method is particularly suitable for situations where the model incorporates endogenous explanatory variables and the panel data displays individual-specific effects. Furthermore, the MMQR demonstrates its capacity to generate dependable estimates in diverse situations, particularly when the underlying model displays nonlinearity. The MMQR method is commonly utilized at a higher frequency compared to other nonlinear approaches, such as the “Nonlinear Autoregressive Distributed Lag (NARDL)” method (Shin et al., 2014). Additionally, the MMQR approach enables the examination of location-specific asymmetries by allowing for potential variations in parameters based on the location of the dependent variable, specifically the carbon emission, within the conditional distribution. Considering the preceding objectives, the MMQR technique is widely recognized as the most appropriate methodology to examine both asymmetric and nonlinear correlations. MMQR is employed to handle non-normal distributions of variables, yielding more resilient and accurate estimates for analysis. Furthermore, it effectively tackles the concerns surrounding heterogeneity and endogeneity. The MMQR exhibits an intrinsic tendency to generate estimations that are distinct among structural quantiles.

This paper presents the following comprehensive description of the conditional quantile estimations for the locational scale variant model.

TABLE 2 Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
CO ₂	155	5.239	3.955	0.647	14.622
GPR	155	3.415	3.424	0.218	16.524
RE	155	25.038	17.395	3.180	52.950
EPS	155	0.841	0.759	0.000	3.140
INV	155	9.634	2.693	3.020	16.920
EG	155	3.939	4.831	-14.531	14.231

$$Y_{it} = \theta_i + W_{it}'\delta + (\gamma_i + X_{it}'v)U_{it} \dots \dots (3)$$

In the given equation, $(\theta, \delta', \gamma, v)'$ represents a vector of parameters, and $P(\gamma_i * X_{it}' * \tau > 0)$ is the probability expression. The values (β_i, γ_i) with $i = 1, 2, 3, \dots, n$ correspond to the fixed effects for individual i . The matrix X is a k -vector consisting of known elements of W , and these elements are differentiable conversions with the l -th component specifically defined as:

$$Xl = Xl(w), l = 1, \dots, k (4)$$

Equation (2) implies that the w_{it} component is distributed in the same manner and with the same characteristics for any given individual at a specific time. Similarly, the u_{it} component follows a symmetrical distribution to w_{it} across all individuals and time points, and it is standardized to meet the requirements specified in Machado and Silva's (2019) study.

$$QY\left(\frac{\tau}{W_{it}}\right) = (\theta_i \gamma_i q(\tau)) + w_{it}' + X_{it}' v q(\tau) (5)$$

In Equation (5), the vector X_{it} represents the independent variables, including GPR, ET, EPS, INV, and EG. On the other hand, $QY(\tau/X_{it})$ represents the dependent variable, that is, CO₂ emission.

Table 2 demonstrates the descriptive statistics of the study. The mean value of ET is the highest 25.038, while EPS has the lowest 0.841 average value. Also, RE has the highest standard deviation of 17.395 while EPS has a lower 0.759 standard deviation value.

4 | RESULTS AND DISCUSSION

The empirical findings of the study are reported and discussed in this section.

4.1 | Multicollinearity test

The effective use of the variance inflation factor (VIF) test is a prevalent approach to detect the presence of multicollinearity. The estimation quantifies the degree to which the variability of a predicted regression variable is augmented as a result of its linear dependence on other explanatory factors (Hassan et al., 2021). According to Kennedy (1992), the potential indication of unsuitable collinearity arises when the value of the VIF index is above 10.

Therefore, this criterion is utilized to detect the existence of multicollinearity in the regression analysis. The issue of multicollinearity may arise when there are significant correlations among numerous explanatory variables inside a model. The observed trend possesses the capacity to induce a significant increase in the standard errors of

parameters and the occurrence of estimations of coefficients that may be deemed “incorrect,” so undermining the validity of statistical inferences. Table 3 demonstrates the VIF results of selected variables.

4.2 | Cross-sectional dependence (CD) test

The assessment of the CD test has paramount significance in selecting appropriate econometric methods for analyzing data, especially in the framework of panel data analysis. According to Pesaran (2004), unit root analysis and cointegration testing are prior tasks. Existence in one country has the ability to spread quickly to the neighboring. The CD test has been used to evaluate the prevalence of CD in certain selected nations. According to the null hypothesis, there is no CD among the chosen nations. The findings are summarized in Table 4.

$$CD = \sqrt{\frac{2T}{N(N-1)} \sum_{l=i}^{N-1} \sum_{j=i+1}^N \hat{ij}} \quad (6)$$

where $CD = 1, 2, 3, 4, 5, \dots, N$.

4.3 | Slope of homogeneity

The study performed the slope homogeneity tests of Pesaran, Yamagata (2008) and Blomquist, Westerlund (2013), as indicated in Table 5. According to the outcome, we reject the null hypothesis, suggesting that the slope coefficient is not heterogeneous.

TABLE 3 Multicollinearity test.

Variable	VIF	1/VIF
RE	1.69	0.59193
GPR	1.55	0.645109
INV	1.11	0.897745
EPS	1.08	0.928859
EG	1.22	0.821037
Mean VIF	1.33	

TABLE 4 Average correlation coefficients & Pesaran (2004) CD test.

Variable	CD-test	p-value	corr	abs (corr)
CO ₂	7.12	.000	0.405	0.610
GPR	1.87	.061	0.106	0.239
RE	10.27	.000	0.583	0.583
EPS	12.24	.000	0.695	0.695
INV	7.05	.000	0.400	0.426
EG	1.65	.099	0.094	0.139
EPS*GINV	6.61	.000	0.376	0.393

Note: Under the null hypothesis of cross-section independence $CD \sim N(0,1)$.

TABLE 5 Slope of homogeneity.

	Delta	p-value
Pesaran, Yamagata. 2008		
Δ	9.418	.000
Δ Adjusted	10.704	.000
Blomquist, Westerlund. 2013		
Δ	8.547	.000
Δ Adjusted	9.714	.000

TABLE 6 Panel unit root test.

Variables	CIPS unit-root test		CADF unit-root test	
	At level	First diff	At level	First diff
CO ₂	-2.452*	-3.046***	-3.067***	-0.305
GPR	-2.682*	-6.004***	-0.017	-3.914***
RE	-2.811	-3.578***	-2.066**	-1.47*
EPS	-2.033	-4.854***	-0.874	-2.614***
INV	-2.734*	-5.417***	-1.947*	-3.563***
EG	-4.338**	-6.19***	-2.008*	-4.831***
EPS*GINV	-3.040***	-5.868***	-2.121*	-3.319**

Note: *, **, *** denotes significant at 10%, 5% and 1% level, respectively.

The decision is based on the need to transition from conventional panel unit root methodologies to ones that are capable of accurately capturing the heterogeneity components of the panel series.

4.4 | Unit root test

Unit root tests are typically performed on the data to determine stationarity before using econometric techniques to analyze the relationships between variables. Table 6 presents the outcomes of the investigation for cross-sectional dependence and the corresponding second-generation panel unit root tests, specifically cross-sectionally augmented IPS (CIPS) as proposed by Pesaran (2007) and cross-sectionally augmented Dickey–Fuller (CADF).

The CIPS and CADF test results verify that all the series are integrated at an I(0) and I(1). All of the results are statistically significant at a significance level of 1%.

4.5 | Cointegration test

A cointegration study is carried out to assess the long-term connection between the chosen variables. In contrast to model estimates produced from individual time series, panel cointegration addresses show greater accuracy. The dependability of the results is strengthened by the use of model estimates, which provide greater flexibility when examining time-series cross-section data. As a result, the current study employs Kao (1999) and Pedroni (1999, 2004) cointegration tests, two different panel cointegration models. We used the cointegration test suggested by Westerlund (2007), which employs the bootstrap approach to lessen the possible influence of cross-sectional

dependency across variables, to address these issues. Table 7 demonstrates the cointegration test results which indicates that there exists a long-run relationship among selected variables.

4.6 | Long run panel estimation analysis outcomes

This study also employs FMOLS and DOLS estimation methods to investigate the long-term association between variables. The outcomes from FMOLS and DOLS estimators are presented in Table 8. The results from DOLS and FMOLS indicate that all the coefficients are statistically significant at a significance level of 1%. The GPR coefficient is 0.2600 and 0.2398, indicating that a 1% increase in GPR leads to a 0.26% and 0.2398% increase in CO₂ emission, respectively. This suggests that higher geopolitical uncertainty results in increased CO₂ emissions among emerging countries and rising geopolitical instability impede the pursuit of SDGs. These findings are consistent with the results reported in earlier literature (Anser et al., 2021; Bashir et al., 2023). Furthermore, the coefficient of EG is 0.30, indicating that a 1% rise in EG leads to a 0.1330% (DOLS) and 0.0635% (FMOLS) increase in CO₂ emissions. Various research has reported consistent findings (Feng et al., 2024a; Balsalobre-Lorente et al., 2024).

TABLE 7 Cointegration tests.

	Statistic	p-value
Kao test		
MDFt	-7.3832	.0000
DFt	-5.4694	.0000
ADFt	-4.0549	.0000
UMDFt	-11.465	.0000
UDFt	-6.1561	.0000
Pedroni test for cointegration		
MPP t	0.8864	.1877
PP t	-3.0744	.0011
ADFt	-2.852	.0022
Westerlund test for cointegration		
Variance ratio	3.7623	.0001

TABLE 8 Panel cointegration analysis.

Variables	DOLS		FMOLS		CCR	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
GPR	0.2600***	0.0443	0.2398***	0.0338	0.23930***	0.03631
RE	-0.1709***	0.0086	-0.1783***	0.007	-0.17832***	0.00731
EPS	-0.5129***	0.17	-0.5191***	0.1271	-0.51953***	0.13605
INV	-0.1738***	0.0282	-0.1441***	0.0206	-0.14549***	0.02252
EG	0.1330***	0.0578	0.0635*	0.0382	0.06296**	0.04479
EPS*INV	-.06060**	0.0239	-.03915*	0.02269	-0.03893**	0.02373
_cons	8.5035***	0.7908	9.2570***	0.5431	9.27097	0.62507

Note: *, **, *** denotes significant at 10%, 5% and 1% level, respectively.

The influence of EG on environmental deterioration seems to be smaller in comparison to that of political risk, which exacerbates environmental degradation. In the context of the energy transition, the coefficients of RE is -0.1709 (DOLS), -0.1783 (FMOLS), and -0.17832 (CCR). This suggests that switching from conventional energy sources to renewable energy sources has resulted in a decrease in CO₂ emissions by reducing human ecological requirements. Similarly, a 1% rise in technological innovation leads to a reduction of CO₂ emissions by 0.1738 (as per DOLS), 0.1441 (as per FMOLS), and -0.14549 (as per CCR). This research aligns with the findings of earlier studies (Del Rio et al., 2022). The coefficient of EPS*INV is -0.06060 for DOLS, -0.3915 for FMOLS, and -0.03893 for CCR, indicating that the enactment of stringent environmental measures promotes green technological innovations thus leading to a reduction in CO₂ emissions in BRICS economies. By implementing stringent environmental laws, regulations, and policies, to foster technological innovation, countries can preserve the environment and pursue reparation for any harm incurred. This strategy paves the way for the attainment of a sustainable environment and green economy.

The outcomes indicate that the strictness of environmental regulations promotes the advancement of innovative approaches in the realm of a sustainable environment. This finding offers evidence supporting the claim that strict environmental policies encourage clean investment and hence have a beneficial impact on green innovation. Therefore, companies adapt to stringent environmental regulations by increasing their investment in research and development (R&D) for sustainable energy sources, resulting in a higher number of patents in green technologies. Stringent environmental policies create a significant market demand for green energy sources and sustainable technologies. This implies that governments of BRICS countries have the potential to improve the state of the environment by adopting eco-friendly technologies that generate less pollution and decelerate the pace of environmental degradation. The findings provide valuable insights for policymakers to reduce CO₂ emissions in BRICS nations through the implementation of diversification strategies and the use of clean energy technology, such as carbon capture and storage. It is crucial to emphasize that the EG and advancement observed in the BRICS nations are susceptible to several environmental challenges. To attain a stable and extending environmental situation, the BRICS nations should not only focus on reducing their consumption and production of non-renewable energy but also enhance their efforts to adopt energy-saving and energy-efficient technologies. This can be achieved by reorganizing and addressing political challenges that may hinder the prompt implementation of sustainable development goals.

Furthermore, the results of the MMQR are presented in Table 9, illustrating the presence of various estimates with statistical significance across different quantiles. The findings suggest that there is a significant and positive relationship between GPR and CO₂ emissions ranging from 0.1857 to 0.2984 from the 10th to 90th quantile, at standard levels of significance (1%, 5%, and 10%). The observed trend exhibits consistency across all quantiles. This implies that an increase in GPR would lead to an increase in CO₂ emissions in countries, regardless of their specific distribution of CO₂ emissions. Therefore, it has been inferred that situations of GPR, such as war and terrorism, would lead to environmental deterioration. The ongoing conflict between Russia and Ukraine has contributed to a significant release of CO₂ and other GHG into the atmosphere of the Earth (de Klerk, 2022). The conflict has resulted in significant detrimental environmental consequences, and it is anticipated that it will impede efforts to tackle climate change mitigation strategies (Pereira et al., 2022; Rawtani et al., 2022). Furthermore, the implementation of reconstruction initiatives during the post-war era has the potential to contribute to the exacerbation of environmental pollution. According to de Klerk et al. (2022), it is anticipated that the post-war reconstruction of civilian infrastructures will culminate in GHG emissions of around 50 million tons of CO₂ equivalent. Bildirici and Gokmenoglu (2020) posit in their recent study that there exists a positive correlation between terrorist attacks and the escalation of environmental pollution.

To address the challenges that arise from war and terrorism, economies enhance their defensive strengths through an approach of militarization, either proactively or reactively. However, the escalation of militarization would be reflected in a corresponding rise in environmental pollution (Bildirici, 2017). As an illustration, it is frequently observed that the United States exhibits a significant degree of militarization, as demonstrated by the prominent status of its Department of Defense (DoD) in terms of defense budget allocation, consistently positioning it as the

TABLE 9 MMQR estimation results.

Quantiles	GPR	RE	EPS	INV	EG	INV*EPS	_cons
0.1	(0.1857)** -0.0857	(-0.1784)*** -0.0157	(-0.2388)* -0.2724	(-0.1858)*** -0.0508	(-0.0058)* -0.0875	(-0.0152) 0.02451	(-8.8366)*** -1.1756
0.2	(0.2069)*** -0.0682	(-0.1782)*** -0.0124	(-0.3262)** -0.217	(-0.1676)*** -0.0405	(0.0198)** -0.0697	(-.002599)* 0.02131	(8.9542)*** -0.9337
0.3	(0.2242)*** -0.0545	(-0.1780)*** -0.01	(-0.3974)** -0.1733	(-0.1528)*** -0.0323	(0.0406)** -0.0557	(-.017228)** 0.019033	(9.0498)*** -0.747
0.4	(0.2330)*** -0.0482	(-0.1779)*** -0.0088	(-0.4338)*** -0.1539	(-0.1453)*** -0.0287	(0.0513)** -0.0494	(-.031065)*** 0.017328	(9.0987)*** -0.6574
0.5	(0.2476)*** -0.0387	(-0.1777)*** -0.007	(-0.4941)*** -0.1239	(-0.1327)*** -0.0232	(0.0689)*** -0.0397	(-.043792)*** 0.016199	(9.1799)** -0.5253
0.6	(0.2599)*** -0.0329	(-0.1776)*** -0.0059	(-0.5447)*** -0.1057	(-0.1222)*** -0.0198	(0.0837)*** -0.0338	(-.051687)*** 0.015927	(9.2478)*** -0.4419
0.7	(0.2716)*** -0.0299	(-0.1775)*** -0.0054	(-0.5929)*** -0.0965	(-0.1122)*** -0.0181	(0.0978)*** -0.0308	(-.062719)*** 0.016096	(9.3126)*** -0.4013
0.8	(0.2855)*** -0.031	(-0.1773)*** -0.0056	(-0.6503)*** -0.0996	(-0.1003)*** -0.0187	(0.1146)*** -0.0318	(-.076047)*** 0.017042	(9.3898)*** -0.418
0.9	(0.2984)*** -0.0361	(-0.1772)*** -0.0065	(-0.7037)*** -0.1154	(-0.0892)*** -0.0216	(0.1302)*** -0.037	(-.088428)*** 0.018977	(-9.4616) -0.4907

Note: *, **, *** denotes significant at 10%, 5% and 1% level, respectively.

foremost military power globally. According to Crawford (2022), it has been determined that the United States' DoD holds the distinction of being the foremost contributor to GHG emissions on a global scale. Over the period spanning from 1975 to 2018, the DoD has been accountable for the release of approximately 4 billion metric tons of CO₂. The study's results suggest that the presence of GPR poses a barrier to achieving net-zero emissions. Furthermore, it can be argued that this phenomenon serves as a contributing element to the occurrence of climate change, which aligns with the recent research of Anser, Syed, and Apergis (2021); Anser, Syed, Lean, et al. (2021); Cengiz and Manga (2022); and Riti et al. (2022). Based on the findings of MMQR analysis, it can be contended that the pursuit of net-zero emissions would pose a significant challenge in light of geopolitical uncertainties. Consequently, the presence of GPR would contribute to the exacerbation of climate change, consequently impeding progress in the global efforts to combat the issue.

Moreover, renewable energy sources consumption (RE) has been widely recognized as an essential aspect in mitigating the negative environmental consequences associated with human activities. The concept of RE consumption pertains to the extent to which countries are transitioning toward alternative sources of energy in substitute of conventional sources. The results reported in Table 9 illustrate a statistically significant correlation between the process of transitioning to alternative energy sources and the levels of CO₂ emissions. The findings of this study indicate a notable and negative association, implying that a rise in the consumption of renewable energy sources is associated with a reduction in emissions. A considerable number of empirical evidence exists to substantiate the claim that the incorporation of renewable energy sources would make a substantial contribution toward the alleviation of environmental pollution. This perspective aligns with the findings of Destek and Aslan (2020) and Ibrahim et al. (2022). Therefore, it is imperative to emphasize the significance of shifting from traditional energy sources to RE with the goal of achieving an environment of net-zero emissions while simultaneously addressing the consequences of environmental deterioration. The increasing need to shift from fossil fuel-dependent energy systems to environmentally sustainable alternatives, specifically renewable energy sources, has been driven by the critical issue of climate



FIGURE 4 Graphical representation of coefficients of variables across different quantiles.

change. Figure 4 indicates the trends of CO₂ emission and its determinants across different quantiles. This indicates that with an increase in GPR, EG, the level of CO₂ emission also increases over a selected period in BRICS economies. While RE, INV, and the interaction of EPS*INV contribute to decreasing CO₂ emissions in the BRICS region. The findings illustrate that a combined effect offers more efficient solutions to address environmental concerns. Through collaborative efforts, they may mitigate the harm caused by human activities to the ecological systems, by reducing emissions and enhancing sustainability in the sample countries.

Furthermore, assessing the impact of strictness in environmental regulations on the state of environmental quality provides an indicator to assess the effectiveness of these regulatory measures in addressing and reducing CO₂ emissions by encouraging green technological innovation. Improving the stringency of environmental policies yields a positive impact on environmental quality, primarily through the long-term reduction of CO₂ emissions (Yirong, 2022). Environmental laws and regulations primarily emphasize the implementation of measures, including the imposition of environmental levies, the promotion of clean energy sources, and the facilitation of energy-saving initiatives (Xie et al., 2023). An effective regulatory framework and the capacity to attract and allocate significant amounts of capital continue to be fundamental elements of a conducive environment. In conjunction with an all-encompassing policy framework pertaining to renewable energy, energy efficiency, and energy accessibility, it is imperative that regulatory frameworks be coordinated with a resilient, ambitious, and credible plan to achieve net zero emissions. This strategy should be reinforced by the implementation of effective carbon pricing mechanisms. A conducive investment environment, marked by a low cost of capital, FDI, and liquidity in domestic markets plays a significant role in facilitating the mobilization of greater amounts of capital for a sustainable environment.

Furthermore, it is imperative for BRICS economies to fulfill their obligation of billion dollars in climate funding to support the development efforts of nations in need. Since 2008, the Chinese government has enacted a series of environmental laws and regulations targeting air pollution, water pollution, and soil pollution to address rising environmental and social problems. The fundamental national development policy of the country is to prioritize the conservation and promotion of natural resources, specifically focusing on the conservation of green waterways and

green mountains, which are considered invaluable assets. BRICS's environmental concerns have been alleviated through the implementation of stringent rules and policies. These results align with Porter's hypothesis that environmental regulations foster innovation (Porter and Van der Linde, 1991). This also demonstrates that well-designed environmental regulations (EPS) and the execution of these policies aimed at reducing energy consumption and emissions are beneficial for fostering the growth of environmentally friendly innovation in the BRICS countries. Enforcement of both national and global environmental regulations and laws by BRICS countries will lead to a substantial reduction in environmental pollution. This initiative aims to enhance sustainable development practices among individuals and businesses to accomplish the sustainable development goals (SDGs). Governments should prioritize their efforts on implementing regulatory requirements for contaminants, implementing restrictions on harmful compounds, executing emissions standards, and implementing initiatives to increase awareness of sustainable energy labeling and long-term activities. The effectiveness of promoting green innovation for environmental sustainability is often influenced by the certainty provided by foresight and regulatory coherence.

Environmental quality is always inclusive of technological innovation. The study results demonstrate that when a country implements strict environmental regulations and exhibits a higher degree of innovation, the adoption and implementation of environmentally friendly technologies play a substantial role in lowering CO₂ emissions and improving the quality of the environment. It can be argued that the negative implications of the combined effect of environmental regulations and INV are often attributed to the implementation of novel technologies, patents, or preservation of the environment measures. The effects of INV exhibited a consistent heterogeneous from quantile 20th to 90th. The diverse effects can be explained by one primary factor which is the investment made in R&D activities in BRICS economies. By consistently allocating resources to R&D, the quality of technology can be enhanced. This enhancement offers advantages not just in the context of modifying current equipment or techniques associated with carbon reduction, but also in expediting the development of novel equipment, techniques, and patents. Therefore, a correlation can be observed between R&D activities and the reduction of CO₂ emissions. These findings are in line with the study of Churchill et al. (2019). They conducted an empirical analysis that further supports the notion that R&D can effectively contribute to the mitigation of carbon emissions by leveraging scale effects and efficient marketing strategies. Regarding the BRICS countries, there is a variation in the level of R&D investments across various countries. To enhance the availability of clean energy and its corresponding technologies, It is crucial to enhance the landscape of innovation in relation to sustainable energy solutions, encompassing hydrogen, alternative fuels, and the capture and storage of carbon. Policies have a crucial role in facilitating innovation, promoting growth, and influencing the development of energy systems to effectively incorporate emerging technology. The prompt and widespread adoption of clean and efficient energy technology is necessary to attain net-zero emissions. For environmental sustainability, BRICS economies are currently incorporating their energy security, climate, and industrial policies into more comprehensive frameworks.

4.7 | Robustness check

The present work utilized the FGLS and BSQR methods to conduct a thorough examination of model estimates, hence improving the reliability of our estimation results. The utilization of an FGLS estimator offers a more efficient methodology for analysis, as it consistently estimates the substantial error covariance matrix in the presence of heteroskedasticity, serial correlations, and cross-sectional correlations. The estimation results from the FGLS study are presented in Table 10. Based on the results shown in Table 10, it can be observed that there exists a persistent negative correlation between RE, EPS INV, and CO₂ emissions. Whereas, GPR and EG are positively correlated with the environmental quality in selected sample countries. Moreover, from the study findings, it can be argued that the phenomenon of natural resource depletion is mitigated by the country's efforts to enhance productivity while utilizing limited resources, owing to advancements in current technology and the implementation of stringent environmental policies. These advancements have led to a reduction in environmental degradation, thereby resulting in a decrease in CO₂ emissions.

TABLE 10 Cross-sectional time-series FGLS regression.

CO ₂	Coef.	Std. Err.	z	p > z	95% Conf.	Interval
GPR	.2446435	.0274667	8.91	.000	.1908098	.2984772
RE	−.1777679	.0056445	−31.49	.000	−.188831	−.1667049
EPS	−.4818269	.1032881	−4.66	.000	−.6842678	−.2793859
INV	−.1352947	.0165026	−8.20	.000	−.1676393	−.1029502
EG	.0653242	.0309578	2.11	.035	.0046479	.1260004
EPS*INV	−.0390424	.0165324	−2.36	.018	−.071445	−.006639
_cons	9.16332	.440786	20.79	.000	8.299395	10.02724

TABLE 11 BSQR-robustness check.

Quantiles	GPR	RE	EPS	INV	EG	INV*EPS	_cons
0.1	(.1358773)*** .0865968	(−.1943587)*** .0128031	(−.206949)*** .157154	(−.1249707)*** .0414718	(.0421791)* .0598015	(−.0035397)* .0174077	(8.590503)*** .8799641
0.2	(.1602404)*** .0661355	(−.1775004)*** .0140414	(−.3010735)*** .1930461	(−.1848719)*** .0287664	(.0106882)* .0513243	(−.0287157)* .0245602	(9.205993)*** .805053
0.3	(.2037978)*** .0281848	(−.1762272)*** .0072385	(−.3867419)*** .1757675	(−.179948)*** .0316076	(.0141305)* .0322009	(−.0416097)** .0292907	(9.381521)*** .3960022
0.4	(.2323983)*** .0347955	(−.1713624)*** .0069138	(−.3828248)*** .1995696	(−.172146)*** .0208484	(.0353401)** .0390608	(−.0240482)** .0308965	(9.149728)*** .3823413
0.5	(.255099)*** .0333305	(−.166844)*** .0044258	(−.616305)*** .2462693	(−.1302328)*** .0391693	(.0725093)** .0350774	(−.0311616)** .0360523	(8.979712)*** .4020273
0.6	(.2659795)*** .041024	(−.1673257)*** .0044204	(−.5821293)*** .1733794	(−.1129613)*** .0336047	(.0866967)** .0388663	(−.0712283)*** .0394281	(8.910645)*** .4330155
0.7	(.2733833)*** .0453469	(−.1712263)*** .0034483	(−.561763)*** .1318361	(−.0936681)*** .0305715	(.0825509)*** .0361421	(−.0771886)*** .0306761	(9.145263)*** .4259577
0.8	(.32705)** .0542382	(−.1768533)*** .006552	(−.754251)*** .1591275	(−.0727169)*** .0261062	(.1077045)*** .0263903	(−.0882809)*** .0256843	(9.344073)*** .461334
0.9	(.2829979)*** .049368	(−.1886363)*** .0096151	(−.7953104)*** .0963589	(−.065082)*** .0192709	(.1041858)*** .0336921	(−.1142335)*** .0178164	(10.06635)*** .7101746

Note: *, ** & *** denotes the significance level at 1%, 5%, & 10%.

A significant and persistent association has been observed between EG and CO₂ emissions. Throughout each stage of economic development, countries strive to increase their output at all costs. Consequently, the emphasis on safeguarding the environment is relegated to a subservient level. The correlation between economic activities and the increase in CO₂ emissions becomes less evident as countries adhere to more environmentally sustainable policies and adopt advanced technologies. The estimates of FGLS confirm the findings of DOLS, FMOLS, and CCR.

Further, to check the robustness of MMQR, the study employs BSQR approach. Table 11 represents the estimated results for BSQR. The outcomes demonstrate that GPR and EG are positively associated with CO₂ emission which reveals that both these variables increase the CO₂ emission across all quantiles in Sample countries. Whereas, RE, EPS, INV, and INV*EPS contribute to lower the CO₂ across different quantiles. The statistical analysis reveals that these factors have a substantial influence on CO₂ levels, with a high degree of confidence at both the 5% and 1% significance levels. This finding further emphasizes the crucial role of these variables in reducing CO₂ emissions. The findings imply that the adoption of RE, EPS, INV, and INV*EPS contributes significantly to environmental sustainability and the reduction of CO₂ emissions.

Conversely, the effects of GPR and EG are primarily positive, leading to a rise in CO₂ levels in sample countries. This suggests that when EG levels increase, there is a corresponding increase in emissions. Similarly, GPR may have a detrimental effect on innovation, R&D, as well as the adoption of renewable energy, ultimately leading to an increase in CO₂ emissions. GPR may incentivize manufacturers to use conventional techniques of production that are detrimental to the environment, resulting in increased levels of CO₂ emissions. The outcomes of BSQR confirm the validity of MMQR results.

4.8 | Causality test

Table 12 presents the results of Dumitrescu and Hurlin (2012) causality study. The findings show that there is a bidirectional causative relationship between RE, GINV, and EPS in sample countries. The association is statistically significant at the 1% and 5% levels. While GPR, EG, and interaction INV*EPS indicate a unidirectional association with CO₂ emission.

In summary, the current study intends to examine the direct influence of GPR, EPS, RE, INV, and EG on CO₂ emissions. Furthermore, the research also examined the moderating effect of EPS on the promotion of GINV to mitigate CO₂ emissions in BRICS countries. The study model is evaluated for the dependent variable using the DOLS, FMOLS, CCR, and MMQR methods. The Granger causality approach examined the causal association. The findings from the DOLS, FMOLS, and CCR models confirm the presence of a long-term relationship between the variables.

5 | CONCLUSION AND POLICY IMPLICATIONS

5.1 | Conclusion

The primary objective of this study is to provide a theoretical contribution by examining the potential influence of GPR on the advancement of attaining a net-zero emissions objective with the RE. Furthermore, the study also examined the impact of the combined effect of EPS and green technological innovation on environmental quality. The study uses panel data encompassing the BRICS countries over the time frame of 1990 to 2020. The econometric analysis yielded empirical findings that support a positive correlation between GPR and CO₂ emissions across

TABLE 12 Dumitrescu and Hurlin (2012) causality test.

Causality directions	W-Stat	Z-Stat	Direction	Probability
CO ₂ $\approx$ GPR	1.1621	0.2563	CO ₂ $\rightarrow$ GPR	.7977
GPR $\approx$ CO ₂	2.4410***	2.2784		.0227
CO ₂ $\approx$ ET	8.1945***	11.3755	CO ₂ $\rightleftharpoons$ ET	.0000
ET $\approx$ CO ₂	7.7674***	10.7002		.0000
CO ₂ $\approx$ GINV	3.5523***	4.0355	CO ₂ $\rightleftharpoons$ GINV	.0001
GINV $\approx$ CO ₂	6.2354***	8.2779		.0000
CO ₂ $\approx$ EPS	3.8132***	4.4480	CO ₂ $\rightleftharpoons$ EPS	.0000
EPS $\approx$ CO ₂	5.9866***	7.8846		.0000
CO ₂ $\approx$ EG	1.4727	0.7474	CO ₂ $\rightarrow$ EG	.4548
EG $\approx$ CO ₂	2.2453***	1.9690		.0490
CO ₂ $\approx$ EPS*INV	2.2571***	1.9876	CO ₂ $\rightarrow$ ERT*INV	.0469
EPS*INV $\approx$ CO ₂	1.3753	0.5934		.5529

Note: *** indicates significant at 1% level.

countries. The results of this research emphasize the vital significance of stringent environmental regulations, environmentally friendly innovative technologies, and the shift to renewable energy sources to encourage BRICS's objective of achieving carbon neutrality by 2060 and reducing CO₂ emissions. The findings also demonstrate that the interaction of INV*EPS is negatively associated with CO₂ levels. To attain sustainable development goals, it is imperative for the BRICS countries to establish policies that facilitate green innovation. This would not only stimulate EG but also reduce emissions. The advancement of sustainable technology can be accelerated by pooling financial and technological resources through the establishment of strict environmental policies and funding programs. Investing in green technologies by BRICS countries would effectively decrease their ecological footprints. This will lower their CO₂ emissions and enhance environmental sustainability in BRICS to SDG 13. The study findings confirm Porter's hypothesis. In 1995, Porter and van der Linde suggested that efficient environmental regulations can encourage businesses to engage in technology innovation. Environmental regulation enhances INV and mitigates environmental pollution. The findings derived from this research have substantial implications for both theoretical and policy realms.

Moreover, the implementation of strict environmental and energy policies aimed at providing rebates and subsidies for the utilization of green technologies could effectively facilitate the shift toward an economy reliant on RE sources and make a significant contribution to the mitigation of climate change. Furthermore, the implementation of feed-in tariff policies, which enable individuals who adopt green technologies to sell surplus electricity back to the national grid, persists to be a crucial approach in facilitating the transition to sustainable energy sources and mitigating the impacts of climate change. Moreover, considering the prevailing monetary limitations encountered by the majority of governments, the successful implementation of energy transition necessitates the active involvement and assistance of the private sector. Moreover, the significance of our findings remains relevant in the context of policy formulation aimed at mitigating climate change. The findings of the econometric analysis indicate that the adoption of RE sources represents a viable and efficient strategy for attaining a state of net-zero emissions. The significance of renewable energy in reducing emissions necessitates policymakers' constant commitment to developing a conducive atmosphere for investment in renewable energy sources. Furthermore, the mitigation of emissions is particularly alleviated by the consumption of RE sources, as demonstrated through the extent of RE consumption. In addition, the analysis reveals that the adoption of RE sources has a tendency to decrease emissions in events where geopolitical influences are insignificant. Governments have the potential to collaborate with the private sector with the goal of allocating resources toward the development and implementation of renewable energy solutions. Policymakers have been assigned the responsibility of formulating and executing national energy policies that possess specific goals and provide incentives to stimulate private investment in RE technologies. A further policy implication arising from the econometric findings indicates that the presence of GPR may pose a challenge to the attainment of net-zero emissions and the mitigation of climate change. The study further offers several policy implications derived from the findings.

Further, study findings demonstrate that geopolitical tensions have the effect of diverting resources away from investments in climate change mitigation solutions, resulting in a negative environment for attracting private sector investment in renewable energy technologies. Based on our analysis, it has been determined that the utilization of renewable energy sources leads to significant decreases in emissions, particularly in situations where there is a decrease in GPR. However, the efficacy of renewable energy in reducing emissions diminishes when there is an escalation in GPRs. The results of this research indicate that it is imperative for international efforts to give priority to the development of a secure geopolitical environment to effectively promote the shift toward sustainable energy sources as a strategy for reducing emissions and tackling the challenges that arise from climate change. Based on the findings of the econometric analysis, it can be posited that an upsurge in geopolitical tension leads to a corresponding increase in military expenditure and operational activities that have detrimental effects on the environment. An illustrative instance is the ongoing conflict between Russia and Ukraine, which has developed the advancement and deployment of military technologies, resulting in aerial bombardments and the consequential destruction of infrastructure and natural surroundings. It is further argued that in situations of GPR, financial

resources that countries have the potential to allocate toward renewable energy solutions are redirected toward military activities, consequently impeding progress in transitioning to renewable energy.

5.2 | Policy implications

Empirical research suggests that increased EG leads to a rise in global warming. Thus, it is crucial to prioritize the development of manufacturing and industry-specific growth while employing environmentally friendly resources. Considering the substantial influence of climate regulations on the sustainability of the environment, strengthening these regulations will assist the BRICS nations in achieving their objective of sustainable development. Policymakers need to provide incentives to encourage enterprises to use green innovative technologies. Potential incentives for businesses that invest in green technologies may encompass tax advantages, subsidies, or grants. These technologies could include solar and wind projects, electric automobiles, or more effective supply chain management systems. Thus, the BRICS countries must intensively promote R&D in green innovative technologies to effectively tackle climate change and achieve the goal of net zero emissions. Inevitably challenges posed by businesses, politics, society, and economic activities contribute to environmental degradation. Thus, by regulating these sectors of the economy, we might potentially foster a world that is both resilient to climate change and carbon-neutral emissions. Further, from a policy viewpoint, it seems that increased political uncertainty, in integrated economies with steady and moderate EG through energy-efficient innovation and renewable energy sources, will contribute to a rise in environmental degradation and thus deteriorate environmental quality. While the present research considers that there is a negative association between the energy transition, EPS, green innovation, and environmental degradation at different phases, this study contends that achieving sustainable development goals would be probably without stable political environments, sustainable economic activities, and strictly controlled global interactions, even if renewable energy sources are utilized for consumption and production purposes. Policymakers should strive to minimize elevated political risk, since it hinders the efficiency and efficiency of addressing economic and business issues, consequently impacting both the overall economy and the environment.

5.3 | Limitations of the study

Prior to concluding the investigation, despite the significant contribution of this paper to the realm of knowledge and policy, it is imperative to recognize certain domains that require further investigation in future research. It is crucial to highlight that no strategy objectives, particularly the one employed in this research, are legitimately considered to encompass all relevant policy components. In this study, the interaction of INV*EPS is used to examine its potential environmental implications by employing the MMQR approach. Future research can check the role of governance in fostering innovation and financial funding to curb environmental degradation. From a policy perspective and to gain a thorough understanding of the environmental consequences of GPR, future research attempts may consider employing a comparative methodology to examine potential variations in the influence of GPR across different nations by employing the role of governance to tackle these challenges. Furthermore, different environmental variables may have a more significant impact on this research. To overcome the limitations of the study, future research can expand the sample size by incorporating more countries, conducting alternative estimations for different geographical regions, and incorporating other important factors and variables into the models. In conclusion, CO₂ emissions variables have been used as indicators to assess the presence and extent of environmental pollution. It is recommended that future studies expand across our analysis by investigating the impact of GPR on broader environmental degradation indicators, such as GHG emissions, ecological footprint, deforestation, and load capacity factor.

CONFLICT OF INTEREST STATEMENT

The authors declare no competing interests.

DATA AVAILABILITY STATEMENT

The data for analysis for the current study is collected from World Bank Indicator Website, OECD statics database.

ENDNOTES

¹ OECD Statistics.

² World Development Indicators | DataBank (worldbank.org).

³ Geopolitical Risk (GPR) Index (matteoiacoviello.com).

REFERENCES

- Abbasi, K. R., Hussain, K., Haddad, A. M., Salman, A., & Ozturk, I. (2022). The role of financial development and technological innovation towards sustainable development in Pakistan: Fresh insights from consumption and territory-based emissions. *Technological Forecasting and Social Change*, 176, 121444.
- Acheampong, A. O., Adams, S., & Boateng, E. (2019). Do globalization and renewable energy contribute to carbon emissions mitigation in Sub-Saharan Africa? *Science of the Total Environment*, 677, 436–446.
- Afshan, S., Yaqoob, T., Meo, M. S., & Hamid, B. (2023). Can green finance, green technologies, and environmental policy stringency leverage sustainability in China: evidence from quantile-ARDL estimation. *Environmental Science and Pollution Research*, 30(22), 61726–61740.
- Akram, R., Ibrahim, R. L., Wang, Z., Adebayo, T. S., & Irfan, M. (2023). Neutralizing the surging emissions amidst natural resource dependence, eco-innovation, and green energy in G7 countries: Insights for global environmental sustainability. *Journal of Environmental Management*, 344, 118560.
- Alsagr, N. (2023). How environmental policy stringency affects renewable energy investment? Implications for green investment horizons. *Utilities Policy*, 83, 101613.
- Amin, N., Shabbir, M. S., Song, H., Farrukh, M. U., Iqbal, S., & Abbass, K. (2023). A step towards environmental mitigation: Do green technological innovation and institutional quality make a difference? *Technological Forecasting and Social Change*, 190, 122413.
- Anser, M. K., Apergis, N., & Syed, Q. R. (2021). Impact of economic policy uncertainty on CO₂ emissions: Evidence from top ten carbon emitter countries. *Environmental Science and Pollution Research*, 28, 29369–29378.
- Anser, M. K., Syed, Q. R., & Apergis, N. (2021). Does geopolitical risk escalate CO₂ emissions? Evidence from the BRICS countries. *Environmental Science and Pollution Research*, 28(35), 48011–48021.
- Anser, M. K., Syed, Q. R., Lean, H. H., Alola, A. A., & Ahmad, M. (2021). Do economic policy uncertainty and geopolitical risk lead to environmental degradation? Evidence from emerging economies. *Sustainability*, 13(11), 5866.
- Assamoi, G. R., & Wang, S. (2023). Asymmetric effects of economic policy uncertainty and environmental policy stringency on environmental quality: evidence from China and the United States. *Environmental Science and Pollution Research*, 30(11), 29996–30016.
- Bai, C., Feng, C., Yan, H., Yi, X., Chen, Z., & Wei, W. (2020). Will income inequality influence the abatement effect of renewable energy technological innovation on carbon dioxide emissions? *Journal of Environmental Management*, 264, 110482.
- Bai, X., Wang, K. T., Tran, T. K., Sadiq, M., Trung, L. M., & Khudoykulov, K. (2022). Measuring China's green economic recovery and energy environment sustainability: econometric analysis of sustainable development goals. *Economic Analysis and Policy*, 75, 768–779.
- Balsalobre-Lorente, D., Nur, T., Topaloglu, E. E., & Evcimen, C. (2024). The dampening effect of geopolitical risk and economic policy uncertainty in the linkage between economic complexity and environmental degradation in the G-20. *Journal of Environmental Management*, 351, 119679.
- Baltagi, B. H., Bratberg, E., & Holmås, T. H. (2005). A panel data study of physicians' labor supply: The case of Norway. *Health economics*, 14(10), 1035–1045.
- Bashir, M. F., Shahbaz, M., Malik, M. N., Ma, B., & Wang, J. (2023). Energy transition, natural resource consumption and environmental degradation: The role of geopolitical risk in sustainable development. *Resources Policy*, 85, 103985.
- Behera, P., Haldar, A., & Sethi, N. (2023). Achieving carbon neutrality target in the emerging economies: Role of renewable energy and green technology. *Gondwana Research*, 121, 16–32.
- Bekun, F. V. (2022). Mitigating emissions in India: accounting for the role of real income, renewable energy consumption and investment in energy. *International Journal of Energy Economics and Policy*, 12, 188–192.

- Bekun, F. V., Alola, A. A., Gyamfi, B. A., & Ampomah, A. B. (2021). The environmental aspects of conventional and clean energy policy in sub-Saharan Africa: Is N-shaped hypothesis valid? *Environmental Science and Pollution Research*, 28, 66695–66708.
- Bildirici, M. (2017). CO₂ emissions and militarization in G7 countries: panel cointegration and trivariate causality approaches. *Environment and Development Economics*, 22(6), 771–791.
- Bildirici, M., & Gokmenoglu, S. M. (2020). The impact of terrorism and FDI on environmental pollution: evidence from Afghanistan, Iraq, Nigeria, Pakistan, Philippines, Syria, Somalia, Thailand and Yemen. *Environmental Impact Assessment Review*, 81, 106340.
- Bordoff, J., & O'Sullivan Meghan, L. (2022). Green upheaval: The new geopolitics of energy. *Foreign Affairs*, 101, 68.
- Bouoiyour, J., Gauthier, M., & Bouri, E. (2023). Which is leading: Renewable or brown energy assets? *Energy Economics*, 117, 106339.
- Bright, R. M., Cattaneo, N., Antón-Fernández, C., Eisner, S., & Astrup, R. (2024). Relevance of surface albedo to forestry policy in high latitude and altitude regions may be overvalued. *Environmental Research Letters*, 19(9), 094023.
- Caglar, A. E., & Ulug, M. (2022). The role of government spending on energy efficiency R&D budgets in the green transformation process: insight from the top-five countries. *Environmental Science and Pollution Research*, 29(50), 76472–76484.
- Caldara, D., & Iacoviello, M. (2022). Measuring geopolitical risk. *American Economic Review*, 112(4), 1194–1225.
- Cengiz, O., & Manga, M. (2022). Is there any relationship between geopolitical risk and climate change? *Ekonomski vjesnik/Econviews-Review of Contemporary Business, Entrepreneurship and Economic Issues*, 35(1), 99–112.
- Chen, L., Gozgor, G., Lau, C. K. M., Mahalik, M. K., Rather, K. N., & Soliman, A. M. (2024). The impact of geopolitical risk on CO₂ emissions inequality: Evidence from 38 developed and developing economies. *Journal of Environmental Management*, 349, 119345.
- Chen, Z., Umar, M., Su, C. W., & Mirza, N. (2023). Renewable energy, credit portfolios and intermediation spread: Evidence from the banking sector in BRICS. *Renewable Energy*, 208, 561–566.
- Chu, L. K., Doğan, B., Abakah, E. J. A., Ghosh, S., & Albeni, M. (2023). Impact of economic policy uncertainty, geopolitical risk, and economic complexity on carbon emissions and ecological footprint: an investigation of the E7 countries. *Environmental Science and Pollution Research*, 30(12), 34406–34427.
- Churchill, S. A., Inekwe, J., Smyth, R., & Zhang, X. (2019). R&D intensity and carbon emissions in the G7: 1870–2014. *Energy Economics*, 80, 30–37.
- Crawford, I. (2022). *Brightening the skies: institutional solutions to the societal and geopolitical risks of space expansionism*. Oxford University Press.
- de Klerk, C. (2022). Transience and more-than-human seascapes in Ronél de Jager's *Myopia* paintings. *South African Journal of Art History*, 37(2), 91–115.
- Dehdar, F., Silva, N., Fuinhas, J. A., Koengkan, M., & Nazeer, N. (2022). The impact of technology and government policies on OECD carbon dioxide emissions. *Energies*, 15(22), 8486.
- Del Rio, D. D. F., Sovacool, B. K., Griffiths, S., Bazilian, M., Kim, J., Foley, A. M., & Rooney, D. (2022). Decarbonizing the pulp and paper industry: A critical and systematic review of sociotechnical developments and policy options. *Renewable and Sustainable Energy Reviews*, 167, 112706.
- Destek, M. A., & Aslan, A. (2020). Disaggregated renewable energy consumption and environmental pollution nexus in G-7 countries. *Renewable Energy*, 151, 1298–1306.
- Ding, T., Li, H., Tan, R., & Zhao, X. (2023). How does geopolitical risk affect carbon emissions?: An empirical study from the perspective of mineral resources extraction in OECD countries. *Resources Policy*, 85, 103983.
- Dogan, E., Hodžić, S., & Šikić, T. F. (2023). Do energy and environmental taxes stimulate or inhibit renewable energy deployment in the European Union? *Renewable Energy*, 202, 1138–1145.
- Dong, C., Wu, H., Zhou, J., Lin, H., & Chang, L. (2023). Role of renewable energy investment and geopolitical risk in green finance development: Empirical evidence from BRICS countries. *Renewable Energy*, 207, 234–241.
- Dong, X., Ibrahim, R. L., Ozturk, I., & Al-Faryan, M. A. S. (2024). Exploring the roles of natural resources on sustainability blueprint in G7 countries amidst green energy, technological innovation, and carbon-tax intervention. In *Natural Resources Forum* (Vol. 48, pp. 120–153). Blackwell Publishing Ltd.
- Du, K., Li, P., & Yan, Z. (2019). Do green technology innovations contribute to carbon dioxide emission reduction? Empirical evidence from patent data. *Technological Forecasting and Social Change*, 146, 297–303.
- Du, Y., & Wang, W. (2023). The role of green financing, agriculture development, geopolitical risk, and natural resource on environmental pollution in China. *Resources Policy*, 82, 103440.
- Dumitrescu, E. I., & Hurlin, C. (2012). Testing for Granger non-causality in heterogeneous panels. *Economic modelling*, 29(4), 1450–1460.
- Feng, S., Jiang, F., Wang, H., Liu, Y., He, W., Wang, H., Shen, Y., Zhang, L., Jia, M., Weimin, J., & Chen, J. M. (2024a). China's fossil fuel CO₂ emissions estimated using surface observations of coemitted NO₂. *Environmental Science & Technology*, 58(19), 8299–8312.
- Feng, X., Li, E., Li, J., & Wei, C. (2023). Critical influencing factors of employees' green behavior: Three-stage hybrid fuzzy DEMATEL–ISM–MICMAC approach. *Environment, Development and Sustainability*, 26, 1–29.

- Feng, Y., Sabir, S. A., Quddus, A., Wang, J., & Abbas, S. (2024). Do the grey clouds of geopolitical risk and political globalization exacerbate environmental degradation? Evidence from resource-rich countries. *Resources Policy*, 89, 104533.
- Feng, Z., Durani, F., Anwar, A., Ahmad, P., Syed, Q. R., & Abbas, A. (2024). From brown to green: Are emerging countries moving in right direction? Testing the validity of LCC hypothesis. *Energy & Environment*. <https://doi.org/10.1177/0958305X241228519>
- Georgatz, V. V., Stamboulis, Y., & Vetsikas, A. (2020). Examining the determinants of CO₂ emissions caused by the transport sector: Empirical evidence from 12 European countries. *Economic Analysis and Policy*, 65, 11–20.
- Guan, Y., Xiao, Y., Rong, B., Lu, W., Zhang, N., & Qin, C. (2023). Assessing the synergy between CO₂ emission and ambient PM_{2.5} pollution in Chinese cities: An integrated study based on economic impact and synergy index. *Environmental Impact Assessment Review*, 99, 106989.
- Guan, Z., Hossain, M. R., Sheikh, M. R., Khan, Z., & Gu, X. (2023). Unveiling the interconnectedness between energy-related GHGs and pro-environmental energy technology: Lessons from G-7 economies with MMQR approach. *Energy*, 281, 128234.
- Han, F., Ibrahim, R. L., Al-Mulali, U., & Al-Faryan, M. A. S. (2023). Tracking the roadmaps to sustainability: what do the symmetric effects of eco-digitalization, green technology, green finance, and renewable energy portend for China? *Environment, Development and Sustainability*, 26, 1–25.
- Hassan, M. U., Nawaz, H., & Faiz, A. U. H. (2021). Revealing the effects of teachers stimulating technological inclusion on university students' educational gains: A comparative study. *Humanities & Social Sciences Reviews*, 9(3), 986–999.
- Hassan, S. T., Khan, S. U. D., Xia, E., & Fatima, H. (2020). Role of institutions in correcting environmental pollution: An empirical investigation. *Sustainable Cities and Society*, 53, 101901.
- Hassan, S. T., Baloch, M. A., Bui, Q., & Khan, N. H. (2024). The heterogeneous impact of geopolitical risk and environment-related innovations on greenhouse gas emissions: the role of nuclear and renewable energy in the circular economy. *Gondwana Research*, 127, 144–155.
- Hou, J., Bai, W., & Sha, D. (2023). Does the digital economy successfully facilitate carbon emission reduction in China? green technology innovation perspective. *Science, Technology and Society*, 28, 535–560.
- Hund, K., La Porta, D., Fabregas, T. P., Laing, T., & Drexhage, J. (2023). *Minerals for climate action: The mineral intensity of the clean energy transition*. World Bank Group. <https://coillink.org/20.500.12592/zfcvb5>
- Husnain, M. I. U., Syed, Q. R., Bashir, A., & Khan, M. A. (2022). Do geopolitical risk and energy consumption contribute to environmental degradation? Evidence from E7 countries. *Environmental Science and Pollution Research*, 29(27), 41640–41652.
- Hwang, Y. K. (2023). The synergy effect through combination of the digital economy and transition to renewable energy on green economic growth: Empirical study of 18 Latin American and caribbean countries. *Journal of Cleaner Production*, 418, 138146.
- Ibrahim, O. A., Navarro-Segarra, M., Sadeghi, P., Sabaté, N., Esquivel, J. P., & Kjeang, E. (2022). Microfluidics for electrochemical energy conversion. *Chemical Reviews*, 122(7), 7236–7266.
- Ibrahim, R. L., Al-Mulali, U., Solarin, S. A., Ajide, K. B., Al-Faryan, M. A. S., & Mohammed, A. (2023). Probing environmental sustainability pathways in G7 economies: the role of energy transition, technological innovation, and demographic mobility. *Environmental Science and Pollution Research*, 30(30), 75694–75719.
- Ibrahim, R. L., Awosusi, A. A., Ajide, K. B., & Ozdeser, H. (2023). Exploring the renewable energy-environmental sustainability pathways: what do the interplay of technological innovation, structural change, and urbanization portends for BRICS? *Environment, Development and Sustainability*, 1–21. <https://doi.org/10.1007/s10668-023-03917-3>
- Ibrahim, R. L., Huang, Y., Mohammed, A., & Adebayo, T. S. (2023). Natural resources-sustainable environment conflicts amidst COP26 resolutions: investigating the role of renewable energy, technology innovations, green finance, and structural change. *International Journal of Sustainable Development & World Ecology*, 30(4), 445–457.
- Jüni, P., Rothenbühler, M., Bobos, P., Thorpe, K. E., da Costa, B. R., Fisman, D. N., Slutsky, A. S., & Gesink, D. (2020). Impact of climate and public health interventions on the COVID-19 pandemic: a prospective cohort study. *CMAJ*, 192(21), E566–E573.
- Kao, C. (1999). Spurious regression and residual-based tests for cointegration in panel data. *Journal of econometrics*, 90(1), 1–44.
- Kartal, M. T., Pata, U. K., Destek, M. A., & Caglar, A. E. (2023). Environmental effect of clean energy research and development investments: Evidence from Japan by using load capacity factor. *Journal of Cleaner Production*, 416, 137972.
- Kashif, U., Shi, J., Naseem, S., Dou, S., & Zahid, Z. (2024). ICT service exports and CO₂ emissions in OECD countries: The moderating effect of regulatory quality. *Economic Change and Restructuring*, 57(3), 94.
- Kennedy, S. J. (1992). *Debiasing audit judgment with accountability: A framework and experimental results*. Duke University.
- Khan, A., Sun, C., Xu, Z., & Liu, Y. (2023). Geopolitical risk, economic uncertainty, and militarization: Significant agents of energy consumption and environmental quality. *Environmental Impact Assessment Review*, 102, 107166.
- Khan, K. A., Thang, P. D., Uyen, P. T. M., Anwar, A., & Abbas, A. (2024). From brown to green: are Asian economies on the right path? Assessing the role of green innovations and geopolitical risk on environmental quality. *Environmental Science and Pollution Research*, 1–13. <https://doi.org/10.1007/s11356-023-31613-2>

- Khan, Q. R., Anwar, A., Muhammad, T., Ghafoori, N., & Ahmad, M. (2024). Asymmetric effects of high-tech industry and presence of pollution-haven hypothesis in APEC countries: fresh evidence with panel quantile regression. *Clean Technologies and Environmental Policy*, 26, 1–18.
- Khan, S. A. R., Sharif, A., Golpîra, H., & Kumar, A. (2019). A green ideology in Asian emerging economies: From environmental policy and sustainable development. *Sustainable Development*, 27(6), 1063–1075.
- Khorram-Manesh, A., & Burkle, F. M. (2023). Civilian population victimization: a systematic review comparing humanitarian and health outcomes in conventional and hybrid warfare. *Disaster Medicine and Public Health Preparedness*, 17, e192.
- Leal Filho, W., Trevisan, L. V., Rampasso, I. S., Anholon, R., Dinis, M. A. P., Brandli, L. L., Sierra, J., Salvia, A. L., Pretorius, R., Nicolau, M., Eustachio, J. H., & Mazutti, J. (2023). When the alarm bells ring: Why the UN sustainable development goals may not be achieved by 2030. *Journal of Cleaner Production*, 407, 137108.
- Li, C., Solangi, Y. A., & Ali, S. (2023). Evaluating the factors of green finance to achieve carbon peak and carbon neutrality targets in China: A delphi and fuzzy AHP approach. *Sustainability*, 15(3), 2721.
- Li, Z., Kuo, Y. K., Mahmud, A. R., Nassani, A. A., Haffar, M., & Muda, I. (2022). Integration of renewable energy, environmental policy stringency, and climate technologies in realizing environmental sustainability: Evidence from OECD countries. *Renewable Energy*, 196, 1376–1384.
- Liu, F., Su, C. W., Qin, M., & Oana-Ramona, L. (2023). Winner or loser? The bidirectional impact between geopolitical risk and energy transition from the renewable energy perspective. *Energy*, 283, 129174.
- Liu, W., Liu, M., Li, Y., & Liu, T. (2022). How to promote China's green economic development? The combination effects of consumption tax and carbon tax policies. *Energy & Environment*, 35(3), 1374–1395. <https://doi.org/10.1177/0958305X221140581>
- Lu, Y., Tian, T., & Ge, C. (2023). Asymmetric effects of renewable energy, fintech development, natural resources, and environmental regulations on the climate change in the post-covid era. *Resources Policy*, 85, 103902.
- Machado, J. A., & Silva, J. S. (2019). Quantiles via moments. *Journal of econometrics*, 213(1), 145–173.
- Milindi, C. B., & Inglesi-Lotz, R. (2022). The role of green technology on carbon emissions: does it differ across countries' income levels? *Applied Economics*, 54(29), 3309–3339.
- Mohsin, M., Orynassarov, D., Anser, M. K., & Oskenbayev, Y. (2023). Does hydropower energy help to reduce CO₂ emissions in European Union countries? evidence from quantile estimation. *Environmental Development*, 45, 100794.
- Nazir, U. (2023). The winds of change are blowing: globalization's impact on renewable energy and environmental challenges. *Archives of the Social Sciences: A Journal of Collaborative Memory*, 2(1), 78–93.
- Niu, X., Niu, X., Ibrahim, R. L., & Al-Faryan, M. A. S. (2023). Do the asymmetric effects of natural resource dependence and financial development amidst green policies make or mar sustainability agenda in E7 countries? *Resources Policy*, 85, 103889.
- Obobisa, E. S. (2022). Achieving 1.5 C and net-zero emissions target: The role of renewable energy and financial development. *Renewable Energy*, 188, 967–985.
- Ofori, E. K., Hayford, I. S., Nyantakyi, G., Tergu, C. T., & Opoku-Mensah, E. (2023). Synergising Sustainable Development Goals—can clean energy (green) deliver UN-SDG geared towards socio-economic-environment objectives in emerging BRICS? *Environmental Science and Pollution Research*, 30, 1–20.
- Pan, B., Adebayo, T. S., Ibrahim, R. L., & Al-Faryan, M. A. S. (2023). Does nuclear energy consumption mitigate carbon emissions in leading countries by nuclear power consumption? Evidence from quantile causality approach. *Energy & Environment*, 34(7), 2521–2543.
- Pan, L., Wang, Y., Sun, X., & Sadiq, M. (2023). Natural resources: A determining factor of geopolitical risk in Russia? Revisiting conflict-based perspective. *Resources Policy*, 85, 104033.
- Pata, U. K., Kartal, M. T., & Zafar, M. W. (2023). Environmental reverberations of geopolitical risk and economic policy uncertainty resulting from the Russia-Ukraine conflict: A wavelet based approach for sectoral CO₂ emissions. *Environmental Research*, 231, 116034.
- Pata, U. K., & Caglar, A. E. (2021). Investigating the EKC hypothesis with renewable energy consumption, human capital, globalization and trade openness for China: Evidence from augmented ARDL approach with a structural break. *Energy*, 216, 119220.
- Pedroni, P. (1999). Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and statistics*, 61(S1), 653–670.
- Pereira, P., Bašić, F., Bogunovic, I., & Barcelo, D. (2022). Russian-Ukrainian war impacts the total environment. *Science of the Total Environment*, 837, 155865.
- Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of applied econometrics*, 22(2), 265–312.
- Pesaran, M. H., & Yamagata, T. (2008). Testing slope homogeneity in large panels. *Journal of econometrics*, 142(1), 50–93.
- Pesaran, M. H., Schuermann, T., & Weiner, S. M. (2004). Modeling regional interdependencies using a global error-correcting macroeconomic model. *Journal of Business & Economic Statistics*, 22(2), 129–162.
- Plümper, T., Troeger, V. E., & Manow, P. (2005). Panel data analysis in comparative politics: Linking method to theory. *European Journal of Political Research*, 44(2), 327–354.

- Qian, L., Zeng, Q., & Li, T. (2022). Geopolitical risk and oil price volatility: Evidence from Markov-switching model. *International Review of Economics & Finance*, 81, 29–38.
- Raihan, A., & Tuspekova, A. (2022). Toward a sustainable environment: Nexus between economic growth, renewable energy use, forested area, and carbon emissions in Malaysia. *Resources, Conservation & Recycling Advances*, 15, 200096.
- Rasoulinezhad, E., Taghizadeh-Hesary, F., Abdoli, G., Jabalameli, F., & Dorbash, S. B. (2022). Determinants of Energy Transition in Asia. In *The Handbook of Energy Policy* (pp. 1–24). Springer Nature Singapore.
- Rawtani, D., Gupta, G., Khatri, N., Rao, P. K., & Hussain, C. M. (2022). Environmental damages due to war in Ukraine: A perspective. *Science of the Total Environment*, 850, 157932.
- Riti, J. S., Shu, Y., & Riti, M. K. J. (2022). Geopolitical risk and environmental degradation in BRICS: Aggregation bias and policy inference. *Energy Policy*, 166, 113010.
- Sachan, A., Sahu, U. K., Pradhan, A. K., & Thomas, R. (2023). Examining the drivers of renewable energy consumption: Evidence from BRICS nations. *Renewable Energy*, 202, 1402–1411.
- Sadiq, M., Chau, K. Y., Ha, N. T. T., Phan, T. T. H., Ngo, T. Q., & Huy, P. Q. (2023). The Impact of green finance, eco-innovation, renewable energy and carbon taxes on CO₂ emissions in BRICS countries: Evidence from CS ARDL estimation. *Geoscience Frontiers*, 15, 101689.
- Sezgin, F. H., Bayar, Y., Herta, L., & Gavrilletea, M. D. (2021). Do environmental stringency policies and human development reduce CO₂ emissions? Evidence from G7 and BRICS economies. *International Journal of Environmental Research and Public Health*, 18(13), 6727.
- Shah, M. I., Usman, M., Obekpa, H. O., & Abbas, S. (2023). Nexus between environmental vulnerability and agricultural productivity in BRICS: what are the roles of renewable energy, environmental policy stringency, and technology? *Environmental Science and Pollution Research*, 30(6), 15756–15774.
- Shah, W. U. H., Hao, G., Yan, H., Zhu, N., Yasmeen, R., & Dincă, G. (2023). Role of renewable, non-renewable energy consumption and carbon emission in energy efficiency and productivity change: Evidence from G20 economies. *Geoscience Frontiers*, 15, 101631.
- Sharif, A., Sofuoglu, E., Kocak, S., & Anwar, A. (2024). Can green finance and energy provide a Glimmer of hope towards sustainable environment in the midst of chaos? An evidence from Malaysia. *Renewable Energy*, 223, 119982.
- Shen, J., Ibrahim, R. L., Ajide, K. B., & Al-Faryan, M. A. S. (2024). Tracking environmental sustainability pathways in Africa: Do natural resource dependence, renewable energy, and technological innovations amplify or reduce the pollution noises? *Energy & Environment*, 35(1), 88–112.
- Shen, J., Ridwan, L. I., Raimi, L., & Al-Faryan, M. A. S. (2023). Recent developments in green hydrogen–environmental sustainability nexus amidst energy efficiency, green finance, eco-innovation, and digitalization in top hydrogen-consuming economies. *Energy & Environment*. <https://doi.org/10.1177/0958305X231153936>
- Shin, Y., Yu, B., & Greenwood-Nimmo, M. (2014). Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. *Festschrift in honor of Peter Schmidt: Econometric methods and applications*, 281–314.
- Syed, M., Folz, R. J., & Ali, U. (2023). Environmental factors and their impact on airway diseases: exploring air pollution, indoor and outdoor allergens, and climate change. *Current Pulmonology Reports*, 12, 1–9.
- Talwar, S., Dhir, A., Luqman, A., Gupta, J., & Gughani, R. (2023). Charting the path toward a greener world: A review of facilitating and inhibiting factors for carbon neutrality. *Journal of Cleaner Production*, 423, 138423.
- Teece, D. J. (2022). A wider-aperture lens for global strategic management: The multinational enterprise in a bifurcated global economy. *Global Strategy Journal*, 12(3), 488–519.
- Uddin, I., Usman, M., Saqib, N., & Makhdom, M. S. A. (2023). The impact of geopolitical risk, governance, technological innovations, energy use, and foreign direct investment on CO₂ emissions in the BRICS region. *Environmental Science and Pollution Research*, 30(29), 73714–73729.
- Udeagha, M. C., & Ngepah, N. (2023a). Striving towards carbon neutrality target in BRICS economies: Assessing the implications of composite risk index, green innovation, and environmental policy stringency. *Sustainable Environment*, 9(1), 2210950.
- Udeagha, M. C., & Ngepah, N. (2023b). Striving towards environmental sustainability in the BRICS economies: the combined influence of fiscal decentralization and environmental innovation. *International Journal of Sustainable Development & World Ecology*, 30(2), 111–125.
- Wan, Q., Miao, X., & Afshan, S. (2022). Dynamic effects of natural resource abundance, green financing, and government environmental concerns toward the sustainable environment in China. *Resources Policy*, 79, 102954.
- Wang, G., Gu, X., Shen, X., Uktamov, K. F., & Ageli, M. M. (2023). A dual risk perspective of China's resources market: Geopolitical risk and political risk. *Resources Policy*, 82, 103528.
- Wang, K. H., Xiong, D. P., Mirza, N., Shao, X. F., & Yue, X. G. (2021). Does geopolitical risk uncertainty strengthen or depress cash holdings of oil enterprises? Evidence from China. *Pacific-Basin Finance Journal*, 66, 101516.
- Wang, W., Balsalobre-Lorente, D., Anwar, A., Adebayo, T. S., Cong, P. T., Quynh, N. N., & Nguyen, M. Q. (2024). Shaping a greener future: The role of geopolitical risk, renewable energy and financial development on environmental sustainability using the LCC hypothesis. *Journal of Environmental Management*, 357, 120708.

- Wang, Y., Ibrahim, R. L., Oke, D. M., & Al-Faryan, M. A. S. (2023). Investigating green energy–environment nexus in post-COP26 era: Can technological innovation, financial development and government expenditure deliver Africa's targets? *International Journal of Finance & Economics*, 29(3), 3263–3285.
- Westerlund, H., & Gaunt, H. (Eds.). (2013). *Collaborative learning in higher music education*. Ashgate Publishing, Ltd.
- Westerlund, J. (2007). Testing for error correction in panel data. *Oxford Bulletin of Economics and statistics*, 69(6), 709–748.
- Wu, C., Zhou, D., Zha, D., & Hong, J. H. (2023). Can carbon emission reduction mitigate the PM2.5 air pollution? Evidence of the co-benefits from mitigating climate change. *Environment, Development and Sustainability*, 1–22. <https://doi.org/10.1007/s10668-023-03896-5>
- Xie, P., Xu, Y., Tan, X., & Tan, Q. (2023). How does environmental policy stringency influence green innovation for environmental managements? *Journal of Environmental Management*, 338, 117766.
- Yan, H., Qamruzzaman, M., & Kor, S. (2023). Charting a sustainable future: The impact of economic policy, environmental tax, innovation, and natural resources on clean energy consumption. *Sustainability*, 15(18), 13591.
- Yan, Y., Ibrahim, R. L., Al-Faryan, M. A. S., & Oke, D. M. (2023). Embracing eco-digitalization and green finance policies for sustainable environment: Do the engagements of multinational corporations make or mar the target for selected MENA countries? *Sustainability*, 15(15), 12046.
- Yao, S., Li, T., & Li, Y. (2023). Promoting sustainable fossil fuels resources in BRICS countries: Evaluating green policies and driving renewable energy development. *Resources Policy*, 85, 103990.
- Yirong, Q. (2022). Does environmental policy stringency reduce CO2 emissions? Evidence from high-polluted economies. *Journal of Cleaner Production*, 341, 130648.
- Yong, J. Y., Yusliza, M. Y., Ramayah, T., Chiappetta Jabbour, C. J., Sehnem, S., & Mani, V. (2020). Pathways towards sustainability in manufacturing organizations: Empirical evidence on the role of green human resource management. *Business Strategy and the Environment*, 29(1), 212–228.
- Yuan, H., Zhao, L., & Umair, M. (2023). Crude oil security in a turbulent world: China's geopolitical dilemmas and opportunities. *The Extractive Industries and Society*, 16, 101334.
- Yuan, R., Ma, Q., Zhang, Q., Yuan, X., Wang, Q., & Luo, C. (2022). Coordinated effects of energy transition on air pollution mitigation and CO2 emission control in China. *Science of the Total Environment*, 841, 156482.
- Yuan, X., Su, C. W., Umar, M., Shao, X., & LobonT, O. R. (2022). The race to zero emissions: Can renewable energy be the path to carbon neutrality? *Journal of Environmental Management*, 308, 114648.
- Yue, X., Zhao, S., Ding, X., & Xin, L. (2022). How the pilot low-carbon city policy promotes urban green innovation: Based on temporal-spatial dual perspectives. *International Journal of Environmental Research and Public Health*, 20(1), 561.
- Zhang, Q., Adebayo, T. S., Ibrahim, R. L., & Al-Faryan, M. A. S. (2023). Do the asymmetric effects of technological innovation amidst renewable and nonrenewable energy make or mar carbon neutrality targets? *International Journal of Sustainable Development & World Ecology*, 30(1), 68–80.
- Zhang, X., Yu, G., Ibrahim, R. L., & Sherzod Uralovich, K. (2024). Greening the E7 environment: how can renewable and nuclear energy moderate financial development, natural resources, and digitalization towards the target? *International Journal of Sustainable Development & World Ecology*, 31(4), 447–465.
- Zhou, F., Bin Samsurijan, M. S., Ibrahim, R. L., & Al-Faryan, M. A. S. (2024). An assessment of the aggregated and dis-aggregated effects of natural resources rents on environmental sustainability in BRICS economies. *International Journal of Sustainable Development & World Ecology*, 31(4), 375–394.
- Zhou, F., Samsurijan, M. S. B., Ibrahim, R. L., & Ajide, K. B. (2023). The conditioning role of institutions in the nonrenewable and renewable energy, trade openness, and sustainable environment nexuses: A roadmap towards sustainable development. *Environment, Development and Sustainability*, 26, 1–30.

How to cite this article: Fatima, N., Yanting, Z., Guohua, N., & Khan, M. K. (2024). The dynamics of green technological innovation and environmental policy stringency for sustainable environment in BRICS economies. *Natural Resources Forum*, 1–30. <https://doi.org/10.1111/1477-8947.12563>