TYPE Original Research
PUBLISHED 04 January 2023
DOI 10.3389/fenvs.2022.1084314

The prominence of fossil energy resources in ecological sustainability of BRICS: The key role of institutional worth

Jie Zhang[1], Sami Ullah[2] and Karamat Khan[3]*

[1]School of Finance, Zhongnan University of Economics and Law, Wuhan, China, [2]Research Center for Labour Economics and Human Resources, Shandong University, Weihai, Shandong, China, [3]School of Economics, Henan University, Kaifeng, China

Introduction: The relationship between fossil fuel energy resources and environmental degradation has been quantified from theoretical and empirical perspectives. However, none of these studies has considered the conditioning role played by institutions in the nexus, especially for BRICS countries. Therefore, the current study examines the moderating role of institutional quality using annual data from 1996–2018 for BRICS countries.

Method: The study employs the novel cross-sectional augmented autoregressive distributed lags (CS-ARDL) estimator, robust to cross-sectional dependency and heterogeneity, for short-run and long-run estimation. Moreover, augmented mean group (AMG) and common correlated effects mean group (CCEMG) estimators are used for robustness analysis.

Results: The finding reveals that fossil fuel energy resources, globalization, and growth significantly positively affect the ecological footprint, whereas the institutional quality significantly negatively effects the ecological footprint in BRICS countries. Furthermore, the interaction term of institutional quality with fossil fuel energy resources significantly negatively moderates the fossil fuel energy-EFP nexus. Finally, we performed the Dumitrescu and Hurlin (DH) panel causality analysis to determine the causality direction between the variables. Except for intuitions quality and growth, we found a unidirectional causality for explanatory variables and EFP.

Discussion: The study provides novel empirical evidence and recommends the importance of institutional quality for environmental sustainability.

KEYWORDS

fossil fuel, ecological footprint, institutions, CS-ARDL, BRICS

OPEN ACCESS

EDITED BY
Zeeshan Fareed,
Huzhou University, China

REVIEWED BY
Crenguţa-Ileana Sinisi,
University of Piteşti, Romania
Magdalena Radulescu,
University of Pitesti, Romania
Irfan Ullah,
Nanjing University of Information Science and Technology, China

*CORRESPONDENCE
Karamat Khan,
karamatkhan88@gmail.com

SPECIALTY SECTION
This article was submitted to Environmental Economics and Management,
a section of the journal
Frontiers in Environmental Science

RECEIVED 30 October 2022
ACCEPTED 12 December 2022
PUBLISHED 04 January 2023

CITATION
Zhang J, Ullah S and Khan K (2023), The prominence of fossil energy resources in ecological sustainability of BRICS: The key role of institutional worth.
Front. Environ. Sci. 10:1084314.
doi: 10.3389/fenvs.2022.1084314

1 Introduction

The intensity of globalization, development, energy use and environmental degradation have constantly grown globally and are expected to rise more in the upcoming time (Rafique et al., 2021; Ullah I. et al., 2022). Many countries' energy infrastructures, whether industrialized or emerging, depend on fossil fuel sources (coal, oil, natural gas) (Ali et al., 2021). Countries are speeding up economic progress, raising living conditions that raise fossil fuel usage in manufacturing and activities associated with fostering economic development, consequently degrading the environmental condition of emerging economies (Saidi et al., 2020). Using fossil fuel resources has several concerns, including environmental repercussions, shortage, supply risk, and price uncertainty, which place them in the core of change to carbon-free economies. Furthermore, greenhouse gas (GHG) emissions are the crucial contributing element, causing global warming and, therefore, environmental impacts; out of that, carbon dioxide (CO_2) emissions constitute 76 percent of the overall GHG emissions (Caglar et al., 2022; Shah et al., 2022). Most CO_2 emissions stem from combusting fossil fuel resources, like coal, oil, and natural gas, that comprise over 80 percent of the global energy needs (Khan K. et al., 2022; Ullah et al., 2022d).

The BRICS (Brazil, Russia, India, China, South Africa) is a group of emerging economies regarded for about 40 percent of the world's population, contributes 21 percent of the GDP, conserves nearly 40 percent of the world's energy, and emits 42 percent of worldwide CO_2 emissions from fossil fuel burning (Ummalla and Goyari, 2021). The economic growth of the BRICS is always expanding as they progress to become industrial economies. As an outcome, the energy demand has increased to accommodate the demand of numerous sectors, such as the industrial, transport, economic, and residential sectors (Adedoyin et al., 2021). Fossil fuels monopolize the aggregate primary energy output in the BRICS economies; however, Brazil consumes a large amount of biofuel in transportation and India consumes a considerable amount of biomass in residential consumption. Hence the percentage of fossil energy resources in primary energy supply fluctuates from 55 percent in Brazil to 75 percent in India and about 90 percent in China, Russia and South Africa, although the world's average is approximately 80 percent (IEA, 2021).

Consequently, the importance of the BRICS nations in the global consumption pattern of natural resources and energy production is expanding substantially. As per British Petroleum (BP) Statistical Review of World Energy (2021), the primary power source of Russia is natural gas and the proportion of gas in its structure of energy consumption in 2021 was 53.6 percent; China, India, and South Africa rely on coal; 61.2%, 57.3%, and 65.4%; however, Brazil relies on oil, 56.3 percent. There is a rise in the proportion of oil in the primary energy usage structure in the BRICS, except for China, whose statistics are inclined to fall from 20.5 percent in 2006 to 18.4 percent in 2021. Whereas the percentage of coal decreased dramatically in all economies apart from India, in which it nearly maintained its 2006–2019 level of 54.9%. Some countries in this group are net importers or exporters of particular fossil resources due to the interrelationship between local consumption and production. China is the world's largest supplier of coal and a substantial producer of petroleum but is also the biggest importer of fossil resources to meet its domestic demand. Russia is a major exporter and producer of fossil fuels of all forms. India generates some local coal, oil, and gas but is a net importer of coal, oil, and gas. Yet, India refines crude oil in surplus of its national requirements and exports it as a refined product. South Africa imports oil and gas while exporting coal, whereas Brazil imports coal and gas and exports oil (IEA, 2021).

Institutions can be regarded as a set of rules, principles, and decision-making mechanisms that operate at the stages of public entities that focus primarily on environmental situations and resource regulations (Nadeem et al., 2022). Individuals and society achieve maximum social protection when they strive to decrease risks to people's lives and advance environmental and social concerns. Sound and high environmental regulations implemented by government entities in a country are among the most important drivers of environmental quality improvement (Jianguo et al., 2022). Thereby, quality institutions must be presumed as inputs for offering valuable laws which, once applied effectively, will assist in reducing environmental threats in the world economy, thereby accelerating the intended level of sustainable development (Saidi et al., 2020). Moreover, robust institutions can impact economic development and ecological deterioration by ensuring polluting companies' locations and limiting pollution havens. In addition, the involvement of institutions could stimulate sustainable development, which might lead to an upsurge in environmental deterioration in the absence of appropriate rules and regulations. According to Azam et al. (2021), improved institutions are required for environmental preservation and sustainable natural resource management. Nevertheless, the function of institutions in environmental sustainability has not been examined thoroughly in the literature, particularly in BRICS economies.

Due to the lack of evidence in prior research and the absence of studies for BRICS, it is essential to conduct more empirical research to recognize the role of institutions and fossil energy resources in environmental sustainability. By evaluating the significance of fossil energy resources and institutional quality in environmental sustainability, this study adds value to the worldwide discussion on environmental sustainability in the BRICS. In addition, the role of institutions in addressing the effects of fossil energy resources on environmental sustainability is estimated to design policies that offset the negative environmental effects of fossil fuels. Given the importance of environmental sustainability, an examination of the importance of institutions in BRICS countries will assist with the development of a better knowledge of the impact of institutional quality and bring new perspectives to environmental quality. Due to a potential heterogeneity among BRICS countries, robust and more contemporary econometric panel methods are used in this study to produce efficient results, which is an additional innovation.

2 Literature review

2.1 Fossil fuels and environment quality

The relationship between ecological sustainability and primary energy usage (energy derived from fossil fuel resources such as coal, oil and gas) is a topic of intense discussion in energy-environment research. Using carbon dioxide (CO_2) emission as a measure of environmental sustainability, numerous studies demonstrate a long-term, unidirectional relationship between CO_2 and primary energy consumption (Caglar et al., 2022; Kanat et al., 2022; Ullah et al., 2022d). Global environmental authorities and prominent environmentalists have identified energy usage as the primary source of environmental contamination (Ullah et al., 2022b). Even so, industrialized nations continue to consume energy and degrade the atmosphere; however, they are willing to accept a carbon price and support the use of renewable energy (Rafique et al., 2021). Numerous studies from the past substantiated energy-use-driven pollution and ecological degradation (Adedoyin et al., 2021; Gyamfi et al., 2021; Ummalla and Goyari, 2021). Luo et al. (2021) examined the impact of energy consumption, green investment, and technological innovations on CO_2 emission in selected Asian countries. The authors found that green investment and innovation are helpful in reducing CO_2 emission, while conventional energy resources such as coal, gas and oil increases the CO_2 emission in selected economies, and hence, damaging the envionomental quality.

Using the novel autoregressive distributed lag approach, Adedoyin et al. (2021) analyzed the effect of energy usage on CO_2 emissions. They revealed that increasing energy usage has a positive effect on CO_2 emissions. Awodumi and Adewuyi (2020) studied the influence of non-renewable energy and economic growth on CO_2 emission for a group of African oil-producing countries by incorporating other factors like trade openness, urbanization and income disparity. The results show that urbanization and income disparity significantly minimize environmental deterioration. In contrast, oil and gas consumption and trade openness degraded the environmental condition in most African countries. Khan et al. (2020) studied the relationship between economic growth, energy consumption, and CO_2 emission in Pakistan from 1965 to 2015 using annual data set. They indicated that long-term and short-term energy use increases CO_2 emissions in Pakistan. In addition, as conventional forms of energy usage, oil and coal raise CO_2 emissions, whereas natural gas usage decreases CO_2 emissions, preserving the health of Pakistan's ecosystem. According to (Munir and Riaz, 2020), a growth in coal, gas, and oil adds to a spike in CO_2 emissions and *vice versa*. However, the emission patterns are not equally applicable to the sample countries.

Ullah I. et al. (2022a) utilized data from low and high globalized OECD nations from 1996 to 2019 to examine the relationship between globalization, financial inclusion, economic complexity, economic growth, energy consumption, and carbon emissions. The authors reported that using fossil energy resources negatively impacts the sustainability of the environment *via* increasing CO_2 emissions in both low and high globalized OECD countries. In contrast, Ozcan et al. (2020) examined the dynamic relationship among energy use, economic growth, and ecological deterioration for 35 OECD economies from 2000 to 2014. The outcomes of the study reported the improvement in environmental quality driven by the energy usage trend and economic growth in these nations. Thus, growth policies and energy usage trends have evolved to align with the environmental strategies of the countries. Likewise, Arminen and Menegaki (2019) found no correlation between high-income countries' energy usage and CO_2 emissions. According to Ullah et al. (2022b)'s analysis, the usage of fossil fuels is the primary cause of Vietnam's rising CO_2 emissions. They also advocate switching from fossil fuels to renewable alternatives to improve environmental sustainability. Ali et al. (2021) reached similar conclusions for Vietnam, concluding that fossil fuel consumption is a major contributor to CO_2 emissions. By using the data of European union countries for the period 1980 to 2018, Zhen et al. (2022) also concluded that conventional energy resources have adverse impact on environmental quality.

2.2 Institutions and environment quality

The link between institutional quality and environmental sustainability has attracted considerable interest in recent years. Current research has highlighted energy consumption, economic growth, trade openness, financial development and foreign direct investment as the main channels by which institutions influence the quality of the environment (Tamazian and Bhaskara Rao, 2010; Adams and Acheampong, 2019; Khan et al., 2019; Saidi et al., 2020; Azam et al., 2021; Ullah et al., 2022b; Jianguo et al., 2022). Dasgupta and De Cian (2018) explained that governance, economic, and social preparedness, institutional quality impacts pollution mitigation. They further indicated that institutions have a key role in creating renewable technology and minimizing environmental deterioration in every economy since they assist policymakers in successfully enforcing and managing environmental regulations.

Abid (2016) investigated the effect of institutional quality on CO_2 emission in African nations and found that effective institutions aid in decreasing CO_2; supported by the data, they concluded that regulations linked with law contribute to improving the environmental quality in Africa. Analyzed by Ibrahim and Law (2016), the same conclusions were reached for African nations. Wang et al. (2018) opted for linear regression instead of a nonlinear one and evaluated corruption's interaction with other factors such as trade, population growth, GDP, and urbanization. The results demonstrated that corruption control directly impacts lowering CO_2 emissions. Yet, the effect varies when incorporating CO_2 and GDP interaction terms. Furthermore, corruption has the indirect influence of delaying the turning point of the EKC curve. Sarkodie and Adams (2018) investigated the effects of renewable and non-renewable energy, institutional quality and CO_2 emissions in South African nations. The results demonstrated that institutions' quality and renewable energy reduce CO_2 emissions in South African countries, whereas non-renewable energy increases CO_2 emissions. Egbetokun et al. (2020) evaluated the impact of institution efficiency on six different indicators of environmental pollutants in Nigeria from 1990 to 2016 using the ARDL model. They found that strong institutions considerably decrease CO_2 emissions. Khan et al. (2019) used Driscoll-Kraay standard error regression analysis to validate the EKC hypothesis for the BRICS countries from 1996 to 2017 and confirmed the EKC association while controlling governance variables.

Nadeem et al. (2022) highlighted the significance of institutions for environmental quality and suggested that effective instituions are important for preserving efficient resource allocation and enhancing the environmental quality. Wang et al. (2018) explained that corruption has direct and indirect effects on environmental quality since it undermines the effectiveness of institutions, encourages rent-seeking activities, and impedes the effectual execution of environmental legislation; however, corruption control assists in reducing emissions. By using the data from 1995 to 2018 and applying modern estimation techniques, Ullah et al. (2022b) explained in case of China that effective regulations significantly promote the environmental quality. Zhang et al. (2016) also indicated that control of corruption decreases carbon emissions indirectly *via* a mediation effect. Employing data from developing nations, Azam et al. (2021) have evaluated the impact of institutional quality on energy usage and environmental sustainability. They discovered that quality institutions positively affect the ecological variables CH4, CO_2, and forest land. Furthermore, they indicated that energy use is also positively affected by institutions' quality.

Another study conducted by (Godil et al., 2020) examined the impact of institutions' quality, economic growth, ICT, and financial openness on Pakistan's CO_2 emissions. According to the study, long-term economic expansion positively impacts CO_2 emissions, whereas institutional quality contributes to limiting CO_2. On the contrary, Hassan et al. (2020) found that the quality of institutions favorably influences CO_2 emission in Pakistan. According to (Asongu and Odhiambo, 2019), implementing environmental regulations reduces CO_2 emissions and improves the quality of the environment.

Salman et al. (2019) likewise found that institutional quality has a favorable impact on CO_2 reduction. Based on their findings, the authors concluded that efficiency institutions are crucial aspects of policies that will aid in reducing CO_2 emissions and boosting economic growth. Ahmed et al. (2020) examined Pakistan's financial growth, institutional quality, and ecological sustainability. According to the findings, there is a long-term symmetric and asymmetric relationship between institutional quality and financial growth, whereas institutional quality has an insignificant effect on ecological sustainability. Le and Ozturk (2020) analyzed the effect of institutional quality, government spending, and financial development on CO_2 emissions in emerging economies. According to the findings, governance, financial growth and energy use enhance CO_2 emissions. Jianguo et al. (2022) assessed the impact of institutional quality on the environmental sustainability of OECD economies and confirmed that CO_2 emission reduction strategies are effective. In addition, the authors indicated that strong institutions significantly moderate the impact of financial development on CO_2 emission reduction in OECD nations. In contrast, Khan H. et al. (2022) estimated the global data for the time 2002 to 2019 and concluded the adverse impact of institutional quality on environmental sustainability. Similarly (Obobisa et al., 2022), used data of 25 African countries for the period 2000–2018, and their results also suggest that promoting institutional quality lead to increase the CO_2 emission and impede the environmental quality.

All of the preceding discussion leads us to conclude that fossil fuel energy resources and institutions directly impact ecological sustainability. Moreover, institutions' effects on environmental quality can also manifest through indirect channels such as energy use, trade, FDI, and financial development. Nevertheless, the effects of fossil fuel energy resources and institutional quality on ecological sustainability are varied and contradictory. In addition, the relative importance of institutions might vary across countries, which can have different policy-related repercussions for the respective countries. Our study explores the dynamic linkages of fossil fuel energy resources and institutional quality in the ecological sustainability of BRICS.

3 Methodology

3.1 Theoretical framework and model

The ecological footprint (EFP) was first established by (Rees, 1996). The EFP measures human demands for natural recourses and comprises six sub-components: carbon footprint, cropland, grazing land, developed land, fishing grounds, and forest products. By integrating these six sub-components, the EFP reacts to the amount of nature nations possess and the extent to which they utilize productive natural resources (Ulucak and Bilgili, 2018). The EFP evaluates environmental deterioration as the use of resources by humans, while overall, earth utilization is a suitable measure of the influence of humans over natural resources. Nonetheless, EFP has arisen as a significant indicator of environmental damage. In addition, a rise in demand and supply of commodities results in increased usage of environmental resources and energy. A country's ecological footprint is growing due to its large demand for conventional fuels (Wang et al., 2020). Therefore, EFP is a comprehensive metric for ecological sustainability and has been used in many studies (Dogan et al., 2020).

Coal, oil, and natural gas are essential resources for a nation's energy output and governmental policies. While seeking sustainable growth, numerous developing nations have enacted different energy-saving and emissions-control legislation. However, owing to rising energy requirements in developing nations, their reliance on fossil energy sources cannot be alleviated in a short time; therefore, fossil fuels have become crucial to meeting energy needs. Fossil fuel energy is not only relevant to a country's national policy and energy sovereignty but also accountable for worldwide greenhouse gas emissions; thus, prior research has concentrated substantially on the consequences of fossil energy use on CO_2 emissions (Pao and Chen, 2019; Ullah et al., 2022d). Jonek-Kowalska (2022) demonstrates that during the energy transition procedure, the proportion of clean energy in the energy balance develops gradually, whereby the decline in the proportion of coal is countered by a rise in the percentage of natural gas. Therefore, developing economies cannot substitute oil and coal with biofuels by trade (Ali et al., 2021). Consequently, natural gas remains the favored alternative source, and fossil energy stays unchangeable. In the setting of a growing disparity between energy demand and supply, fossil resources are essential for developing economies to attain energy equilibrium. The dramatic surge in energy use will ultimately result in a rise in resource utilization and impact ecological sustainability. To promote sustainable growth, it is crucial to understand the impact of fossil-based energy sources on ecological sustainability in one of the fast-developing groups such as the BRICS.

Since the pioneering work of North (1990), this key role of institutions has been widely recognized in the literature. Institutions stimulate the private sector, enhance the efficiency of contract implementation, safeguard property ownership, and ensure the rule of law, and their freedom from political interference makes the execution of policy initiatives more effective (Salman et al., 2019). However, poor institutions present opportunities for corruption, an ineffective bureaucratic structure, rent-seeking by investors, and the absence of comprehensive environmental policy legislation (Khan et al., 2019). Institutions play a vital part in a country's growth also in environmental quality, and they can either improve or degrade ecological sustainability (Hassan et al., 2020). A strong institutional structure can enhance the government's abilities to properly manage environmental policy and combat corruption that may directly or indirectly affect the quality of the environment (Wang et al., 2018). Similarly, it is anticipated that institutional quality would play a significant influence on the social, political, and economic readiness to minimize environmental damage since institutions may contribute to the equal allocation of resources and power, hence improving environmental sustainability (Zhang et al., 2016). For the application of environmental laws, however, the importance of institutions soundness cannot be overstated, as institutional arrangements combat corruption and pave the way for strict environmental regulations necessary for a safe environment (Khan H. et al., 2022).

Given this theoretical context, it is clear that fossil energy resources and institutions' quality significantly impact ecological sustainability. Meanwhile, EFP's rise as a broader indicator of environmental sustainability gained prominence. The investigation of the influence of fossil fuel energy resources and institutions quality on EFP has received the least focus to date, particularly for BRICS. Eq. 1 gives the statistical means to demonstrate the model hypothesis:

$$\begin{aligned} ln\,EFP_{it} = \beta_1 lnOil_{it} + \beta_2 lnGas_{it} + \beta_3 lnCoal_{it} + \beta_4 lnINQ_{it} \\ + \beta_5 lnGLB_{it} + \beta_6 lnGDP_{it} + \varepsilon_{it} \end{aligned} \quad (1)$$

In Eq. 1, EFP denotes ecological footprint *per capita* (hectares *per capita*), Oil, Gas, and Coal are the production of oil, gas, and coal. INQ is the composite index of institutional quality, GLB and GDP are the control variables, respectively denoting the level of globalization and gross domestic product *per capita*.

Furthermore, to empirically access the role of institutional quality in fossil energy resources and ecological sustainability nexus, the following Eq. 2 is estimated

$$\begin{aligned} ln\,EFP_{it} = \beta_1 lnOil_{it} + \beta_2 lnGas_{it} + \beta_3 lnCoal_{it} + \beta_4 lnINQ_{it} \\ + \beta_5 lnOil*INQ_{it} + \beta_6 lnGas*INQ_{it} \\ + \beta_7 lnCoal*INQ_{it} + \beta_8 lnGLB_{it} + \beta_9 lnGDP_{it} + \varepsilon_{it} \end{aligned} \quad (2)$$

3.2 Data

The study employed the data of BRICS economies from 1996 to 2018, which consists of the longest available data for all the sample countries. The ecological footprint *per capita* (global hectares) is used to proxy EFP and obtained from Global Footprint Network. The data on fossil fuel energy resources, including coal, oil, and gas (consumption), is taken from BP statistics. The World Governance Indicators are used to proxy institutional quality. We considered all six components of WGI: corruption control, government effectiveness, rule of law, voice and accountability, political stability and regulatory quality. Then, a single index for institutional quality (INQ) is calculated by taking the average of these six components.

Finally, the data of control variable economic growth (GDP *per capita*) is taken from World Development Indicators (WDI) and the KOF globalization index is used to proxy the level of globalization.

3.3 Estimation method

3.3.1 CD and slope homogeneity

The suggested model must be supported by empirical evidence. Consequently, the most recent econometric approaches are employed for this goal, with panel data concerns. For instance, cultural, economic, and geographical linkages among the sampled countries may lead to cross-sectional dependence (CD), a critical element of panel data analysis. Driven by economic linkages, the BRICS countries are likely to be cross-sectionally dependent. Consequently, it is essential to assess the possibility of CD, as ignoring CD issue would lead to inappropriate and unreliable assessments of cointegration and stationarity characteristics (Adedoyin et al., 2021; Luo et al., 2021). The Pesaran (2015) CD check is performed to determine the dependence of cross-sections using the following equation.

$$CSD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=0}^{N-1}\sum_{j=i+1}^{N} p_{ij}\right) \quad (3)$$

In Eq. 3, *CSD* and *N* represent cross-sectional dependency and number of cross-sections, respectively, term *T* shows time, and *p* indicates error correlation among *j* and *i*.

In addition to cross-section dependency, it is essential to investigate slope heterogeneity issues, as regression coefficients are expected to vary across cross-sections. This is asserted that neglecting slope heterogeneity concerns results in ambiguous estimates. Although chosen BRICS countries are interconnected in various respects, there are substantial differences among them regarding this study. For instance, they vary n terms of EFP *per capita*, energy resource use, globalization, and other macroeconomic aspects. Consequently, the slope homogeneity test developed by Hashem Pesaran and Yamagata (2008) has been adopted. Eqs 4, 5 illustrate the standard mathematical form of SHT.

$$\tilde{\Delta}_{SH} = (N)^{\frac{1}{2}}(2k)^{\frac{1}{2}}\left(\frac{1}{N}\tilde{S} - k\right) \quad (4)$$

$$\tilde{\Delta}_{SH} = (N)^{\frac{1}{2}}\left(\frac{2k(T-k-1)}{T+1}\right)^{\frac{1}{2}}\left(\frac{1}{N}\tilde{S} - 2k\right) \quad (5)$$

3.3.2 Panel unit root test (CADF, CIPS)

Identifying the stationary levels of the variables has been a vital part of empirical estimates in the literature on environmental economics, particularly when the dataset does include multiple economic indicators (Wang et al., 2018; Khan et al., 2019). Although it is important to determine the integration order to obtain dynamic parameters, the literature suggests several tests for panel units' roots. This study focuses on the BRICS economies, each with its own fossil resources and ecological footprint levels. Therefore, the conventional panel unit root tests would generate inaccurate and skewed results. To overcome this, we employ robust panel estimate approaches, such as CIPS and CADF, proposed by (Pesaran, 2007). CIPS is an enhanced form of IPS that determines CADF statistics for the whole panel using the average of each CADF test result. In the context of a cross-section dependency problem and heterogeneity, both CIPS and CADF tests are efficient and provide reliable results. The following Eq. 6 is used to calculate CIPS statistics.

$$\widehat{CIPS} = \frac{1}{N}\sum_{i=1}^{n} CADF_i \quad (6)$$

3.3.3 Westerlund cointegration

Considering both CD and heterogeneity issues, the panel cointegration method gives more accurate and efficient results. Possibly, the panel cointegration approach is essential that is generally appropriate for the shorter cross-sectional's time-series elements. Recent research (Jianguo et al., 2022; Zhen et al., 2022) has attempted to apply (Westerlund, 2007) the panel cointegration method, which is based on the assumption of CSD. The Westerlund test for panel cointegration accounts for CSD and SLH, which are the critical aspect in panel data estimation (Zhen et al., 2022). The approach consists of four statistical tests, including Gt, Ga, Pt, and Pa. The Gt and Ga are group statistics that are autonomous of the information aggregated by the error correction technique. The calculation conditions for the cointegration test of Westerlund are represented in Eq. 7.

$$\Delta y_{it} = \sigma_i d_t + \delta_i\left(y_{i(t-1)} + \varnothing_i x_{i(t-1)}\right) + \sum_{j=1}^{m}\delta_{ij}\Delta z_{i(t-1)} + \sum_{j=1}^{m}\theta_{ij}\Delta x_{i(t-1)} + \epsilon_{it} \quad (7)$$

3.3.4 CS-ARDL

Finally, the cross-section's dependency is addressed by employing a recently developed CS-ARDL approach. Unlike other standard and pooled mean group techniques, the CS-ARDL is an effective and reliable method for estimating long-term effects (Zhen et al., 2022). In addition, the CS-ARDL method is effective against slope heterogeneity and cross-sectional dependency problems but also for a number of other concerns, such as non-stationarity, endogeneity, and unknown variances, which omission may lead to misleading and erroneous outcomes (Wang et al., 2018). The mathematical form of the CS-ARDL model can be represented as:

TABLE 1 CSD and slope homogeneity results.

Variables	Test-statistics
EFP	17.514*** (0.0000)
Oil	19.712*** (0.0000)
Gas	22.367*** (0.0000)
Coal	28.637*** (0.0000)
INQ	31.367*** (0.0000)
GLB	27.374*** (0.0000)
GDP	21.672*** (0.0000)
Slope homogeneity test	
Statistics	Values
Delta-tilde	28.357*** (0.0000)
Delta-tilde Adjusted	23.822*** (0.0000)

Note: *** explicate 1% significance level; values in ( ) are *p*-values.

$$\Delta EFP_{it} = \sigma_0 + \sum\nolimits_{j=1}^{p} \pi_{it} \Delta \mathrm{EFP}_{it-j} + \sum\nolimits_{j=0}^{p} \gamma_{it} Z_{it-j} + \sum\nolimits_{j=0}^{p} \delta \bar{X}_{it,t-j} + \mu_{it} \quad (8)$$

Where in Eq. 8 $\bar{X}_t = (\Delta\overline{EFP}_t, \bar{Z}_t)$, Whereas $\Delta\overline{EFP}_t$ and $\bar{Z}_t$ are, respectively averages of the dependent and independent variables. The term p shows lags of respective variables in the model. Furthermore, $\Delta \mathrm{EFP}_{\mathrm{it}}$ is the dependent variable, and Z_{it} denotes all explanatory variables, including oil, gas, coal, INQ, GDP, and GLB. To confirm the stability of CS-ARDL results, we applied AMG and CCEMG tests for robustness. The AMG and CCEMG tests are efficient in handling heterogeneity and cross-sectional dependence problem by using a common dynamic process (Pesaran, 2007; Luo et al., 2021).

3.3.5 Causality DH

The CS-ARDL estimate approach gives long-run coefficients and cannot identify the causal direction among covariates, while causality is vital for making policy direction. Parallel to the study of (Khan et al., 2019), we also perform the panel causality analysis developed by Dumitrescu and Hurlin (2012) to determine the relationship among fossil fuel resources, institutional quality, globalization, GDP, and EFP. The Dumitrescu and Hurlin (DH) causality method qualifies for heterogeneity and conditional dependence (CD) in the panel data, whereas the vector error correction model (VECM) granger causality test does not. Furthermore, the DH method effectively gives consistent results for limited data. The following Eq. 9 is estimated to examine the causal relationship among variables.

$$y_{it} = \sigma_i + \sum\nolimits_{i=1}^{p} \gamma_i^p y_{it-n} + \sum\nolimits_{i=1}^{p} \varphi_i^p x_{it-1} + \varepsilon_{it} \quad (9)$$

Where x and y are underlying variables for n cross-sections in t time. The terms γ_i^p and φ_i^p indicate the autoregressive parameters and regression coefficient across countries, respectively.

4 Results and discussion

We begin our analysis by examining the cross-sectional dependency (CSD) and slope homogeneity (SLH) tests to select the appropriate regression method. As confirmed by Luo et al. (2021), the first-generation tests give inconsistent results in the presence of CSD. Table 1 represents the results of CSD test proposed by (Pesaran, 2015), which confirms the rejection of the null hypothesis (no CSD) for each selected variable, as the *p*-values are significant at 1% level. This indicates that a shock in any variable in one sample country will also affect the other sample countries. Similarly, the lower panel of Table 1 also confirms the rejection of the null hypothesis that the slope is homogeneous and confirms the slope heterogeneity.

The confirmation of CSD and slope heterogeneity indicates that further analysis should be carried out using second-generation econometric techniques. Consequently, the next important step is to check the stationarity level of the

TABLE 2 Stationarity results.

Variables	Level		First-difference		Order of integration
	CADF	CIPS	CADF	CIPS	
EFP	−2.432	−2.121	−3.536***	−4.546***	I (1)
Oil	−1.475	−1.474	−3.473***	−4.373***	I (1)
Gas	−2.138	−1.574	−4.271***	−4.537***	I (1)
Coal	−1.433	−1.574	−4.647***	−4.182***	I (1)
INQ	−1.485	−2.462	−4.546***	−4.456***	I (1)
GLB	−1.474	−1.548	−3.467***	−4.372***	I (1)
GDP	−2.374	−1.647	−3.536***	−4.812***	I (1)

Note: *** explicate 1% significance level.

TABLE 3 Cointegration results.

Statistic	Values	Z-values	*p*-values	Robust *p*-values
Gt	−5.647	−3.372	0.039	0.018
Ga	−9.281	−4.372	0.000	0.000
Pt	−14.356	−3.811	0.000	0.000
Pa	−11.893	−4.219	0.001	0.001

TABLE 4 CS-ARDL results.

Explanatory variable	Coefficients	t-stats	*p*-values
Long-run estimates			
Oil	0.241**	2.327	0.028
Gas	0.129**	2.738	0.019
Coal	0.211***	4.384	0.000
INQ	−0.091***	−3.833	0.000
Oil*INQ	−0.117*	−1.738	0.049
Gas*INQ	−0.098**	−2.829	0.015
Coal*INQ	−0.081***	−3.948	0.000
GLB	0.078**	−2.882	0.015
GDP	0.251***	4.532	0.000
Short-run estimates			
ECM	−0.319***	−3.564	0.000
Δ Oil	0.201*	−1.814	0.049
Δ Gas	0.181**	2.135	0.038
Δ Coal	0.092**	2.347	0.028
Δ INQ	−0.051*	−1.911	0.046
Δ Oil*INQ	−0.073**	−2.711	0.020
Δ Gas*INQ	−0.081	−1.397	0.611
Δ Coal*INQ	−0.067***	−4.728	0.000
Δ GLB	0.026***	4.382	0.000
Δ GDP	0.118***	5.291	0.000

Note: "***," "**," and "*" explicate 1%, 5%, and 10% significance level.

variables. Considering the CSD, the second-generation unit root tests CADF and CIPS are applied and results are given in Table 2 The stationarity results in Table 2 indicate that all the variables are stationary at the first difference by both tests at 1% significance level.

The long-run relationship among variables is confirmed by employing (Westerlund, 2007) cointegration, as it is considered a robust approach in the presence of CSD (Jianguo et al., 2022). Table 3 reports the cointegration results. The *p*-values of all four

TABLE 5 AMG and CCEMG results.

Explanatory variable	AMG	CCEMG
Oil	0.323** (.003)	0.273*** (0.001)
Gas	0.183*** (.000)	0.093*** (0.001)
Coal	0.217*** (.001)	0.219*** (0.001)
INQ	−0.072*** (.001)	−0.087*** (0.000)
Oil*INQ	−0.083** (.041)	−0.171** (0.021)
Gas*INQ	−0.112*** (.002)	−0.067*** (0.000)
Coal*INQ	−0.091* (.0521)	−0.129** (0.011)
GLB	−0.213*** (.000)	−0.189*** (0.000)
GDP	0.327*** (.000)	0.278*** (0.000)
RMSE	0.0073	.0071
Wald	45.237	35.758
Prob	(0.000)	(0.000)

Note: "***," "**," and "*" explicate 1%, 5%, and 10% significance level.

statistics Gt, Ga, Pt, and Pa are found significant, hence, rejecting the null hypothesis of no cointegration and confirming the long-run relationship among the selected variables.

After confirming the long-run relationship among variables, the long and short-term parameters are estimated through the CS-ARDL method. The CS-ARDL results in Table 4 revealed that oil, gas, and coal significantly contribute to the ecological footprint in BRICS, both in the long and short run. A 1% increase in oil, gas, and coal upsurge the ecological footprint by .241%, .129%, and .211% in long run, while .201%, .181%, and .092% in short run, respectively. This indicates that fossil fuel energy resources are the substantial cause of environmental degradation in BRICS, as evident by the positive impact of oil, gas and coal on the ecological footprint. The larger environmental damage is done by oil as compared to gas and coal. Overall, the findings are consistent with outcomes of some previous studies carried out in BRICS economies (Dogan et al., 2020; Ummalla and Goyari, 2021; Caglar et al., 2022) and reinforce that fossil fuel energy resources are responsible for a high ecological footprint in BRICS. For institutions' quality, the results indicate that 1% rise in INQ condenses the ecological footprint by .091% in the long run, whereas .051% in the short run. Our findings are similar to those of (Dogan et al., 2020; Saidi et al., 2020), who investigated the institution's quality-environment nexus and contradict those of (Khan H. et al., 2022; Obobisa et al., 2022). The mixed empirical results in the literature indicate that institutional quality could play a moderating role as bad institutions result in inefficiencies and environmental degradation, whereas good institutions improve environmental quality. We, therefore, introduced the interactive term between institutions' quality and fossil fuel energy resources

TABLE 6 DH causality results.

Null hypothesis	W-stats	Z bar-stats	Prob	Result
Oil –» EFP	5.748	2.923	0.002	Unidirectional causality
EFP –» Oil	3.575	1.525	0.398	
Gas –» EFP	4.857	2.273	0.021	Unidirectional causality
EFP –» Gas	2.811	.489	0.631	
Coal –» EFP	5.914	3.092	0.001	Unidirectional causality
EFP –» Coal	3.793	1.281	0.211	
INQ –» EFP	6.578	3.759	0.000	Bidirectional causality
EFP –» INQ	6.649	3.818	0.000	
GLB –» EFP	5.684	2.763	0.002	Unidirectional causality
EFP –» GLB	2.792	.483	0.629	
GDP –» EFP	5.858	3.083	0.001	Bidirectional causality
EFP –» GDP	5.499	2.685	0.003	

to investigate whether INQ can moderate the resources-environment nexus. Our estimates show that the interaction of INQ with all fossil resources, including oil, gas, and coal, negatively affects the ecological footprint in both the long and short run. The results are statistically significant for all interaction terms except the interaction of (Gas*INQ), which is insignificant; yet carries a negative sign. Therefore, the moderating influence of INQ indicates that the adverse impact of fossil fuel energy resources can be mitigated with the sound quality of institutions in BRICS. The result supports the arguments found in the literature that good institutions are critical to the transformation of fossil fuels sources into sustainable environmental outcomes through appropriate technology, improved policy-making and execution (Saidi et al., 2020; Azam et al., 2021). Rules aimed at improving environmental quality are more likely to be enforced in a setting with high institutional quality than in one with low institutional quality (Khan et al., 2019).

Turning to the effect of control variables, we found that globalization (GLB) significantly contributes to the ecological footprint (EFP). A 1% increase in GLB increases the EFP by .078% and .026%, respectively, in the long and short run. Le and Ozturk (2020) assert that increased globalization as a result of greater trade, urbanization, and industrialization leads to environmental quality degredation because of the heavy reliance on primarily fossil fuel-based energy sources. Finally, we found that economic growth (GDP) also has an augmenting effect on EFP. A 1% increase in GDP uplift the EFP by .251% in the long run and .118% in the short run. The results are in line with recent literature suggesting that countries at their early stage of development pay less attention to the quality of their environment while striving to achieve more growth (Salman et al., 2019; Saidi et al., 2020; Ullah et al., 2022d; Jianguo et al., 2022).

The robustness of the CS-ARDL results is confirmed by employing AMG and CCEMG methods. The AMG and CCEMG test results in Table 5 show that all the explanatory variables are statistically significant and consistent with the CS-ARDL results given in Table 4, thus ensuring the robustness of long-run results.

Finally, the results of the causal association between explanatory variables and ecological footprint (EFP) are given in Table 6. Accordingly, there is unidirectional causality between oil and EFP, gas and EFP, coal and EFP, and, GLB and EFP. It shows that fossil fuel resources are not sustainable for BRICS since natural resources cannot regenerate (Nathaniel et al., 2021). Thus, this leads to lose the biocapacity and causes EFP. These findings are consistent with previous studies indicating a unidirectional relationship between fossil fuels and ecological footprint (Zafar et al., 2019; Ibrahiem and Hanafy, 2020). However, there is bidirectional causality between INQ-EFP and GDP-EFP. The rapid economic growth in BRICS countries prompted the high use of natural resources and increased the dependency on fossil energy resources, consequently increasing the EFP level. Similarly, the institution's quality is significant causing factor to EFP as it endorses the setting and implementation of environmental regulations and promotes environmental quality.

5 Conclusion and policy suggestions

Our analysis focuses on empirically examining the impact of fossil energy resources and institutional worth on the environmental sustainability of BRICS for the period 1996–2018. The study employed second-generation tests to identify the long-run relationship and stationarity level of the variables, and the CS-ARDL approach to estimate the long-run coefficients, which is considered an efficient method against cross-sectional dependency and heterogeneity issues. The robustness of the findings is confirmed by AMG and CCEMG methods.

We individually estimated the impact of each fossil energy resource, i.e., coal, oil and gas, and institutional quality (INQ), on environmental sustainability, which is proxy by ecological footprint. The study findings revealed that the increase in the usage of all fossil energy resources significantly increases the ecological footprint in BRICS, causing environmental degradation. In contrast, the INQ significantly promotes environmental quality by decreasing the ecological footprint. Additionally, the results regarding the interacting effect of INQ and fossil energy resources show that all the fossil energy resources negatively and significantly affect the ecological footprint, indicating that with better environmental regulations and institutional measures, fossil energy resources can promote the environmental quality in BRICS.

Considering the negative effects of fossil fuels on the environment, we urge the BRICS countries' decision-makers to reduce their reliance on fossil fuels for the benefit of environmental quality while also putting in place policies that would ensure the responsible use of those resources. As INQ can reduce ecological footprints, thus, the quality of policy formulation and the government's credibility in implementation is also very important. The further improvement of institutions will promote environmental sustainability because better institutions entail more access to information and greater political freedom, both of which contribute to a rise in public desire for improved environmental quality and an increase in public awareness of environmental issues. As a result, people's desire for a clean environment culminates in the implementation of environmental legislation, which, in turn, leads to a decrease in emissions from fossil fuels and a reduction in the risk that these emissions would have on human health.

Like all other research studies, this particular study is not without some limitations. Firstly, the study considered BRICS countries over 1996–2018 for analysis. Secondly, due to the lack of data, the analysis is focused on specific determinants and ignores many crucial factors that influence the quality of the environment. However, the current study provides a fruitful direction for further future research. The researcher can use both times series and extensive panel framework to investigate the moderating role of institutions between fossil fuel energy resources and CO_2 emissions. The research can be expanded by considering developing countries and a comparative analysis on developed and developing countries by employing advanced methods. By covering up these research gas, the present study would be pretty practical from a policy aspect for other emerging and developing economies.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Materials, further inquiries can be directed to the corresponding author.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Abid, M. (2016). Impact of economic, financial, and institutional factors on CO2 emissions: Evidence from Sub-Saharan Africa economies. *Util. Policy* 41, 85–94. doi:10.1016/j.jup.2016.06.009

Adams, S., and Acheampong, A. O. (2019). Reducing carbon emissions: The role of renewable energy and democracy. *J. Clean. Prod.* 240, 118245. doi:10.1016/j.jclepro.2019.118245

Adedoyin, F. F., Ozturk, I., Bekun, F. V., Agboola, P. O., and Agboola, M. O. (2021). Renewable and non-renewable energy policy simulations for abating emissions in a complex economy: Evidence from the novel dynamic ARDL. *Renew. Energy* 177, 1408–1420. doi:10.1016/j.renene.2021.06.018

Ahmed, Z., Zafar, M. W., and Mansoor, S. (2020). Analyzing the linkage between military spending, economic growth, and ecological footprint in Pakistan: Evidence from cointegration and bootstrap causality. *Environ. Sci. Pollut. Res.* 27, 41551–41567. doi:10.1007/s11356-020-10076-9

Ali, K., Bakhsh, S., Ullah, S., Ullah, A., and Ullah, S. (2021). Industrial growth and CO2 emissions in Vietnam: The key role of financial development and fossil fuel consumption. *Environ. Sci. Pollut. Res.* 28, 7515–7527. doi:10.1007/s11356-020-10996-6

Arminen, H., and Menegaki, A. N. (2019). Corruption, climate and the energy-environment-growth nexus. *Energy Econ.* 80, 621–634. doi:10.1016/j.eneco.2019.02.009

Asongu, S. A., and Odhiambo, N. M. (2019). Inclusive development in environmental sustainability in sub-Saharan Africa: Insights from governance mechanisms. *Sustain. Dev.* 27, 713–724. doi:10.1002/sd.1936

Awodumi, O. B., and Adewuyi, A. O. (2020). The role of non-renewable energy consumption in economic growth and carbon emission: Evidence from oil producing economies in Africa. *Energy Strateg. Rev.* 27, 100434. doi:10.1016/j.esr.2019.100434

Azam, M., Hunjra, A. I., Bouri, E., Tan, Y., and Saleh Al-Faryan, M. A. (2021). Impact of institutional quality on sustainable development: Evidence from developing countries. *J. Environ. Manage.* 298, 113465. doi:10.1016/j.jenvman.2021.113465

British Petroleum Statistical Review of World Energy (2021). Statistical Review of world energy. Available at: https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html.

Caglar, A. E., Zafar, M. W., Bekun, F. V., and Mert, M. (2022). Determinants of CO2 emissions in the BRICS economies: The role of partnerships investment in energy and economic complexity. *Sustain. Energy Technol. Assessments* 51, 101907. doi:10.1016/j.seta.2021.101907

Dasgupta, S., and De Cian, E. (2018). The influence of institutions, governance, and public opinion on the environment: Synthesized findings from applied econometrics studies. *Energy Res. Soc. Sci.* 43, 77–95. doi:10.1016/j.erss.2018.05.023

Dogan, E., Ulucak, R., Kocak, E., and Isik, C. (2020). The use of ecological footprint in estimating the Environmental Kuznets Curve hypothesis for BRICST by considering cross-section dependence and heterogeneity. *Sci. Total Environ.* 723, 138063. doi:10.1016/j.scitotenv.2020.138063

Dumitrescu, E. I., and Hurlin, C. (2012). Testing for Granger non-causality in heterogeneous panels. *Econ. Model* 29, 1450–1460. doi:10.1016/j.econmod.2012.02.014

Egbetokun, S., Osabuohien, E., Akinbobola, T., Onanuga, O. T., Gershon, O., and Okafor, V. (2020). Environmental pollution, economic growth and institutional quality: Exploring the nexus in Nigeria. *Manag. Environ. Qual. An Int. J.* 31, 18–31. doi:10.1108/MEQ-02-2019-0050

Godil, D. I., Sharif, A., Agha, H., and Jermsittiparsert, K. (2020). The dynamic nonlinear influence of ICT, financial development, and institutional quality on CO2 emission in Pakistan: New insights from QARDL approach. *Environ. Sci. Pollut. Res.* 27, 24190–24200. doi:10.1007/s11356-020-08619-1

Gyamfi, B. A., Ozturk, I., Bein, M. A., and Bekun, F. V. (2021). An investigation into the anthropogenic effect of biomass energy utilization and economic sustainability on environmental degradation in E7 economies. *Biofuels, Bioprod. Biorefining* 15, 840–851. doi:10.1002/bbb.2206

Hashem Pesaran, M., and Yamagata, T. (2008). Testing slope homogeneity in large panels. *J. Econom.* 142, 50–93. doi:10.1016/j.jeconom.2007.05.010

Hassan, S. T., Khan, D., Din, S. U., Xia, E., and Fatima, H. (2020). Role of institutions in correcting environmental pollution: An empirical investigation. *Sustain. Cities Soc.* 53, 101901. doi:10.1016/j.scs.2019.101901

Ibrahiem, D. M., and Hanafy, S. A. (2020). Dynamic linkages amongst ecological footprints, fossil fuel energy consumption and globalization: An empirical analysis. *Manag. Environ. Qual. An Int. J.* 31, 1549–1568. doi:10.1108/MEQ-02-2020-0029

Ibrahim, M. H., and Law, S. H. (2016). Institutional quality and CO2 emission–trade relations: Evidence from Sub-Saharan Africa. *South Afr. J. Econ.* 84, 323–340. doi:10.1111/saje.12095

IEA (2021). World energy outlook 2021. Available at: https://www.iea.org/reports/world-energy-outlook-2021.

Jianguo, D., Ali, K., Alnori, F., and Ullah, S. (2022). The nexus of financial development, technological innovation, institutional quality, and environmental quality: Evidence from OECD economies. *Environ. Sci. Pollut. Res.* 29, 58179–58200. doi:10.1007/s11356-022-19763-1

Jonek-Kowalska, I. (2022). Towards the reduction of CO2 emissions. Paths of pro-ecological transformation of energy mixes in European countries with an above-average share of coal in energy consumption. *Resour. Policy* 77, 102701. doi:10.1016/j.resourpol.2022.102701

Kanat, O., Yan, Z., Asghar, M. M., Ahmed, Z., Mahmood, H., Kirikkaleli, D., et al. (2022). Do natural gas, oil, and coal consumption ameliorate environmental quality? Empirical evidence from Russia. *Environ. Sci. Pollut. Res.* 29, 4540–4556. doi:10.1007/s11356-021-15989-7

Khan, D., Muhammad Awais, B., and Wang, B. (2019). Analyzing the role of governance in CO2 emissions mitigation: The BRICS experience. *Struct. Chang. Econ. Dyn.* 51, 119–125. doi:10.1016/j.strueco.2019.08.007

Khan, H., Weili, L., Khan, I., and Han, L. (2022a). The effect of income inequality and energy consumption on environmental degradation: The role of institutions and financial development in 180 countries of the world. *Environ. Sci. Pollut. Res.* 29, 20632–20649. doi:10.1007/s11356-021-17278-9

Khan, K., Zhang, J., Gul, F., and Li, T. (2022b). The "carbon curse": Understanding the relationship between resource abundance and emissions. *Extr. Ind. Soc.* 11, 101119. doi:10.1016/j.exis.2022.101119

Khan, M. K., Khan, M. I., and Rehan, M. (2020). The relationship between energy consumption, economic growth and carbon dioxide emissions in Pakistan. *Financ. Innov.* 6, 1. doi:10.1186/s40854-019-0162-0

Le, H. P., and Ozturk, I. (2020). The impacts of globalization, financial development, government expenditures, and institutional quality on CO2 emissions in the presence of environmental Kuznets curve. *Environ. Sci. Pollut. Res.* 27, 22680–22697. doi:10.1007/s11356-020-08812-2

Luo, R., Ullah, S., and Ali, K. (2021). Pathway towards sustainability in selected Asian countries: Influence of green investment, technology innovations, and economic growth on CO2 emission. *Sustain* 13, 12873. doi:10.3390/su132212873

Munir, K., and Riaz, N. (2020). Asymmetric impact of energy consumption on environmental degradation: Evidence from Australia, China, and USA. *Environ. Sci. Pollut. Res.* 27, 11749–11759. doi:10.1007/s11356-020-07777-6

Nadeem, M., Lou, S., Wang, Z., Sami, U., Ali, S. A., Abbas, Q., et al. (2022). Efficiency of domestic institutional arrangements for environmental sustainability along the way to participate in global value chains: Evidence from asia. *Econ. Res. Istraživanja*, 1–20. doi:10.1080/1331677X.2022.2077793

Nathaniel, S. P., Yalçiner, K., and Bekun, F. V. (2021). Assessing the environmental sustainability corridor: Linking natural resources, renewable energy, human capital, and ecological footprint in BRICS. *Resour. Policy* 70, 101924. doi:10.1016/j.resourpol.2020.101924

North, D. C. (1990). *Institutions, institutional change and economic performance*. Cambridge, Cambridge University Press.

Obobisa, E. S., Chen, H., and Mensah, I. A. (2022). The impact of green technological innovation and institutional quality on CO2 emissions in African countries. *Technol. Forecast. Soc. Change* 180, 121670. doi:10.1016/j.techfore.2022.121670

Ozcan, B., Tzeremes, P. G., and Tzeremes, N. G. (2020). Energy consumption, economic growth and environmental degradation in OECD countries. *Econ. Model.* 84, 203–213. doi:10.1016/j.econmod.2019.04.010

Pao, H. T., and Chen, C. C. (2019). Decoupling strategies: CO2 emissions, energy resources, and economic growth in the group of twenty. *J. Clean. Prod.* 206, 907–919. doi:10.1016/j.jclepro.2018.09.190

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *J. Appl. Econom.* 22, 265–312. doi:10.1002/jae.951

Pesaran, M. H. (2015). Testing weak cross-sectional dependence in large panels. *Econom. Rev.* 34, 1089–1117. doi:10.1080/07474938.2014.956623

Rafique, M. Z., Doğan, B., Husain, S., Huang, S., and Shahzad, U. (2021). Role of economic complexity to induce renewable energy: Contextual evidence from G7 and E7 countries. *Int. J. Green Energy* 18, 745–754. doi:10.1080/15435075.2021.1880912

Rees, W. E. (1996). Revisiting carrying capacity: Area-based indicators of sustainability. *Popul. Environ.* 17, 195–215. doi:10.1007/BF02208489

Saidi, H., El Montasser, G., and Ajmi, A. N. (2020). The role of institutions in the renewable energy-growth nexus in the MENA region: A panel cointegration approach. *Environ. Model. Assess.* 25, 259–276. doi:10.1007/s10666-019-09672-y

Salman, M., Long, X., Dauda, L., and Mensah, C. N. (2019). The impact of institutional quality on economic growth and carbon emissions: Evidence from Indonesia, South Korea and Thailand. *J. Clean. Prod.* 241, 118331. doi:10.1016/j.jclepro.2019.118331

Sarkodie, S. A., and Adams, S. (2018). Renewable energy, nuclear energy, and environmental pollution: Accounting for political institutional quality in South Africa. *Sci. Total Environ.* 643, 1590–1601. doi:10.1016/j.scitotenv.2018.06.320

Shah, M. H., Salem, S., Ahmed, B., Ullah, I., Rehman, A., Zeeshan, M., et al. (2022). Nexus between foreign direct investment inflow, renewable energy consumption, ambient air pollution, and human mortality: A public health perspective from non-linear ARDL approach. *Front. Public Heal.* 9, 814208. doi:10.3389/fpubh.2021.814208

Tamazian, A., and Bhaskara Rao, B. (2010). Do economic, financial and institutional developments matter for environmental degradation? Evidence from transitional economies. *Energy Econ.* 32, 137–145. doi:10.1016/j.eneco.2009.04.004

Ullah, I., Rehman, A., Svobodova, L., Akbar, A., Shah, M. H., Zeeshan, M., et al. (2022a). Investigating relationships between tourism, economic growth, and CO2 emissions in Brazil: An application of the nonlinear ARDL approach. *Front. Environ. Sci.* 10. doi:10.3389/fenvs.2022.843906

Ullah, S., Ali, K., Shah, S. A., and Ehsan, M. (2022b). Environmental concerns of financial inclusion and economic policy uncertainty in the era of globalization: Evidence from low & high globalized OECD economies. *Environ. Sci. Pollut. Res.* 29, 36773–36787. doi:10.1007/s11356-022-18758-2

Ullah, S., Luo, R., Adebayo, T. S., and Kartal, M. T. (2022c). Dynamics between environmental taxes and ecological sustainability: Evidence from top-seven green economies by novel quantile approaches. *Sustain. Dev.* doi:10.1002/sd.2423

Ullah, S., Nadeem, M., Ali, K., and Abbas, Q. (2022d). Fossil fuel, industrial growth and inward FDI impact on CO 2 emissions in Vietnam: Testing the EKC hypothesis. *Manag. Environ. Qual. An Int. J.* 33, 222–240. doi:10.1108/MEQ-03-2021-0051

Ulucak, R., and Bilgili, F. (2018). A reinvestigation of EKC model by ecological footprint measurement for high, middle and low income countries. *J. Clean. Prod.* 188, 144–157. doi:10.1016/j.jclepro.2018.03.191

Ummalla, M., and Goyari, P. (2021). The impact of clean energy consumption on economic growth and CO2 emissions in BRICS countries: Does the environmental Kuznets curve exist? *J. Public Aff.* 21. doi:10.1002/pa.2126

Wang, Z., Bui, Q., Zhang, B., and Pham, T. L. H. (2020). Biomass energy production and its impacts on the ecological footprint: An investigation of the G7 countries. *Sci. Total Environ.* 743, 140741. doi:10.1016/j.scitotenv.2020.140741

Wang, Z., DanishZhang, B., and Wang, B. (2018). The moderating role of corruption between economic growth and CO2 emissions: Evidence from BRICS economies. *Energy* 148, 506–513. doi:10.1016/j.energy.2018.01.167

Westerlund, J. (2007). Testing for error correction in panel data. *Oxf. Bull. Econ. Stat.* 69, 709–748. doi:10.1111/j.1468-0084.2007.00477.x

Zafar, M. W., Zaidi, S. A. H., Khan, N. R., Mirza, F. M., Hou, F., and Kirmani, S. A. A. (2019). The impact of natural resources, human capital, and foreign direct investment on the ecological footprint: The case of the United States. *Resour. Policy* 63, 101428. doi:10.1016/j.resourpol.2019.101428

Zhang, Y.-J., Jin, Y.-L., Chevallier, J., and Shen, B. (2016). The effect of corruption on carbon dioxide emissions in apec countries: A panel quantile regression analysis. *Technol. Forecast. Soc. Change* 112, 220–227. doi:10.1016/j.techfore.2016.05.027

Zhen, Z., Ullah, S., Shaowen, Z., and Irfan, M. (2022). How do renewable energy consumption, financial development, and technical efficiency change cause ecological sustainability in European Union countries? *Energy Environ.* doi:10.1177/0958305X221109949