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The role of institutional quality and environment-related technologies in environmental degradation for BRICS

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A B S T R A C T

An expanding body of literature has highlighted the environment–growth nexus. However, the literature is scarce on the role of environmental technologies and institutional quality in environmental pollution. The present study aims to contribute to the existing knowledge by utilizing environment-related technologies (ERT), institutional quality (IQ), and energy consumption to investigate ecological footprints (EF) as a proxy for the environment in BRICS economies in a framework based on environmental Kuznets curve (EKC) theory. By using data from 1992 to 2016, long- and short-term relationships are estimated through cross-section augmented autoregressive distributive lag model, augmented mean group estimator, and common correlated effects mean group. The second-generation econometric tools indicate that IQ and ERT negatively affect ecological footprints, thereby implying reductions in environmental degradation. The EKC hypothesis is not validated, implying that an increase in economic activities causes an increase in pollution. Overall, BRICS economies should improve their quality of institutions and enhance investments in environmental technologies to achieve a sustainable environment in the future. Findings are robust to practical policy implications.

1. Introduction

The discourse on the environment–growth nexus has been a focus of environmental scientists since the inception of the environmental Kuznets curve (EKC) hypothesis (Grossman and Krueger, 1991, 1995). Numerous studies have contributed to the EKC literature in many panel and single-country investigations, and EKC has become a global phenomenon. Web of Science has recently reported 3014 research-based studies published with 78,319 citations in the last two decades (Dogan et al., 2020). However, extreme climatic change during this period has been reported owing to substantial industrial and economic growth (Wang and Dong, 2019). On the one hand, structural and paradigm shifts have transformed high carbon-intensive industries into low carbon emission industries in developed countries (Shahbaz et al., 2018). Moreover, sustainable environmental policies, technological innovations, and quality of institutions have reduced environmental degradation in developed economies (Danish et al., 2019). On the other hand, limited advanced technologies have resulted in developing countries emerging as havens of high carbon emissions with worse environments (Sarkodie, 2018; Wang et al., 2018). Given a continuous increase in growth level, these countries are expected to opt for advanced technologies with enhanced rule of law, thereby leading to improved environmental practices (Hassan et al., 2019). Meanwhile, a high GDP will also increase the demand for fuel, thereby increasing ecological pressure that will lead to worse environment (Dogan and Seker, 2016; Baloch et al., 2019; Charfeddine and Kahia, 2019). Therefore, developing countries are leaving chaos to study further developments for a sustainable environment. Accordingly, the current study aims to investigate the role of institutional quality (IQ) and environment-related technologies (ERT) in a panel of developing countries.

Among the developing countries, this study selects the economies of Brazil, the Russian federation, India, China, and South Africa (BRICS) as sample based on the following logic. Remarkable economic growth has been evident in BRICS in the last few decades.

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Moreover, investment in BRICS is rapidly increasing (Wang et al., 2020). With over 3 billion people, BRICS countries represent 42% of the world population (Worldometers, 2019). This large population reflects high growth potential but with high pressure on the environment (Apergis and Ozturk, 2015). Furthermore, BRICS countries have upgraded their positions in the "global innovation index" (GII; i.e., China has significantly improved its position in the top 20, India at 52nd, Russia at 46th, Brazil at 66th, and South Africa 63rd) (Global Innovation Index, 2019). In terms of technological innovation in the form of patent applications, BRICS cumulatively led globally with 34% in 2018 compared with 29% in 2016 (EI Bank of India, 2018). These technological innovations are helping clean the environment (Shahbaz et al., 2020). Moreover, BRICS contribute nearly 51% to the world GDP. On this premise, BRICS may be suitable for investigating IQ and ERT in the context of environmental degradation.

Apart from the aforementioned improvements, note that BRICS countries also face numerous challenges (Wang et al., 2018). Prominent among these challenges are as follows: political instability, accelerated corruption, weak institutional quality caused by social injustice, and environmental stress resulting from the extensive use of fossil fuels and traditional technology (Awais and Wang, 2019). Consequently, these countries are responsible for over 40% of the world's carbon emissions (He et al., 2020). Among other challenges, IQ has emerged as an important issue to be considered for sustainable development (Mehlum et al., 2006). Strong quality of institutions leads to smooth procedures, thereby facilitating the planning of strategies that may place pressure to rectify environmental degradation, and vice versa (Salman et al., 2019). Furthermore, efficient institutions provide means to facilitate the reduction of transaction costs and, ultimately, improvement of economic performance. Therefore, institutional reforms are of utmost importance for enhanced economic performance through the enforcement of the rule of law and fair practices. Institutions with a fair legal framework may also help to promote environment protection measures. Accordingly, institutions may be beneficial sources in formulating policies to reduce environmental degradation. Therefore, the role of IQ in environmental degradation mitigation in BRICS economies is worthy of investigation.

Although BRICS has shown significant economic growth speed, they continue to lack environmental technologies. However, ERT is found to be beneficial in carbon emission reduction in emerging economies (Hussain et al., 2020b). ERT is a technology used in the production or processing of goods without any harm to the environment. Abad-Segura et al. (2020) indicated the role of industrial processes management in the implementation of efficient models to achieve sustainable societies. Besides, sustainable development via green growth is also supported by increasing investment in environmental technologies (Danish and Ulucak, 2020). Therefore, an interesting endeavor would be to examine the role of environment-related technologies on environmental degradation in BRICS economies.

The literature has indicated that environmental degradation is traditionally measured by carbon dioxide (CO_2) emissions (Nasir and Ur Rehman, 2011; Tiwari et al., 2013; Dogan and Inglesi Lotz, 2017; Rehman and Rashid, 2017; Destek et al., 2018; Xu et al., 2018; Mahmood et al., 2019; Danish and Ulucak, 2020). However, ecological footprint has emerged as a comprehensive measure of environmental degradation. "Ecological footprint (EF) refers to the biologically productive land and sea area used by people in a particular country" (Aşıcı and Acar; Charfeddine, 2017; Danish and Wang, 2019). Furthermore, an increase in production and consumption of goods leads to high utilization of ecological resources and energy use, and substantial consumption of traditional fuels is increasing ecological footprint in a country. Hence, EF is a considerably broad measure for consideration while examining environmental degradation. EF has been observed in numerous important studies (Aydin et al., 2019; Danish et al., 2020; Dogan et al., 2020; Solarin and Ozturk, 2016; Ulucak and Bilgili, 2018).

Given the preceding premise, this study contributes to the existing literature in two ways. First, to our knowledge, this research is the first attempt to examine the role of ERT and IQ in determining EF by controlling for energy consumption, GDP, and the square of GDP in the EKC framework in BRICS economies for the latest data set from 1992 to 2016. The reviewed literature has indicated that the role of ERT and IQ in the environment is limited and should be further investigated. Second, the latest econometric techniques (i.e., second-generation econometric approaches), particularly cross-sectional dependence (CSD) test, cross-sectional augmented Im–Pesaran–Shin (CIPS) panel unit root test, Westerlund co-integration technique, cross-sectional augmented autoregressive distributive lag (CS-ARDL), augmented mean group estimator (AMG), and common correlated effects mean group (CCEMG), are applied to study the aforementioned nexus. All proposed techniques deal with the issues of CSD and heterogeneity. The remainder of this paper is organized as follows. Section 2 presents a brief literature review. Section 3 provides the methodology in detail, including the data, model construction, results, and discussion. Lastly, Section 4 presents the conclusion and policy implications.

2. Literature review

The literature on EKC is continuously expanding. Since Kraft and Kraft (1978), numerous studies globally have focused on the energy–environment and growth nexus in their empirical investigations. In addition, the inception of the EKC hypothesis (G. Grossman and Krueger (1991; 1995) has revolutionized the environment and growth literature. Moreover, the majority of the previous studies have used CO_2 emissions as environmental degradation proxy, although EF has also emerged as a comprehensive measure of environmental degradation but rarely used in the context of the BRICS panel. Table 1 summarizes previous studies with EF as environmental proxy in the panel and single country analysis.

In the panel investigations of ecological footprint, Destek and Sarkodie (2019) examined the roles of financial development, energy consumption, and economic growth by applying the AMG estimation. Inverted U-shaped EKC is evident in newly industrialized economies from 1977 to 2013. In selected Organization of the Petroleum Exporting Countries (OPEC) countries, the inverted U-shaped form of EKC is also validated in a comprehensive study in 1996–2016 by using the WALS model (Fakher, 2019). A panel study of 45 high-, middle-, low-income countries has validated the EKC hypothesis by using data from 1961 to 2013 using the CUP-FM and CUP-BC models. Trade openness, economic growth, human capital, and bio-capacity are studied to examine EF (Ulucak and Bilgili, 2018). Aydin et al. (2019) conducted a panel study of 26 EU countries and examined EKC for EF by using data from 1990 to 2013. In particular, EF's six sub-components were separately studied, in which an invalid EKC is evident with the PSTR model. Meanwhile, a comprehensive panel study of 131 countries in 1971–2017 explored the role of financial development in determining EF by using the Fixed effect, Random effect, Panel Ordinary Least Square, and General Method of Moments models. Financial development has been found to be supportive in decreasing EF globally, while economic growth and energy consumption increase EF (Tariq and Muhammad, 2019). Ozturk et al. (2016) analyzed the EKC hypothesis for a panel of 144 countries by using the data from 1988 to 2008 using the GMM model. GDP in terms of tourism, trade openness,

Table 1
Summary of literature review on ecological footprint.

Author(s), year	Period	Country	Environmental Proxy	Methodology
Destek and Sarkodie (2019)	1977–2013	11 Newly industrialized countries	EF	AMG, Heterogeneous Panel Causality
Fakher (2019)	1996–2016	7 OPEC Countries	EF	BMA and WALS
Ulucak and Bilgili (2018)	1961–2013	45 High, middle and low income countries	EF	CUP-FM,CUP-BC
Danish et al. (2019)	1970–2014	Pakistan	EF	ARDL
Charfeddine (2017)	1970–2015	Qatar	EF and Carbon footprint	Equilibrium model, Markov Switching
Aşıcı and Acar	2004–2008	116 countries	EF	Panel FE
Ozturk et al. (2016)	1988–2008	144 countries Time series	EF	GMM
Al-Mulali et al. (2015)	1980–2008	93 countries	EF	Panel FE, GMM
Acar and Asici (2015)	2006	105 countries	EF	Cross-section analysis
Dogan et al. (2020)	1980–2014	BRICST	EF	FMOLS, DOLS, AMG
Altıntaş and Kassouri	1990–2014	14 EU countries	CO_2, EF	IFE, D-CCE, DH
Danish et al. (2020)	1992–2016	BRICS	EF	FMOLS, DOLS

Notes on abbreviations: EF = Ecological Footprints; ECF = CO_2= Carbon dioxide Emissions; CCEMG = Mean Group Common Correlated Effects; DH = Dumitrescu-Hurlin casaulity test; IFE= Interactive Fixed Effects; D-CCE= Dynamic Common Correlated Effects; FMOLS= Fully-Modified OLS; DOLS = Dynamic OLS; AMG = Augmented Mean Group; FE= Fixed Effects; GMM = Generalized Methods of Moments; ARDL = Autoregressive Distributed Lag; CUP-EM = continuously updated bias corrected; CUP-FM = continuously updated fully modified; WALS= Weighted Averaging Least Squares; BMA= Bayesian model averaging.

energy consumption, and urbanization has been revealed to have a negative coefficient with EF. Dogan et al. (2020) re-investigated EKC in BRICS countries using energy intensity and energy structure, in which EKC was determined to be invalid from 1980 to 2014 using the FMOLS, DOLS, and AMG models. Moreover, a study of BRICS countries investigated the following determinants of EF such as natural resource rents, energy consumption, and urbanization (Danish et al., 2020). Danish et al. (2019) performed a single country analysis and used the ARDL model with a structural break to explore EF, particularly by recruiting human capital and bio-capacity, and found the positive role of all variables in increasing EF in Pakistan in 1971–2014. Charfeddine (2017) investigated and analyzed the effects of economic growth and energy consumption in Qatar in 1970–2015 by using the U-shaped EKC for economic growth and ecological footprint.

To date, the existing literature based on the environment–growth nexus has indicated several factors, which are found to be determinants of EF (Adebola Solarin, Al-Mulali, and Ozturk, 2017; Al-Mulali et al., 2015; Danish et al., 2020; Dogan et al., 2020). In addition, the linkage among IQ, ERT, and environmental degradation are inadequately debated, and important studies on this linkage are given as under.

2.1. IQ and environmental degradation

Jung (2020) reported that an improvement of institutional quality in the emerging economies induces pervasive technology-upgrading effects in the advanced economies, which generates aggregate productivity gains. Furthermore, IQ is defined as the governing regulations for interaction in economic, social, and political settings that reflect human behavior (Hussain et al., 2020a). These regulations consist of formal and informal rules in society, such as the legal and political systems, rule of law, norms, values, and traditions. The available literature on the linkage of IQ and the environment has been mixed. Some studies have reported the positive impact of IQ on the environment, while others have found the opposite. Moreover, IQ's index varies in different studies. Azam, Liu, and Ahmad (2020) determined that IQ increases energy consumption and environmental pollution in 66 developing countries. They found that IQ is indifferent in decreasing pollution in the recent era of globalization. Moreover, the aforementioned research used the traditional measure of environmental degradation (i.e., CO_2 emissions). By contrast, quality institutions have been determined to be constructive input for improved environmental quality in 47 developing countries (Ali et al., 2019). Unlike the first study reported in the aforementioned linkage, the current research found that a better IQ can facilitate the reduction of CO_2 emissions and improve environmental quality. Furthermore, Awais and Wang (2019) analyzed the role of governance in CO_2 emission mitigation in 1996–2017. They reported that better governance quality can facilitate the mitigation of CO_2 emissions in BRICS economies, thereby decreasing environmental degradation in these countries. Other studies have also explained the linkage between IQ and CO_2 emissions (Ibrahim and Law, 2016; Asif and Majid, 2018; Hassan et al., 2019). However, the preceding studies have failed to consider the linkage between IQ and EF. Therefore, we intend to fill in this research gap by investigating the linkage between IQ and EF, thereby contributing to the BRICS literature.

2.2. ERT and environmental degradation

ERTs are technologies used in the production or processing of goods to mitigate environmental degradation. The ERT and EF nexus is uncommon in the literature. In particular, studies that have considered ERT are reviewed. Danish and Ulucak (2020) determined that ERT and renewable energy support green growth in BRICS economies. They also checked the role of ERT in traditional production- and consumption-based CO_2 emissions, and their findings confirmed the negative linkage. Similarly, technological innovations' effects are quantified in 28 Organization for Economic Co-operation and Development (OECD) countries, in which negative coefficients are reported. The findings reveal the encouraging role of ERT in green growth targets (Mensah et al., 2019). Furthermore, consumption-based CO_2 emissions are reduced by the adoption of ERT in emerging economies, thereby providing smooth means for sustainable development (Hussain et al., 2020b). However, the roles of ERT and IQ is not recruited with EF in the context of the BRICS economies. To fill in this research gap, we extend the nexus of IQ, ERT, and EF by controlling for GDP, GDP square for EKC, and energy consumption.

3. Methodology, model, and results

3.1. Theoretical background model specification

Theoretically, the concept of EKC emerged in the literature in the 1990s (Grossman and Krueger, 1995). After the inception of the environment–growth nexus, it has become widely debated theoretically and empirically in environmental economics (Baek, 2016; Dinda, 2004; Dong et al., 2018; Koçak and Ulucak, 2019; Rosa and Dietz, 1998). For example, the sustainable growth path is explained by using directed technologies, innovations, emission taxes, and patents (Aghion et al., 2016). In addition, ERT adoption may facilitate the reduction of CO_2 emissions and promotion of green growth (Danish and Ulucak, 2020). Worthy of consideration is the rebound effect, which results from technological development and causes CO_2 emissions to increase rather than decrease (Gu et al., 2019). Therefore, environmental degradation can be rectified by using efficient energy and technology innovation together with improved IQ (Mensah et al., 2019; Salman et al., 2019; Sohag et al., 2019). Meanwhile, EF's emergence as a wider measure of environmental degradation has also gained attention (Danish and Wang, 2019; Dogan et al., 2020; Ulucak and Bilgili, 2018). To date, the least attention has been directed on investigating EF, environmental technologies, and IQ.

Several studies have re-investigated the EKC hypothesis along with the roles of ERT, IQ, and energy consumption in BRICS (Aşıcı and Acar; Danish and Wang, 2019; Dogan and Ozturk, 2017; Grossman and Krueger, 1995; Inglesi-Lotz and Dogan, 2018; Koçak and Ulucak, 2019; Ulucak and Bilgili, 2018). Equation (1) presents the statistical means to show the hypothesized model:

$$EF_{it} = \beta_1 + \beta_2 GDP_{it} + \beta_3 GDPSQ_{it} + \beta_4 EC_{it} + \beta_5 ERT_{it} + \beta_6 IQ_{it} + \mu, \tag{1}$$

where EF is the EF consumption per capita, GDP is gross domestic product, GDPSQ is GDP square used for EKC, ERT is an investment in ERT, EC is the total energy consumption, and IQ is institutional quality, β_1 is a constant, $\beta_{2,3,4,5,6}$ are the coefficients of each assumed variable, μ_{it} is an error term, and it represents cross-sections and time. The natural log of each variable is also computed. Fig. 1 shows EF and bio-capacity of BRICS, in which Brazil and Russia have ecological surplus owing to their vast areas. However, China, India, and South Africa show ecological deficit owing to their massive population, which is alarming (GFN, 2019). In the context of the Equation (1) and the literature, IQ is assumed to rectify environmental degradation in BRICS economies. Therefore, the coefficient of IQ is assumed to be negative. Moreover, ERT can play a substantial role in correcting EF. hence, ERT's coefficient is also assumed to be negative. In addition, BRICS economies are growing adequately. High economic growth creates additional demand for energy, and energy consumption is directly exerting pressure on ecological resources. Therefore, the GDP and EC coefficients are assumed to be positive.

3.2. Data and econometric techniques

The annual data of ERT, IQ, GDP, and EF from 1992 to 2016 are extracted from the following sources. "ERT is the environmental change mitigation technologies investment in production and processing of goods." The ERT data are sourced from the OECD Stats (2020) and environment data. Innovation and ERT's technology development sub-head are selected. Furthermore, the country-level data of climate change and mitigation technologies used in production or processing of goods are utilized. Danish and Ulucak (2020) also used the referred measure. For IQ, a 12-point index of "international country risk guide (ICRG)" is used. This index refers to "government stability, socio-economic conditions, investment profile, internal conflict, external conflict, corruption, military in politics, religious tensions, law and order, ethnic tensions, demographic accountability, and bureaucratic quality" (PRS Group, 2020). Single ICRG's index for IQ is computed by taking the average of all indices used by Asif and Majid (2018); Calderón et al. (2016). EF data are taken from the Global Footprint Network (GFN, 2018), and is measured as "ecological footprint consumption per capita." Lastly, data on energy consumption are downloaded from the Energy Information Administration (EIA) (Total Energy Annual Data - U.S. Energy Information Administration (EIA), 2020), while GDP per capita (constant 2010 US$) data are borrowed from the "World development indicators" (WDI, 2019).

Empirical proof is needed to achieve the proposed model. Therefore, the latest econometric techniques are selected for this purpose, particularly by considering panel data issues. In the panel data, the issues of homogeneity and CSD are common. Therefore, these issues should be checked before the selection of the model. To address this issue, a CSD test is conducted (Pesaran, 2015).

After the CSD check, the next step is to observe the unit root properties of the variables. For this purpose, the LLC and CIPS unit root tests are used. LLC is a first-generation unit root test, which cannot consider the CSD problem. Therefore, the CIPS unit root test is used, which is capable of handling the CSD issue in the panel data. Thereafter, co-integration is used Kao (1999); Pedroni (1999, 2004); Westerlund (2007)). Eventually, the cross-section dependence is dealt with using a newly proposed CS-ARDL technique. The advantage of using this estimation is that it can handle CSD and equally good in dealing with endogeneity problems. However, drawbacks of this estimation technique is its inability to allow feedback effects to the regressors. In the presence of AR polynomial roots close to the circle, its small sample performance is not up to the mark (Chudik et al., 2015).The model for "cross-section augmented autoregressive distributive lag (CS-ARDL)" is as follows:

$$\Delta Y_{it} = C_i + \sum_{l=1}^{p} \pi_{il} \Delta Y_{i,t-1} + \sum_{l=0}^{p} \theta'_{il} Z_{i,t-1} + \sum_{l=0}^{p} \gamma'_{il\overline{X}_{t-1}} + \mu_{it} \tag{2}$$

where (2) $\overline{X_t} = (\overline{\Delta Y_t}, \overline{Z_t}')'$, $\overline{\Delta Y_t}$ and $\overline{Z}_t$ are for the averages of the cross-sections of the independent and dependent variables, respectively, and p indicates the lags of each variable. Moreover, ΔY_{it} is used for the dependent variable, which is EFt consumption per capita. By contrast, $Z_{i,t-1}$ represents all independent variables, such as GDP, energy consumption, IQ, and ERT.

CS-ARDL estimates the long- and short-run coefficients of the regressors (Khan et al., 2020). For the robustness of the results, we apply the AMG technique and CCEMG estimator, which are also compatible to handle CSD and heterogeneity by the common dynamic process (Bond et al., 2010; Eberhardt and Bond, 2009; Pesaran, 2006).

3.3. Results and discussions

To provide the linkage of the theoretically hypothesized relationships with empirical analysis, the aforementioned econometric methodology is applied. The analysis starts with the CSD statistics proposed by Pesaran (2015).

Table 2 shows that the null hypothesis of no CSD is rejected because the p-values of each of the sampled variables are significant. This result is an indication of the presence of CSD. After the CSD test, the next step is to check the data stationarity. Accordingly, we perform the LLC and CIPS panel unit root tests. The LLC unit root test is a basic technique to check the properties of a unit root. However, in the presence of CSD, the CIPS unit root test is the most suitable option, which deals with CSD issues (Pesaran, 2007). Table 3 presents the results, in which the null hypothesis of no stationarity cannot be rejected in case of institutional quality, environment-related technology, energy consumption, and GDP (GDP^2), except for ecological footprint, which is at a stationary level. After taking the first difference, we have to reject the null hypothesis for all variables because all their p-values are statistically significant.

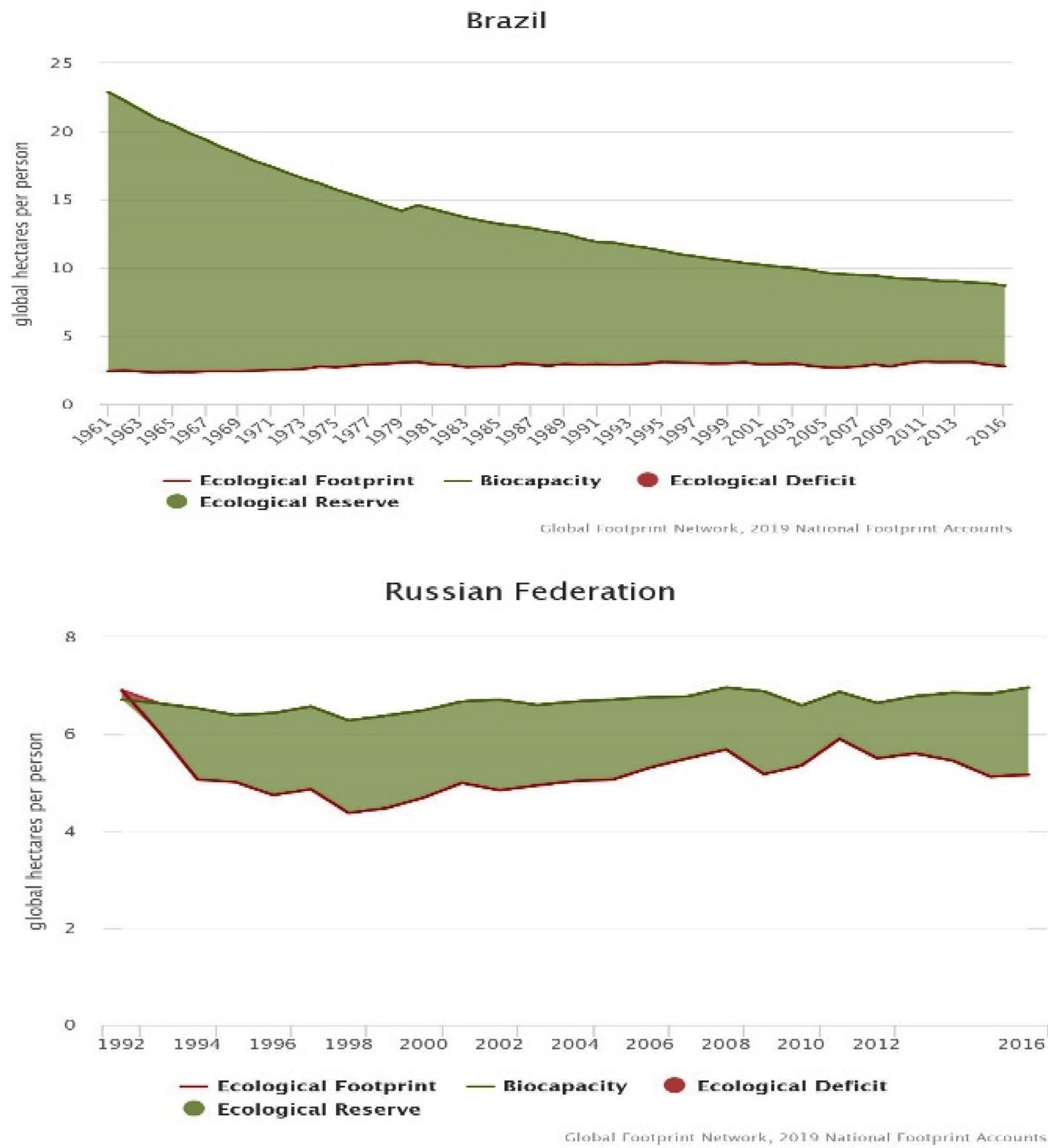
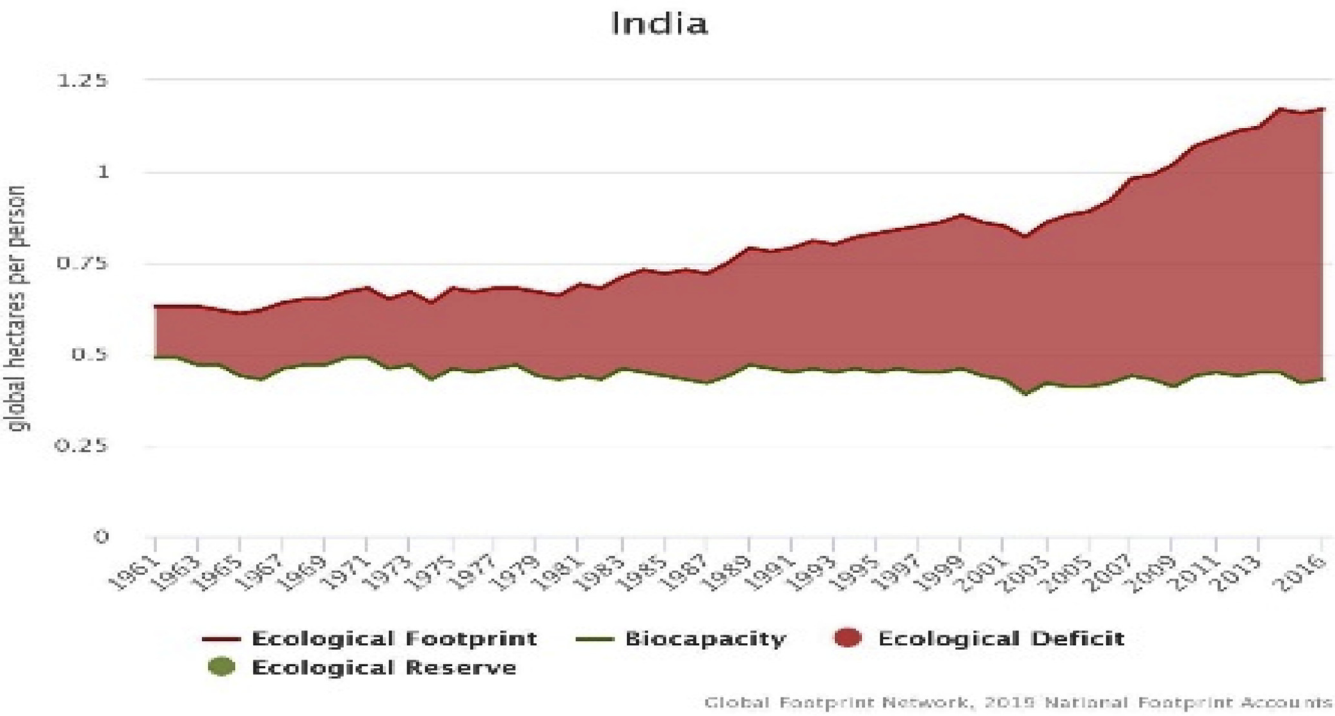


Fig. 1. Ecological footprint and biocapacity of BRICS, source: Global Footprint Network (GFN, 2019).

After the declaration of panel data stationarity, the long-term relationships of the considered variables are estimated through co-integration. Table 4 presents the results of co-integration. Evidently, six out of seven statistics of Pedroni's co-integration are statistically significant (Pedroni, 1999, 2004), which is an indication of the rejection of the null hypothesis of no co-integration. That is, EF, ERT, IQ, EC, and GDP (GDP^2) are co-integrated. Moreover, we also check for the robustness of these results by applying co-integration developed by Kao (1999) and Westerlund (2007). These techniques are applied in the presence of



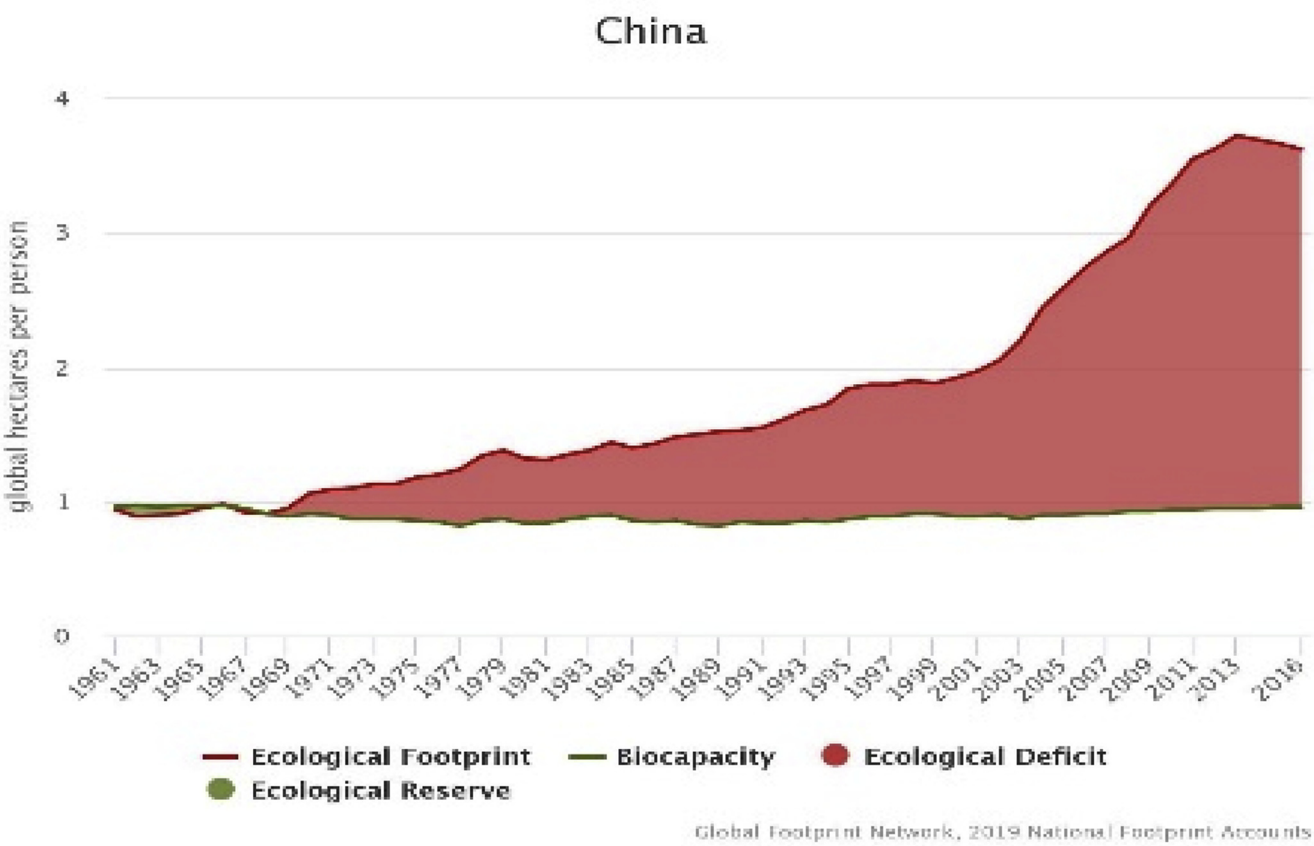


Fig. 1. (*continued*).

CSD in the panel data.

After the confirmation of co-integration, Table 5 shows the long- and short-term results of CS-ARDL. The impact of GDP on EF is reported to be significant with a positive coefficient in the long- and short-terms. This impact indicates that a 1% increase in GDP increases EF by 0.1876% and 0.1581% in the long and short terms, respectively, in BRICS. In the AMG and CCEMG results, GDP has a significant and positive impact on EF. These results are also supported by the literature (Awais and Wang, 2019; Danish and Wang, 2019; Ulucak and Bilgili, 2018). Although BRICS economies are developing, in which a continuously increasing GDP is also evident, a mere increase in income does not mean a decrease in environmental degradation without technological advancements and strong environment regulations (Sarkodie, 2018). Meanwhile, GDPSQ's coefficient is positively significant, thereby presenting a U-shaped EKC for BRICS. That is, the EKC hypothesis is not valid for BRICS economies during the study period; this outcome also has evidence in the literature (Charfeddine, 2017; Charfeddine and Mrabet, 2017; Shahbaz et al., 2016). Moreover, this result is supported by the AMG and CCEMG tests (Table 6).

In the case of ERT, the negative and significant coefficient in the short term, along with the highly significant and negative coefficient in the long term, which highlights the supportive role of ERT towards the reduction of EF in BRICS. That is, a 1% increase in ERT investments can reduce EF by 0.0122% and 0.017% in the long and short terms, respectively. Moreover, AMG and CCEMG also confirm this result by reporting a negative and significant relationship between ERT and EF. This result is also consistent with the literature (Danish and Ulucak, 2020; Mensah et al., 2019). In addition, this outcome leads to the further attraction of highly productive ERT

Table 2
CSD (Pesaran, 2015) test results.

	EF	IQ	ERT	GDP	EC
CSD test	2.503978*	5.450763*	2.340703*	12.739*	8.636***
P-value	0.0123	0.000	0.0129	0.000	0.000

Note: * level of significance at 5%.

Table: 3
LLCandCIPS-Panel Unit root test.

	LLC		CIPS	
	At Level	At First Difference	At Level	At First Difference
EF	0.10016	−3.02965***	−2.372**	−3.823***
IQ	−0.64992	−7.12016***	−1.975	−4.788***
ERT	−1.23571	−7.01697***	−4.766	−6.154***
GDP	0.02460	−2.14678**	−2.382	−3.433***
EC	−0.17135	−2.10513 **	−2.64	−3.409***

Note: *, **, *** significance at 10%, 5%, 1% respectively.

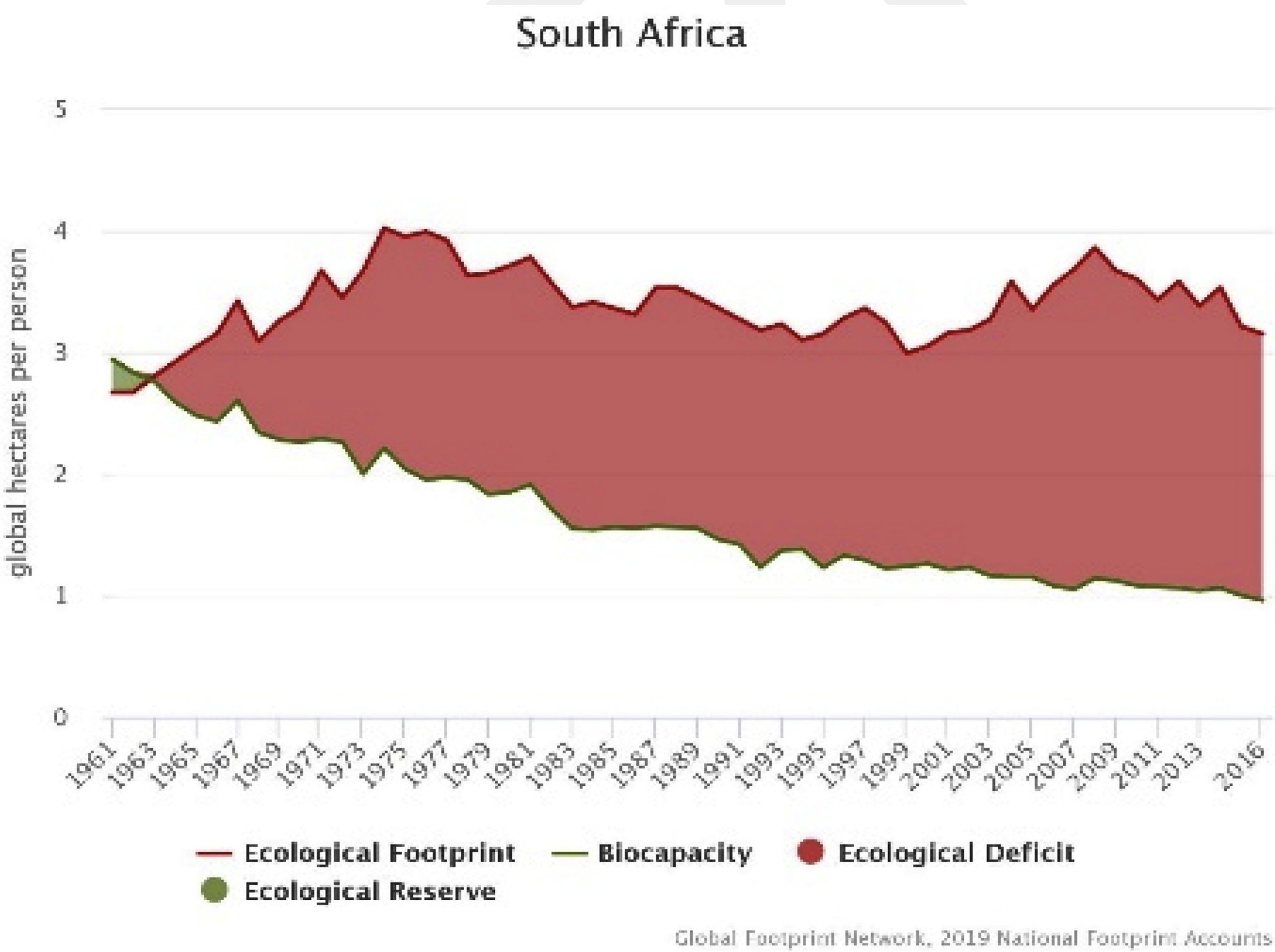


Fig. 1. (*continued*).

Table 4
Results from pedroni, kao and westerlund cointegration.

	(Pedroni, 1999, 2004)				
Within-dimension	Statistic	Prob.	Between-dimension	Statistic	Prob.
Panel v-Statistic	1.7864**	0.0370	Group rho-Statistic	1.3143	0.9056
Panel rho-Statistic	0.649157	0.7419	Group PP-Statistic	−2.2271**	0.0130
Panel PP-Statistic	−2.3267**	0.0100	Group ADF-Statistic	−2.3154**	0.0103
Panel ADF-Statistic	−2.4170***	0.0078	Westerlund (2007)		
				Z-Value	**P-Value**
	Kao (1999)		Gt	−4.069***	0.000
	t-Statistic	**Prob.**	Ga	1.658	0.951
ADF	−2.1741**	0.014	Pt	−3.145***	0.000
			Pa	-.862	0.194

Note: *** significance at 1%, ** at 5%, while * at 10% level.

Table 5
CS-ARDL (Chudik et al., 2015).

	Long Run Results		Short Run Results	
Variables	Coefficients	P-Value	Coefficients	P-Value
GDP	0.1876***	0.007	0.1581**	0.019
GDP^2	0.3465***	0.007	.3188**	0.014
ERT	−0.0122***	0.000	−0.01703***	0.000
EC	0.5443***	0.000	0.4789***	0.000
IQ	−0.0383***	0.000	−0.0476**	0.017
ECM	−0.9232***	0.000	–	–

Note: ***, ***, * level of significance at 1%, 5%, 10% respectively.

Table 6
Robustness of long-run estimates.

	AMG		CCEMG	
Variables	Coefficients	P-Value	Coefficients	P-Value
GDP	0.1678***	0.000	0.2366**	0.021
GDP^2	0.1634***	0.003	0.2697***	0.000
ERT	−0.0551**	0.000	−0.081***	0.000
EC	0.6301***	0.000	0.3873***	0.000
IQ	−0.0129**	0.005	−0.0180***	0.000

Note: *, **, *** are the statistical significance levels 10, 5 and 1% respectively.

investments because BRICS economies have shown a significant increase in their production of goods in the last two decades, and further increases are also anticipated. Thus, enhancing investments, particularly in ERT of production and processing of goods, will lead BRICS to achieve the goal of a sustainable environment.

In the cases of the long- and short-term results of energy consumption, EF significantly increases by energy consumption in BRICS. Empirically, a 1% increase in energy consumption can increase EF by 0.54% and 0.47% in the long and short terms, respectively. These results are also supported by the AMG and CCEMG estimations. Moreover, the literature has been consistent with these outcomes (Ahmad et al., 2016; Mahmood et al., 2019). That is, energy consumption is significantly responsible for the high ecological footprint in BRICS. They may revise their energy consumption patterns to move toward sustainable environmental goals. According to the long- and short-term results, IQ's coefficient is negative and significant. In particular, a 1% increase in the quality of institutions in BRICS can facilitate the reduction of 0.038% and 0.047% EF in the long and short terms, respectively. On the bases of the results taken from AMG and CCEMG for robustness, the coefficients are also negative and significant (i.e., −0.0129 and −0.018, respectively), thereby indicating consistency with the CS-ARDL results and those with the existing literature as well (Awais and Wang, 2019; Hassan et al., 2019). Arguably, BRICS economies should undertake corrective measures on the quality of institutions to mitigate environmental degradation.

4. Conclusion and policy implications

The current study aims to contribute to the environment−growth nexus by using a comprehensive measure (i.e., EF instead of CO_2 emissions). The roles of ERT, IQ, energy consumption, GDP, and the square of GDP are explored to explain EF and the EKC hypothesis in BRICS economies for the period 1992−2016. To empirically support our propositions, a series of econometric techniques are applied (i.e., CSD statistics, panel unit root tests (LLC and CIPS), Pedroni, Kao and Wester Lund co-integration, CS-ARDL, AMG, and CCEMG. The outcomes of the CSD statistics reveal CSD in the sampled panel. Thereafter, panel unit root tests depict data stationarity at first difference. Thus, panel co-integration techniques confirm the long-term equilibrium relationships among the sampled variables. Moreover, CS-ARDL reveals the significantly negative impact of ERT and IQ on EF, whereas EC, GDP, and the square of GDP are positively significant effect, thereby showing a U-shaped EKC for BRICS. The robustness of the results is also assured with AMG and CCEMG.

Important implications for the policy can be drawn from the results of this study. First, IQ can reduce EF, which is a widely accepted measure of environmental degradation. Thus, improvement in the quality of institutions is suggested for BRICS' policy makers. Although developing economies along with many other challenges face a malicious circle of weak but fair institutions can lead to promoting such measures, thereby possibly motivating every stakeholder to understand and implement superior laws related to environment protection. By doing so, the sustainable environmental goal can be achieved.

Second, ERT may help reduce environmental degradation in the long and short terms. Investments in ERT involved in the production and processing of goods should be enhanced, which may facilitate the reduction of the EF level in BRICS economies. Moreover, policy makers should suggest such attractive policies to enhance investments in ERT, thereby leading to a sustainable environment in BRICS economies.

Third, energy consumption increases EF in a threatening manner. BRICS policy makers should consider it on the immediate grounds. In the end, being the stakeholder of BRICS economies, every individual can play a positive role through social media awareness to promote consciousness of the scarcity of ecological resources. Moreover, educational institutions can be beneficial sources that offer environmental protection courses for everyone to save BRICS and the entire world.

Along with the preceding implications, this study also presents some limitations, which could serve as a direction for future research. First, this study focused only on BRICS economies, which may not be generalized in developed countries. Moreover, BRICS economies are developing at a substantial speed compared with other developing countries, thereby possibly apprehend diverse characteristics in environmental degradation. Future research should consider country-level investigations in developed and low-income countries to bring additional facts. Second, this study considers only the role of IQ and ERT in abating EF owing to the unavailability of data. Lastly, other contributing factors, such as green finance, may result in interesting contributions in the existing body of knowledge.

CRediT authorship contribution statement

Muzzammil Hussain: Data curation, Methodology, Writing – original draft. **Eyup Dogan:** Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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