Nexus between Energy Consumption, Economic Growth and Quality of Environment in BRICS and Next 11 Countries: A Panel Dynamic Study

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Abstract

This study sets out to explore the nexus between energy consumption, economic growth, and quality of the environment within the separate contexts of BRICS and the Next 11 Countries. The empirical analysis is carried out using the Feasible Generalized Least Squares (FGLS) modeling approach, which considers cross-sectional dependency analysis, cross-sectional heterogeneity, and cointegration analysis. The empirical results show that BRICS countries support the EKC hypothesis, but the Next-11 countries have a U-shaped path between economic growth and environmental degradation, which is contrary to the conventional EKC hypothesis. Moreover, the nexus between economic growth share in the quality of the environment and energy consumption is also seen to exhibit nonlinearity. Besides, unidirectional causations are confirmed between CO_2 emissions and energy consumption for BRICS countries. However, a unidirectional causal linkage moves from CO_2 emissions to energy consumption for the Next 11 countries. Thus, these findings have profoundly important policy consequences for the achievement of the BRICS and the Next 11 countries' energy stability and environmental protection, mainly by reducing the higher energy usage of these countries.

JEL Classification: C51, F64, O13, O44, P18

1. Introduction

The relationship between economic growth (EG), energy consumption (EC), and environmental quality have long been unquestionable. As countries' economies rise, energy usages increase; GDP growth retracts in effect if energy is constrained. This back-and-forth situation has been the issue since the beginning of the industrial revolution (Akay and Uyar 2019). Nevertheless, the history of energy economics is not necessarily a prologue. As part of a multi-year research initiative to explore the production and consumption of 55 energy forms over 30 industries in 146 countries worldwide, the latest Global Energy Perspective (2020) indicates decoupling between EG rates and energy demand will become much more pronounced within a decade. Thus, the successful use and production of a country's energy reserves is of considerable significance for the improvement and welfare of the population and overall economic development. However, the conservation of the environmental quality and the development of the economy go hand in hand. The degradation of the environment's quality and the worsening of climate change hardships worldwide have contributed to an agreement on connecting worldwide policies with the parallel preservation of environmental characteristics.

Climate change action means reducing emissions and rising climate adaptation while at the same time helping countries diversify their economies. In addition to carbon dioxide (CO_2) emissions, the consequences of global warming and climate change have been immense. Among other pollutants contributing to climate change, more than 75% of greenhouse gas (GHG) emissions are made up of CO_2 emissions, about 80% of which are emitted by the energy industry (Mert and Bölük 2016). For these reasons, the international community has agreed that addressing climate change is a top priority and an incentive to transition over a world low-carbon economy. For instance, the Paris Agreement, adopted in December 2015 under the 197 countries' ratification of the United Nations Framework Convention on Climate Change (UNFCC), is committed to accelerating and intensifying the measures and funding required for a prosperous low-carbon future. The existing literature claims that countries can adopt environmentally unfriendly production processes in the early phases of economic development.

EC, EG, and the quality of the environmental nexus have significantly focused on the energy economics literature. There have been two parallel pieces of literature on the relationship between EG, EC, and environmental degradation. The first strand (Khan *et al.* 2020, 2019; Wasti and Zaidi 2020; Sarkar *et al.* 2019; and Uddin and Wadud 2014) is related to EG and CO_2 emission nexus. Ahmad et al. (2018); and Pao and Tsai (2010) examine the relationship between EC and CO_2 emissions. A relatively new research field has been created by combining these two literary works, in which the relationship between EC, EG, and CO_2 emissions is explored within a multivariate context. Most researches that have been concentrated on these lines for both the developed countries (Magazzino 2015; Alshehry and Belloumi 2014; Ozturk and Acaravci 2010; Apergis and Payne 2009; Ang 2007) and developing countries (Ferdaus et al. 2020; Oh and Bhuyan 2018; Chandia et al. 2018; Rafindadi 2016; Ohlan 2015; Shahbaz et al. 2013; Hussain et al. 2012) and have returned contradictory and mixed outcomes.

The second group of studies (Alaali and Naser 2020; Appiah et al. 2020; Magazzino et al. 2020; Ahmad et al. 2018; Javid and Sharif 2016; Sinha and Shahbaz 2017; Sehrawar et al. 2015) is based on the quality of the environment and the EG nexus, which are directly linked to examining the relevance of the theory of the Environmental Kuznets Curve (EKC). EKC posits an inverted U-shaped association between per capita GDP and long-term environmental deterioration. Current literature stresses the significance of undermining the climate of achieving economic development. Although current studies have investigated the impacts of EC and EG on environmental quality using a linear paradigm, the inherent nonlinearity of the nexus between CO_2 emissions and EC has yet to be addressed. Thus, the quadratic relation between these variables can be overcome from the presumption that EC does not cause environmental quality, following the failure to experience environmental quality due to a significant proportion of the national outputs.

This paper aims to assess the impact of EC and EG on the quality of the environment and verify the validity of EKC across BRICS and Next-11 countries. The following questions are explicitly answered in this study in the context of the selected BRICS and Next-11 countries: (a) Is the relationship between CO_2 and EG non-linear? (b) Does EG hamper the quality of the environment? (c) Is there any causality between EC and CO_2 emissions? The study period covers 1990–2019. Two data sets are examined: the first data set (Panel A), which contains only BRICS countries, and the second data set (Panel B) includes only Next-11 countries. We comprise the BRICS countries as OECD-member industrialized countries and economies in transition and the Next-11 countries as developing countries. After demonstrating the nonlinearity of the data sets, experiments are conducted to select the model, and the transformation functions to be used are determined. Also, to check whether the two regime models are adequate or not, the residual heterogeneity has been tested.

This study makes a unique contribution to the existing literature in two phases: First, a sophisticated econometric approach, the Feasible Generalized Least Squares (FGLS) technique, is used, which helps the researcher to evaluate the EKC curve's various turning points. In general, the recent literature on the robustness of EKC uses linear methods of estimation. Though a part of the literature uses non-linear methods of calculation, none of this has determined the EKC's numerous turning points. Second, this study uses a dataset covering both BRICS and Next-11 countries. Estimates are performed independently for the consolidated dataset and categories of BRICS and Next-11 countries. The results of this analysis will also shack light on the current debate about the legitimacy of the EKC in the BRICS and Next-11 countries. The estimation results from the FGLS model suggest that BRICS countries are supportive of the existence of the EKC hypothesis, which shows that CO_2 emissions rise with an increase in EG at the initial level of growth, and this emission starts to decline when the economy attains a sustainable economic growth by reaching a threshold level of growth. However, the results from the negative-positive coefficient pattern for Next-11 countries suggest a U-shaped path between EG and the quality of the environment for these countries, which is contrary to the conventional EKC hypothesis.

The remainder of the paper is structured as follows: an outline of the concerning theoretical and scientific literature is presented in section 2. The analytical model and the dataset properties are discussed in section 3. Section 4 discusses the methodological approach. The results from the econometric models are addressed in section 5. Finally, section 6 concludes and emphasizes the potential implications for strategy.

2. Literature Review

The literature review section documented the empirical evidence on the impact of energy consumption and economic growth on the quality of the environment or CO2 emissions and the empirical evidence on the validity of the EKC hypothesis.

2.1 Empirical evidence on the impact of energy consumption and economic growth on the quality of environment

Wasti and Zaidi (2020) have done a study for Kuwait over the period 1971–2017 and found CO_2 emissions are positively associated with EG. An equivalent result is found by Khan *et al.* (2020) for Pakistan, by Sarkar *et al.* (2019) for Malaysia between 1980–2016, by Khan *et al.* (2019) for Pakistan, and by Uddin and Wadud (2014) for seven SAARC countries over the period 1972–2012 by using Vector Error Correction Model. Another study has conducted by Ahmad *et al.* (2018), utilizing data from 1971 to 2013 for China, found that CO_2 emissions positively affected EC in the long term. A unidirectional causal relationship is found between GDP and CO_2 emissions by using the Granger causality test. Similarly, Pao and Tsai (2010) conduct a study on a panel of BRIC countries from 1971 to 2005 and found EC has a statistically significant positive effect on CO_2 emissions.

Chandia *et al.* (2018) have also done empirical research for Pakistan for the period 1971–2016. Findings from both the OLS model and VECM reveal a significant positive relationship between EC and CO_2 emissions and between EG and CO_2 emissions. Similar findings are also explored by Rafindadi (2016) for Nigeria and Rahman *et al.* (2020) for Bangladesh, by Ohlan (2015) for India between 1970–2013, and by Shahbaz *et al*. (2013) for Indonesia for the study period spanning from 1975Q1 to 2011Q4. In comparison, Hussain *et al*. (2012) find that EC has a positive influence and EG negatively influences CO_2 emissions in the long-term in Pakistan.

Oh and Bhuyan (2018) use data from 1975 to 2013 for Bangladesh and identify an insignificant negative impact of EG on CO_2 emissions while EC has a significant positive influence on CO_2 emissions, both in the short-term and long-term. The same findings are also obtained from the study by Begum *et al.* (2015) for Malaysia during 1970–2009. A study by Ozturk and Acaravci (2010) reveals that CO_2 emission was negatively related to the EG in Turkey during the period 1968–2005.

Haseeb and Azam (2015) confirm the presence of the unidirectional causal link is stemming from EC to CO_2 emissions; and the bidirectional causal nexus between CO_2 emissions and EG, in the case of Pakistan. In contrast, Magazzino (2015) finds a unidirectional causality moves from EG to EC and CO_2 emissions in Israel. Alshehry and Belloumi (2014) have done the research for Saudi Arabia, using data from 1971 to 2010 and the existence of a bidirectional long-term causal association between CO_2 emissions and EG, and a unidirectional long-term causality between EC and CO_2 emissions. Khoshnevis Yazdi and Golestani Dariani (2019) have identified that EG and EC positively influence CO_2 emissions for a panel of 18 Asian countries in the long-term. The study has also discovered a bidirectional causal linkage between CO_2 emissions and EG for the panel group. Zaidi and Ferhi (2019) have employed Dynamic Simultaneous-Equations Models to test the causal relationships among EC, EG, and CO_2 emissions in 35 selected Sub-Saharan countries over the period 2000–2012. Using GMM estimation, the study finds that EG has a significant positive effect on CO_2 emissions, and EC has a significant positive effect on EG in these countries.

2.2 Empirical evidence on the EKC hypothesis

Studies by Magazzino *et al.* (2020) on South Africa and by Ahmad *et al.* (2018) on China confirm the long-term validity of the EKC hypothesis. Similarly, Alaali and Naser (2020) state that the EKC hypothesis is valid for Bahrain and a similar result is also found for Pakistan by Javid and Sharif (2016). Whereas, Kunnas and Myllyntaus (2007) fail to validate the EKC hypothesis statistically from the perspective of Finland. Similarly, Murshed (2020) and Nasreen *et al.* (2017) support the validity of the EKC hypothesis for South Asian countries. Studies by Sehrawar *et al.* (2015) and Shahbaz *et al.* (2015) on India also confirm the existence of the EKC hypothesis. Sinha and Shahbaz (2017) also find the existence of an inverted U-shaped EKC for India.

Zaman *et al.* (2016) support the presence of inverted U-shaped EKC hypothesis in the panel of three different world regions, including High-income OECD Non-OECD countries, East Asia & Pacific, and the European Union. Similarly, Pao and Tsai (2010) confirm inverted EKC hypothesis is valid in a panel of BRIC countries. On the contrary, a study by Ozturk and Acaravci (2010) reveals that the EKC hypothesis is not effective for Turkey. At the same time, Ozcan (2013) considers 12 Middle East countries for his study and found that U-shaped EKC is valid for 5 Middle East countries and inverted U-shaped curve is valid for 3 Middle East countries.

Table 1
Summary of EKC studies of CO_2

Environmental Indicators	*Period*	*Country*	*Turning Point*	*Authors*
SO_2, NO, CO_2	*1979–1981*	*22 OECD countries and 8 developing countries*	*Yes*	*Selden and Song (1994)*
CO_2	*1960–1996*	*110 countries*	*Yes*	*Galeotti and Lanza (1999)*
CO_2	*1870–1997*	*Sweden*	*Yes*	*Lindmark (2002)*
CO_2	*1960–1999*	*Austria*	*Yes*	*Friedl and Getzner (2003)*
CO_2	*1985*	*76 developed/developing countries*	*Yes*	*Maradan and Vassiliev (2005)*
SO_2, CO_2, and PM_{10}	*1968–2003*	*Turkey*	*Yes*	*Akbostanci et al. (2009)*
CO_2	*1971–1997*	*Non-OECD countries*	*Relationship varied*	*Aslanidis and Iranzo (2009)*
CO_2 and SO_2	*1971–2007*	*China and India*	*N/A*	*Jayanthakumaran et al. (2012)*
Green House Gasses	*2001–2007*	*131 countries (Annex I and non-Annex I)*	*N/A*	*Kumazawa (2012)*
CO_2	*1971–2007*	*98 countries*	*N/A*	*Wang (2012)*
CO_2	*1857–2007*	*Spain*	*Yes*	*Sephton and Mann (2013)*
CO_2	*1985–2012*	*36 countries*	*N/A*	*Chen and Huang (2014)*
CO_2	*1980–2008*	*5 ASEAN countries*	*Yes*	*Heidari et al. (2015)*
CO_2	*1993–2010*	*11 transition countries*	*Yes*	*Zortuk and Ceken (2016)*
CO_2	*2002–2010*	*21 Kyoto Annex countries*	*N/A*	*Mert and Bölük (2016)*
CO_2	*1960–2010*	*USA*	*N/A*	*Dogan and Turkekul (2016)*
CO_2	*1970–2013*	*16 middle-income countries*	*N/A*	*Mohammadi (2017)*
CO_2	*1971–2013*	*31 developing countries*	*N/A*	*Aye and Edoja (2017)*
CO_2	*1995–2010*	*16 Annex II; 58 non-Annex countries*	*N/A*	*Akay and Uyar (2019)*
CO_2	*1960–2012*	*47 countries, including Annex I and non-Annex countries*	*Yes*	*Şentürk et al. (2020)*

Source: Authors' compilation

Therefore, we evident from the unclear assumptions drawn in the country-specific studies alluded to above, and cross-country empirical studies that increase energy consumption do not guarantee environmental quality. Besides, plenty of variability in favor of the existence of CO_2 emissions-energy use nexus is also apparent, given regional-specific characteristics. The current literature works have ignored the potential nonlinearity among these factors, which may help understand the inadequacy of higher energy demand in fostering the phenomenon of environmental quality. This study tries to address this gap in the literature by modeling the CO_2 emissions-energy consumption relationship in a non-linear framework within the scope of the BRICS and Next-11 countries.

3. Empirical Model Specification And Data

This study uses an empirical model to assess the impacts of EC and EG on the quality of the environment and also test the validity of EKC across BRICS and Next-11 countries are specified based on the relevant economic concepts. The empirical model can be specified as follows:

$$lnCO_{2it} = \beta_0 + \beta_1 lnEC_{it} + \beta_2 lnRGDPPC_{it} + \beta_3 lnRGDPPC_{it}^2 + \beta_4 lnTO_{it} + \beta_5 lnURB_{it} + \beta_6 lnGI_{it} + \epsilon_{it} \ldots (1)$$

Where, the subscript *i* and *t* indicate the individual cross-sectional units and the studied period, respectively. $\beta_i (i = 1, ..., 5)$ refer the elasticity of parameters to be considered, and ε is combined time series and cross-section error term where, $\varepsilon_{it} \sim N(0, \sigma^2)$. The dependent variable CO_2 is per capita CO_2 emissions, calculated in terms of metric tons, used as a proxy for environmental degradation, and the independent variable EC is per capita energy consumption, calculated in kg of oil equivalents. RGDPPC and $RGDPPC^2$ represent real GDP per capita and its squared term, respectively, evaluated in terms of constant 2010 US$. The value of the squared term is included to examine the existence of the EKC hypothesis in the presence of EC. Another three explanatory variables, TO denotes the trade openness, measured in percent of exports, and imports of GDP, GI represents globalization index and URB denotes the urbanization, measured in percent of the urban population of the total population, are critical determiners of quality of the environment, which are included in the econometric model considering the theoretical justifications.

All the variables are converted into their natural logarithmic form to generate more accurate and consistent empirical results. The validity of the EKC hypothesis for the respective quality of environment indicators will be confirmed by the predicted signs and statistical significance of the calculated parameters related to lnRGDPPC and $lnRGDPPC^2$. Thus, the threshold level of RGDPPC at the turning point in the context of the specified model in Eq. (1) can be calculated as follows:

$$TurningPointLevelofRGDPPC = \frac{\beta_2}{2\beta_3}$$

Annual time-series data covering the period 1990–2019 for all the five BRICS and eleven Next-11 countries are used in this study. The panel groups of two data sets are used for this study. The first data set consists of yearly data of 150 observations for BRICS countries, called panel A. The second data set contains yearly data of 330 observations for the Next-11 countries, called panel B. All data are sourced from World Development Indicators (WDI) database 2020, prepared by World Bank and our world in data 2020.

4. Methodology

This study has employed panel databased econometric models for empirical analyses. The econometric analyses are performed by examining the cross-sectional dependency among the panel series.

4.1 Cross-sectional Dependency Analysis

Usually, cross-sectional dependency occurs when one of a country's economic data is influenced by the same economic data in another country, whereas countries in the panel dataset are interconnected either regionally or globally (Murshed 2020). According to Breusch and Pagan (1980) and Pesaran (2004), if cross-sectional dependency exists between panel series but is not considered, then empirical results may have affected the time of analysis, and the results may become biased and inconsistent. This study has used the cross-sectional dependence (CD) test given by Pesaran (2004) and the Breusch-Pagan Lagrange Multiplier (LM) test suggested by Breusch and Pagan (1980). Pesaran CD test is valid in both cases, with small *N* and large *T* or when with large *N* and small *T* and Breusch-Pagan LM test is valid only in case of a panel with small *N* and large *T*. Both the tests are conducted assuming null hypothesis of no cross-sectional dependency against the alternative hypothesis of cross-sectional dependency. The equations are as follows:

$$\mathrm{CD} = \sqrt{\frac{2T}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij} N(0,1) \ (2)$$

$$LM = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^{2} \chi^{2} \frac{N(N-1)}{2} \ (3)$$

where, *N* denotes the sample size, *T* is the time period, and where $\hat{\rho}_{ij}$ is the sample estimate of the pairwise correlation of the residuals of country *i* and *j*.

4.2 Panel Unit Root Analysis

If cross-section dependence among the panel series is evidenced, it influences the other econometric analysis tests. Then second-generation unit root tests are appropriate because they can explore the issue of cross-sectional dependency. In this study, Cross-sectionally Augmented Dickey-Fuller (CADF) and Cross-sectionally augmented Im, Pesaran, and Shin (CIPS) panel unit root tests have been applied to identify the order of integration of the corresponding variables. The CADF and CIPS statistics are developed by Pesaran (2007). CADF and CIPS test statistics can be calculated from the following regressions:

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + \delta_i T + \sum_{j=1}^{k} \phi_{ij} \Delta y_{i,t-j} + \epsilon_{it} \ (4)$$

where *i = 1, 2, …, N* denotes the cross-sectional member; *t = 1, 2, …, T* indicates the time period, y_{it} means the analyzed variable; α is constant, *T* means time trends, and ε_{it} is the error term.

$$CIPS = \frac{1}{N} \sum_{i=1}^{N} CADF_i \ (5)$$

where, $CADF_i$ is cross-sectionally augmented Dickey-Fuller test statistic for the *i*th cross-sectional unit.

4.3 Panel Cointegration Analysis

To examine the long-term relationship among the panel series, a cointegration test is proposed by Westerlund (2007), which can handle the cross-sectional dependency issue. Westerlund cointegration test considers the error-correction model as follows:

$$\Delta y_{it} = \delta'_i d_t + \alpha_i y_{i,t-1} + \beta'_i x_{i,t-1} + \sum_{j=1}^{p_i} \alpha_{ij} \Delta y_{i,t-1} + \sum_{j=-q_i}^{p_i} \gamma_{ij} \Delta x_{i,t-1} + \epsilon_{it} \ (6)$$

where *i* refers to the cross-sections, *t* refers to time-series, α_i computes the speed of adjustment where the system corrects return to the equilibrium after an unpredicted shock, d_t means the deterministic components, p_i means lag lengths, and q_i is lead orders.

Westerlund cointegration test employs two tests to identify the alternative hypothesis of cointegration for the whole panel (G_t and G_a), while another two tests are reviewed to explore the alternative hypothesis that a minimum of one cross-sectional unit is cointegrated (P_t and P_a). The panel statistics can be calculated using the formula mentioned below:

$$G_t = \frac{1}{N} \sum_{i=1}^{N} \frac{\widehat{\alpha}_i}{SE(\widehat{\alpha}_i)} and G_\alpha = \frac{1}{N} \sum_{i=1}^{N} \frac{T\widehat{\alpha}_i}{\widehat{\alpha}_i(1)} (7)$$

$$p_t = \frac{\widehat{\alpha}_i}{SE(\widehat{\alpha})} and p_\alpha = T\widehat{\alpha} \ (8)$$

where, *SE* stands for conventional standard error of $\widehat{\alpha}_i$.

4.4 Panel Regression Analysis

The long-run elasticities are estimated by the Feasible Generalized Least Squares (FGLS) estimation technique, which depends on the specification and estimation of the skedastic regression. FGLS estimator requires the assumption of correct conditional mean, making its efficiency stronger.

4.5 Panel Causality Analysis

To ascertain the causal relationship and the direction of causality among the concerned variables, the study has employed Dumitrescu-Hurlin (DH) panel causality test designed by Dumitrescu and Hurlin (2012) and simplified version Granger (1969). Normal distribution based on this test considers unobserved heterogeneity in the panel data and can also be performed in both cases when $T > N$ also when $N > T$. This test has two distributions; one is asymptotic, and another one is semi-asymptotic. If $T > N$, asymptotic distribution is applied, and when $N > T$, semi-asymptotic distribution is employed. The following linear model is taken into consideration:

$$y_{it} = \alpha_i + \sum_{k=1}^{K} \gamma_i^{(k)} y_{i,t-k} + \sum_{k=1}^{K} \beta_i^{(k)} x_{i,t-k} + \epsilon_{it} \ (9)$$

Where, α_i is intercept term, K is lag length, $\gamma_i^{(k)}$ refers to an autoregressive parameter, and $\beta_i^{(k)}$ is the regression coefficient which may vary across cross-sectional units.

For the Dumitrescu-Hurlin (DH) panel causality test, the null hypothesis assumed that there is no causal relationship for any of the cross-sectional units of the panel, and this assumption is referred to as the Homogenous Non-Causality (HNC) hypothesis. However, the alternative hypothesis assumed that causal linkage is present between these variables in at least one of the cross-sections, and this assumption is referred to as the Heterogeneous Non-Causality (HENC) hypothesis. The average statistic of the HNC hypothesis can be specified as follows:

$$W_{N,T}^{HNC} = \frac{1}{N} \sum_{i=1}^{N} W_{i,T} \ (10)$$

Where, $W_{i,T}$ represents the individual Wald statistical values for the cross-section.

Now, the average statistic of the HNC hypothesis having asymptotic distribution can be defined as follows:

$$Z_{N,T}^{HNC} = \sqrt{\frac{N}{2M}} \left(W_{N,T}^{HNC} - M \right) \overset{\overrightarrow{d}}{\underset{T,N \to \infty}{}} N\left(0{,}1\right) (11)$$

Where, N stands for the number of cross-sections and M is the optimal lag.

The average statistic of the HNC hypothesis having semi-asymptotic distribution can be defined as follows:

$$Z_{N}^{HNC} = \frac{\sqrt{N}}{\sqrt{N^{-1} \sum_{i=1}^{N} Var\left(W_{i,T}\right)}} \left[W_{N,T}^{HNC} - N^{-1} \sum_{i=1}^{N} E\left(W_{i,T}\right) \right] N \to \infty, N\left(0{,}1\right) (12)$$

Where, $E\left(W_{i,T}\right)$ and $Var\left(W_{i,T}\right)$ are the variant statistics.

5. Results And Discussion

The empirical results of the CD analysis are demonstrated in Table 2. For both panels, the statistically significant Pesaran and Breusch-Pagan LM tests of CD analysis reject the null hypothesis of the cross-sectional independence and assure the existence of the cross-sectional dependence between the two panels.

Table 2: Results from the cross-sectional dependency (CD) analysis

Tests	Panel A	Panel B
Peasaran CD	2.732*	9.722*
Breusch-Pagan LM	19.261**	476.458*

*(Notes: The optimal lags are estimated based on Schwarz Information Criterion (SIC), and P-values for the statistical significance of the coefficients are * and ** represent at 1% and 5% levels, respectively.)*

Since cross-sectional dependency among both panels is evidenced by CD analysis, the second-generation panel econometric framework is applied to control the cross-sectional dependency problems.

According to the second-generation panel unit root test results in Table 3, the test statistics are determined based on both constant and level through the null hypothesis to the alternative hypothesis of data stationarity. Using CADF and CIPS tests for both panels, the variables are not stationary at a level I(0); however, they become stationary after the first differencing I(1).

Table 3: The Test Result of the Second-generation Panel Unit Root Model

Panel	Panel A				Panel B			
Tests	CADF		CIPS		CADF		CIPS	
Variables	Level I(0)	1st diff. I(1)	Level I(0)	1st diff. I(1)	Level I(0)	1st diff. I(1)	Level I(0)	1st diff. I(1)
LCO_2	-1.958	-5.014*	-2.081	-3.935*	-0.507	-5.976*	-1.918	-4.688*
LEC	-1.509	-2.005*	-2.015	-6.100*	-1.215	-6.936*	-2.125	-4.968*
LRGDPPC	-0.566	-2.643*	-2.006	-2.906*	-1.377	-5.772*	-1.367	-3.458*
$LRGDPPC^2$	-0.366	-2.195**	-1.919	-2.712**	-2.077	-5.573*	-1.163	-3.400*
LTO	-2.279	-7.808*	-2.048	-5.147*	-1.062	-5.713*	-2.081	-4.903*
LURB	0.688	-2.337**	-0.896	-3.035**	-2.062	-2.333**	-2.050	-2.867*
LGI	-1.438	-3.118*	-2.107	-5.270*	1.588	5.174**	-2.034	-5.038*

*(Notes: The optimal lags are estimated based on Schwarz Information Criterion (SIC), and P-values for the statistical significance of the coefficients are * and ** represent at 1% and 5% levels respectively)*

Table 4: The test result Panel Cointegration Test

Test	Westerlund			
Test Statistic	G_t	G_a	P_t	P_a
Panel A	-4.031*	-3.459**	-3.923**	-4.235*
Panel B	-4.818*	-3.627**	-3.448**	-3.355**

*(Notes: P-values for the statistical significance of the coefficients are * and ** represent at 1% and 5% levels respectively)*

Table 4 portrays the test statistics from the second-generation panel cointegration model by Westerlund (2007), which confirms the long-term cointegrating associations among the variables; economic growth, carbon emission, energy usage, trade openness, and urbanization. The test result reveals that there is no cointegration exists under the null hypothesis; however, the alternative hypothesis suggests there is cointegration between variables. This cointegrating relationship paves the way to evaluating long-term elasticity by employing the appropriate regression estimator for panel data considering CD issues across the panels.

Table 5: Results of long-run elasticities estimate

Estimator	FGLS								
Regressors	*LEC*	*LRGDPPC*	*$LRGDPPC^2$*	*LTO*	*LURB*	*LGI*	*Constant*	*Obs.*	*Turning Point (US$)*
Panel A	*0.106**	*-0.458***	*0.028**	*-1.531**	*-1.617**	*-1.705**	*-9.143**	*150*	*3563.759*
	(0.029)	*(0.701)*	*(0.049)*	*(0.017)*	*(0.069)*	*(.169)*	*(3.072)*		
Panel B	*0.908**	*0.406***	*-0.025**	*-0.356**	*0.422**	*1.025**	*8.021**	*330*	*3361.021*
	(0.011)	*(0.749)*	*(0.003)*	*(0.010)*	*(0.038)*	*(0.037)*	*(0.184)*		

*(Notes: The standard errors are reported within the parentheses; * and ** denotes the statistical significance of z-statistics at 1% and 5% level respectively.)*

The FGLS panel regression method is used to calculate the long-term elasticities of regressors of both panels. The results of the long-term coefficient are represented in Table 5. The coefficient value of EC is positive and statistically significant at a 1% level of significance in both panels, which indicates a significant positive effect of EC on environmental degradation in BRICS and Next-11 countries. An increase of 1% per capita EC will increase per capita CO_2 emission by 0.11% in BRICS countries and 0.91% in Next-11 countries, ceteris paribus. This finding is also found by Khan and Qayyum (2007), Halicioglu (2009), Jalil and Mahmud (2009), Pao and Tsai (2010), Hossain (2011), Javid and Sharif (2016), Nasreen *et al.* (2017) and Rahman and Majumder (2020). This result suggests that EC reduces the quality of the environment by emitting CO_2, which refers to one of the primary sources of environmental degradation.

The impact of EG on CO_2 emissions is negative for BRICS countries where rising EG will reduce environmental degradation but positive for the Next-11 countries. However, the inducement of EG will enhance the quality of the environment. The results portray that if real GDP per capita increases by 1%, it will reduce per capita CO_2 emissions by 0.46% in BRICS countries and raise per capita CO_2 emissions by 0.41% in Next-11 countries, ceteris paribus. The finding of a positive impact of EG on CO_2 emission is also evidenced from the researches by Shahbaz (2013), Sehrawat *et al.* (2015), Nasreen *et al.* (2017), Mbarek *et al.* (2017), Rahman and Velayutham (2020) and Rahman and Benjamin (2020). The result of a negative effect of EG on CO_2 emission is also found by Ozcan (2013).

Table 5 shows a non-linear association between EG and environmental degradation. The results suggest that the coefficient value regarding economic growth (LRGDPPC) for BRICS countries is negative; however, the coefficient of squared of economic growth ($LRGDPPC^2$) is positive. Both LRGDPPC and $LRGDPPC^2$ are statistically significant at a 1% level of significance. This positive-negative coefficient pattern of a panel for BRICS countries is supportive for the existence of the EKC hypothesis, which claims that CO_2 emission rises with an increase in EG at the initial level of growth, and this emission starts to decline when the economy attains a sustainable economic growth by reaching a threshold level of growth. This result suggests an inverted U-shaped path between EG and environmental degradation for BRICS countries. This finding is coherent with the results of Song *et al.* (2008), Halicioglu (2009), Fodha and Zaghdoud (2010), Menyah and Wolde-Rufael (2010), Nasir and Rehman (2011), Ozturk and Acaravci (2013), Sehrawat *et al.* (2015), Zaman *et al.* (2016), Shahbaz *et al.* (2016), Dogan and Seker (2016) and Nasreen *et al.* (2017). Based on this result, we can infer that the conventional EKC hypothesis comprises reasonable for BRICS countries. The turning point where CO_2 emissions start to fall is estimated at 9759.051 per capita real GDP (constant in 2010 USD).

In the case of Next-11 countries, the coefficient regarding economic growth (LRGDPPC) and squared economic growth ($LRGDPPC^2$) are positive and negative, respectively, and statistically significant at a 5% and 1% level of significance. This positive-negative coefficient pattern for Next-11 countries suggests a U-shaped path between EG and environmental degradation for those countries, which represents contrary to the conventional EKC hypothesis. This result means that, as a country starts to develop, its environmental degradation begins to fall but begins to increase when economic growth reached a certain point. This result is also obtained by Wang *et al.* (2011) for 28 provinces of China and Nasreen *et al.* (2017) for Nepal. Based on this output, it can be concluded that U-shaped EKC holds for the Next-11 countries over the study period. The estimated turning point at which CO_2 emissions start to rise is 17777.951 of per capita real GDP (constant in 2010 US$).

The results also portray that; TO, GI and URB have a significant negative influence on CO_2 emissions in BRICS countries, which reveal that an increase of 1% in TO and GI are accompanied by a reduction in CO_2 emissions up to 1.53% and 1.71% respectively, ceteris paribus, and an increase of 1% in URB lead to a reduction in CO_2 emissions by 1.62%, ceteris paribus. Similar results are found by Shahbaz *et al.* (2012) and Rahman and Benjamin (2020) for TO and Hossain (2011), and Gasimli *et al.* (2019) for URB. In the Next-11 countries, CO_2 emissions are explained by a positive coefficient of URB and GI, a negative coefficient of URB. An increase of 1% in TO leads to a reduction in CO_2 emissions up to 0.36%, ceteris paribus, and a 1% growth in URB and GI causes to increase CO_2 emissions by 0.42% and 1.03% respectively, ceteris paribus in the Next-11 countries. These results are also evidenced from the works by Jayanthakumaran *et al.* (2012) and Sehrawat *et al.* (2015) for India for TO and Dhakal (2009), Liddle and Lung (2010), Kashem and Rahman (2019), Rahman and Benjamin (2020) in case of Canada for URB. So, it can be inferred from these findings that, in Next-11 countries, TO and urban population considerably contribute to environmental degradation.

Table 6: The results from the FMOLS and DOLS regression analyses

Panel Group	*Panel A*		*Panel B*	
Model Estimator	*FMOLS*	*DOLS*	*FMOLS*	*DOLS*
LEC	*0.187* (0.049)*	*0.012 (0.017)*	*0.155*** (0.091)*	*0.365* (0.108)*
LRGDPPC	*-0.195 (0.428)*	*-1.372 (0.882)*	*1.728* (0.416)*	*1.786* (0.265)*
$LRGDPPC^2$	*0.049* (0.016)*	*0.132* (0.050)*	*-0.070* (0.023)*	*-0.097* (0.012)*
LTO	*1.914* (0.142)*	*-0.037 (0.063)*	*-0.270* (0.062)*	*-0.625* (0.093)*
LURB	*-0.032 (0.535)*	*4.458* (1.169)*	*0.302 (0.226)*	*0.511 (0.402)*
LGI	*-2.193* (0.337)*	*0.199 (0.179)*	*1.334* (0.175)*	*1.982* (0.380)*
Adj. R^2	*0.848*	*0.895*	*0.983*	*0.886*

*Notes: The robust standard errors are given within the parentheses; *, ** and *** denote statistical significance at 1%, 5% and 10% levels, respectively*

The FMOLS and DOLS estimators have been used for checking the robustness of the long-run estimates of elasticity. The obtained results reported in Table 6 similar to the findings found from the FGLS estimation. Therefore, it can be concluded that the overall results are homogeneous across various regression estimation approaches. So it is clear that at the initial stage, the trade-off between economic growth and environmental degradation was accepted across the BRICS economies, but after reaching a certain level of economic growth the degradation of the environment started to decline because of successful environmental welfare policy implementation. But in the case of the Next 11 countries, an opposite scenario has been observed which clear from the estimated results because N-11 countries are known as developing or emerging economies where the development process driving by massive industrialization, energy consumption, and other economic activities.

Table 7: Dumitrescu & Hurlin (2012) Panel Granger Causality Test Results

Panel Group	Panel A		Panel B	
Direction of Causality	Z-Stat.	Decision	Z-Stat.	Decision
LCO_2→LEC	-0.101	Unidirectional	0.572	Unidirectional
LEC→LCO_2	1.905**		6.132*	
LCO_2→LRGDPPC	9.085*	Bidirectional	3.361*	Bidirectional
LRGDPPC→LCO_2	3.639*		2.385**	
LCO_2→LTO	3.515*	Bidirectional	1.113	Unidirectional
LTO→LCO_2	3.145*		2.788*	
LCO_2→LURB	5.238*	Bidirectional	9.149*	Bidirectional
LURB→LCO_2	12.699*		7.571*	
LCO_2→LGI	2.417**	Bidirectional	1.239	Unidirectional
LGI→LCO_2	3.492*		2.484**	

*(Note: * and ** denote statistical significance of Z-statistics at 1% and 5% levels respectively)*

Finally, the Dumitrescu-Hurlin (2012) heterogeneous panel causality test is conducted to detect the possible causality directions among the variables used. The results of the causality analysis are reported in Table 7. For panel A, unidirectional causations are confirmed between CO_2 emissions and EC. Bidirectional causality was found between CO_2 emissions and EG, CO_2 and GI and also between CO_2 emissions and URB. These feedback associations suggest that EC, EG, GI, and URB are responsible for CO_2 emissions and promote environmental degradation. However, these CO_2 emissions further cause EC, EG, GI, and URB across BRICS countries. A bidirectional causal relationship between CO_2 emissions and TO is also evidenced from the results, meaning CO_2 emissions cause to trade openness and trade openness cause CO_2 emissions across BRICS countries. For panel B, a unidirectional causal linkage moves from CO_2 emissions to EC, which means that CO_2 emissions induce EC, but the energy consumption is not responsible for CO_2 emissions across Next-11 countries. Another unidirectional causality stems from TO and GI to CO_2 emissions, which implies that TO and GI are responsible for reducing the quality of the environment across Next-11 countries. Bidirectional causations are also identified between CO_2 emissions and EG and between CO_2 emissions and URB. These feedback linkages can be interpreted as EG, and urbanization is attributing to CO_2 emissions, which lowers the environmental quality across Next-11 countries. Further, these CO_2 emissions are causing energy consumption and urbanization across the Next-11 countries.

6. Conclusions And Policy Recommendations

This research aims to add to the literature on environmental sustainability by analyzing the nexus of economic development, energy uses, and quality of the environment for the BRICS and Next-11 countries by using an innovative econometric approach for the period 1990–2019. In the future, growing questions about energy use and the quality of the environment have prompted the need for a cohesive agenda worldwide. This study uses second-generation panel unit root tests after examining the cross-sectional dependency (CD) problem. The overall findings of the econometric evaluations provide statistical robustness on the non-linear U-shaped relation between EC and environmental degradation. Based on the estimates, the turning point at which CO_2 emissions start to rise is per capita real GDP of 17777.951 (constant in 2010 US$). Thus, the calculated coefficient trend for the BRICS panel affirms the existence of the EKC hypothesis, notes that the CO_2 emissions rise as economic activity rises at the early phase of growth and that emissions continue to decrease as the economy reaches sustained EG after reaching a growth threshold level. However, the results from the negative-positive coefficient pattern for Next-11 countries suggest a U-shaped path between EG and environmental degradation for these countries, contrary to the conventional EKC hypothesis.

Among the other significant finding, observational data has found a similar non-linear relationship between energy usage and CO_2 emissions in the overall final EC statistics. Furthermore, the findings also suggest that the relationship between trade openness, globalization index, and urbanization have a significant negative influence on CO_2 emissions in BRICS countries; however, globalization index and urbanization positively affect CO_2 emissions in Next-11 countries. Finally, in the Next-11 countries, globalization index and urban population considerably contribute to environmental degradation than BRICS countries. For BRICS countries, unidirectional causations are confirmed between CO_2 emissions and EC where bidirectional causality estimated between CO_2 emissions and EG, CO_2 emissions and globalization index, and also between CO_2 emissions and urbanization. A unidirectional causal linkage moves from CO_2 emissions to EC, which means that EC causes CO_2 emissions, but the energy consumption is not responsible for CO_2 emissions across Next-11 countries.

Therefore, in line with the findings mentioned above, the allied governments can adopt suitable strategies to gradually phase out conventional energy dependence for the BRICS and Next-11 countries, which is likely to facilitate the overall CO_2 emission phenomenon significantly. The empirical findings of this study will also help the policy makers to design a better policy for a future low-carbon society. Urbanization and industrialization increase environmental pollution; therefore, countries require to promote sustainable green opportunities and environmentally friendly public transportation. Although capital accumulation could assist funding in economic activities that generate environmental pollution as a by-product, the credit provision for investment in the use and development of clean and green technologies should be given preference by financial institutions. Financial institutions can contribute to environmental sustainability and carbon footprints by charging a lower interest rate on contracts. Hence, a wide variety of environmental policies will also need to be enforced by the BRICS and Next-11 countries to ensure environmental protection, which will induce businesses to introduce new technologies and reduce environmental emissions.

Our study is limited to the following aspects. First, the unavailability of up-to-date data on energy consumption was one of the major limitations of this study, which curbed the identification of the impact of energy consumption on environmental quality in recent years. Also, because of the unavailability of long annual data of some studied countries, country-specific assessments could not possibly be performed. Second, data unavailability constrained this study to incorporate the decisive explanatory variables into the regression models for empirical analysis and limited the current study's scope to integrate one belt one road-related countries besides BRICS and the Next 11 countries. As part of the future research extent, this study can be repeated independently for the BRICS and Next-11 countries to identify the possible heterogeneous impacts of economic development, efficient energy usage, and environmental degradation level using the second-generation FGLS model. Moreover, this study can also be carried out from the perspective of the technologies and the quality of the environment to understand the heterogeneous dynamics of cleaner technologies' diffusion in the long run.

Declarations

Authorship contribution statement

SCM: Conceptualization, Supervision, Methodology, Data curation, Software, Formal analysis, Writing – original draft, Writing – review & editing. MHR: Formal analysis, Writing – review & editing. JF: Formal analysis, Data curation, Writing – original draft. MMR: Methodology, Data curation, Formal analysis. MZA & NR: Investigation, Formal analysis.

Data Availability

Annual time-series data covering the period 1990-2019 for all the five BRICS and eleven Next-11 countries are used in this study. The panel groups of two data sets are used for this study. The first data set consists of yearly data of 150 observations for BRICS countries, called panel A. The second data set contains yearly data of 330 observations for the Next-11 countries, called panel B. All data are sourced from World Development Indicators (WDI) database 2020, prepared by World Bank and our world in data 2020.

Ethical approval: This study ensures that, the ethnical approval is maintained and no ethnical contradiction.

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