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Novel research methods for estimating the impact of energy use on ecological environment: evidence from B.R.I.C.S. economies

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ABSTRACT

The current study looked at the influence of fossil-fuel energy (E.U.) consumption, renewable power generation and greenhouse gas emissions in Brazil, Russia, India, China, and South Africa (B.R.I.C.S.) between 1990 and 2020. The latest study also takes into account the influence of gross domestic product (G.D.P.) and technological innovation on carbon emissions. Using cross-sectional dependence and slope heterogeneity, the order of the unit root is also determined. The findings acquired by the application of moment quantile regression. The research finds that G.D.P. and the usage of E.U. increase carbon emissions at the 25th, 50th, 75th and 90th quantiles. On the other hand, renewable energy generation and technical innovation reduce carbon emissions at the 25th, 50th, 75th and 90th quantiles. Furthermore, while implementing B.R.I.C.S. economies' energy, environment, and growth policies based on empirical data, policymakers should analyse the asymmetry behaviour of G.D.P., E.U. consumption, renewable power output and technological innovation.

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1. Introduction

The universal environmental crisis has lately received substantial attention and awareness as a result of catastrophic climate change and humanity's attempts to preserve the world livable for the foreseeable future. The 2015 Paris Agreement, issued by the U.N. Framework Convention on Climate Change, proved to be historic stage forward in this context. The agreement entered into force on 4 November 2016, after being accepted by 147 nations. The primary resolution of this treaty is to condense global greenhouse gas (G.H.G.) emissions while keeping the universal increase in yearly temperature intensity by 2 °C (United Nations, 2015). Carbon dioxide emissions, a kind of G.H.G., are one of the record contributors to the global G.H.G. effect. By sending contamination into the exosphere from where carbon contributes to global warming.

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Carbon emissions have grown histrionically due to the Industrial Revolution. Notwithstanding the U.N.'s attempts to urge strategy reforms that would limit global warming, several nations have failed to sanction the Paris Agreement for regional cost-effective and administrative reasons.

The biggest causes of worry are emerging countries, notably the industrialised Brazil, Russia, China, and South Africa (B.R.I.C.S.) nations. While B.R.I.C.S. countries accepted the treaty and strived for sustainable options, Russia is still refusing to sign on. Since the Russian economy is essentially based on coal, steel and specifically oil, which add drastically to regional air pollution, prominent business leaders should oppose ratification of the deal. Despite this, Russia ranks seventh in the world in terms of G.H.G. emissions per capita. Therefore, Russia's sanction of the treaty is acute in dealing with the worldwide ecological catastrophe.

The B.R.I.C.S. are important for the ecosystem as per their stage of development that dictates industrial advancement, leading the country to employ transitory solutions. Brazil desires improved eco-friendly management of environment through the strict implication of environment related rules and regulations. Still, Russia relies largely on E.U. consumption and India relies substantially on coal and nuclear-powered energy. Notwithstanding, China is making considerable efforts to become more sustainable and cut carbon emissions. Similarly, the initiatives are taken by South Africa to modify their industrial activities to more eco-friendly solutions to improve atmosphere, (Chang, 2015). Largely, countries included in B.R.I.C.S. still have a long journey to become 'green', and considerable environmental policy reforms are necessary. As a result, creating suitable environmental and economic policies in B.R.I.C.S. countries needs understanding of the sources of carbon emissions and finding the link between energy consumption, carbon emissions and economic growth (E.G.).

Over the previous two decades, the B.R.I.C.S. economies have seen extraordinary growth. In 2018, the B.R.I.C.S. countries contributed 21% of international G.D.P., 40% of global energy consumption (E.C.), and over 40% of international population, while also significantly contributing to global carbon emissions. Between 2001 and 2011, the B.R.I.C.S. nations' carbon emission ratio increased from 27.35% to 37.78%, which currently accounts for 41.3% of world emissions. China was the planet's prevalent carbon emitter in 2013, reporting 29% of international carbon emissions of 11 billion tonnes, with India coming in fourth (2.6 billion tonnes), Russia fifth (2 billion tonnes), Brazil eleventh (6.1% with rising emissions), and South Africa far behind in B.R.I.C.S. economies carbon emissions. The B.R.I.C.S. economies combined G.D.P. was 1888.76 billion U.S.D. in 2017, reporting for 23.3% of international G.D.P. Furthermore, India's entire commerce exports were US$32.216 billion, reporting for 18% of the worldwide total, positioning it at the world's third-largest exporter, while India was the world's eighth-largest importer (W.T.O.).[1]

Novel Research Methods for Estimating the Impact of E.C. on the Ecological Environment: Evidence from B.R.I.C.S. Economies from 1990 to 2020 is the subject of the current study. Furthermore, the current research study investigates the influence of renewable power generation on consumption-based carbon emissions in the B.R.I.C.S. nations, which has never been investigated before. Unique and sophisticated econometric methodologies, such as second and third-generation cointegration and unit root methods, are used in this work. Moment Quantile Regression (M.M.Q.R.), Pesaran slope heterogeneity, panel unit root and cross-section dependency tests, Westerlund error correction mechanism (W.E.C.M.) test and Dumitrescu Hurlin panel causality tests were all used in this work. The next section is laid out in the following manner: The second section dives into previous empirical and theoretical investigations in greater depth. The variables and their data sources are discussed in Section 3, as well as the hypothetical framework, model construction, and associated methodologies. The fourth section dives into the practical findings. The fifth section finishes with key policy suggestions based on the findings.

2. Literature review

For the purposes of this discussion, studies, papers, and investigation on the strong correlation between use of energy and E.G. can be divided into three categories: studies, papers on the correlation between E.G. and carbon emissions, carbon emissions and technological innovation (T.I.), and research on the strong correlation between use of energy and E.G. This section will discuss each of these three types of research.

2.1. TI and carbon emissions

Wahab et al. (2021) employed C.S.-A.R.D.L. to examine T.I. with trade-adjusted carbon emissions for G-7 economies from 1996 to 2017. The author used A.M.G. and C.C.M.G. for robustness. According to S. Wahab's results, technical innovation has an inverse connection with carbon emissions, and export has the same negative association with carbon emissions. Whereas, imports and G.D.P. possess positive association with carbon emissions. Furthermore, Wang and Zhu (2020) evaluated carbon emission, use of green energy, financial growth, green E.C., and T.I. in the N-11 nations. The Pesaran (2007) Root Unit Test, the Typical Associated Impact Mean Group and the Enhanced Mean Group were used to create empirical estimations. According to the research, there is a favourable relationship concerning carbon emissions, financial evolution and G.D.P. T.I. and the use of renewable energy (R.E.) are negatively associated with G.H.G. emissions. Furthermore, the paper by Ulucak et al. (2020) investigates the impact of sustainable technology on green growth. The currencies of the B.R.I.C.S. countries are known as the B.R.I.C.S. currencies. By regulating the use of R.E. and non-RE, the study explores the shock of sustainable energy on green growth in the B.R.I.C.S. countries. The research employs complicated panel data prediction approaches with high heteroskedasticity, cross-sectional dependence outcomes and endogeneity. Environmental technology has had a significant effect on green growth, according to empirical evidence. The research also suggests that R.E. promotes long-term development whereas non-renewable energy stymies green development. According to the research, B.R.I.C.S. nations should advance their energy technologies for the purpose to achieve E.G. while being ecologically conscientious. Between 1990 and 2017, Su et al. (2020) investigated the influence of international transportation of goods and services and T.I. on U.S. consumption-based carbon emissions. The A.R.D.L. techniques, Phillips-Perron (P.P.), A.D.F. tests, and Zivot-

Andrews root test were all used in this study. According to the study's findings, the listed variables have complex nexus between T.I. and carbon emissions, which varies based on consumption. Exports and carbon emissions generated significant results depending on how they were utilised. In addition, the study found that T.I. benefits in carbon emission reduction.

2.2. Economic growth and carbon emissions

Kasman and Duman (2015) conducted research on the link amid carbon emissions, usage of energy, trade, urbanisation, and economic development in European Union Member States and listed countries from 1992 to 2010. The outcome of the bench cointegration approach, the panel-causality-test, and the unit-root test, all tests indicate that there is unilateral causation between E.C., commerce and urbanisation and carbon emissions. Short-run results shows that there is a causal relationship between E.U. consumption, urbanisation, and economic development, as well as trade, demand for energy, urbanisation, and investment. Long-run carbon emissions, E.C., trade and E.G. all contribute their share. In case of Malaysia, Begum et al. (2015) inspected the association between E.G. and carbon emissions from 1970 to 2009. As a result of international economic activities, the A.R.D.L.- dynamic ordinary least squares (D.O.L.S.) approach has resulted in considerable carbon emissions. Long et al. (2015) employed data cointegration evaluation using China as the sampling field between 1952 and 2012. The outcomes of the study demonstrated a bi-directional association amid E.G. and carbon emissions, as well as a relationship between economic development and carbon emissions. In a panel of eight Asian-Pacific nations, Niu et al. (2011) also studied economic development, E.C., and carbon emissions reduction between 1971 and 2005. A panel V.E.C.M. and a Granger-causality test were employed, which revealed a strong correlation amid G.D.P. and carbon emissions.

2.3. The dynamic link between E.G., pollution and energy consumption

The tertiary study strand looks on the vigorous link among E.G., E.C. and pollution. Wahab et al. (2021) investigated energy productivity with carbon emission for G-7 economies from 1996 to 2017 using C.S.-A.R.D.L., which is one of the most famous research in this field. According to S. Wahab's research, energy production has an inverse connection with carbon emissions, just as technical innovation and export have a contrary association amid carbon emissions. Whereas E.G. and trade have a favourable relationship with carbon emissions. Furthermore, Wahab et al. (2022) used a spatial Durbin model to analyse R.E. and financial stability in relation to carbon emissions for B.R.I.C.S. nations from 1995 to 2018. According to S. Wahab's results, R.E. has a counter connection to carbon emissions, and export has an opposite connection with carbon emissions. Carbon emissions have a positive relationship with G.D.P. and imports. Furthermore, Ang (2007) examined the vigorous causality between E.G., E.C. and pollutions using French data between 1960 and 2000 using cointegration approach and error correcting mechanism (E.C.M.). The researcher discovers a long-term association between the three factors. E.C. and economic development also have a short-run unidirectional causal analysis. Ang uses the D.O.L.S. approach to study the dynamic connection in China (2009). According to his research, energy efficiency and trade openness cut carbon emissions. Carbon emissions elasticity in association with E.C. is anticipated to be 1.101–1.175%, whereas CO_2 emissions elasticity in relation to trade openness is expected to be 0.144–0.160%. Rehman et al. investigated export diversification, agriculture and energy consumption over air pollution for Asian countries from 1996 to 2014 while using M.M.Q.R. Finding shows that export diversification and agriculture have significantly negative relation while on the other hand energy increases G.H.G. emission. Moreover, Yan et al. investigated foreign investment, economic development and education over sustainable environment for B.R.I. countries from 1996 to 2016 while using M.M.Q.R. Finding shows that economic development has significantly positive relation while on the other foreign investment and education have negative relation on carbon emission.

Another notable paper in this collection is Soytas et al. (2007) analysis on the United States. The researchers use the Granger causality test to determine that E.C. drives carbon emissions but not wealth. This conclusion proposes that E.G. might not be the most effective way to address the world's contemporary environmental issue. Halicioglu (2009) also looks at the vibrant relationship between E.G., E.C. and pollution. Halicioglu examines the connection in Turkey from 1960 to 2005 using bound-testing and cointegration approaches. The researcher reveals a long-run influence of carbon emissions on E.C., income and foreign trade, further long-run impact of carbon emissions, E.C., and international trade on income. Finally, the expected outcomes indicate that Turkey's macroeconomic policy should consider environmental disaster to minimise carbon emissions.

A study on the B.R.I.C.S. uses panel causality analysis to consider the causal link among electricity consumption, economic development, and carbon emissions while adjusting for cross-sectional reliance among states (Cowan et al., 2014). According to the experts, E.K.C. theory is only valid in case of Russia. Furthermore, South Africa has a unidirectional causality between G.D.P. and carbon emissions, but in Brazil, there is a unidirectional causality between carbon emissions and G.D.P. Cowan et al. found a unidirectional causality between electricity usage and carbon emissions in India, but none in the other countries. Sebri and Ben-Salha (2014) used D.O.L.S. and fully modified D.O.L.S. to examine the correlation between E.G., R.E. consumption, carbon emissions and level of international trade in the B.R.I.C.S. from 1971 to 2010, and cointegration among the listed variables. Researcher are also using the Granger Causality test to assess a bidirectional relationship among R.E. use and E.G. R.E., according to researchers, is critical for policies related to the environment and E.G. in the B.R.I.C.S.

In many aspects, the study adds to the current body of knowledge. For instance, Hassan et al. (2022a), Wahab (2021), Yuan et al. (2011), Wahab et al. (2021) and Hassan et al. (2022b) all focused on E.E. and R.E. rather than carbon (Abban et al., 2020; Iftikhar et al., 2016; Özbuğday & Erbas, 2015; Wu et al., 2012; Zhou et al., 2018). Second, current study is the first one to examine how the E.U., renewable electricity output (R.E.O.), and carbon emissions influence the B.R.I.C.S. nations. Third, the paper presents acute information on the B.R.I.C.S. nations' causal relationship between E.U., R.E.O., T.I., and carbon emissions. This information can help policymakers discover effective carbon-reduction strategies. Fourth, the E.K.C. theory and the S.T.I.R.P.A.T. model (Liddle, 2011, 2013a, 2015) were used in the majority of previous studies (Khan et al., 2019; Rahman & Ahmad, 2019), while current study uses second and third-generation cointegration and unit root methods, are used in this work. M.M.Q.R., Pesaran slope heterogeneity, panel unit root and cross-section dependency tests, W.E.C.M. test, and Dumitrescu Hurlin panel causality tests were all used in this work. The next section is laid out in the following manner; the remainder of the research is structured as follows.

3. Methodology

3.1. Data description

Novel Research Methods for Estimating the Impact of E.C. on the Ecological Environment: Evidence from B.R.I.C.S. Economies from 1990 to 2020 is the goal of this project. This study adopts a unique strategy in that it employs novel exogenous variables such as E.U. use and renewable power output. This study also leverages one of the recently established econometric approaches to reach the results. Furthermore, the list of B.R.I.C.S. countries, denoted by '*i*' from 1990 to 2020 and '*t*', is the ideal region as a sample for this. The most recent data is for the B.R.I.C.S. countries. Because the most recent data for all nations was available, the current analysis focused on the period 1990–2020. All the data sets were gathered from various web pages for the chosen variables. Our dependent variable was assessed in the current study. The data on carbon emissions comes from the Global Carbon Atlas (G.C.A.), measured in kilograms and designated by the letter 'CO2'. Furthermore, this study uses G.D.P., E.U. consumption, Renewable power output, and TI as explanatory factors. The data for Gross Domestic Product (constant 2015 US$) and denoted by 'GDP', E.U. consumption (percentage of total E.C.) and denoted by 'EU', Renewable electricity output (percentage of total electricity output) and denoted by R.E.O., and T.I. (Patents by residents and non-residents) and denoted by 'TI' were obtained from the World Bank.[2]

3.2. Theoretical framework

The goal of current research is to come up with new research methods for estimating the impact of E.C. on the environment. This study offers a unique approach by incorporating E.U. use and renewable power output as modern explanatory variables and employing a distinct econometric method to performance. Furthermore, the B.R.I.C.S. sample region for this analysis is specified by subscription I for the period 1990–2020 and designated by subscription 't'. The model specification is as under:

$$\mathrm{CO_2PC_{i,t}} = \mathrm{f}(EU_{\mathrm{i,t}}, \mathrm{REO_{i,t}}, \mathrm{GDP_{i,t}}, \ \mathrm{TI_{i,t}}) \tag{1}$$

The fundamental econometric equation is provided as:

$$CO_2PC_{i,t} = \vartheta_0 + \vartheta_1 EU_{i,t} + \vartheta_2 REO_{i,t} + \vartheta_3 GDP_{i,t} + \vartheta_4 \ TI_{i,t} + \in_{i,t} \tag{2}$$

The current study with a strong hypothetical reason is principally responsible for using the chosen variables in Equation (2). Carbon emissions from every country where goods are purchased. In evaluating variables that increase or decrease carbon emissions in B.R.I.C.S. countries, it is critical to include the impact of trade. Coal or oil-fired power plants produce heat, which is subsequently converted into steam, which powers turbines that generate electricity. When fossil-fuels are burned, they emit a significant amount of carbon. Carbon emissions, which trap heat in the atmosphere, are to blame for climate change. E.C., unlike fossil-fuels, has a positive link with carbon emissions. .$\vartheta_1 = \frac{\partial CO_2 i.t}{\partial IEU_{i,t}} > 0$. Based on previous findings, the link is positive, meaning that growing per capita G.D.P. leads to increased carbon emissions. According to some views, there is no tipping point at which emissions begin to decline when G.D.P. reaches a specific level. Increases in G.D.P. may offer a foundation for improving production efficiency, but they do not appear to reduce net environmental output. However, as G.D.P. rises, a structural shift occurs, with poverty decreasing and the share of manufacturing services and the urban population gradually rising. As a result, the G.D.P.-carbon emissions relationship is likely to be positive. Such as $\vartheta_2 = \frac{\partial CO_2 i.t}{\partial IGDP_{i,t}} > 0$. However, R.E. is projected to have a negative relationship with carbon emissions, as indicated. Wind, hydropower, solar, biomass, and geothermal energy can provide electricity without contributing to climate change in the same way that fossil fuels do. This is because R.E. sources such as the sun and wind emit no carbon dioxide or other G.H.G., which cause global warming $\vartheta_3 = \frac{\partial CO_2 i.t}{\partial REO_{i,t}} < 0$. Similarly, T.I. is an important factor to consider; TI improves enterprise production, efficiency, and helps businesses transition to R.E. (for example, Álvarez-Herránz et al., 2017). Although most studies look at the direct influence of T.I. on carbon emissions, technology may be thought of as a moderating variable that improves the link between carbon emissions and their drivers. Energy-related T.I., on the other hand, is more likely to have an impact on consumption, which in turn has an impact on carbon emissions. T.I. is closely linked to technology and is increasingly vital for lowering carbon emissions and improving environmental quality (Balsalobre-Lorente et al., 2018). Consumption-based carbon emissions are projected to be inversely correlated with T.I., which is critical for reducing carbon emissions (Álvarez-Herránz et al., 2017; Garrone & Grilli, 2010; Shahbaz et al., 2019; Wong et al., 2013) such as $\vartheta_4 = \frac{\partial CO_2 i.t}{\partial TIPC_{i,t}} < 0$. In short, the expected result is $\vartheta_1 > 0$, $\vartheta_2 > 0$, $\vartheta_3 < 0$ and $\vartheta_4 < 0$ also shown in Figure 1.

3.3. Econometric strategies

3.3.1. Diagnostic check tests

This test's null hypothesis states that the data are regularly distributed, but the alternative states that they are not. Pesaran and Yamagata (2008) test for heterogeneous

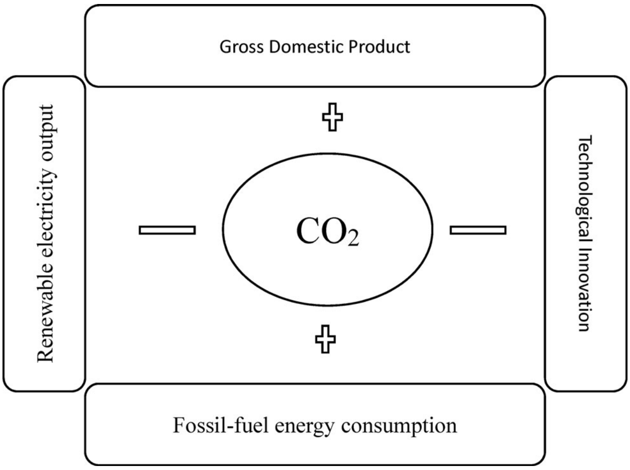

Figure 1. Logical relationship among variables.
Source: Author's own calculations.

slope coefficients and Pesaran test for cross-sectional dependency should also be utilised. After these issues have been identified, the next step is to use appropriate stationary testing. The null hypothesis for this test is that cross-sections are independent and that there are no spill-over effects. In other words, the countries are self-sufficient and resistant to local and global economic shocks. It is critical to identify these issues using the econometric tools listed above before applying unit root, cointegration, or long-run estimation. Otherwise, the results (while ignoring these concerns) may lead to skewed outcomes.

3.4. Unit root and cointegration check

The cross-sectional augmented Im, Pesaran and Shin (C.I.P.S.) technique is used to verify for stationarity (Pesaran, 2007). This test can be used to cope with cross-sectional dependency and diverse slope coefficients. As a result, this method is preferred to typical panel unit root tests, which only address one of the two issues mentioned above. The standard equational form for the C.I.P.S. test is as follows:

$$\widehat{CIPS} = \frac{1}{N}\sum_{i=1}^{N} CADF_i \tag{3}$$

(C.A.D.F. stands for cross-sectionally augmented dickey fuller)

Similarly, Westerlund employs the cointegration technique of the E.C.M. As previously stated, even when slope coefficients are various and cross-sections are dependent, this test is useful for obtaining efficient results.

$$G_t = \frac{1}{N}\sum_{i=1}^{N}\frac{\alpha_i}{SE\alpha_i} \tag{4}$$

$$G_t = \frac{1}{N} \sum_{i=1}^{N} \frac{T\alpha_i}{\alpha_i(1)} \tag{5}$$

$$P_t = \frac{\alpha}{SE(\alpha)} \tag{6}$$

$$P_t = T\alpha \tag{7}$$

The M.M.Q.R. is described in detail in the next section.

3.5. Method of Moments Quantile Regression

According to the normality testing, the data in this study is not regularly distributed. As a result, the M.M.Q.R. technique offered by Machado and Silva (2019) can be used. Although the fundamental quantile regression method is non-normality resistant, it overlooks the issue of unobserved variability inside the particular panel. Apart from that, when combined with the T.I. and G.D.P., this method may be utilised to evaluate the conditional heterogeneous covariance impact of E.U. and R.E.O. Electricity on carbon emissions. Individual effects might now have a ripple effect throughout the distribution. This strategy is equally effective when the model comprises endogenous independent variables (Anwar et al., 2021). The generic equational version of the M.M.Q.R. method is as follows:

$$Q_y\ \left({}^{\tau}/_{X_{it}}\right) = (\sigma_i + \vartheta_i q(\tau)) + X'_{it}\beta + Z'_{it}yq(\tau) \tag{8}$$

where, X_{it} Contains all independent variables such as E.U., R.E.O., T.I. and G.D.P. $Q_y\ \left({}^{\tau}/_{X_{it}}\right)$ is the quantile distribution of conditional distribution of carbon emission on X_{it}. $\sigma_i + \vartheta_i q(\tau)$ is scalar coefficient indicating quantile fixed effect τ for each cross-sections i. Moreover, $q(\tau)$ is for the quantile calculated via τth optimisation problem as follows:

$$\text{Minimise } q \sum_i \sum_t p\tau\ (R_{it} - Z'_{it}yq(\tau)) \qquad \text{eq.9}$$

Here, $p\tau$ is check function denoted as, $p\tau$ (A) $= (\tau - 1)AI\{A \leq 0\} + TAI\{A > 0\}$.

In addition, the robustness tests in this paper are performed using a simple quantile regression technique. In addition, when the E.U. and R.E.O. are paired with the T.I. and G.D.P., the panel causality test (Dumitrescu & Hurlin, 2012) is utilised to investigate the causal impact of E.U. and R.E.O. on carbon emissions.

4. Results and discussions

The descriptive data are presented in Table 1. We discovered that the maximum carbon emissions value was 7.013404, while the minimum value was 5.29. Carbon emissions innovation had a mean value of 6.1293. The mean value for G.D.P. was 12.216, while the minimum and maximum values were 11.667 and 13.165, respectively. The mean value for the E.U. was 1.8534, with minimum and maximum values of 1.7094 and 1.9703, respectively. The mean value of R.E.O. use was 1.4311, with a minimum of 1.0811 and a maximum of 1.979. The minimum and maximum readings were 3.5345 and 6.1880, respectively. TI was found to have a mean value of 4.544702.

The average values, volatility, and range for each variable are shown in Table 1, along with a normality check. Carbon emissions, followed by G.D.P., E.U. consumption, renewable power output, and T.I. are all volatile. Furthermore, by rejecting the null hypothesis of normal distribution for carbon emissions, G.D.P., E.U. consumption, renewable power generation and TI, Jarque-Bera (J.B.) results show that the data is not normally distributed. The findings are statistically significant at numerous levels, including 1%, 5% and 10% for each variable.

In addition, as shown in Table 2, the empirical outcomes of B.R.I.C.S. economies have varied slope coefficients, as indicated by $\widetilde{\Delta}$ and $\widetilde{\Delta}$ **Adjusted** with values of 13.750*** and 15.312***, respectively. This shows that these countries are not homogeneous in terms of G.D.P., E.U. consumption, renewable power output, T.I., and carbon emissions. Similarly, the cross-section dependence test results are presented in the lower area of the table. The findings support B.R.I.C.S. economies' cross-sectional reliance. This implies that in the present period, independence is rare and that the bulk of economies is interconnected. The results of this study's unit root test are presented in Table 3 in the following stage.

The empirical findings of the C.I.P.S. test are shown in Table 3. Heterogeneity and cross-sectional dependence have no effect on the outcomes of this test. According to the findings, all variables are non-stationary at the level. This indicates that the means

Table 1. Descriptive statistics.

	CO_2	GDP	EU	REO	TI
Mean	6.129365	12.21693	1.853488	1.431191	4.544702
Median	6.182469	12.11807	1.862738	1.266493	4.461318
Maximum	7.013404	13.16530	1.970329	1.979573	6.188085
Minimum	5.297235	11.66768	1.709404	1.081173	3.534534
Std. Dev.	0.479100	0.354974	0.088236	0.309914	0.603540
Skewness	0.138981	1.097335	−0.137463	0.961675	1.124632
Kurtosis	2.186950	3.651613	1.485363	2.074805	4.160084
Jarque-Bera	3.537754	25.11398	11.35486	21.82729	30.69055
Probability	0.170524	0.000004	0.003422	0.000018	0.000000

Note that the significance levels for 1%, 5% and 10% are shown by the letters ***, ** and *.
Source: Author's own calculations.

Table 2. Diagnostic tests.

Heterogeneity/Homogeneity check		
Statistics	$\widetilde{\Delta}$	$\widetilde{\Delta}_{Adjusted}$
	13.750***	15.312***
Cross − sectional dependence		
CO_2	GDP	TI
7.488***	16.066***	10.396***
EU	REO	–
0.691	−2.192**	–

Note that the significance levels for 1%, 5%, and 10% are shown by the letters ***, ** and *.
Source: Author's own calculations.

Table 3. Unit root test.

Statistics	Trend and Intercept I(0)	Trend and Intercept I(1)
CO2	−1.78	−3.99***
GDP	−1.62	−3.05***
EU	−1.20	−5.26***
REO	−2.24	−5.73***
TI	−2.46	−4.81***

Note that the significance levels for 1%, 5% and 10% are shown by the letters ***, ** and *.
Source: Author's own calculations.

Table 4. Cointegration testing.

Statistics	Value	$p-$value
G_t	−7.663***	0.000
G_a	−14.358*	0.080
P_t	−15.116***	0.000
P_a	−14.884**	0.004

Note that the significance levels for 1%, 5% and 10% are shown by the letters ***, ** and *.
Source: Author's own calculations.

Table 5. M.M.Q.R.

			Quantiles			
Dep. Var.: CO_2	Location	Scale	$Q_{0.25}$	$Q_{0.50}$	$Q_{0.75}$	$Q_{0.90}$
GDP	1.450***	−0.0325	1.480**	1.459***	1.411***	1.398***
	[0.399]	[0.339]	[0.682]	[0.477]	[0.236]	[0.310]
EU	3.602***	−0.289	3.870**	3.679***	3.255***	3.136***
	[0.937]	[0.796]	[1.567]	[1.098]	[0.550]	[0.719]
REO	−0.051	0.048	−0.095	−0.063	−0.006	−0.026
	[0.098]	[0.084]	[0.166]	[0.116]	[0.058]	[0.076]
TI	−0.438	−0.062	−0.381	−0.422	−0.512***	−0.537**
	[0.289]	[0.246]	[0.495]	[0.346]	[0.171]	[0.225]
Constant	−16.236***	1.285	−17.425**	−16.578***	−14.691***	−14.164***
	[4.721]	[4.762]	[7.978]	[5.583]	[2.779]	[3.641]

Note that the significance levels for 1%, 5% and 10% are shown by the letters ***, ** and *.
Source: Author's own calculations.

of these variables are not returning to zero. Furthermore, G.D.P., E.U. consumption, Renewable power output, and T.I. do not all fluctuate simultaneously. As a result, these parameters appear to fluctuate depending on the cross-section. As a result, at I, all variables have become stationary (1). After that, a cointegration test is performed.

Table 4 shows the results of a cointegration test using an E.C.M. The results of the group and pane statistics are Gt, Ga, Pt and Pa. The findings reveal a long-run cointegrating relationship between G.D.P., E.U. consumption, R.E.O., TI and carbon emissions.

Table 5 shows the results of the M.M.Q.R. approach for the 25th, 50th, 75th and 90th quantiles. According to the data, a 1% growth in G.D.P. results in a 1.480% increase in carbon emissions at the 25th quantile. A 1% increase in E.U. at the 25th quantile can result in a 3.870% increase in carbon emissions, while a 1% increase in R.E.O. can result in a −0.095% decrease in carbon emissions. Similarly, the average reduction in carbon emissions attributable to increased technical innovation is −0.381% at the 25th quantile.

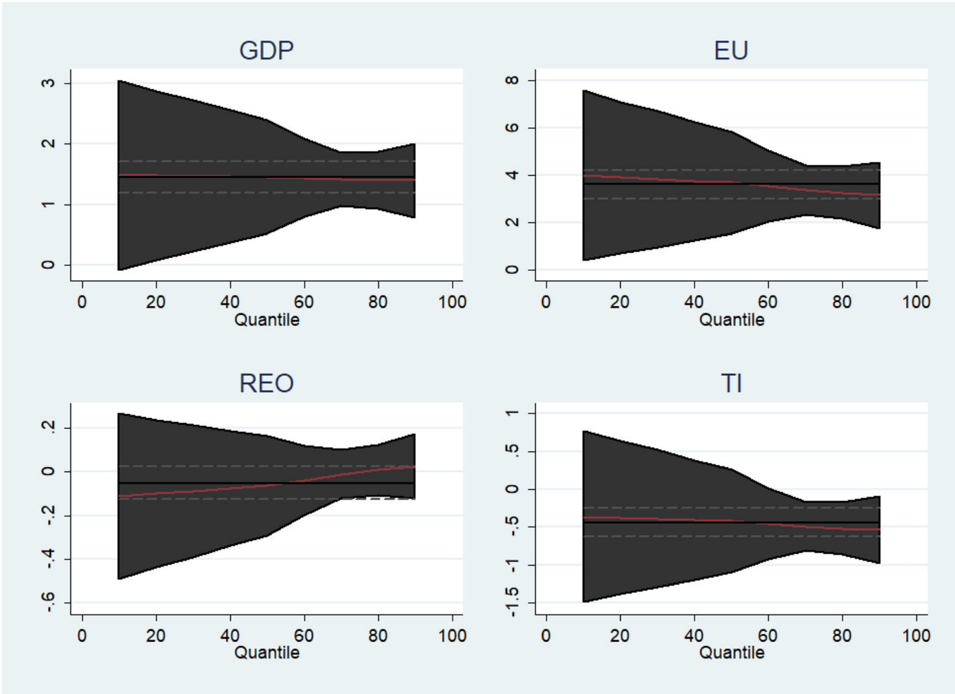

Figure 2. M.M.Q.R. graph.
Source: Author's own calculations.

Table 6. Dumitrescu-Hurlin panel causality test.

H_o	$Wald_{Stats}$	$\bar{Z}_{Stats}$	$p-$ value
GDP – CO2	2.69772**	2.040	0.0413
CO2 – GDP	5.41761***	5.553	0.0000
EU – CO2	5.05789***	4.214	0.000
CO2 – EU	4.66936***	4.586	0.000
REO – CO2	4.83730***	4.803	0.000
CO2 – REO	3.99679***	3.718	0.0002
TI – CO2	2.57801*	1.885	0.0593
CO2 – TI	5.58773***	5.772	0.000

Note that the significance levels for 1%, 5% and 10% are shown by the letters ***, ** and *.
Source: Author's own calculations.

Similarly, the results show that R.E.O. and T.I. reduce carbon emissions at the 50th, 75th and 90th quantiles. In the 90th quantile, G.D.P. causes an average increase of 1.398%. In the same way, the E.U. had a 3.136% increase in carbon emissions. R.E.O., on the other hand, reduces carbon emissions by −0.026% at the 90th quantile. Furthermore, T.I. reduces carbon emissions connected to energy by −0.537%. According to the theoretical framework, the total outcome for the 25th, 50th, 75th and 90th quantiles suggests that R.E.O. and T.I. reduce carbon emissions. Furthermore, expanding G.D.P. and the E.U. result in increased carbon emissions. Additionally, the results for the 25th, 50th, 75th and 90th quantiles are statistically significant at 1%, 5% and 10%, respectively. Figure 2 backs these assertions. Furthermore, the findings confirm the idea that R.E.O. and T.I. have a detrimental impact on carbon emissions.

Table 6 shows the results of the Dumitrescu-Hurlin panel causality technique. Similarly, any strategy prioritising G.D.P., E.U. consumption, R.E. production or T.I. will impact carbon emissions. In addition, there is a bidirectional causal link between carbon emissions and G.D.P., E.U. consumption, R.E. generation, and T.I. Similarly, the results are substantial and statistically significant at standard 1%, 5% and 10%.

5. Conclusion and policy implication

The current analysis investigates the impact of the E.U. and R.E.O. on B.R.I.C.S. carbon emissions between 2000 and 2019. This study also looks at the impact of G.D.P. and T.I. on carbon emissions. The study used the M.M.Q.R., Pesaran slope heterogeneity, panel unit root and cross-section dependency tests, the W.E.C.M. test and the Dumitrescu Hurlin panel causality test. The empirical findings began with the J.B. normality test, which demonstrated that the data is non-normally distributed and that using parametric results will result in biased conclusions, proposing the moment quantile regression strategy (M.M.Q.R.). The data also revealed that cross-sections had varying slopes and interdependence. The panel unit root test proved the data's non-stationarity at the level of all variables. The long-run cointegration link between the E.U., R.E.O., G.D.P. and T.I. about carbon emissions has also been shown.

The M.M.Q.R. test indicated that R.E.O. and T.I. have a negative connection with carbon emissions. G.D.P. and the E.U., on the other hand, have a positive association with carbon emissions. The size of each coefficient grows with each quantile, i.e., the 25th, 50th, 75th and 90th quantiles, respectively. According to the causation test, any policy aimed at G.D.P., E.U., R.E.O. or T.I. will impact carbon emissions. In terms of policy implications, the report recommends that the B.R.I.C.S. economies lower regulatory barriers to technical innovation to benefit the R.E.O. industry in the B.R.I.C.S. countries. Finally, the B.R.I.C.S. countries should invest in R.E.O. research and development. They need to invest more in R.E.O. to meet industrialisation's energy demands while also minimising energy-related G.H.G. emissions. In addition, when designing energy, environmental, and E.G. policies, policymakers should consider the E.U.'s and G.D.P.'s asymmetric behaviour. Because the study's findings are limited to the B.R.I.C.S. countries, the findings cannot be applied to other countries. A similar study might be conducted for a number of other countries. Future research could look at the nonlinear behaviour of the energy, growth, and environment nexus based on the study's asymmetric findings. The asymmetric N.P.A.R.D.L. can be employed in a single framework with quantile regression to integrate regional asymmetries. In light of our findings, this study suggests that:

- Promoting environmentally friendly technologies aids in the reduction of carbon emissions.
- According to the findings, to reduce the influence of G.D.P. and imports on carbon emissions, they should target domestic consumption, particularly those sectors that are more energy intensive or the primary source of carbon emissions.

- According to the findings, these countries consume a lot of energy; thus, their economies must strive for a balance in terms of energy productivity, G.D.P., international commerce and TI.

The void in the current area might be filled with more research by looking at the relationship between green finance and carbon emissions. Furthermore, the current analysis identifies robust, pragmatic outcomes; hence, additional investigations in different nations should be done with different techniques like A.R.D.L./C.S.-A.R.D.L. or more.

Notes

1. WTO, *World Trade Statistical Review 2016*, A9. Leading exporters and importers in world trade in commercial services (including intra-EU(28) trade), 2015 www.wto.org/english/res_e/statis_e/wts2016_e/wts16_toc_e.htm
2. https://databank.worldbank.org/source/world-development-indicators#

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References

Abban, O. J., Wu, J., & Mensah, I. A. (2020). Analysis on the nexus amid CO_2 emissions, energy intensity, economic growth, and foreign direct investment in Belt and Road economies: Does the level of income matter? *Environmental Science and Pollution Research International*, *27*(10), 11387–11402.

Álvarez-Herránz, A., Balsalobre, D., Cantos, J. M., & Shahbaz, M. (2017). Energy innovations-GHG emissions nexus: Fresh empirical evidence from OECD countries. *Energy Policy*, *101*, 90–100. https://doi.org/10.1016/j.enpol.2016.11.030

Ang, J. B. (2007). CO_2 emissions, energy consumption, and output in France. *Energy Policy*, *35*(10), 4772–4778. https://doi.org/10.1016/j.enpol.2007.03.032

Anwar, A., Siddique, M., Dogan, E., & Sharif, A. (2021). The moderating role of renewable and non-renewable energy in environment-income nexus for ASEAN countries: Evidence from Method of Moments Quantile Regression. *Renewable Energy*, *164*, 956–967. https://doi.org/10.1016/j.renene.2020.09.128

Balsalobre-Lorente, D., Shahbaz, M., Roubaud, D., & Farhani, S. (2018). How economic growth, renewable electricity and natural resources contribute to CO_2 emissions? *Energy Policy*, *113*, 356–367. https://doi.org/10.1016/j.enpol.2017.10.050

Begum, R. A., Sohag, K., Abdullah, S. M. S., & Jaafar, M. (2015). CO_2 emissions, energy consumption, economic and population growth in Malaysia. *Renewable and Sustainable Energy Reviews*, *41*, 594–601. https://doi.org/10.1016/j.rser.2014.07.205

Chang, M. C. (2015). Room for improvement in low carbon economies of G7 and BRICS countries based on the analysis of energy efficiency and environmental Kuznets curves. *Journal of Cleaner Production*, *99*, 140–151. https://doi.org/10.1016/j.jclepro.2015.03.002

Cowan, W. N., Chang, T., Inglesi-Lotz, R., & Gupta, R. (2014). The nexus of electricity consumption, economic growth and CO_2 emissions in the BRICS countries. *Energy Policy*, *66*, 359–368. [Database] https://doi.org/10.1016/j.enpol.2013.10.081

Dumitrescu, E. I., & Hurlin, C. (2012). Testing for Granger non-causality in heterogeneous panels. *Economic Modelling*, *29*(4), 1450–1460. https://doi.org/10.1016/j.econmod.2012.02.014

Garrone, P., & Grilli, L. (2010). Is there a relationship between public expenditures in energy R&D and carbon emissions per GDP? An empirical investigation. *Energy Policy*, *38*(10), 5600–5613. https://doi.org/10.1016/j.enpol.2010.04.057

Halicioglu, F. (2009). An econometric study of CO_2 emissions, energy consumption, income and foreign trade in Turkey. *Energy Policy*, *37*(3), 1156–1164. https://doi.org/10.1016/j.enpol.2008.11.012

Hassan, T., Song, H., & Kirikkaleli, D. (2022a). International trade and consumption-based carbon emissions: Evaluating the role of composite risk for RCEP economies. *Environmental Science and Pollution Research International*, *29*(3), 3417–3437. https://doi.org/10.1007/s11356-021-15617-4

Hassan, T., Song, H., Khan, Y., & Kirikkaleli, D. (2022b). Energy efficiency a source of low carbon energy sources? Evidence from 16 high-income OECD economies. *Energy*, *243*, 123063. https://doi.org/10.1016/jj.energy.2021.123063

Iftikhar, Y., He, W., & Wang, Z. (2016). Energy and CO_2 emissions efficiency of major economies: A non-parametric analysis. *Journal of Cleaner Production*, *139*, 779–787. https://doi.org/10.1016/j.jclepro.2016.08.072

Kasman, A., & Duman, Y. S. (2015). CO_2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: A panel data analysis. *Economic Modelling*, *44*, 97–103. https://doi.org/10.1016/j.econmod.2014.10.022

Khan, Z., Sisi, Z., & Siqun, Y. (2019). Environmental regulations an option: Asymmetry effect of environmental regulations on carbon emissions using non-linear ARDL. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *41*(2), 137–155.

Liddle, B. (2011). Consumption-driven environmental impact and age structure change in OECD countries: A cointegration-STIRPAT analysis. *Demographic Research*, *24*, 749–770. https://doi.org/10.4054/DemRes.2011.24.30

Liddle, B. (2013a). Population, affluence, and environmental impact across development: Evidence from panel cointegration modeling. *Environmental Modelling & Software*, *40*, 255–266. https://doi.org/10.1016/j.envsoft.2012.10.002

Liddle, B. (2013b). Urban density and climate change: A STIRPAT analysis using city-level data. *Journal of Transport Geography*, *28*, 22–29. https://doi.org/10.1016/j.jtrangeo.2012.10.010

Liddle, B. (2015). What are the carbon emissions elasticities for income and population? Bridging STIRPAT and EKC via robust heterogeneous panel estimates. *Global Environmental Change*, *31*, 62–73. https://doi.org/10.1016/j.gloenvcha.2014.10.016

Long, X., Naminse, E. Y., Du, J., & Zhuang, J. (2015). Nonrenewable energy, renewable energy, carbon dioxide emissions and economic growth in China from 1952 to 2012. *Renewable and Sustainable Energy Reviews*, *52*, 680–688. https://doi.org/10.1016/j.rser.2015.07.176

Machado, J. A., & Silva, J. S. (2019). Quantiles via moments. *Journal of Econometrics*, *213*(1), 145–173. https://doi.org/10.1016/j.jeconom.2019.04.009

Niu, S., Ding, Y., Niu, Y., Li, Y., & Luo, G. (2011). Economic growth, energy conservation and emissions reduction: A comparative analysis based on panel data for 8 Asian-Pacific countries. *Energy Policy*, *39*(4), 2121–2131. https://doi.org/10.1016/j.enpol.2011.02.003

Özbuğday, F. C., & Erbas, B. C. (2015). How effective are energy efficiency and renewable energy in curbing CO_2 emissions in the long run? A heterogeneous panel data analysis. *Energy*, *82*, 734–745. https://doi.org/10.1016/j.energy.2015.01.084

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, *22*(2), 265–312. https://doi.org/10.1002/jae.951
Pesaran, M. H., & Yamagata, T. (2008). Testing slope homogeneity in large panels. *Journal of Econometrics*, *142*(1), 50–93. https://doi.org/10.1016/j.jeconom.2007.05.010
Rahman, Z. U., & Ahmad, M. (2019). Modeling the relationship between gross capital formation and CO_2 (a)symmetrically in the case of Pakistan: An empirical analysis through NARDL approach. *Environmental Science and Pollution Research*, *26*(8), 8111–8124. https://doi.org/10.1007/s11356-019-04254-7
Sebri, M., & Ben-Salha, O. (2014). On the causal dynamics between economic growth, renewable energy consumption, CO_2 emissions and trade openness: Fresh evidence from BRICS countries. *Renewable and Sustainable Energy Reviews*, *39*, 14–23. https://doi.org/10.1016/j.rser.2014.07.033
Shahbaz, M., Balsalobre-Lorente, D., & Sinha, A. (2019). Foreign direct investment–CO_2 emissions nexus in Middle East and North African countries: Importance of biomass energy consumption. *Journal of Cleaner Production*, *217*, 603–614. https://doi.org/10.1016/j.jclepro.2019.01.282
Soytas, U., Sari, R., & Ewing, B. T. (2007). Energy consumption, income, and carbon emissions in the United States. *Ecological Economics*, *62*(3-4), 482–489. https://doi.org/10.1016/j.ecolecon.2006.07.009
Su, C. W., Naqvi, B., Shao, X. F., Li, J. P., & Jiao, Z. (2020). Trade and technological innovation: The catalysts for climate change and way forward for COP21. *Journal of Environmental Management*, *269*, 110774.
Ulucak, R., Khan, S. U. D., Baloch, M. A., & Li, N. (2020). Mitigation pathways toward sustainable development: Is there any trade-off between environmental regulation and carbon emissions reduction? *Sustainable Development*, *28*(4), 813–822.
United Nations. (2015). *Paris Agreement*. http://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf
Wahab, S. (2021). Does technological innovation limit trade-adjusted carbon emissions? *Environmental Science and Pollution Research*, *28*, 1–11.
Wahab, S., Imran, M., Safi, A., Wahab, Z., & Kirikkaleli, D. (2022). Role of financial stability, technological innovation, and renewable energy in achieving sustainable development goals in BRICS countries. *Environmental Science and Pollution Research*, *29*, 1–12.
Wahab, S., Zhang, X., Safi, A., Wahab, Z., & Amin, M. (2021). Does energy productivity and technological innovation limit trade-adjusted carbon emissions? *Economic Research-Ekonomska Istraživanja*, *34*(1), 1896–1912. https://doi.org/10.1080/1331677X.2020.1860111
Wang, Z., & Zhu, Y. (2020). Do energy technology innovations contribute to CO_2 emissions abatement? A spatial perspective. *The Science of the Total Environment*, *726*, 138574.
Wong, J. K., Li, H., Wang, H., Huang, T., Luo, E., & Li, V. (2013). Toward low-carbon construction processes: The visualisation of predicted emission via virtual prototyping technology. *Automation in Construction*, *33*, 72–78. https://doi.org/10.1016/j.autcon.2012.09.014
Wu, F., Fan, L. W., Zhou, P., & Zhou, D. Q. (2012). Industrial energy efficiency with CO_2 emissions in China: A nonparametric analysis. *Energy Policy*, *49*, 164–172. https://doi.org/10.1016/j.enpol.2012.05.035
Yuan, J., Kang, J., Yu, C., & Hu, Z. (2011). Energy conservation and emissions reduction in China – Progress and prospective. *Renewable and Sustainable Energy Reviews*, *15*(9), 4334–4347. https://doi.org/10.1016/j.rser.2011.07.117
Zhou, N., Khanna, N., Feng, W., Ke, J., & Levine, M. (2018). Scenarios of energy efficiency and CO_2 emissions reduction potential in the buildings sector in China to year 2050. *Nature Energy*, *3*(11), 978–984. https://doi.org/10.1038/s41560-018-0253-6