Does political risk drive environmental degradation in BRICS countries? Evidence from method of moments quantile regression

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Abstract
As a contribution to the political risk–environmental degradation literature, this study examines whether political risk drives environmental degradation in a multivariate framework. To achieve our study objective, we employed the method of moments quantile regression (MMQR) approach to analyze the effect of renewable energy use, economic growth, political risk, and globalization on quantiles of carbon emissions. The study utilized dataset stretching between 1990 and 2018 to investigate this interrelationship in the BRICS nations. The results generated from the MMQR mimic those of the three heterogeneous linear panel estimation techniques conducted (for robustness check), in terms of coefficient sign, magnitude, and significance. Using the MMQR technique, empirical results show that across quantiles (0.1–0.90), political risk, economic growth, and globalization positively affects environmental degradation. Renewable energy consumption, on the other hand, curbs environmental degradation across all quantiles (0.10–0.90). Furthermore, the outcomes of the FMOLS, DOLS, and FEOLS corroborated the MMQR outcomes. In addition, the outcomes of the Dumitrescu-Hurlin panel causality revealed that renewable energy use, political risk, economic growth, and globalization can significantly predict CO2 emissions in the BRICS nations. The findings offer intuition for policymakers to lessen CO2 emissions in BRICS nations via diversification and clean energy technologies such as carbon capture and storage.

Keywords Political risk · Globalization · Economic growth · Renewable energy · MMQR · BRICS

Introduction
Environmental quality plays a critical role in the attainment of sustainable development goals globally. Thus, the rising trend of environmental degradation poses a threat to health, clean energy, food security, life below water, prosperity, and long-term growth, all of which constitute some of the key deliverables of the SDGs (Awosusi et al. 2022; Shan et al. 2021). Interestingly, environmental quality is achievable via the instrumentality of institutional quality (Kirikkaleli and Adebayo, 2021; Zhang et al. 2009). The quality of government institutions, in terms of their effectiveness and efficiency, is overarching in political risk considerations. As such, political risks dictate the pace and destination of investments, thereby driving productive activities that culminate into long-term economic growth and development (Hayakawa et al. 2011; Khan and Akbar 2013; Adebayo et al. 2022). However, such growth, though desirable, represents the remote trigger for elevated CO2 emissions—especially in countries that rely mainly on fossil fuels rather than renewable energy in driving their...
production process, such as in Brazil, Russia, India, China, and South Africa (BRICS).

The BRICS economies are characterized by spectacular growth over the years at the expense of environmental quality. Carbon emissions in the BRICS countries is reported to have grown from 27.35% of the world total in 2001 to 41.3% in 2016, while accounting for over 40% of the global energy consumption and 21% of the global GDP (He 2020). The integration of these economies jointly contributes to the increased greenhouse gases emissions globally. Specifically, China is the largest GHG emitter, releasing about 10.67 billion metric tonnes of CO₂ emissions in 2020 (Statista 2020). China is also among the most prestigious and largest emerging nations globally. This is due to the nation’s endowment in terms of population and significant economic development. For example, it accounts for 45% of the world population, with a yearly growth rate of 6.5% (Baloch et al. 2021; Salman et al. 2019; Güngör et al. 2021; Adebayo and Kirikkaleli 2021).

The BRICS nations contribute about 40% to the world’s energy consumption and are massive contributors to the global GHG emissions, as a result of their economic activities (Hussain and Dogan 2021; Wang 2019). It is paramount to state here that the economic expansion and growth recorded in the BRICS nations is prone to several environmental issues. To achieve sound and sustainable environmental quality, the BRICS nations should not only consider cutting down on their use of non-renewable energy in consumption and production activities, but also improve on their quest for energy-saving and energy-efficient technologies by restructuring and curbing political issues that might delay prompt responses and policies for sustainable development goals (Akadiri and Adebayo 2021; Dingru et al. 2021).

The link between political risk and environmental quality is strong and can indeed be complex (Vu and Huang 2020). For instance, political institutions may limit the extent of environmental degradation through the design and implementation of appropriate policies; yet, they may also compromise with polluters as compensation for past political and economic support (Helland and Whitford 2003). Although governments are often expected to ensure their countries remain on a production path that creates a balance between economic gains and environmental degradation, this is often difficult in the face of rent-seeking behavior. As articulated by Biswas et al. (2012) and Sekrafi and Sghaier (2018), corruption or lack of transparency constrains the ability of public institutions to effectively provide the needed supervision and control to ensure environmental protection. This could drive the unsettled debate on the political risk-CO₂ emission nexus. Hence, it is imperative to examine this interaction for policymakers to pay attention to the impact of political risk on environmental degradation vis-à-vis other critical issues like globalization, economic growth, and renewable energy consumption, most especially for the BRICS nations.

A large body of existing studies have investigated the impacts of numerous determinants of environmental degradation, such as foreign direct investment (Gentry 1999; Nguyen 2020; Waqih et al. 2019), trade (Copeland and Taylor 2013), population and consumption (Dasgupta and Ehrlich 2013), globalization (Nguyen and Le 2020), financial risk (Zhao et al. 2021), democracy (Li and Reuveny 2006), renewable energy and technological innovation (Kirikkaleli et al. 2022a, b; Hussain and Khan 2021; Hussain and Dogan 2021; Zhao et al. 2021; Hassan et al. 2020), as well as climate change, carbon risk, and firm-level sustainability targets (Akhtar et al. 2020; Khan et al. 2021; Ullah and Nasim 2021). However, only a few studies have focused on the effect of political risk on environmental degradation. Some studies have employed corruption and other measures of institutional quality as proxies for political risk as a result of the difficulty involved in quantifying political risks. Specifically, studies including Su et al. (2021), Candau and Dienesch (2017), Cole (2007), Desai (1998), Masron and Subramaniam (2018), and Sekrafi and Sghaier (2018) all affirm that corruption increases CO₂ emission, while Zhang et al. (2016) report otherwise. The empirical work of Gani (2012) on the nexus between environmental degradation and five selected areas of governance (political stability, government effectiveness, regulatory quality, rule of law, and corruption) reveals that good governance indeed facilitates lower carbon emission. Similarly, some recent studies have shown that better political environments lead to a significant decline in environmental pollution (Su et al. 2021; Wand et al. 2020; Zhang and Chiu 2020). However, studies such as by Vu and Huang (2020) disagree with this position.

This study thus contributes empirically and methodologically to literature and derives its motivation from the sparseness of empirical literature on the subject as well as the need to explicitly establish the link between political risk and environmental degradation, especially in the BRICS economies which are designated to become the primary sources of global development in the near future (Sarkodie 2018). Therefore, the objective of the study is to determine whether political risk drives CO₂ emissions in the BRICS economies within the context of the sustainable development goals. In view of the above, this paper contributes to the existing literature in two folds. First, it examines the long-run effects of political risk on environmental degradation in the BRICS economies over the period 1990–2018, using a suite of econometric techniques—method of moments quantile regression (MMQR), fixed effects ordinary least squares (FEOLS), dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS), and Dumitrescu-Hurlin panel causality—which is limited in literature and for the sampled economies, to the best of the
The theoretical framework, data, and methodology

Theoretical framework

The discourse regarding carbon emissions and its regressors is the major highlight of this section. Economic expansion has the potential to affect environmental quality in three phases. First, it is critical to comprehend that when manufacturing continues to expand, more raw materials are required, which boosts economic activity while also degrading ecological quality. As a result, economic expansion raises the ecological footprint; this phase is regarded as the scale effect. The second phase is the composition effect, which implies that the sectorial framework of a nation influences the trends of raw material for manufacturing and pollution levels. As an illustration, the service sector of any nation usually produces less pollution because raw materials are not needed. This phase marks a turning point in the effort to limit environmental deterioration. Composition channels help to minimize some of the negative effects of economic growth on the environment. The third phase is the technique effect, which suggests that governments may enhance environmental quality by using environmentally friendly technologies that produce less pollution and slow down the rate of environmental deterioration.

Globalization is a term that transcends trade liberalization and flow of capital. It comprises of economic, social, and political dimensions. On a global level, the globalization process results in several environmental issues, such as the depletion of the ozone layer, increased resource usage, deforestation, and desertification (He et al. 2021). Globalization also increases the emission of CO₂ and other GHGs by encouraging economic activity and energy usage. Conversely, it can contribute to enhancing the quality of the environment by promoting ecologically friendly energy technology (Ansari et al. 2021). Renewable energy is the purest kind of energy and does not result in emissions or depletion of resources; thus, its usage benefits the environment. Solar, hydro, and wind energy are the most environmentally friendly sources of energy. Renewable energy, unlike fossil fuels, is unlimited.

Political stability is expected to raise wealth levels, which in turn increases people’s awareness of environmental emissions and climate change. This scenario often enhances the political pressures on policymakers to achieve a sustainable environment (Su et al. 2021). Therefore, lowering political risk in a country can reduce carbon emissions, which means that political risk is likely to be a vital factor in the deterioration of ecosystems and the environment. Based on the discussion above, the following economic function is formulated:

\[
CO_{2t} = f(GDP_t, PR_t, REC_t, GLOB_t)
\]  

Data

This study assesses the influence of political risk (PR) on carbon emissions (CO₂) in the BRICS nations, while controlling for the effects of globalization (GLO), economic growth (GDP), and renewable energy consumption (REC). The panel dataset used stretches between 1990 and 2018.¹ Information on the variables utilized (i.e., source, sign, and measurement) are presented in Table 1. Table 2 presents the

¹ Carbon emissions data (which represents the variable of interest) is only available until 2018. Thus, the study period is based solely on data availability.
data description of the variables. The mean of GDP (5919.1) is the highest, ranging between 575.50 and 11993.2, followed by that of PR (62.508) which ranges between 3.1805 and 58.652, then that of GLO (41.964) which ranges between 14.743 and 58.691, that of REC (26.283) which ranges between 3.1805 and 58.653, and lastly, that of CO2 (5.500) which ranges between 0.6626 and 17.116. The Jarque–Bera values for all the variables affirm that all the indicators are not normally distributed.

**Methodology**

In this study, the dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS), and fixed effects ordinary least squares (FEOLS) are utilized for a comparative analysis. We employ the method of moments quantile regression (MMQR) method, which allows us to assess the impact of several regressors over different quantiles. The FEOLS approach with Driscoll and Kraay standard errors, which are resistant to broad forms of cross-sectional dependence and autocorrelation up to a specified lag, are used. Heterogeneity issues such as discrepancies in means between cross sections and variation in cross-sectional change to the cointegrating equilibriums of the CO2 conditional distribution, which are useful for a more detailed examination of the empirical interrelatedness, are crucial factors to consider in dynamic cointegrated panels estimation (Pedroni 2004). The FMOLS model initiated by Pedroni contains individual intercepts and allows for a wide range of serial correlation features of error processes across panel members; thus, it adequately tackles these difficulties. In addition, the DOLS model as advanced by Kao and Chiang (2001) extends the estimator and centers on Monte Carlo simulations. The DOLS estimator is unbiased, and augments lagged and lead differences in series to reduce or minimize endogenous feedback.

Due to limitations in the panel approaches discussed above, the quantile regression (QR) estimator is utilized to analyze the distributional and heterogeneous effects across each quantile (Anwar et al. 2021). Developed by Bassett and Koenker (1978), this approach is typically used to determine the conditional median of different response quantiles. As a result, the quantile-on-quantile regression (QQR) is more sensitive to the presence of outliers in estimations, and it can also be used to describe the weak correlation between the conditional means of two indicators (Binder and Coad 2011). Nevertheless, an improved QQR, designated as methods of moments quantile regression (MMQR), that considers fixed effects is proposed by Machado and Santos Silva (2019). This approach is effective in detecting the effect of covariance of CO2 emission determinants under conditional heterogeneity. This approach is also useful when the model contains endogenous explanatory variables and is entrenched with individual effects. For location-scale
variation framework, the conditional quantiles \( Q_y(\tau|X) \) are depicted as follows:

\[
Y_{it} = \alpha_i + X_{it}'\beta + (\delta_i + Z_{it}'\gamma)U_{it} \tag{2}
\]

where the probability \( \{\delta_i + Z_{it}'\gamma > 0\} = 1 \) and \( (\alpha, \beta', \delta, \gamma)' \) are the assessed parameters. \( (\alpha_i, \delta_i) \), \( i = 1, 2, \ldots, n \) presents the discrete FE. \( Z \) denotes \( K \)-vector in unknown modules \( X \), which are different modifications of \( f \). This is illustrated below:

\[
Z_i = Z_i(X), l = 1, \ldots, k \tag{3}
\]

\( U_{it} \) and \( X_{it} \) are similarly distributed beyond time-period \( (t) \) and individual \( (i) \). For any fixed \( U_{it}, X_{it} \) is normally distributed and time-independent \( (t) \). As stated by Machado and Santos Silva (2019), \( U_{it} \) is the standardized momentum conditions orthogonal to \( X_{it} \). This is illustrated as follows:

\[
Q_y(\tau|X_{it}) = (\alpha_i + \delta_i q(\tau)) + X_{it}'\beta + Z_{it}'\gamma q(\tau) \tag{4}
\]

In Eq. (4), \( X_{it} \) is a descriptive variable vector and is described in natural log of all the regressors, i.e., GDP, PR, REC, and GLO. The quantile distribution of \( Y_{it} \) is illustrated by \( Q_y(\tau|X_{it}), \) which is restrictive on the explanatory position \( X_{it}' \), \( -\alpha i (\tau) = \alpha i + \delta_i q(\tau); \) the scalar to unveil fixed effects of quantile-\( \delta \) across individual \( I \) and the sample quantile is depicted by \( q(\delta) \). This is evaluated by addressing optimization in the manner described below:

\[
\min_q \sum \rho_i(R_{it} - (\delta_i + Z_{it}'\gamma)q) \tag{5}
\]

where \( \rho_i(A) = (\tau - 1)AI\{A \leq 0\} + TAI\{A > 0\} \) indicates the check function.

### Results, findings, and discussion

#### Pre-estimations outcomes

In this section, we report the empirical results and discuss the findings. We employ second-generation panel techniques that control for possible cross-sectional dependence (CSD) and heterogeneity inherent in panel data, which first-generation panel techniques fail to account for. It is paramount to state here that the inability to capture these factors may not only have an impact on the true parameter due to common unobserved shocks, but also reduce the efficiency benefits of carrying out panel studies (Phillips and Sul 2009). Table 2 reports the descriptive statistics of the data, with a unique feature of nonlinearity as shown via the Jarque–Bera test.

We conduct the slope homogeneity test as reported in Table 3. Based on the result, we reject the null hypothesis; thus, the slope coefficient is heterogeneous. This informs the decision to switch from conventional panel unit root techniques to ones that capture the heterogeneity components of the panel series. Table 4 reports the results of the test for cross-sectional dependence and the associated second-generation panel unit root tests—cross-sectionally augmented IPS (CIPS) as advanced by Pesaran (2007) and cross-sectionally augmented Dickey-Fuller (CADF). The CSD test results indicate that the test statistics of all variables under observation are significantly different from zero across panels at 1% significance level (have common unobserved shocks), while the CIPS and CADF test results confirm that all the series are integrated at first order I(1). The results are all significant at 1% significance level.

#### Cointegration outcomes

Bootstrap Westerlund and Edgerton (2007) cointegration test results are reported in Table 5. Based on the reported results, we confirm the rejection of the null hypothesis of no long-run cointegration relationship; thus, there is an existence of cointegration among the variable series in the long run. Having confirmed the existence of a long-run nexus, we proceed towards the estimation of long-run parameters. It is crucial to reiterate that the underlying data series for this study are cross-sectionally dependent. In order to capture this factor, our panel estimation method must integrate panel econometric methods that are efficient, reliable, and robust to the impact of CSD to take out the potential size distortions. Thus, in compliance, a group of heterogeneous panel estimations methods that effectively account for these problems is utilized as discussed earlier.

#### Long-run estimators (FMOLS, DOLS, and FEOLS) outcomes

Table 6 reports the outcomes of FMOLS, DOLS, and FEOLS, respectively. We observe that the magnitude, sign, and significance of all coefficients obtained from FMOLS, DOLS, and the FEOLS specifications are substantially similar. This affirms the reliability and robustness of the estimates. Table 6 shows that political risk, economic growth, and globalization contribute positively and significantly to increase in environmental degradation in the BRICS countries at 1 and 5% significance levels, while renewable energy consumption is inversely related to environmental degradation. These findings resonate with those of Akadiri et al. (2020), Akadiri and Adebayo (2021), and Saint et al. (2019).
Empirical results show that political risk dampens environmental degradation. This result contradicts the findings of Vu and Huang (2020) for Vietnam, where they argue that political risk has an inverse impact on the environment. However, our findings resonate with that of Su et al. (2021), who find that a better political environment would improve environmental quality. It is paramount to say here that the combination of political risk and environmental risk could have a grievous impact on individual and private businesses, for instance, the trade war between China and the USA, as well as the COVID-19 pandemic which was escalated by globalization. In addition, we find that globalization and economic growth also contribute positively to environmental degradation in BRICS, while renewable energy use improves environmental quality across all quantiles. This is the first of its kind in literature, where political risk and its impact on carbon emissions across quantiles are documented.

Method of moments quantile regression outcomes

Table 7 presents the MMQR results. Across all quantiles (0.1–0.90), the effect of economic growth on CO2 emissions is positive. Furthermore, as we move into the higher quantiles, the strength of the coefficients becomes stronger. Therefore, economic expansion in BRICS nations contributes to environmental degradation across all quantiles (0.1–0.90) in the BRICS nations. Moreover, the effect of political risk on CO2 emissions is positive across all quantiles (0.1–0.90) with an increasing trend as we move into the higher quantiles. This simply implies that political risk in the BRICS nations harms the quality of the environment in the BRICS nation. Besides, across all quantiles (0.1–0.90), we observed positive interrelationship between globalization and CO2 emissions, which implies that globalization, deteriorate the quality of the environment in the BRICS nations. In addition, we observed a decreasing trend regarding the coefficients of globalization as we move to the higher quantiles. This outcome also validates the pollution-haven hypothesis for the BRICS nations. Lastly, renewable energy consumption affects CO2 emissions negatively across all quantiles (0.1–0.90). In addition, we observed a decreasing trend regarding the coefficients of globalization as we move to the higher quantiles. Therefore, renewable energy use helps to abate environmental degradation in the BRICS nations. Figure 1 shows graphical plots of MMQR. It reflects the interconnection among the variables at different quantiles. In addition, Fig. 2 shows the comparison between the coefficients of MMQR, FEOLS, FMOLS, and DOLS while Fig. 3 shows the summary of the empirical findings.

Dumitrescu-Hurlin panel causality test outcome

Figure 2 presents graphical plots comparing the results of all the panel techniques employed. In general, results show that all the models report similar findings in terms of magnitude, sign, and significance. However, MMQR shows results that are more concise on the true relationships that exist among individual regressors and the dependent variable across quantiles. Table 8 shows the findings of the Granger causality test advanced by Dumitrescu and Hurlin (2012). We observe from the $p$-value of the estimates reported that there is a one-way causal relationship running from globalization, political risk, and renewable energy consumption to carbon emission at $1\%$ significance level. We however find a two-way causality between economic growth and carbon emission at $1\%$ significance level. These results align with

| Variables | CSD | CIPS | CADF |
|-----------|-----|------|------|
| Pesaran scaled LM | Pesaran CD | I(0) | I(I) | I(0) | I(I) |
| CO$_2$ | 65.593* | 22.522* | −2.103 | −4.470* | −1.835 | −3.454* |
| GDP | 117.88* | 34.080* | −2.143 | −3.227* | −1.714 | −2.900* |
| GLOB | 68.131* | 24.601* | −2.033 | −4.745* | −2.074 | −3.519* |
| REC | 26.915* | 10.103* | −1.801 | −4.094* | −2.303 | −3.972* |
| PR | 6.1269* | 3.6240* | −1.832 | −4.217* | −2.121 | −4.189* |

*, **, and *** represent $P < 1\%$, $P < 5\%$ and $P < 10\%$, respectively. Note that all variables are stationary at first difference.

**Table 4** CSD, CIPS, and CADF unit root test results

| Statistics | Gt | Ga | Pt | Pa |
|------------|----|----|----|----|
| Value | −1.997 | −5.647 | −4.651 | −5.562 |
| $P$-value | 0.094 | 0.529 | 0.027 | 0.081 |

**Table 5** Westerlund (2007) cointegration outcomes

| Statistics | GDP | PR | REC | GLOB |
|------------|-----|----|-----|------|
| FMOLS | 0.1482** | 0.2278** | −0.6004* | 0.2542* |
| D-OLS | 0.1743* | 0.3481** | −0.6941* | 0.3144* |
| FEOLS | 0.1972*** | 0.4141* | −0.7921* | 0.2976** |

*, **, and *** stand for $P < 1\%$, $P < 5\%$, and $P < 10\%$, respectively.
existing findings (see Akadiri et al. 2019; Saint Akadiri et al. 2020a, b).

Conclusion and policy recommendations

Conclusion

As a contribution to the political risk-environmental degradation literature, this study examines whether political risk drives environmental degradation in a multivariate framework. We employ reliable, robust, and efficient novel panel estimation methods over the period 1990–2018 in the case of BRICS. To achieve our study objective, we employ the MMQR approach to analyze the many effects of the exogenous variables over the range of diverse quantiles of carbon emissions. Results generated from the MMQR mimic those of the three heterogeneous linear panel estimation techniques conducted (for robustness check) in terms of coefficient sign, magnitude, and significance. The results generated from the MMQR mimic those of the three heterogeneous linear panel estimation techniques conducted (for robustness check), in terms of coefficient sign, magnitude, and significance. Using the MMQR technique, empirical results show that across quantiles (0.1–0.90), political risk, economic growth, and globalization positively impact environmental degradation. Renewable energy consumption, on the other hand, curb environmental degradation across all quantiles (0.10–0.90). Furthermore, the outcomes of the FMOLS, DOLS, and FEOLS corroborated the MMQR outcomes. In addition, the outcomes of the Dumitrescu–Hurlin panel causality revealed that renewable energy use, political risk, economic growth, and globalization can significantly predict CO2 emissions in the BRICS nations.

Policy recommendations

From a policy perspective, it appears that heightened political risk, in a globalized economy with moderate and consistent economic growth via energy-efficient technology (renewable energy source), would escalate environmental degradation and thus reduce environmental quality. Although this study reports an inverse relationship between renewable energy consumption and environment degradation across quantiles, we are of the opinion that putting in place a renewable energy source (for consumption and production activities) without stable political atmospheres, environmentally friendly economic activities and more regulated global dealings would make the attainment of the sustainable development goals unlikely. Policymakers should avoid heightened political risk, as it delays the process and timeframe of responding to economic and business issues, thereby affecting both the economy and the environment at large.

Table 7 Outcomes of MMQR

| Variables | Location | Scale |
|-----------|----------|-------|
| GDP       | 0.1905** | 0.1710* |
| PR        | 0.3194** | 0.2131** |
| REC       | 0.3252** | 0.3029** |
| GL        | 0.3252** | 0.3029** |

*, **, and *** stand for 1%, 5%, and 10% significance levels, respectively.
This study is not without its limitation. A baseline measure of carbon emissions is used in this study to capture environmental degradation. Future research may focus on other environmental metrics such as load capacity factor, and other key drivers of environmental pollution such as information communication technology and structural change. Future research may also sample other blocs of countries such as MINT, and ASEAN, using the same econometric techniques or more advanced ones as deemed fit.
Author contribution  Tomiw a collected and analyzed the data. Elijah wrote the introduction and literature review. Seyi Saint Akadiri wrote the results, conclusion and policy suggestion. Yetunde worked on study development and proofreading.

Data availability  Corresponding authors can provide the data used in the study on appropriate request.

Table 8  Dumitrescu-Hurlin panel causality test outcome

| Causality path | W-stat | Zbar-stat | Prob  |
|----------------|--------|-----------|-------|
| GDP→CO₂        | 9.94664| 7.12198   | 0.0000|
| CO₂→GDP        | 6.39118| 3.85322   | 0.0001|
| GLOB→CO₂       | 5.47897| 3.01456   | 0.0026|
| CO₂→GLOB       | 3.70755| 1.38599   | 0.1657|
| PR→LCO₂        | 7.36597| 4.74940   | 0.0000|
| CO₂→PR         | 3.36092| 1.06731   | 0.2858|
| REC→CO₂        | 5.40792| 2.94924   | 0.0032|
| CO₂→REC        | 2.85556| 0.60270   | 0.5467|

Fig. 3  Empirical findings from MMQR, FMOLS, DOLS, and FEOLS

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| CO₂→REC        | 2.85556| 0.60270   | 0.5467|

Declarations

Competing interests  The authors declare no competing interests.

References

Adebayo TS, Kirikkaleli D (2021) Impact of renewable energy consumption, globalization, and technological innovation on environmental degradation in Japan: application of wavelet tools. Environ Dev Sustain 23(11):16057–16082

Adebayo TS, Agyekum EB, Kamel S, Zawbaa HM, Altuntaş M (2022) Drivers of environmental degradation in Turkey: designing an SDG framework through advanced quantile approaches. Energy Rep 8:2008–2021

Akadiri SS, Adebayo TS (2021) Asymmetric nexus among financial globalization, non-renewable energy, renewable energy use, economic growth, and carbon emissions: impact on environmental sustainability targets in India. Environ Sci Pollut Res 4(5):1–13

Akadiri SS, Bekun FV, Taheri E, Akadiri AC (2019) Carbon emissions, energy consumption and economic growth: a causality evidence. Int J Energy Technol Policy 15(2–3):320–336

Akadiri SS, Lasisi TT, Uzuner G, Akadiri AC (2020) Examining the causal impacts of tourism, globalization, economic growth and carbon emissions in tourism island territories: bootstrap panel Granger causality analysis. Curr Issue Tour 23(4):470–484

Akhtar P, Ullah S, Amin SH, Kabra G, Shaw S (2020) Dynamic capabilities and environmental sustainability for emerging economies’ multinational enterprises. Int Stud Manag Organ 50(1):27–42
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. Renew Energy 164:956–967. https://doi.org/10.1016/j.renene.2020.09.128

Ansari MA, Haider S, Masood T (2021) Do renewable energy and globalization enhance ecological footprint: an analysis of top renewable energy countries? Environ Sci Pollut Res 28(6):6719–6732

Awossusi AA, Adebayo TS, Altuntaş M, Agyekum EB, Zawbaa HM, Kameł S (2022) The dynamic impact of biomass and natural resources on ecological footprint in BRICS economies: a quantile regression evidence. Energy Rep 8:1979–1994

Baloch MA, Danish, Quy Y (2021) Does energy innovation play a role in achieving sustainable development goals in BRICS countries? Environ Technol 5(5):1–10

Bassett G, Koenker R (1978) Asymptotic theory of least absolute error regression. J Am Stat Assoc 73(363):618–622. https://doi.org/10.1080/01621459.1978.10480065

Binder M, Coad A (2011) From Average Joe’s happiness to Miserable Jane and Cheerful John: using quantile regressions to analyze the full subjective well-being distribution. J Econ Behav Organ 79(3):275–290. https://doi.org/10.1016/j.jebo.2011.02.005

Biswas AK, Farzanegan MR, Thum M (2012) Pollution, shadow economy and corruption: theory and evidence. Ecol Econ 75(C):114–125. https://doi.org/10.1016/j.ecolec.2012.01.007

Candau F, Dienesch E (2017) Pollution haven and corruption paradise. J Environ Econ Manag 85(C):171–192. https://doi.org/10.1016/j.jeem.2017.05.005

Cole S (2007) Beyond authenticity and commodification. Ann Tour Res 34(4):943–960

Copeland BR, Taylor MS (2013) Trade and the environment: theory and evidence. Trade Environ Theory Evid 6(6):56–69. https://doi.org/10.2307/3552527

Dasgupta PS, Ehrlich PR (2013) Pervasive externalities at the population, consumption, and environment nexus. Science 340(6130):324–328. https://doi.org/10.1126/science.1224664

Desai U (1998) Environmental degradation and economic growth in developing countries. Ecol Polit Dev Countries 23(4):1–46

Dingru L, Ramzan M, Irfan M, Gülmez O, İskİ H, Husam R (2021) The role of renewable energy consumption towards carbon neutrality in BRICS nations: does globalization matter? Front Environ Sci 5(18):555–569

Dumitrescu EI, Harlín C (2012) Testing for Granger non-causality in heterogeneous panels. Econ Model 29(4):1450–1460

Gani A (2012) The relationship between good governance and carbon dioxide emissions: evidence from developing economies. J Econ Dev 37:77–93

Gentry B (1999) Foreign direct investment and the environment: boon or bane. Foreign Direct Invest Environ 3(12):21–45

Güngör H, Kirikkaleli D, Adebayo TS (2021) Consumption-based carbon emissions, renewable energy consumption, financial development and economic growth in China. Bus Strat Environ 9(4):23–38

Hassan ST, Baloch MA, Tarar ZH (2020) Is nuclear energy a better alternative for mitigating CO2 emissions in BRICS countries? An empirical analysis. Nucl Eng Technol 52(12):2969–2974

Hayakawa K, Kimura F, Lee H-H (2011) How does country risk matter for foreign direct investment. Institute of Developing Economics Discussion Paper No. 281

He X (2020) Consumption-based carbon emissions in Mexico: An analysis using the dual adjustment approach. Sustain Prod Consum 27:947–957. https://doi.org/10.1016/j.spc.2021.02.020

He Y, Wang Z, Wang H, Wang Z, Zeng G, Xu P, …, Zhao Y (2021) Metal-organic framework-derived nanomaterials in environment-related fields: fundamentals, properties and applications. Coord Chem Rev 429:213618

Helland E, Whitford AB (2003) Pollution incidence and political jurisdiction: evidence from the TRI. J Environ Econ Manag 46(3):403–424. https://doi.org/10.1016/S0099-0969(03)00033-0

Hussain M, Dogan E (2021) The role of institutional quality and environment-related technologies in environmental degradation for BRICS. J Clean Prod 304:127059

Hussain M, Khan JA (2021) The nexus of environment-related technologies and consumption-based carbon emissions in top five emitters: empirical analysis through dynamic common correlated effects estimator. Environ Sci Pollut Res 12(10):1–10

Kao C, Chiang MH (2001) On the estimation and inference of a cointegrated regression in panel data. In: Nonstationary panels, panel cointegration, and dynamic panels. Econometrica 4(10):66–79

Khan MM, Akbar MI (2013) The impact of political risk on foreign direct investment. Int J Econ Financ 5(8):1916–9728. Published by Canadian Center of Science and Education

Khan MK, Trinh HH, Khan IU, Ullah S (2021) Sustainable economic activities, climate change, and carbon risk: an international evidence. Environ Dev Sustain 25:12491–12506. https://doi.org/10.1007/s11356-018-1473-9

Kirikkaleli D, Adebayo TS (2021) Do public-private partnerships in energy and renewable energy consumption matter for consumption-based carbon dioxide emissions in India? Environ Sci Pollut Res 28(23):30139–30152

Kirikkaleli D, Awossusi AA, Rjoub H, Agyekum EB, Adebayo TS (2022a) The influence of renewable energy usage on consumption-based carbon emissions in MINT economies. Heliyon 8(2):12–24

Kirikkaleli D, Güngör H, Adebayo TS (2022b) Consumption-based carbon emissions, renewable energy consumption, financial development and economic growth in Chile. Bus Strat Environ 31(3):1123–1137

Li Q, Reuveny R (2006) Democracy and environmental degradation. Int Stud Quart 50(4):935–956

Machado JAF, Santos Silva JMC (2019) Quantiles via moments. J Econ 213(1):145–173. https://doi.org/10.1016/j.jeconom.2019.04.009

Masron TA, Subramaniam Y (2018) The environmental Kuznets curve in the presence of corruption in developing countries. Environ Sci Pollut Res 25:12491–12506. https://doi.org/10.1007/s11356-018-1473-9

Nguyen CH (2020) The impact of foreign direct investment, aid and exports on economic growth in Vietnam. J Asian Financ Econ Bus 7(10):581–589

Nguyen TCV, Le QH (2020) Impact of globalization on coal consumption in Vietnam: an empirical analysis. J Asian Financ Econ Bus 7(6):185–195

Pedroni P (2004) Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. Economet Theor 20(3):597–625. https://doi.org/10.1017/S0266466604020373

Pesaran MH (2007) A simple panel unit root test in the presence of cross-section dependence. J Appl Economet 22(2):265–312

Phillips PC, Sul D (2009) Economic transition and growth. J Appl Economet 24(7):1153–1185

Qin L, Raheem S, Murshed M, Miao X, Khan Z, Kirikkaleli D (2021) Does financial inclusion limit carbon dioxide emissions? Analyzing the role of globalization and renewable electricity output. Sustain Dev 29(6):1138–1154

Saint SA, Adebayo TS, Akpan U, Aladenika B (2020) Asymmetric effect of financial globalization on carbon emissions in G7 countries: Fresh insight from quantile-on-quantile regression. Energy Environ 4(2):24–38. https://doi.org/10.1080/09589947.2019.17084290

Saint SA, Adebayo TS, Riti JS, Tony Odu A (2019) Interaction among geopolitical risk, trade openness, economic growth, carbon emissions and its implication on climate change in India. Energy Environ 1(9):10–25. https://doi.org/10.1177/09589947221083236
Saint Akadiri S, Alola AA, Akadiri AC (2019) The role of globalization, real income, tourism in environmental sustainability target. Evidence from Turkey. Sci Total Environ 687:423–432
Saint Akadiri S, Alola AA, Bekun FV, Etokakpan MU (2020a) Does electricity consumption and globalization increase pollutant emissions? Implications for environmental sustainability target for China. Environ Sci Pollut Res 27(20):25450–25460
Saint Akadiri S, Alola AA, Olasehinde-Williams G, Etokakpan MU (2020b) The role of electricity consumption, globalization and economic growth in carbon dioxide emissions and its implications for environmental sustainability targets. Sci Total Environ 708:134653
Salman M, Long X, Dauda L, Mensah CN, Muhammad S (2019) Different impacts of export and import on carbon emissions across 7 ASEAN countries: a panel quantile regression approach. Sci Total Environ 686:1019–1029
Sarkodie SA (2018) The invisible hand and EKC hypothesis: what are the drivers of environmental degradation and pollution in Africa? Environ Sci Pollut Res 25(22):21993–22022
Sekrafi H, Sghaier A (2018) Examining the relationship between corruption, economic growth, environmental degradation, and energy consumption: a panel analysis in MENA region. J Knowl Econ 9(3):963–979. https://doi.org/10.1007/s13132-016-0384-6
Shan S, Ahmad M, Tan Z, Li RYM, Kirikkaleli D (2021) The role of energy prices and non-linear fiscal decentralization in limiting carbon emissions: tracking environmental sustainability. Energy 234:121243
Statista (2020) https://www.statista.com/. Accessed 20 January 2022
Su ZW, Umar M, Kirikkaleli D, Adebayo TS (2021) Role of political risk to achieve carbon neutrality: evidence from Brazil. J Environ Manag 294:113463
Ullah S, Nasim A (2021) Do firm-level sustainability targets drive environmental innovation? Insights from BRICS economies. J Environ Manag 294:112754
Vu T, Huang DC (2020) Economic development, globalization, political risk and CO₂ emission: the case of Vietnam. J Asian Financ Econ Bus 7(12):21–31
Wand S, Jammazi R, Aloui C, Ahmad P, Shariif A (2020) On the nonlinear effects of energy consumption, economic growth, and tourism on carbon footprints in the USA. Environ Sci Pollut Res 28(16):20128–20139
Wang Z (2019) Does biomass energy consumption help to control environmental pollution? Evidence from BRICS countries. Sci Total Environ 670:1075–1083
Waqih MAU, Bhutto NA, Ghumro NH, Kumar S, Salam MA (2019) Rising environmental degradation and impact of foreign direct investment: an empirical evidence from SAARC region. J Environ Manage 243:472–480. https://doi.org/10.1016/j.jenvman.2019.05.00
Westlund J (2007) Testing for error correction in panel data. Oxf Bull Econ Stat 69(6):709–748
Westlund J, Edgerton DL (2007) A panel bootstrap cointegration test. Econ Lett 97(3):185–190
Zhang W, Chiu YB (2020) Do country risks influence carbon dioxide emissions? A non-linear perspective. Energy 206:118048
Zhang J, Terrones M, Park CR, Mukherjee R, Monthioux M, Koratkar N, …, Bianco A (2016) Carbon science in 2016: Status, challenges and perspectives. Carbon 98(70):708-732
Zhao J, Shahbaz M, Dong X, Dong K (2021) How does financial risk affect global CO₂ emissions? The role of technological innovation. Technol Forecast Soc Chang 168:120751
Zhang XP, Wang TS, Cheng XM (2009) Energy consumption, carbon emissions, and economic growth in China. Ecol Econ 68:2706–2712

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