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RESEARCH ARTICLE

Revisiting the energy-economy-environment relationships for attaining environmental sustainability: evidence from Belt and Road Initiative countries

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Abstract

The Belt and Road Initiative (BRI) is an ambitious development project initiated by the Chinese government to foster economic progress worldwide. In this regard, this study aims to investigate the dynamics of energy, economy, and environment among 42 BRI developing countries using an annual frequency panel dataset from 1995 to 2019. The major findings from the econometric analyses revealed that higher levels of energy consumption, economic growth, population growth rate, and FDI inflows exhibit adverse environmental consequences by boosting the CO_2 emission figures of the selected developing BRI member nations. However, it is interesting to observe that exploiting renewable energy sources, which are relatively cleaner compared to the traditionally-consumed fossil fuels, and fostering agricultural sector development can significantly improve environmental well-being by curbing the emission levels further. On the other hand, financial development is found to be ineffective in explaining the variations in the CO_2 emission figures of the selected countries. Besides, the causality analysis shows that higher energy consumption, FDI inflows, and agricultural development cause environmental pollution by boosting CO_2 emissions. However, economic growth, technology development, financial progress, and renewable energy consumption are evidenced to exhibit bidirectional causal associations with CO_2 emissions. In line with these findings, several relevant policies can be recommended for the BRI to be environmentally sustainable.

Keywords Energy consumption · GDP growth · Agricultural development · Carbon emissions · Renewable energy · Environmental sustainability · Belt and Road Initiative

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Introduction

The Belt and Road Initiative (BRI), conceptualized by the Chinese government, has recently received significant degrees of international focus primarily due to its major economic and environmental implications for the associated countries. Since its inception in 2013, this initiative has promoted strong economic cooperation among many Asian, European, and African nations (Irshad 2015). The BRI is similar to the ancient silk road that played a critical role in connecting the West and the East on various socioeconomic fronts for many centuries. In the same way, the BRI campaign is envisioned to bring about a win-win economic environment for its associated countries through massive infrastructure development and improved modes of transportation and connectivity. In the last 5 years, the number of member nations under the BRI has remarkably increased; for instance, in 2018, there were 91 countries from the five different continents, which increased to 138 by March 2020 (Chen et al. 2020a, b; Coenen et al. 2020). Therefore, it can be asserted that the BRI is aiming to become a global network to initiate noteworthy changes that would stimulate the economic momentum in its member countries.

The BRI member nations constitute nearly 70% of the world population and account for more than 50% of the global output level (World Bank 2020). Although the BRI is assumed to face some opposition in the near future, its successful execution is presumed to position its member countries, particularly China, as influential regional and global leaders. As of now, the very objective of BRI is to strengthen trade and commerce within this region by eradicating the existing barriers these countries have endured in the past (Chan et al. 2020). Accordingly, the Chinese government has devised an extensive investment plan in this region for infrastructure development and the setting up of economic corridors. The Commerce Ministry of China reported that Chinese companies made a total investment of about 29 billion US dollars from 2017 to 2018 in 56 BRI member nations. Moreover, in the first half of 2019, Chinese companies invested around 8.97 billion US dollars in these countries which is 12.4% more than the amount invested in the previous year. The value of the total contract under the BRI also rose by more than 60% from the same period of the previous year (MOFCOM 2019). Besides, the International Energy Agency estimated that energy investments in BRI projects have more than doubled with time (IEA 2014). Furthermore, as per the estimates by the China power team (2017), the value of infrastructure investments in Asia-Pacific countries would reach close to 23 trillion US dollars by 2030 under the BRI. It can be said that about two-thirds of the total investments under the BRI have gone into the developing countries with the ultimate intention of accelerating their rates of economic development. Meanwhile, more than 7000 new development projects are said to be initiated under the BRI that comprises projects related to power plants, transportation, and poverty reduction, in particular. These investment profiles collectively portray that the BRI is likely to induce substantial degrees of energy demand across the member nations in the years to come.

The BRI, along with stimulating economic gains, is also expected to exert severe environmental consequences given the fact that the execution of the BRI is likely to substantially enhance the energy requirements of the member countries (Baloch et al. 2019; Wen et al. 2020). Moreover, since more developing countries are opting to join the BRI scheme, the energy consumption-induced environmental problems can be expected to escalate in the years to come. This is because the developing countries are predominantly fossil fuel-intensive whereby a lion's share of their respective electricity outputs from gas, coal, and furnace oils (Rehman et al. 2019; Murshed and Tanha 2021; Murshed et al. 2021a). Besides, it is believed that the developing countries, in quest of globalization, tend to prioritize attainment of economic growth at the cost of environmental degradation (Murshed 2020a, b; Murshed et al. 2021b, 2021c). Hence, under such circumstances, the execution of the BRI can be hypothesized to cause environmental distress across the developing countries that are members of this initiative. Moreover, keeping the fossil fuel dependency and the economic growth-environmental degradation tradeoff of the developing countries into consideration, several existing studies have scrutinized the energy-economy-environment nexus in the context of the developing countries; but the findings are inconclusive. Besides, whether or not the BRI is going to ensure environmentally sustainable development within the developing low- and middle-income BRI member countries is yet to be extensively explored in the literature. Against this milieu, this study aims to investigate the dynamics of the energy-economy-environment nexus in the context of 42 developing countries under the BRI using annual frequency data from 1995 to 2019.

From the energy-economy-environment literature per se, this study stands out from the rest in the following ways. Firstly, although the existing studies have predominantly focused on the BRI nations irrespective of the income group those economies belong to, this current study is the first to consider only the middle- and low-income developing countries under the BRI region. The analysis of the developing countries is important because these nations are relatively more vulnerable to environmental hazards associated with industrialization and economic growth. Secondly, this study further contributes to the literature by controlling for agricultural value-added, gross domestic credit provided by private sector organizations for energy, economic growth, and environmental well-being that relate to the BRI. Moreover, this current study stresses the prospects and problems associated with energy use, sustainable economic development, and environmental problem-solving that the BRI developing countries will have to deal with in the future. Lastly, from the methodological point of view, this current study uses a cross-sectional dependency approach which most of the previous studies have not considered. Overlooking the issue of cross-sectional dependence in the data leads to the estimation of biased outcomes (Li et al. 2021; Murshed et al. 2021d). Hence, it is pertinent to control for cross-sectional dependency within the analysis.

The remainder of the study is structured as follows. In "Literature review," the literature review is presented followed by the methodology of research put forward in "Methodology." The analysis of the findings is presented in "Data analysis and interpretation," while "Discussion on the findings" discusses the findings. Finally, "Conclusion" concludes with key policy recommendations.

Literature review

Energy use has been critical to the success of almost every economy throughout this now globalized world (Ozturk 2010; Ozturk and Acaravci 2010; Murshed 2020a). Be it infrastructure, agricultural, or technological development, the role of energy has been indispensable (Tang et al. 2016; Murshed 2020b). However, the economics and politics of energy have triggered a debate among academicians (Yuan et al. 2008). Though several studies found a strong energy intensity and GDP growth linkage in different countries and regions, many of them revealed conflicting results. For example, in a Granger causality test-based study conducted by Lee (2005) for 18 countries, the authors showed that energy consumption caused GDP growth without feedback. Padhan et al. (2020), in their study of the energy use and economic growth relationship for the Organization for Economic Cooperation and Development (OECD) countries, found that extensive energy use fosters economic growth in these countries. Munir et al. (2020) studied the empirical links between energy consumption and national income growth in the Association of Southeast Asian Nations (ASEAN) countries and found statistical evidence of both unidirectional and bidirectional relationships between these crucial macroeconomic variables. Meanwhile, Lawal et al. (2020) concluded in favor of bidirectional causality between energy use and economic growth in the context of African countries. On the other hand, Jobert and Karanfil (2007) studied the energy-income causality analysis of Turkey using 40 years of data and claimed that energy intensity and economic growth possess no connection in the long term both at cumulative and industrial levels. So, it is evident that these studies propose different causality directions between economic growth and energy consumption. This postulates a lack of agreement on the dynamic nature of the energy-growth nexus.

Following the seminal study by Kraft and Kraft (1978), the energy-economy nexus was explored for both developing and developed countries (Tugcu et al. 2012; Jebli et al. 2016; Ozcan and Ozturk 2019). The results from these studies have been mixed. For example, Sharma (2010) examined the impacts of energy consumption on economic growth concerning 66 global countries using dynamic panel data approaches and found that energy use significantly contributes to economic progress; however, for some specific regions, the outcome was different. Besides, Jafari et al. (2012) also tested the Granger causality between GDP growth and carbon dioxide (CO_2) emissions for the case of Indonesia by applying the Toda–Yamamoto method and found no causal association between the variables. In another empirical study by Altunbas and Kapusuzoglu (2015), the authors concluded that energy consumption has either a mixed or neutral role in respect of accelerating economic growth. Furthermore, the authors claimed that economic development and environmental sustainability can co-exist if energy consumption is efficient and well managed. Table 1 summarizes the existing literature on the energy consumption-economic growth nexus.

A wide array of existing studies have stressed that apart from energy use, economic growth influences environmental quality. The economic growth-environmental quality nexus is popularly discussed in the literature through the lens of the environmental Kuznets curve (EKC) which was first introduced in the seminal study by Grossman and Krueger (1991). As per this hypothesis, economic growth exerts inverted U-shaped impacts on environmental quality which implies that initially, economic growth degrades the environment while improving it later on (Murshed and Dao 2020; Murshed et al. 2021e; Zeraibi et al. 2021). Following this work, researchers endeavored to explore this inverted U-shaped EKC proposition. Results showed that during the earlier phases of economic development, policymakers usually stressed on achieving economic growth while accepting the environmental pollution concerns (Grossman and Krueger 1995).

The existing studies have documented equivocal evidence regarding the authenticity of the EKC hypothesis. Hence, the existing literature on the EKC hypothesis can be divided into two different schools of thought. The first school is in line with the EKC proposition while the second one is not. For example, among the previous studies that have established the EKC hypothesis, Apergis and Ozturk (2015) tested the EKC hypothesis for 14 Asian economies focusing on the nexus of GDP and CO_2 emissions. This panel GMM-based study established the EKC hypothesis for those countries. Similarly, studies conducted by Chen and Taylor (2020) found the validity of the EKC hypothesis. Ali et al. (2020) studied the short- and long-term associations between energy consumption and environmental degradation within the EKC hypothesis framework in the context of Pakistan. They found

Table 1 The literature on the energy consumption-economic growth nexus

Study	Country/countries (period of analysis)	Findings on the energy consumption-economic growth nexus
Ahmed et al. (2021)	Japan (1971–2016)	Fossil fuel consumption Granger causes economic growth in the long run. No causality in the short run
Adebayo et al. (2021)	Chile (1990–2018)	No causal relationship between renewable energy consumption and economic growth
Ahmed et al. (2020a)	Pakistan (1971–2016)	No causality
Wang and Wang (2020)	34 OECD countries (2005–2016)	Higher renewable energy consumption stimulates greater economic growth
Ahmed et al. (2020b)	India (1980–2015)	Industrial value-added Granger causes transport sector energy consumption
Gozgor et al. (2018)	29 OECD countries (1990–2013)	Higher renewable and non-renewable energy consumption stimulate greater economic growth in the long run
Munir et al. (2020)	5 ASEAN countries (1980–2016)	Bidirectional causality between energy consumption and economic growth
Destek and Aslan (2017)	17 Emerging economies (1980–2012)	Renewable energy consumption causes economic growth in Peru. Economic growth causes renewable energy consumption in Columbia and Thailand. No causality between economic growth and renewable energy consumption in 12 emerging economies. Bidirectional causality between renewable energy consumption and economic growth for Greece and South Korea. Non-renewable energy consumption causes economic growth in the cases of China, Colombia, Mexico, and the Philippines. Economic growth causes non-renewable energy consumption in the cases of Egypt, Peru, and Portugal. Bidirectional causality between economic growth and non-renewable energy consumption for Turkey. No causality between economic growth and non-renewable energy consumption in nine emerging economies

that the EKC hypothesis is valid in both the short-run and long-run scenarios. Meanwhile, the second school of thought argues that the EKC hypothesis does not hold for every circumstance. For example, Sirag et al. (2018) denied the relevance of the EKC hypothesis in the context of developing economies saying that they are yet to reach the desired income level at which economic growth will contribute to lower environmental pollution. Moreover, the EKC hypothesis was acknowledged by Rauf et al. (2018) in their panel data study on 65 BRI countries with pooled mean group (PMG) analysis. However, this PMG-based study claims that the EKC hypothesis was supported in advanced economies only. Table 2 summarizes the literature concerning the EKC hypothesis.

This extensive proliferation of the urban population demands efficient energy management and sustainable economic and social progress (Yasin et al. 2020). Adjei Mensah et al. (2020) argued that developing and low-income countries are exclusively prone to higher energy consumption and this is

Table 2 The literature on the EKC hypothesis for CO_2 emissions

Study	Country/countries (period of analysis)	Findings on the EKC hypothesis
Pata (2018)	Turkey (1974–2014)	EKC is valid
Ali et al. (2021)	Pakistan (1975–2014)	EKC is valid
Işık et al. (2019)	10 US states (1980–2015)	EKC is valid for Florida, Illinois, Michigan, New York, and Ohio
Koc and Bulus (2020)	South Korea (1971–2017)	EKC is not valid
Gokmenoglu and Taspinar (2018)	Pakistan (1971–2014)	EKC is valid
Dong et al. (2018)	14 Asia-Pacific countries (1970–2016)	EKC is valid
Murshed (2020a, b)	6 South Asian countries (1972–2013)	EKC is valid for Pakistan and Bhutan. EKC is not valid for Bangladesh, Sri Lanka, Nepal, and Afghanistan
Mahmood et al. (2019)	Tunisia (1971–2014)	EKC is valid
Alola and Donve (2021)	Turkey (1965–2017)	EKC is not valid
Altıntaş and Kassouri (2020)	14 European countries (1990–2014)	EKC is not valid

linked to income growth. Some recent studies have also ruled out the validity of the EKC hypothesis in certain economies. For example, Demissew Beyene and Kotosz (2020) tested it for 14 countries of East Africa by applying the PMG method and found that a bell-shaped relationship exists between GDP and carbon discharge and thus the EKC hypothesis is not supported. Yilanci and Pata (2020a), on the other hand, investigated the validity of the EKC hypothesis for China. This Fourier ARDL-based investigation found that due to the highly elastic long-run growth of gross domestic product (GDP), the EKC hypothesis is not supported for China.

However, there are some studies in this direction that reveal mixed results as well. For example, Isik et al. (2019) studied the presence of EKC assumption for different parts of the USA. The outcome of that augmented mean group (AMG) and common correlated effects (CCE)-based study showed that AMG estimation supported the EKC hypothesis but CCE did not support the same. Meanwhile, Ng et al. (2020) on the EKC hypothesis based on the cross-sectional dependence test and asymmetric effect for 76 countries showed that the EKC hypothesis moderately supported the sample countries. They concluded that EKC does not hold for every country due to different economic and energy use frameworks. Some studies indicated very different outcomes for the EKC hypothesis. For example, Amri (2018) analyzed the causalities between energy consumption, total factor productivity, trade, ICT development, financial development, and CO_2 emissions in Tunisia for the years 1975–2014 by applying the ARDL model. The results did not confirm the EKC hypothesis for higher total factor productivity in the long run but in the short run, it did. The results also highlighted that both CO_2 and ICT wielded only a minor influence as a component of pollution. However, another ARDL-based study for testing the EKC hypothesis conducted by Ozatac et al. (2017) for the case of Turkey supported the EKC.

As far as the environmental impacts of energy consumption are concerned, it is widely acknowledged in the literature that energy consumption is inextricably associated with environmental well-being (Ma et al. 2021; Murshed and Alam 2021; Nathaniel et al. 2021a, b; Xue et al. 2021). In this regard, the existing studies have predominantly documented evidence of unclean energy consumption boosting CO_2 emissions while greater use of cleaner energy resources is said to be effective in reducing the emissions (Murshed 2018; Ahmed et al. 2019; Murshed 2021a, b; Habib et al. 2021). In a relevant study on 16 European nations, Bekun et al. (2019) concluded that enhancing renewable energy use in Europe can be effective in mitigating the CO_2 emissions figures of the selected nations. Similarly, Shafiei and Salim (2014), in the context of selected OECD nations, opined that non-renewable and renewable energy consumptions were responsible for increasing and decreasing the CO_2 emission figures, respectively. Erdogan et al. (2020) also found identical results in their study concerning 25 OECD countries over the 1990–2014 period. In another study on Ghana, Abokyi et al. (2019) asserted that changes in the share of fossil fuels in the total energy consumption figures cannot explain the variations in Ghana's CO_2 emissions levels. Moreover, in a recent study on five European nations, Balsalobre-Lorente et al. (2021) concluded that energy innovation can help to curb CO2 emissions by greening the European international tourism industry.

It can be summarized from these different studies that the economic growth and environmental nexus vary due to the collective nature of the dataset. Besides, there is another perception that several researchers do not control the external economic shocks as important indicators. Rauf et al. (2018) argue that for a robust outcome, researchers should use the dataset of individual countries categorically and analyze them with similar econometric tools. It is argued that the determinants of economic and industrial growth are usually responsible for CO_2 release in different economies. However, China's strategic Belt and Road strategy allows the country to allocate carbon-producing ventures to the BRI associate countries. This has been evident from the fact that almost 65% of the energy-intensive investment within the BRI scheme is planned for coal power projects (Xiong et al. 2019). The portion of the fund for clean energy production is found to be extremely negligible. China is on the way to establishing 240 coal energy power projects in 25 BRI associate nations. Moreover, the country intends to establish 92 more such plants in 27 other BRI countries (Xiong et al. 2019).

Massive Chinese infrastructure financing offered to the BRI countries is generating more commerce and trade in these regions. This in turn is increasing carbon emissions to an alarming degree. Research shows that CO_2 emissions from energy use in BRI countries are about 80% which is more than enough to produce environmental degradation (Zhao et al. 2018). It is apparent from the aforementioned findings that the BRI scheme must be environmentally sustainable for its associated countries. It cannot be denied that to continue economic development, the BRI is going to put environmental stress on the associated countries due to the massive energy use and pollution emissions. BRI projects with their intended infrastructure will be a prime supplier of global CO_2 emissions in the coming years which might account for more than half of new sources. It is projected that the BRI can hold 60% of the world's infrastructure funds in the next two decades (Qureshi 2016).

The literature suggests that an empirical investigation is necessary to understand the dynamics of energy intensity, GDP growth, agricultural development, and environmental pollution for developing nations in the BRI region. This study, therefore, explores how environmentally sustainable the BRI projects are. Accordingly, this study considers examining the extent of the relationship between energy use, financial development, FDI, GDP growth, agricultural development, and CO_2 emissions in 42 BRI countries which are in the low-income, lower-middle-income, and upper-middle-income brackets using 25 years of data from 1995 to 2019.

Methodology

Data and variables

This study considers data of 42 developing countries under the BRI (see Table 15 in Appendix for the list of the selected countries). Initially, about 65 countries were considered for the study but due to the unavailability of data for certain variables, only 42 countries could be chosen for the analysis. Besides, the high-income BRI countries and small islands are excluded due to the fact that this study specifically focuses on the energy-economy-environment nexus in the context of the developing BRI member nations only. Data for this study are obtained from the World Development Indicators (WDI) database of the World Bank (2020) for the selected 42 BRI nations over the 1995 to 2019 period. In the empirical model, the CO_2 emissions per capita figures are considered the dependent variable. On the other hand, energy consumption, population growth, foreign direct investment (FDI) inflows, the share of the medium and high-tech industries in the manufacturing value-added, financial development, renewable energy consumption share in total final energy use, and GDP per capita are chosen as the independent variables. The description of the variables of concern is given in Table 3.

Econometric analysis

Model development

To test the relationship between the variables of concern, i.e., CO2, EPC, FD, GDP, FDI, MHI, AGRVA POPG, and REC, a primary equation is devised as follows:

$$CO_2 = f(EPC, FD, GDP, \mathrm{FDI}, MHI, AGRVA\ POPG, REC,) \tag{1}$$

The equation that creates the relationships among the investigated variables is constructed by following Gulistan et al. (2020), Haseeb and Azam (2020), Khan et al. (2019), Doğan et al. (2019), Behera and Dash (2017), and Al-Mulali et al. (2015). Equation 1 is an appropriate representation of the baseline model. This model is re-written in the natural log form of data which can be shown as:

$$\begin{aligned} CO_{2i,t} = \alpha &+ \beta_1 \ln EPC_{i,t} + \beta_2 \ln FD_{i,t} + \beta_3 \ln GDP_{i,t} \\ &+ \beta_4 \ln FDI_{i,t} + \beta_5 \ln MHI_{i,t} + \beta_6 \ln AGRVA_{i,t} \\ &+ \beta_7 \ln POPG_{i,t} + \beta_8 \ln REC_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{2}$$

Here in Eq. 2, the superscript "i" stands for country numbers in for the full panel and "t" refers to the time series. Besides, ln refers to the natural logarithm, "α" refers to the intercept and "β" to the parameters while "$\varepsilon_{i,\ t}$" refers to the error term for the equations. Moreover, all the series data were converted into a natural log form. This transformation prevents the dataset from having enlarged coefficients, multicollinearity, and autocorrection problems.

The analysis for this study comprises the following steps. Firstly, tabulation of the descriptive statistics and correlation analysis for the selected variables is undertaken. Secondly, tests are done on the cross-sectional dependency of the panel data to confirm the reliability of the estimation. Outcomes of the cross-sectional dependency tests are then proposed for the unit root tests. If a cross-sectional dependency is present, the power of estimation is considered to be inadequate. In this case, the first generation of unit root test does not satisfy. Therefore, both the first and second generations of unit root test introduced by Pesaran (2007), Im et al. (2003), and Levin et al. (2002) and ADF Fisher Chi-square by Choi (2001) are applied. Outcomes of these tests then guide testing the long-term cointegration among the selected variables (Appiah et al. 2018). Thirdly, the fully modified OLS (FMOLS) and the

Table 3 Data description

Variables	Description
Energy consumption (EC)	Energy use (in kg of oil equivalent per capita)
Carbon dioxide emission (CO_2)	CO_2 emissions (in metric ton per capita)
Population growth ((POPG)	Population growth (annual %)
Foreign direct investment (FDI)	Foreign direct investment, net inflows (% of GDP)
Agricultural development (AGD)	Agriculture, value-added (% of GDP)
Financial development (FD)	Domestic credit provided to the private sectors (% of GDP)
Renewable energy consumption (REC)	Renewable energy consumption (% of total energy use)
Medium and high-tech industry (MHTI)	Medium and high-tech industry (% of manufacturing industry value--added)
Gross domestic product (GDP)	GDP per capita (constant 2010 US$)

Source: https://data.worldbank.org/

dynamic OLS (DOLS) methods are applied to investigate equilibrium in the long run among the variables for the entire time series. Fourthly and finally, a robustness test for the panel is conducted by applying the Dynamic Seemingly Unrelated Regression (DSUR).

Cross-sectional dependency test

A cross-sectional dependence test is critical to the formation of any econometric model. Though the first-generation panel unit root tests find cross-sectional dependency within the variables, such an assumption has some shortcomings in a real-life situation. Munir et al. (2020) state that the same types of economic events can affect the time series data for different countries which can eventually establish cross-sectional dependency among the variables. If this is the case, then other investigations that follow should be following such cross-sectional dependency. Hence, following Shahbaz et al. (2019), this study applies the cross-sectional dependency test proposed by Pesaran (2004), the Lagrange Multiplier (LM) test suggested by Yilanci and Pata (2020b), and the bias-corrected scaled LM test suggested by Baltagi et al. (2012). They serve to investigate the presence of cross-sectional dependency among the variables reviewed here. In the case of cross-sectional dependence, the basic assumption is that there is no such dependence within the dataset. Therefore, both these tests are structured in the following ways:

$$LM = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{\rho}_{ij}\right)\frac{(T-k)\widehat{\rho}_{ij}^{2}-E(T-k)\widehat{\rho}_{ij}^{2}}{Var(T-k)\widehat{\rho}_{ij}^{2}} \tag{3}$$

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{\rho}_{ij}\right)\sim N(0,1)i,j = 1,2,3\ldots 42\ldots N \tag{4}$$

In Equations 3 and 4, $\widehat{\rho}_{ij}^{2}$ indicates the correlation of the residuals in variables and its estimation has been drawn by applying the ordinary least squares (OLS) method. In Table 4, the results of these two cross-sectional dependency analyses reveal that the null hypothesis (H0) is rejected at the 1% level of significance. Hence, these estimates verify the existence of cross-sectional dependency in the data.

Table 4 Cross-sectional dependence (CD) test results

Test	Statistic
Breusch-Pagan LM	5947.35***
Pesaran scaled LM	122.5715***
Bias-corrected scaled LM	121.6965***
Pesaran CD	44.05826***

“***” denotes the statistical significance level of 1%

Table 5 Cross-sectional dependence (CD) test results (for residuals)

Test	Statistic
Pesaran CD test	44.058***
Friedman test	233.491***
Frees test	5.900***

“***” denotes the statistical significance level of 1%

The test of cross-sectional dependency for the residuals is also undertaken to investigate the cross-sectional dependence in the dynamic panels. On this issue, along with the parametric test suggested by Frees (2004), Pesaran’s (2004) and Friedman’s (1937) semi-parametric tests are applied taking a larger cross section for the short term to find the residual-based cross-sectional dependency in the dataset. In this study, 25 years are characterized as “t” and 42 countries are characterized as “i” for the convenience of testing error-oriented cross-sectional dependency. The results from all these three tests, as shown in Table 5, reject the null hypothesis to verify the issue of cross-sectional dependence in the data.

Unit root tests

The dataset of this study takes a larger time series which might extend the degrees of freedom and spells out the multicollinearity issue in the estimation of the OLS equation. Therefore, this dataset fits into the advanced statistical measures that follow the normal distribution. Several panel unit root tests have been recommended to check the stationarity of the dataset. For example, Im et al. (2003) suggest a unit root test for heterogeneous panel data and Choi (2001) advocates the ADF Fisher Chi-square test. Meanwhile, for the finite samples, Levin et al. (2002) suggest an even stricter unit root test. Therefore, this study applies the LLC, IPS, and ADF Fisher Chi-square test for testing the unit root to hold the order of cointegration among the variables. The following equation is formed for the LPS Panel unit root test:

$$\Delta y_{i,t} = \alpha_i + \beta_i y_{i,t-1}\textstyle\sum_{j=1}^{pi}\rho_{ij}\Delta y_{i,t-j} + \varepsilon_{i,t}\ i = 1,\ldots t = 1,\ldots T \tag{5}$$

In Equation 5, $y_{i,\,t}$ as the dataset containing *i* countries for *t* time but the lag operators are denoted with *i*. Here, $\varepsilon_{i,\,t}$ stands for the error term for the normally distributed low-income, lower-middle-income, and upper-middle-income BRI economies. Here, both the null (H0) and alternative (H1) hypotheses are tested to validate the stationarity of the series. Both H0 and

H1 are accepted or rejected by comparing the asymptotically encoded values on the tabulation.

The investigation results of the cross-sectional dependence depicted in Tables 4 and 5 prove that the data are cross-sectionally dependent. Hence, following Sharma et al. (2021) and Liu et al. (2021), this study undertakes the cross-sectionally adjusted Im, Pesaran, and Shin (CIPS) and the Augmented Dickey-Fuller (CADF) panel unit root tests of Pesaran (2007). These tests control for cross-sectional dependence in the data and reveal robust outcomes related to the stationarity properties of the variables of concern. These fit into their existing format for asymptotic assumption and thus do not count for N/∞. Hence, the test is further established as follows:

$$\Delta y_{i,t} = c_i + \alpha_i y_{i,t-1} + \beta_i \overline{y}_{t-1} + \sum_{j=0}^{p} \gamma_{ij} \Delta \overline{y}_{i,t-j} + \sum_{j=1}^{p} \delta_{ij} \Delta \overline{y}_{i,t-j} + \eta_{i,t}\ i = 1, \ldots n \tag{6}$$

In Equation 6, c_i is depicted as the constant and "$\overline{y}$ " is depicted as the mean of cross sections for the period "t". Besides, "p" stands for the lag operator. It is supposed that t_i (N, TM) is parallel to the t-ratio of α_i. Consequently, the mean statistics of t-ratios can be written as follows:

$$CIPS\ (N, T_m) = \frac{\sum_{i=1}^{N} t_{i,}(N, T_{m,})}{N} \tag{7}$$

Here, $t_{i,}(N, T_{m,})$ is Augmented Dickey-Fuller (CADF) indicators for the i^{th} cross-sections.

Cointegration tests

After the confirmation of stationarity of data by applying first- and second-order unit root tests, this study applies cointegration tests as suggested by Pedroni (1995) to establish the extent of cointegration among the variables. Moreover, the cointegration test popularized by Westerlund (2007) checks the cointegration level to attain cross-sectional dependency among the variables. The cointegration test popularized by Pedroni (1995) was established on the Engle-Granger method and extended by Westerlund et al. (2015), to fix the long-run relationship within all the studied variables. Likewise, the Pedroni cointegration test augmented the following equation:

$$CO2_{i,t} = \alpha + \delta_i t + \beta_1 lnEPC_{i,t} + \beta_3 lnFD_{i,t} + \beta_2 lnGDP_{i,t} + \beta_4 lnFDI_{i,t} + \beta_5 lnMHI_{i,t} + \beta_5 lnAGRVA_{i,t} + \beta_5 lnPOPG_{i,t} + \beta_5 \mathrm{ln}REC_{i,t} + \varepsilon_{i,t} \tag{8}$$

where $i = 1, \ldots t = 1, \ldots T$

In Equation 8, the cointegration test is extended where α_i stands as the constant for each country, and $\delta_i t$ stands for the country-specific deterministic trends for the full panel. The Pedroni cointegration tests reveal eleven statistical results to investigate the null and alternative hypotheses (H0 and HI). However, for the cointegration of "H0," β_1 is considered homogenous and in the case of "H1," it is deemed to be heterogeneous for the entire statistical dimension. The homogeneity in the variables is distributed normally and functions in line with the Pedroni cointegration test. This may be portrayed with the following equation:

$$\sqrt{\frac{N'_{N,T} - \mu\sqrt{N}}{\sqrt{V}}} \rightarrow N\ (0, 1) \tag{9}$$

In Equation 9, μ and V stand for the Monte Carlo oriented adjustment measures. Both parametric and non-parametric data are considered for the cointegration test which can be extended from one to eleven empirical results. For robustness check, we also employ the Kao (1999) cointegration analysis.

However, since both these methods do not account for the cross-sectional dependency issue in the data, the Westerlund (2007) estimator is also employed to ascertain the cointegrating properties among the macroeconomic variables.

The regression analysis

After checking for cointegration among the variables, the panel fully modified ordinary least squares (FMOLS) regression analysis suggested by Pedroni (2000) and the dynamic ordinary least squares (DOLS) regression analysis suggested by Kao and Chiang (2000) and Stock and Watson (1993) are conducted to measure the long-run elasticity parameters. Both models serve mainly to remove the issue of endogeneity and consider the correlation of error terms for the variables. The following equations for FMOLS and DOLS are presented:

$$\widehat{\beta}_{\mathrm{NT}} = \left[\frac{\sum_{\mathrm{i}=1}^{\mathrm{N}} \sum_{\mathrm{t}=1}^{\mathrm{T}} \left(\mathrm{x}_{\mathrm{it}} - \overline{\mathrm{x}}_{\mathrm{i}}\right)\left(\mathrm{y}_{\mathrm{it}} - \overline{\mathrm{y}}_{\mathrm{i}}\right) - \mathrm{T}\widehat{\gamma}_{\mathrm{i}}}{\sum_{\mathrm{t}=1}^{\mathrm{T}} \left(\mathrm{x}_{\mathrm{it}} - \widehat{\mathrm{x}}_{\mathrm{i}}\right)^2}\right] \tag{10}$$

where $\widehat{\gamma}_{\mathrm{i}} = \widehat{\Gamma}_{21\mathrm{i}} + \widehat{\Omega}_{21\mathrm{i}}^{0} - \underline{\widehat{\Omega}_{21\mathrm{i}}} \quad \widehat{\Omega}_{21\mathrm{i}}\left(\widehat{\Gamma}_{22\mathrm{i}} + \widehat{\Omega}_{22\mathrm{i}}^{2}\right)$ and $\widehat{\Omega}_{\mathrm{i}} = \widehat{\Omega}_{\mathrm{i}}^{0} + \widehat{\Gamma}_{\mathrm{i}} + \widehat{\Gamma}'_{\mathrm{i}}$. Here "$\widehat{\Omega}_i$ " refers to the long-run stationarity matrix followed by $\widehat{\Omega}_{21i}^{0}$ and this rejects the presence of covariance between error terms relevant to stationarity. Moreover, "$\widehat{\Gamma}_i$ " refers to the modified covariance terms between the independent variables of the panel.

The causality test

Before determining the cogency of the estimation, the panel Granger causality analysis is conducted to find the direction of causalities among the variables; such causalities are found by applying the econometric model which absorbs the heterogeneity from the diagonal to the cross sections. To solve the problem of causality-based nexus, Dumitrescu and Hurlin's (2012) non-causality investigation for the heterogeneous panel is implemented. This method was also considered in the previous study by Banerjee and Murshed (2020).

Model robustness assessment

In the context of panel data, both heterogeneity and cross-section dependency are the most common issues, and to consider those, this study employs the Dynamic Seemingly Unrelated Regression (DSUR) estimator of Mark et al. (2005) to re-estimate the models as a robustness check of the elasticity estimates across alternative methods.

Figure 1 illustrates the econometric methodology of research considered in this study.

Data analysis and interpretation

Descriptive statistics

The descriptive statistics for all the variables are tabulated in Table 6. It considers 42 countries and a 25-year time series holding a total of 1050 observations. These variables have been transformed into natural log values to avoid the problem of heteroscedasticity and linearity over the sampled period. The GDP and EPC vary concerning their mean values of 7.90432 and 5.091065, respectively. Meanwhile, the discharge of CO_2 emissions appears to be lower in the sample cross sections, indicating a volatile fossil fuel consumption pattern in this region.

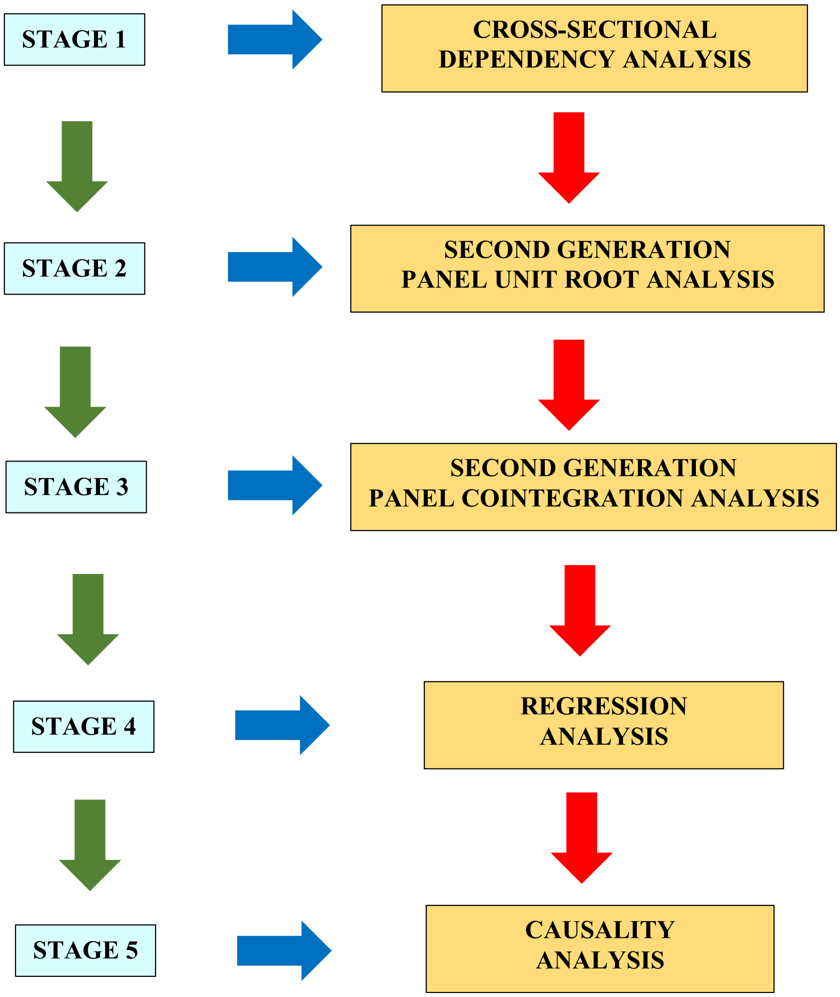

Fig. 1 The econometric methodology

Table 6 Descriptive Statistics

Variable	EPC	CO_2	POPG	FDI	AGRVA	FD	MHI	REC	GDP
Obs	1050	1050	1050	1050	1050	1050	1050	1050	1050
Mean	5.0910	0.5889	0.9036	0.8449	2.3606	2.5720	2.3528	1.9978	7.9043
Std. Dev.	3.0672	1.0449	1.2842	1.2306	0.76321	1.7212	1.2720	1.9978	1.0408
Min	0.0000	−2.3263	−9.0806	−12.9423	0.00000	0.0000	−1.3912	−2.8309	0.0000
Max	8.5500	2.7502	7.7860	4.0087	4.0472	5.1039	4.0495	4.5188	9.6203

Authors' calculation and tabulation

Correlation analysis

The correlation matrix concerning the variables is displayed in Table 7. It shows a positive and statistically significant correlation between energy consumption per capita 0.3303, foreign direct investment 0.2060 GDP per capita 0.6107, medium and high-tech industries 0.4353, and CO_2 emissions, respectively, whereas population −0.1884, agricultural value-added −0.3877, and renewable energy consumption −0.3879 are negatively and significantly correlated with CO_2 emissions in the 42 middle- and low-income BRI countries. The statistics confirm a strong correlation among energy consumption, medium and high-tech industries, GDP growth, and carbon emissions. However, a fairly weaker link is seen between financial development and carbon emissions. So it can be well assumed that massive energy consumption, GDP growth, and the rise of medium and high-tech industries contribute more to pollution than other variables. Though the correlation statistics give us clear insights, it is not sufficient to establish any proposition. That is why this study undertakes a series of estimations to validate the conceived proposition.

Analysis of unit root test

To see whether the panel data are stationary, this study undertakes both first-generation (LLC, IPS and ADF) and second-generation (CIPS and CADF) panel unit root tests. The variables were investigated individually to check whether they are stationary or not. It is observed from the unit root results reported in Table 8 that the variables are stationary at first difference. Hence, a common order of integration among the variables is ascertained.

Cointegration analysis

The Pedroni (1995) cointegration test allows large cross sections and time series to predict the cointegration phenomenon in panel data. The outcome of the Pedroni (1995) test is portrayed in Table 9. The outcome of the test shows that seven out of eleven test statistics are statistically significant at the level of 1% which implies that there are long-run associations between the variables included in the model.

Like the Pedroni (1995) method, the Kao (1999) cointegration approach also considers examining the long-run linkage among the studied variables. The Kao test results

Table 7 Correlation statistics

Variables	$LNCO_2$	LNAGRVA	LNEPC	LNFD	LNFDI	LNGDP	LNMHI	LNPOPG	LNREC
$LNCO_2$	1.0000								
LNAGRVA	−0.3877***	1.0000							
LNEPC	0.3303***	0.0931***	1.0000						
LNFD	0.0032	0.0350	−0.1955***	1.0000					
LNFDI	0.2060***	−0.0626**	0.0475	0.0425	1.0000				
LNGDP	0.6107***	−0.3173***	0.0183	0.2031***	0.1554***	1.0000			
LNMHI	0.4353***	−0.0575*	0.4485***	0.0744**	−0.0747**	0.2304***	1.0000		
LNPOPG	−0.1884***	0.1058***	−0.0923***	0.1122***	-0.1304***	−0.1498***	−0.1816***	1.0000	
LNREC	−0.3879***	0.4154***	0.3746***	0.0034	0.0487**	−0.3281***	0.2409***	−0.1016***	1.0000

Author's calculation. Here, LN CO_2 denotes carbon dioxide emissions; LNAGRVA denotes agricultural value-added; LNEPC depicts energy consumption per capita; LNFD represents financial development; LNFDI represents foreign direct investment inflows; LNGDP represents GDP per capita; LNMHI represents medium and high technology industry; LNPOPG represents population growth; and finally LNREC depicts consumption of renewable energy. Here *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively

Table 8 Results of the unit root test

At level

Methods	**EC**	**CO_2**	**POPG**	**FDI**	**AGD**	**FD**	**MHTI**	**REC**	**GDP**
Levin, Lin and Chu	7.1106	4.1749	−13.910***	−3.0491***	0.1396	−1.4358	17.9628	5.2670	−3.7089***
Im, Pesaran and Shin	6.4288	3.6041	−14.189***	−7.4096***	0.9365	1.0717	5.1677	5.4657	−1.43807
ADF - Fisher Chi-square	18.7057	57.0706	405.237***	211.165***	89.3819	78.6956	63.1099	34.8976	308.264***
CIPS	−1.794	−2.500	−2.319	−3.715***	−2.38	−2.567*	−2.738***	−2.408	−2.11
CADF	−1.612	−2.554**	−3.033***	−3.196***	−1.998	−2.302	−2.562**	−2.069	−2.56**
At first difference									
Methods	**EC**	**CO_2**	**POPG**	**FDI**	**AGD**	**FD**	**MHTI**	**REC**	**GDP**
Levin, Lin and Chu	−17.1042***	−16.0061***	−17.1158***	−12.6011***	12.9439	−11.0018***	3.1451	−15.7286***	−182.785***
Im, Pesaran and Shin	−12.1156***	−13.0029***	−20.1424***	−19.6298***	−10.4139***	−9.6746***	−0.3118	−13.1841***	−38.0516***
ADF - Fisher Chi-square	299.133***	324.396***	534.183***	506.981***	288.364***	283.563***	119.561***	328.188***	504.636***
CIPS	−3.958***	−4.803***	−2.231**	−5.468***	−4.517***	−4.358***	−5.366***	−4.733***	−3.567***
CADF	−2.648***	−3.905***	−3.458***	−4.263***	−3.077***	−3.284***	−3.963***	−3.585***	−2.996***

Authors' calculation. *, **, and *** stand for statistical significance at the 10%, 5%, and 1% levels, respectively

shown in Table 10 show consistency with the Padroni (1995) test findings to affirm the existence of long-run associations amid the variables.

However, both the Pedroni (1995) and Kao (1999) cointegration tests have limitations concerning the inability to account for the issue of cross-sectional dependency in the data (Ridzuan et al. 2017). Therefore, the cointegration test of Westerlund (2007) is employed to check for cointegration among the variables. The finding of the Westerlund (2007) test, as shown in Table 11, once again confirms long-run associations amid the variables of concern.

The FMOLS and DOLS estimators are applied to predict the long-run elasticities of CO_2 emissions. The elasticity estimates, as shown in Table 12, reveal that higher energy consumption, FDI inflows, economic growth, the share of medium and high-tech industries in the manufacturing value-added, and population growth rate hurt the environment by triggering CO_2 emissions. Meanwhile, it is interesting to see that financial development, proxied by the share of domestic credit extended to the private sector in the GDP, does not impact CO_2 emission levels. However, agricultural sector expansion and greater share of renewable energy in total energy consumption is evidenced to curb CO_2 emissions in the long run.

Robustness analysis

To validate the robustness of the DOLS and FMOLS outcomes, this study employs the DSUR approach to re-estimate the models. The corresponding results, presented in Table 13, corroborate with the findings from the DOLS and FMOLS analyses in respect of the predict signs of the elasticity estimates. Hence, the robustness of the findings across alternative estimation techniques is affirmed.

Causality test analysis

This study performs the test of Granger panel causality to validate the presence of short-run causality between the dependent variable and independent variables. Dumitrescu and Hurlin's (2012) causality test which addresses the heterogeneity issue is applied. Table 14 shows a variety of outcomes revealing that energy consumption, population growth, FDI, and agricultural development carry a unidirectional

Table 9 Result of Pedroni cointegration test

Statistics name	Statistic	Prob.	Weighted statistic	Prob.
Panel v-Statistic	2.5574***	0.0053	−0.0548	0.5219
Panel rho-Statistic	1.8471	0.9676	1.2252	0.8898
Panel PP-Statistic	−2.7401***	0.0031	−5.6625***	0.0000
Panel ADF-Statistic	−7.7309***	0.0000	−8.2642***	0.0000
Group rho-Statistic	4.2118	1.0000		
Group PP-Statistic	−5.3655***	0.0000		
Group ADF-Statistic	−7.7040***	0.0000		

Author's calculation: *** indicates statistical significance at the 1% level

Table 10 Result of Kao cointegration test

	t-statistic	Prob.
ADF	−2.3631***	0.0091
Residual variance	0.0902	
HAC variance	0.0895	

Author's calculation: *** indicates statistical significance at the 1% level

Table 11 Result of Westerlund cointegration test

Statistic	Value	*Z*-value	*P*-value
Gt	−10.134***	−49.216	0.0000
Ga	−1.262	11.516	1.0000
Pt	−21.136***	−4.123	0.0000
Pa	−1.572	8.456	1.0000

Author's calculation: *** indicates statistical significance at the 1% level

relationship with environmental pollution. Meanwhile, economic growth, medium and hi-tech development, financial progress, and renewable energy consumption carry a bidirectional relationship.

Discussion on the findings

The results from the dynamic panel data analyses clearly show that energy demand adversely influences environmental well-being in BRI member nations of concern. This is an expected finding since the majority of the BRI nations considered in this study are developing nations that have traditionally been fossil fuel dependent. Hence, a rise in the energy consumption per capita level is likely to trigger the levels of energy consumption-induced CO_2 emissions. Therefore, if the fossil fuel dependency issue is not addressed, these countries might be exposed to massive environmental destruction following the execution of the BRI. Accordingly, the policymakers should strive for achieving technology innovation which is needed to make a transition from the use of fossil to relatively cleaner fuels like wind, nuclear, biomass, solar, and hydropower. These findings are consistent with those by Lawal et al. (2020), Zaman and Moemen (2017), and Bekhet et al. (2017) for African countries, high, low, and middle-income countries, and Gulf Cooperation Council (GCC) countries, respectively. On the other hand, as far as the effects of financial development are concerned, the statistical significance of the associated elasticity estimates imply that the financial sectors of the developing BRI nations are yet to be developed enough to influence the environmental indicators. Hence, it is pertinent for the governments to re-strategize financial development in an environmentally friendly manner.

Table 12 Results for FMOLS and DOLS for all panels

Estimator	**Coefficients**		**Standard error**	
	FMOLS	**DOLS**	**FMOLS**	**DOLS**
Regressors				
LNEPC	0.1208***	0.1666***	0.0105	0.0111
LNFD	0.0110	−0.0070	0.0167	0.0160
LNFDI	0.2125***	0.1188***	0.0246	0.0255
LNGDP	0.0738***	0.0801***	0.0136	0.0149
LNMHI	0.2823***	0.1582***	0.0254	0.0283
LNPOPG	0.1129***	−0.1163***	0.0216	0.0204
LNREC	−0.3893***	−0.2561***	0.0207	0.0212
LNAGRVA	−0.2449***	−0.2676***	0.0367	0.0365

Author's calculation: Here CO_2 represents carbon emissions; LNEPC denotes energy consumption; LNFD denotes financial development; LNFDI represents foreign direct investment; LNGDP denotes GDP per capita; LNMHI denotes medium and high-tech industries; POPG represents population growth; LNREC represents consumption of renewable energy; and LNAGRVA represents agricultural value-added. *** stands for statistical significance at the 1% level

Table 13 Dynamic seemingly unrelated regression results

Regressors	Coefficient	t-statistic	Prob.
LNEPC	0.0932***	22.5084	0.0000
LNFD	0.0068	1.2720	0.2036
LNFDI	0.0831***	16.4152	0.0000
LNGDP	0.2336***	18.0061	0.0000
LNMHI	0.1596***	13.8747	0.0000
LNPOPG	0.0304***	−4.9752	0.0000
LNREC	−0.2298***	−20.1364	0.0000
LNAGRVA	−0.0714***	−5.6074	0.0000

***indicates statistical significance at the 1% level

Besides, the finding of FDI inflows triggering greater CO_2 emissions affirms the pollution haven hypothesis. It implies that the developing BRI nations are being targeted by foreign investors to invest in pollution-intensive industries by exploiting the less-stringent environmental regulations in these countries. Under such circumstances, it is necessary for the governments to inhibit the inflows of dirty FDIs and rather attract cleaner FDIs that can safeguard their environmental attributes. The pollution haven hypothesis was also verified in the previous studies by Al-Mulali and Tang (2013) and Terzi and Pata (2019) for GCC countries and Turkey, respectively. Moreover, the finding that economic growth is not beneficial for the environment in the selected BRI nations implies that the economic growth policies of these nations are directed at boosting economic well-being while accepting poor environmental quality. At the same time, this finding also suggests that the economic growth levels of these developing nations are yet to reach the point beyond which further growth would enable these nations to enact stringent environmental protection policies to attain complementarity between economic and environmental welfare. Hence, the economic growth policies of the BRI member nations need to be aligned with the environmental protection

Table 14 The analysis of Dumitrescu Hurlin panel causality

Null hypothesis	Zbar-statistic	Probability	Relationship directions		
LNEPC $\neq$ LNCO$_2$	46.9575***	0.0000	LNEPC	$\rightarrow$	LN CO$_2$
LN CO$_2$ $\neq$ LNEPC	0.56576	0.5716			
LNFD $\neq$ LNCO$_2$	40.5894***	0.0000	LNFD	$\leftrightarrow$	LNCO$_2$
LNCO2 $\neq$ LNFD	21.5626***	0.0000			
LNFDI $\neq$ LNCO$_2$	−0.44992	0.6528	LNFDI	$\leftarrow$	LNCO$_2$
LNCO2 $\neq$ LNFDI	4.27438***	0.0000			
LNGDP $\neq$ LNCO$_2$	2.21961**	0.0264	LNGDP	$\leftrightarrow$	LNCO$_2$
LNCO2 $\neq$ LNGDP	8.40507***	0.0000			
LNAGRVA $\neq$ LNCO$_2$	0.40203	0.6877	LNAGRVA	$\leftarrow$	LNCO$_2$
LNCO2 $\neq$ LNAGRVA	14.4348***	0.0000			
LNMHI $\neq$ LNCO$_2$	−2.6427***	0.0082	LNMHI	$\leftrightarrow$	LNCO$_2$
LNCO2 $\neq$ LNMHI	181.943***	0.0000			
LNPOPG $\neq$ LNCO$_2$	1.28659	0.1982	LNPOPG	$\leftarrow$	LNCO$_2$
LNCO2 $\neq$ LNPOPG	23.939***	0.0000			
LNREC $\neq$ LNCO$_2$	80.8119***	0.0000	LNREC	$\leftrightarrow$	LNCO$_2$
LNCO2 $\neq$ LNREC	2.2346**	0.0254			

"$\neq$" refers to the term "does not Granger cause"; *** and ** denote statistical significance at 1% and 5% significance level, respectively

objectives. Similar findings were reported by Zeraibi et al. (2021) for the ASEAN countries.

The findings also reveal that the industrialization processes within the BRI member countries have not complemented their environmental well-being objectives. The finding of the positive relationship between the share of medium and high-tech industries in the manufacturing value-added and CO$_2$ emissions implies that these industries are highly fossil-fuel dependent. Consequently, as the level of energy consumed within these industries increases, so does the levels of energy consumption-induced CO$_2$ emissions. Hence, it is necessary for the governments of the BRI nations to reduce their respective fossil fuel dependencies and elevate the renewable energy shares in the national energy mixes to neutralize the adverse environmental impacts associated with industrialization. Similarly, the finding of a higher population growth rate being responsible for greater CO$_2$ emissions is expected since an increase in the size of the population is synonymous with a rise in energy demand. This, in turn, can be expected to boost the energy consumption-related CO$_2$ emissions in the BRI member countries.

On the other hand, the finding that a higher share of renewables in the total final energy consumption figures of the selected BRI member nations is effective in reducing the CO$_2$ emissions implies that transitioning from unclean to cleaner energy use is efficient in improving the level of environmental well-being. Since these nations are predominantly fossil-fuel dependent, it is imperative for them to reduce this monotonic fuel dependency and diversify their energy mixes by adding renewable energy resources into their respective national energy baskets. Finally, agricultural expansion should also be considered a means of curbing CO$_2$ emissions since the negative correlation between the share of agriculture in the GDP and CO$_2$ emissions implies that the agriculture sectors of the BRI nations are not energy intensive. Besides, it is also important to make use of renewable energy resources in the agriculture sector which would be further effective in mitigating the energy consumption-associated emissions.

Conclusion

This study documents fresh evidence on the dynamics associated with the energy-economy-environment nexus for 42 developing countries that are members of the BRI. The period of analysis stems from 1995 to 2019. To test the relationships, a robust econometric approach is employed to addresses cross-sectional dependency in the data. The major findings from the econometric analysis revealed that higher degrees of energy consumption, economic growth, population growth rate, and FDI inflows exhibit adverse environmental consequences by boosting the CO$_2$ emission figures of the selected developing BRI nations. However, it is interesting to observe that exploiting renewable energy sources, which are relatively cleaner compared to the traditionally-consumed fossil fuels, and fostering agricultural sector development can significantly improve environmental well-being by curbing the emission levels. On the other hand, financial development is found to be ineffective in explaining the variations in CO$_2$ emission figures of the selected BRI member countries. In line with these findings, several relevant policies can be recommended.

Firstly, the governments of the selected BRI nations must undertake energy policies that can effectively reduce the demand for energy which can be achieved through improving the energy efficiency levels. Striving to increase the energy efficiency levels would ensure that the energy demand is met using a relatively lower level of energy. Consequently, the energy consumption-induced carbon emissions can be contained to a large extent. Secondly, these nations should also strategize and revisit their economic growth policies to attain environmentally sustainable growth performances. Accordingly, these nations should integrate the environmental welfare issues within the economic growth policies; consequently, the trade-off between economic growth and environmental degradation can be phased out. Therefore, it is imperative for the concerned governments to green their respective national output production processes, especially through greater employment of cleaner energy resources. Thirdly, it is important to invest in projects aimed at the development of the renewable energy sectors in the selected BRI nations since greater use of cleaner energy in these countries can be expected to curb the energy use-related emissions. Lastly, agricultural development should be a prioritized agenda for these governments. In this regard, the governments should provide concessional loans for investment in the agriculture sector. Since the agriculture sector, in comparison with the industrial sector, is relatively less energy-intensive in nature, such investments for agricultural development can be presumed to further reduce the energy consumption-induced carbon emissions.

Data unavailability is the only limitation faced in conducting this study. Consequently, only 42 developing countries that are members of the BRI could be incorporated within the analyses. As part of the future direction of research, this study can be extended by evaluating the authenticity of the EKC hypothesis to assess whether or not the selected BRI member countries are yet to achieve the threshold level of national income beyond which economic growth can be achieved without axing environmental well-being.

Author contribution MS conceptualized, conducted the econometric analysis, and wrote the introduction. HY conceptualized, conducted the econometric analysis, and supervised the work. AR wrote the methodology and edited the draft. MMA summarized the literature review and wrote the discussion part. MM conducted the literature review, wrote the conclusions and recommendations, and compiled the overall manuscript. HM reviewed the literature, compiled the policy implications, and edited the draft.

Data Availability The data sets used during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent to publish Not applicable.

Competing interests The authors declare no competing interests.

Appendix

Table 15 The list of 42 BRI-associated countries from the lower, lower-middle and upper-middle-income group

No. of countries	Low income	No. of countries	Lower middle income	No. of countries	Upper middle income
1	Nepal	1	Bangladesh	1	Albania
2	Tajikistan	2	Cambodia	2	Algeria
3	Yemen, Rep.	3	Egypt, Arab Rep.	3	Armenia
		4	Georgia	4	Azerbaijan
		5	Indonesia	5	Belarus
		6	Kyrgyz Republic	6	Bosnia and Herzegovina
		7	Moldova	7	Bulgaria
		8	Mongolia	8	China
		9	Morocco	9	Fiji
		10	Myanmar	10	Iran, Islamic Rep.
		11	Pakistan	11	Iraq
		12	Philippines	12	Kazakhstan
		13	Sri Lanka	13	Lebanon
		14	Tunisia	14	Malaysia

Table 15 (continued)

No. of countries	Low income	No. of countries	Lower middle income	No. of countries	Upper middle income
		15	Ukraine	15	Maldives
		16	Vietnam	16	Montenegro
				17	North Macedonia
				18	Romania
				19	Russian Federation
				20	Serbia
				21	Thailand
				22	Tonga
				23	Turkey

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