Journal of the Knowledge Economy (2024) 15:7852–7872
https://doi.org/10.1007/s13132-023-01407-5

Assessing the Role of Energy Depletion and Energy Import with Carbon Dioxide Emissions in Belt and Road Countries

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Received: 27 January 2022 / Accepted: 22 April 2023 / Published online: 2 June 2023

Abstract
In this paper, we empirically investigate the association between carbon emissions (CO_2), economic growth, energy depletion, and energy import in the Belt and Road Initiatives of panel data over the time 1985 to 2021. The econometric outcomes confirm the co-integrating relationships among the variables. Moreover, the results of the Granger causality test support the causal linkage among the study variables in Belt and Road countries. Based on the augmented mean group (AMG) and common correlated effects mean group (CCEMG) models, it is confirmed that a 1% increase in energy depletion emissions will increase CO_2 emissions by 0.26% and 0.30%, respectively. Furthermore, a 1% increase in energy import will reduce CO_2 emissions by 0.02% and 0.08%, respectively. The results suggest the significance of Belt and Road countries' development for governments and policymakers to restructure their policies for containing the consequences of carbon emissions and curb energy utilization for the everlasting environment to its primary level. Overall, our findings suggest that energy depletion and energy import are significant drivers of CO_2 emissions in Belt and Road countries. These results have important implications for policymakers and stakeholders involved in the Belt and Road countries highlighting the need for sustainable energy policies and investments that reduce energy depletion and promote renewable energy use.

Keywords CO_2 emissions · Energy depletion · Energy import · Belt and Road · AMG, CCEMG model

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Introduction

Carbon dioxide (CO_2) emissions have been identified as a significant contributor to global climate change. The world's reliance on fossil fuels for energy production has led to an increase in CO_2 emissions, resulting in the degradation of the environment and natural resources. However, it is not just the use of fossil fuels that results in CO_2 emissions, but the amount of energy used and the sources of energy used to meet our demands. According to Liu et al. (2013), fossil fuel utilization in association with economic development and human activities drive the formation of around (33.2) billion tons of CO_2 globally. Conventional energy consucmption such as (coal, gas and oil), agriculture emissions, political risk, natural resourece deplation are the main source of increasing CO_2 emission worldwide (Khan & Liu, 2023; Khan et al., 2019, 2022a, 2023). The depletion of energy sources and energy imports are both factors that have a direct impact on CO_2 emissions. Energy depletion refers to the reduction in the availability of energy sources due to the extraction, consumption, or exhaustion of these resources (Abbasi et al., 2021). On the other hand, energy imports refer to the acquisition of energy resources from other countries, often to meet domestic energy demands.

Environmental pollution is primarily caused by the pursuit of rapid economic growth, which many countries are struggling to achieve. For this reason, the study of Khan et al. (2022b, c) suggested that effective governance and lower economic policy uncertainty can effectively mitigate CO_2 emissions. Additionally, the development of new technology and economic advancement contributes to the increase in pollution and CO_2 emissions. The twentieth century witnessed remarkable progress in human civilization, driven by significant advancements in science and technology. The continuous innovation of new technologies, with varying economic and technical features, potential applicability, and capabilities for future energy systems, are continually being introduced and tested. The interconnection between energy depletion, energy imports, and CO_2 emissions has become a crucial area of research. As countries aim to reduce their CO_2 emissions and transition to cleaner energy sources, understanding the role of energy depletion and energy imports is essential. This research aims to assess the role of energy depletion and energy imports in CO_2 emissions by examining the relationship between energy consumption, energy depletion, energy imports, and CO_2 emissions. By understanding the role of energy depletion and energy imports in CO_2 emissions, policymakers and energy planners can make informed decisions that promote sustainable energy practices. This research will contribute to the broader conversation on climate change and provide valuable insights for energy transition strategies. Figure 1 proportion of energy-related engagement in the Belt and Road.

In response to the negative impacts of climate change and global warming, governments and policymakers in developing economies have taken steps to reduce environmental pollution, including implementing renewable energy and environmental taxation policies. The study of Ibrahim and Law (2016) Sub-Saharan African nations found that trade openness can increase pollution in

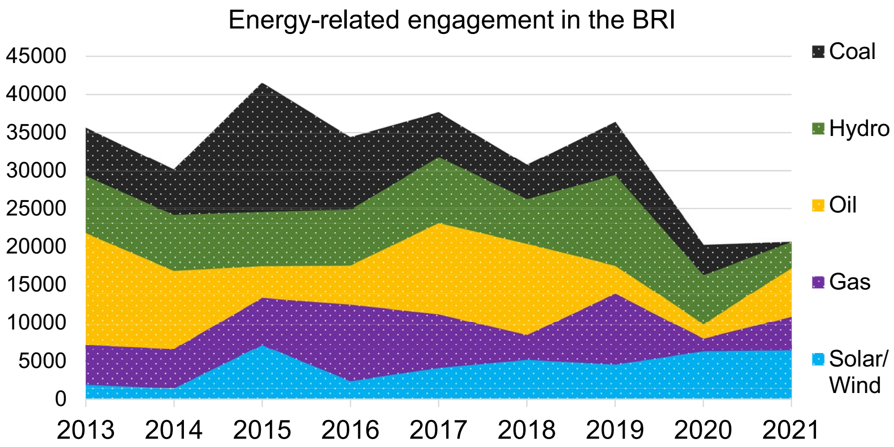

Fig. 1 Illustrates the proportion of energy-related engagement in the Belt and Road

countries with strong institutional quality, while countries without significant institutional quality reforms can suffer environmental damage. In addition, the study of Gök (2020) found that economic growth contributes to air pollution, indicating the need for environmental regulations. The Kyoto Protocol, introduced by Japan in 1997, is one such effort to mitigate greenhouse gas emissions. The latest study proposed by Khan (2021) research on four Asian countries suggests that economic policy uncertainty can impact CO_2 emissions. Furthermore, (Hassan et al., 2021) conducted research on RCEP economies and found that lower political stability can reduce carbon emissions, while lower economic, financial, and composite risks can increase them.

The significance of this study for Belt and Road countries lies in its contribution to understanding the relationship between carbon emissions, economic growth, energy depletion, and energy import in these countries. The study provides empirical evidence and confirms the co-integrating relationships among these variables, which can inform policymakers in the development of sustainable energy policies and investments. The present study findings suggest that energy depletion and energy import are significant drivers of CO_2 emissions in Belt and Road countries. This implies that policymakers and stakeholders need to restructure their policies for containing the consequences of carbon emissions and curb energy utilization to the primary level. The study's results can help policymakers prioritize energy efficiency and conservation measures while promoting renewable energy use, reducing energy depletion, and mitigating the effects of climate change. Overall, the study implications for Belt and Road countries highlight the need for sustainable energy policies and investments that promote renewable energy use and reduce energy depletion. These measures can help reduce the carbon footprint of Belt and Road countries and create a more sustainable environment for their citizens.

Energy Depletion and CO_2 Emissions Nexus

Carbon emissions and energy depletion are closely related. Energy depletion refers to the decline in the availability of natural resources that can be used to produce energy, such as fossil fuels like coal, oil, and natural gas. These fossil fuels are non-renewable and finite, which means they will eventually run out. The burning of fossil fuels is the primary source of carbon emissions, which are a major contributor to climate change. When fossil fuels are burned, carbon dioxide (CO_2) is released into the atmosphere, which traps heat and causes the Earth's temperature to rise. This phenomenon is known as the greenhouse effect. As the energy demand continues to increase, so does the burning of fossil fuels, which leads to higher levels of carbon emissions. This, in turn, contributes to the depletion of natural resources and exacerbates the negative impacts of climate change. To address this issue, there is a growing need to transition to cleaner and more sustainable sources of energy, such as wind, solar, and hydropower, which do not emit carbon dioxide or deplete natural resources.

The demand for renewable energy consumption must be adopted since energy depletion has a significant impact on economic growth and development, making it costly to reduce energy consumption. Even though higher energy use may boost productivity, it is crucial to implement limitations on energy sources that deteriorate the environment and emit carbon dioxide. The extent to which limitations on the supply of energy resources (depletion rate) would ensure that carbon emissions are significantly reduced and environmental degradation is curbed is a topic of contention. Due to its importance in industrial processes and other economic activities, total energy consumption and oil use result in economic progress in all countries. Contrary to common perception, carbon dioxide emissions only negatively affect economic growth in low-income and developing countries while renewable energy usage positively influences it in high-income countries (Antonakakis et al., 2017; Khan et al., 2022b, 2023).

Many studies on the connection between energy depletion and CO_2 have been conducted in the literature on energy and environmental economics. In contrast, numerous studies have advocated substituting renewable energy sources for conventional non-renewable ones in order to enhance environmental quality, advance sustainable development, and support economic growth. The current study, however, aims to broaden the scope of the research already present in the literature by carefully examining how the rate of energy depletion can be taken into account in the connected model between energy import and CO_2 in belt and road countries while taking into account the effects of the two widely acknowledged energy sources.

The current study examines the relationship between energy depletion, energy import, economic growth, and CO_2 emissions for the first time in the case of Belt and Road economies from 1985 to 2021. This study adopted the AMG and CCEMG models to investigate the variation in the nexus between energy depletion, energy import, economic growth, and CO_2 emissions. To our ability, there is no empirical study to cover the selected variables such as energy depletion and energy import in the case of Belt and Road countries to conduct the current study by employing a series of econometric analyses. Moreover, this research provides insights into the extent to which Belt and Road countries are dependent on energy imports to fuel their economic growth. This study finds that these countries are heavily reliant on imported energy sources, policymakers could be encouraged to invest in developing their domestic energy sources to reduce their dependence on foreign energy, potentially reducing their carbon footprint in the process. Another potential contribution of this study identifies specific sectors or industries that are particularly energy-intensive and emit high levels of carbon dioxide. By targeting these sectors or industries for efficiency improvements or carbon reduction strategies, policymakers could potentially reduce the overall carbon footprint of the country while also promoting sustainable economic development.

The rest of the paper is organized as follows: in the "Literature Review" section overviews a variety of literature. The "Data Source and Econometric Strategy" section" reported the data source and econometric strategy. The "Results and Discussions" section describes the empirical results and discussions. Finally, the "Further Discussion" section is the conclusions and policy recommendations.

Literature Review

In recent years, industrialization and globalization have led to increased energy demand and imports, and the growing population's use of electronics has further exacerbated this issue, contributing to global climate change. Our analysis focused on the relationship between CO2 emissions, energy depletion, energy imports, and GDP in Belt and Road countries, which has been a time-consuming topic in the energy literature. Our findings provide compelling evidence that the adoption of renewable energy sources is beneficial for the environment.

Researchers such as (Wang et al., 2011) conduct a study on the metropolitan area of Shanghai, and there is a connection between CO_2 emissions and energy intensity. The study empirical model, STIRPAT, demonstrates that the rise in urbanization leads to increased carbon dioxide emissions. On the other hand, the research shows that the level of CO_2 emissions can be reduced by decreasing energy intensity. To achieve this, policymakers must reform industrialization and improve the energy structure. According to Zhou et al. (2013) conducted analysis of panel data from 30 provinces in China spanning from 1995 to 2009, the researchers have found evidence to support the causal relationship between industrialization and increased levels of CO_2 emissions. Specifically, their results indicate that industrialization has a significant positive effect on carbon emissions. Another study by Lin et al. (2009) conducted on environmental pollution between 1978 and 2006 using a panel dataset has found that economic growth, industrialization, and energy intensity have a comparatively lower significant impact on environmental pollution. The analysis shows that economic growth contributes to a 38% increase in environmental impact, while the rapid decrease in energy intensity is the primary factor in reducing the environmental impact in China. A study explored by Wu et al. (2016) conducted at provincial and regional levels found that the reduction of carbon emissions (CO_2) is closely linked to the energy intensity. The study suggests that introducing new technology and restructuring the energy sector are the main factors that can help reduce carbon emissions.

The connection between carbon dioxide emissions, energy scarcity, and reliance on imported energy sources presents both practical difficulties and intellectual complexities in current research (Lin & Ouyang, 2014). It has been observed that the rise in energy demand has a component that cannot be adjusted easily. Additionally, we have investigated how the use of renewable energy is linked to economic growth and its impact on CO_2 emissions in economies that are part of the Belt and Road initiative (Liu et al., 2017). The study revealed that in the BRICS economies, both renewable energy and economic growth have had adverse effects on CO_2 emissions (Apergis & Payne, 2014). Examine how renewable energy is related to the output and CO_2 emissions in Central American economies by using the Vector Error Correction (VEC) model. Researchers such as (Payne, 2012; Sadorsky, 2009a, b; Salim & Rafiq, 2012) used the ARDL bound test method to analyze the relationship between energy consumption in the short and long term within a demand model framework. They also used panel co-integration estimation to analyze their data. Their findings indicated a positive and significant long-term relationship between CO_2 emissions and energy consumption output using the panel elasticity approach (Cole & Neumayer, 2004; Shen et al., 2005; Wang, 2014; Zhang & Lin, 2012). Industrialization has resulted in significant challenges concerning energy usage, environmental stress, and greenhouse gas emissions. In the following section, we outline the research that has examined the relationship between urbanization, renewable energy, carbon dioxide emissions, and economic progress in various nations. The studies are presented chronologically.

Nexus Between Energy Imports and CO_2 Emissions

In recent times, there has been a greater focus among scholars and policymakers on energy imports and the issue of CO_2 emissions (Li et al., 2022). A study examining the environmental impact of the phosphorus industry discovered that the ecological footprint, as measured by CO2 emissions, is notably influenced by energy imports in the short term, with a delayed positive effect. Similarly, the author(Mahmood, 2022) conducted a study on the connection between industrialization, pollution emissions, and green and circular economies from 1980 to 2019. The findings suggested that industrialization contributes to an increase in CO2 emissions, but trade openness may help reduce them. The author recommended imposing carbon taxes on industrialization as a necessary and crucial step. While some researchers have highlighted the harmful effects of energy import constructions on CO2 emissions, this study emphasized the importance of controlling emissions from industrialization. According to Shahbaz et al. (2016) energy utilization has a negative impact on CO2 emissions in Indonesia, but only after a certain level of economic growth has been achieved. The study also found evidence that a new type of urbanization, characterized by green spaces and high quality, can effectively reduce CO2 emissions. Likewise, the background of China, (Liu & Bae, 2018) concluded that the energy expansion and transformation caused environmental degradation from 1970 to 2015, On the other hand, the empirical study suggested by Wang et al. (2019) found that in China, the use of technology can reduce CO_2

emissions. This study also suggests that there are specific threshold effects in the relationship between new urbanization and CO_2 emissions. Given these conflicting findings, it can be concluded that there is no agreement among different countries on the impact of conventional energy imports on CO_2 emissions.

Nexus Between Energy Depletion and CO_2 Emissions

When the rate of consumption of natural or energy resources exceeds the rate of replenishment, those resources become depleted. This is because the value of a resource is linked to how easily it is available in nature and the cost of extracting it. As the resource becomes scarcer, its value increases. Resources that are being depleted more quickly are therefore more valuable. However, it may be possible to slow down the rate of depletion of energy resources in order to reduce carbon emissions (Mitra, 2019). To minimize carbon dioxide levels, it is crucial to implement stringent measures aimed at reducing carbon emissions and discouraging the use of energy sources that emit high amounts of carbon.

In light of the urgent challenge posed by climate change, there has been growing interest in exploring the connection between the use of renewable energy and the release of CO_2 into the atmosphere, as opposed to the traditional focus on non-renewable energy sources. Many studies have emphasized the crucial role of renewable energy consumption in reducing CO_2 emissions, particularly as technological advancements make it more cost-effective and accessible. The adoption of renewable energy sources is thus seen as contingent on their relative affordability and ease of implementation (Bilgili et al., 2016; Haldar & Sethi, 2021; Zaidi et al., 2018). According to the study Shafiei and Salim (2014), OECD countries experienced economic growth fuelled by non-renewable energy sources which resulted in a significant rise in CO_2 emissions between 1980 and 2011. However, the study also found that the rate of increase in CO_2 emissions slowed down after 2008 because of a shift towards greater use of renewable energy sources (Zafar et al., 2019), empirically verified that ERC improves environmental quality by reducing CO_2 emission intensity for both G-7 countries and N-11 countries (Kirikkaleli et al., 2022). It has been verified that both renewable energy consumption (REC) and financial development can lower the number of CO_2 emissions based on consumption in Chile. On the other hand, an increase in economic growth is likely to result in higher levels of consumption-based CO_2 emissions. In contrast, according to a study (Apergis et al., 2010) based on data from 19 developed and developing countries between 1984 and 2007, it was concluded that the use of renewable energy sources does not have an immediate impact on reducing CO_2 emissions. The authors of the study emphasized the need for governments to establish and implement long-term policies aimed at increasing the use of renewable energy and promoting sustainable economic growth. Similar findings were reported by Farhani and Shahbaz (2014) highlighting the complex relationship between ERC and CO_2 emissions when considering various economies and controlling for different variables. This emphasizes the importance of gathering more evidence to enhance our understanding of the connection between these two factors.

Nexus Between Economic Growth and CO_2 Emissions

In the literature regarding the connection between economic growth (EG) and CO2 emissions, the findings of previous studies can be categorized into three groups: those that suggest a direct correlation between the two, those that suggest an indirect correlation, and those that find no significant correlation at all. The first group suggests that EG leads to either an increase or a decrease in CO_2 emissions. In the period between 1979 and 2018, India's CO2 emissions have been influenced by both economic globalization and international trade, as highlighted by Biswas and Bag (2022). On the other hand, (Wei & Huang, 2022) discovered that the USA's promotion of green finance has a significant impact on reducing carbon emissions in the short-term, but without long-term policies, this effect is not sustainable. Additionally, the connection between economic growth and CO_2 emissions is not straightforward, as demonstrated by studies that test the Environmental Kuznets Curve hypothesis or use threshold effect models. These approaches reveal a non-linear relationship between economic growth and CO_2 emissions (Ali et al., 2021). Several studies have explored the long-term relationships between economic growth (EG), fossil fuel consumption, foreign direct investment (FDI), and carbon dioxide (CO_2) emissions in Pakistan. They have found evidence supporting an inverted U-shaped relationship between EG and CO_2 emissions. Furthermore, the impact of globalization on CO_2 emissions has been widely discussed in recent years due to the increasing trend of globalization. The findings of Leal and Marques (2020) suggested that high-globalized countries show evidence of an Environmental Kuznets Curve (EKC) phenomenon, whereas low-globalized countries do not. The study suggests that political globalization can be beneficial in reducing CO_2 emissions, while economic globalization may have a detrimental impact on the environment. In a study using a dynamic panel threshold model, researchers (Aye & Edoja, 2017) analysed the impact of EG (presumably referring to economic growth) on CO_2 emissions. The findings indicated that in the low-growth regime, EG has a negative effect on CO_2 emissions, while in the high-growth regime, it has a positive effect, with a greater impact than in the low-growth regime. In addition, a study conducted on the relationship between CO_2 emissions and economic growth in Kazakhstan from 1992 to 2013 found that the evidence did not support the Environmental Kuznets Curve (EKC) hypothesis for Kazakhstan (Hasanov et al., 2019). Similarly, (Cai et al., 2018) no co-integration was found between EG and CO_2 emissions in some of the G7 countries including Canada, France, Italy, the USA, and the UK.

Data Source and Econometric Strategy

In the current study, we acquired the data for this study from the World Bank indicator (WDI). This study employed a balanced panel dataset of 65 countries under B&R initiatives from 1985 to 2021, comprised of a total of 2368 observations. Moreover, we explain all the selected variables obtained from the World Development Indicator (WDI) as follows: the data on economic growth (illustrated here as per capita GDP), energy consumption (EC) (defined as per capita total primary energy consumption); CO_2 emissions are (per capita CO_2

emissions), and energy imports, net (% energy use). The panel data set for all the study variables were obtained from the World Development Indicators. Table 1 illustrates the data description, source, and period.

Panel Co-integration Tests

The paper utilized a panel co-integration test to examine whether there is a co-integration relationship among the variables of the study, which include CO_2 emissions, energy depletion, and energy import. As a result, various types of panel co-integration techniques were developed by Pedroni (1999, 2001, 2004) as well as Pedroni, Kao, and Fisher tests. This paper utilized the Pedroni co-integration method to examine the co-integration relationship between the chosen variables. Furthermore, various statistical techniques, including the Pedroni panel co-integration test, were employed to investigate the null hypothesis of H0, which states that there is no co-integration for the B&R panel. The residuals of the regression were classified into two groups of tests: the first group consisted of four tests for the within dimension and the second group included three tests for the between dimension. Nevertheless, the null hypothesis of no co-integration was examined for both groups of tests. However, the two methods differ in the characteristics of the alternative hypothesis H1, with the between-dimension test having a heterogeneous alternative, and the within-dimension test having a homogeneous alternative. The empirical tests were conducted based on the regression equations:

$$y_{it} = \alpha_{,i} + \lambda_{it} + \sum_{j=1}^{m} \beta_{ji} x_{jit} + \varepsilon_{it} \quad (1)$$

where "t" represents the period and "m" denotes the number of regressors. In order to determine the residuals, it is mandatory to examine the following techniques for each group.

Panel Granger Causality Test

This paper utilized panel co-integration estimation to investigate the presence of directional causality between the chosen variables. Khan et al. (2019) the panel Granger causality estimation was utilized in this study to investigate the causal relationship

Table 1 Definition and sources of variables

Variable	Definition	Source	Period
CO_2	CO_2 emissions (metric tons per capita)	WDI	1985–2021
ED	Energy depilation (current US $)	WDI	1985–2021
EI	Energy imports, net (% energy use)	WDI	1985–2021
GDP	Economic growth as the real annual GDP growth (constant 2010 US $)	WDI	1985–2021

between climate changes and trade. This test was deemed superior because it identifies short-term causality based on F-statistics. On the other hand, co-integration estimation can further examine long-term causality based on the error correction term ECT (− 1). The explanation of the Granger causality test can be outlined as follows:

$$\Delta CO_{2it} = \alpha_{1i} + \sum_{i=1}^{1} \alpha_{11it}\mathrm{ED}_{it-1} + \sum_{i=1}^{1} \alpha_{12it}\mathrm{GDP}_{it-1} + \sum_{i=1}^{1} \alpha_{13i}\mathrm{EI}_{it-1} + \alpha_1 ECT_{it-1} + \mu_{1it} \tag{2}$$

$$\Delta ED_{it} = \alpha_{2i} + \sum_{i=1}^{1} \alpha_{21it}\mathrm{EI}_{it-1} + \sum_{i=1}^{1} \alpha_{22it}\mathrm{GDP}_{it-1} + \sum_{i=1}^{1} \alpha_{23i}\mathrm{CO}_{2it-1} + \alpha_2 ECT_{it-1} + \mu_{2it} \tag{3}$$

$$\Delta GDP_{it} = \alpha_{3i} + \sum_{i=1}^{1} \alpha_{31it}\mathrm{ED}_{it-1} + \sum_{i=1}^{1} \alpha_{32it}\mathrm{EI}_{it-1} + \sum_{i=1}^{1} \alpha_{33i}\mathrm{CO}_{2it-1} + \alpha_3 ECT_{it-1} + \mu_{3it} \tag{4}$$

$$\Delta EI_{it} = \alpha_{i1} + \sum_{i=1}^{1} \alpha_{41it}\mathrm{ED}_{it-1} + \sum_{i=1}^{1} \alpha_{42it} GDP_{it-1} + \sum_{i=1}^{1} \alpha_{43i}\mathrm{CO}_{2it-1} + \alpha_4 ECT_{it-1} + \mu_{4it} \tag{5}$$

In the above equation, Δ represents the first difference, (*ECT*) represents the error-correction term, and “*l*” represents the lag length.

Model Specifications

The primary objective of our study is to examine the relationship between the selected variables used in this paper. In general, to obtain this goal, we run various panel dataset econometric models for B&R economies which are comprised of 65 countries from 1990 to 2017. Panel data analysis has certain privileges because of its uniqueness and consolidation results in scientific research. We design model equations that can be explained as follows:

$$\mathrm{CO}_{2\mathrm{it}} = \mathrm{f}(\mathrm{ED}_{\mathrm{it}}, \mathrm{OI}_{\mathrm{it}}, \mathrm{GDP}_{\mathrm{it}}) \tag{6}$$

$$\mathrm{ED}_{\mathrm{it}} = \mathrm{f}(\mathrm{EI}_{\mathrm{it}}, \mathrm{CO}_{2\mathrm{it}}, \mathrm{GDP}_{\mathrm{it}}) \tag{7}$$

$$\mathrm{GDP}_{\mathrm{it}} = \mathrm{f}(\mathrm{ED}_{\mathrm{it}}, \mathrm{EI}_{\mathrm{it}}, \mathrm{CO}_{2\mathrm{it}}) \tag{8}$$

$$\mathrm{EI}_{\mathrm{it}} = \mathrm{f}(\mathrm{ED}_{\mathrm{it}}, \mathrm{CO}_{2\mathrm{it}}, \mathrm{GDP}_{\mathrm{it}}) \tag{9}$$

where GDP defines per capita gross domestic product calculated at the constant price (2005 US $), CO_2 represents per capita carbon dioxide emissions, and ED denotes energy depletion (current US $). Finally, EI represents the energy imports and net (% of energy use), respectively. While “*t*” denotes the year and “*i*” denotes the cross-sections of B&R countries.

Summary Statistics

The descriptive statistics provide a general idea and understanding of our data set, which includes the mean, standard deviation, skewness, Jarque–Bera, kurtosis statistics, and observations for the full-panel and sub-panels reported in Table 2. The mean value of CO_2 emissions is reported as 1.025 while the standard deviation is 1.450. The mean value of GDP is reported as 7.90 while the standard deviation value is 1.39. The energy depletion mean value is accounted for 7.60 and the standard deviation value is 2.75. Finally, the energy import mean value is reported at −0.26 and the standard deviation value is 3.12. A total of 2368 observations were reported in the study. Moreover, cross-section and period identifiers are also presented for reference. These statistics are shown as a rough sketch of the selected variables in the full-panel of selected B&R economies.

Panel Unit Root Test

Table 4 displays the results of the unit root test. The panel unit root test is a crucial method for examining spurious outcomes and assessing the stationarity properties of the observed variables in the study model. In this study, three distinct forms of unit root tests were utilized. Choi (2001 and Im et al. (2003) augmented dicky fuller (ADF), (Pasaran et al., 1995), ADF Fisher type was utilized in this study to examine whether the study variables were stationary at levels 1(0) or first difference 1(1). The null hypothesis for all three-unit root tests was that there is a unit root in all the panels (H0), while the alternative hypothesis was that there is no unit root in all the selected panels (H1). The results indicate that all the selected variables in this study were stationary at first difference 1(1). The following equations provide an explanation of the unit root test interpretation.

$$\Delta y_{i,t=}\beta_i y_{i,t-1}\sum_{j=1}^{Pi} p_{i,t}\Delta y_{i,t}+\varepsilon_{i,t}\mathrm{I} = 1, \ldots .\mathrm{T} \tag{10}$$

$$Y_t - Y_{t-1} = \rho Y_{t-1} - Y_{t-1} + \in_t \tag{11}$$

$$Y_t - Y_{t-1} = \Delta Y_{t-1} + \in_t \tag{12}$$

Table 2 Summary statistics

Full sample								
Variables/ratios	N	Mean	Median	Std	Min	0.25	0.75	Max
CO2 per capita	2368	1.025	1.311	1.450	−3.386	0.022	2.022	4.250
GDP per capita		7.900	7.833	1.393	4.546	6.859	8.964	11.391
ED		7.602	8.436	2.750	0	6.578	9.503	11.372
Energy import		−0.268	−0.244	3.124	−9.648	−2.285	2.626	4.200

We converted the following equations as follows:

$$\Delta Y_t = \delta Y_{t-1} + \in_t \tag{13}$$

In Eq. (4), $\delta = (\rho - 1)$ and Δ represent the first difference estimation. We consider that all the study variables will be stationary at the 1st difference 1(1), while, Y_t is coherent of the order 1 or supposedly assimilated unit root, conditionally, if Y_t is non-stationary but ΔY_t is stationary.

$$Y_t - Y_{t-1} = \beta Y_{t-1} - Y_t + \varepsilon_t \tag{14}$$

$$\Delta Y_t = \beta 1 + \delta Y_{t-1} + \varepsilon_t \tag{15}$$

$$\Delta Y_t = \beta + \delta Y_{t-1} + \varepsilon_t \tag{16}$$

$$\Delta Y_t = \beta + \beta 2 + \delta Y_{t-1} + \varepsilon_t \tag{17}$$

In the above equations, we consider that the residual which is represented by (ε_t) is not statistically associated. Alternatively, if the residual (ε_t) is statistically associated. Researchers such (Dickey & Fuller, 1979) have first developed a test analyzed as the Augmented Dickey-Fuller test known as (ADF). Additionally, the augmented technique is corresponding to the subsequent model equation.

$$\Delta Y_t = \beta 0 + \beta 1 t - 1 + \sum_{i=1}^{m} \beta i \Delta Y_{t-1} + \varepsilon_t \tag{18}$$

$$\Delta Y_t = \beta 1 + \beta 2 t + \delta Y_{t-1} + \sum_{i=1}^{m} \propto \Delta Y_{t-1} + \varepsilon_t \tag{19}$$

In Eqs. (9) and (10), we are supposed to include appropriate terms so that the error term in the equation is serially uncorrelated.

The output of the unit root test is tabulated in Table 3. Panel unit root tests are typically used in econometrics to analyze panel data, which is a dataset consisting of observations of the same variables over multiple units or entities, such as countries, firms, or individuals. There are several different types of panel unit root tests,

Table 3 Unit root test

Variables	LLC		IPS		ADF	
	Level	1st difference	Level	1st difference	Level	
CO_2	3.004	−24.40***	82.72	−30.16***	111.1	1638.9***
ED	−8.69***	−24.46***	323.4***	−32.36***	250.7	1047.7***
EI	−10.27***	−27.85***	376.1***	−34.73***	283.1***	1094.7***
GDP	7.642	−14.46***	24.72	−21.86***	21.81	721.2***

*; ** and *** represent the level of significance at 10%, 5%, and, 1%, respectively

Table 4 Cross-sectional dependence test

Test	Statistic	d.f	Prob
Breusch-Pagan LM	23887.91	2016	0.0000
Pesaran scaled LM	344.4503		0.0000
Pesaran CD	87.84547		0.0000

including the Levin-Lin-Chu (LLC) test, the Im-Pesaran-Shin (IPS), and the Augmented Dicky-Fuller (ADF) test. These tests typically involve estimating a regression model with lagged dependent variables and/or trend variables, and then testing whether the estimated model residuals have a unit root. If the panel unit root test indicates that the data has a unit root, it may be necessary to transform the data or use alternative modeling techniques to account for non-stationarity and prevent spurious regression results.

Table 4 exhibits the outcomes of the Cross-sectional dependence test. CSD occurs when the observations within a dataset are not independent of each other, but instead, exhibit some form of interdependence or correlation. This can arise in many contexts, such as panel data analysis, spatial econometrics, and network analysis. To test for cross-sectional dependence, there are several methods available, including the Breusch-Pagan Lagrange Multiplier (LM) test: this test is based on regressing each observation on all the other observations in the sample and then testing whether the residuals from these regressions exhibit any correlation. The Pesaran CD test: this test is based on estimating a common factor model for the data and then testing whether the factor loadings are equal across all observations. If the factor loadings are different, then there is cross-sectional dependence.

The outcomes of the panel co-integration test are presented in Table 5. Panel co-integration tests are used to examine the long-term equilibrium relationship between two or more variables in a panel dataset. Co-integration tests are often used in econometric analysis to determine whether a set of variables move together in the long run.

Table 5 Panel Co-integration test

Alternative hypothesis: common AR coefs. (within-dimension)				
	Weighted			
	Statistic	Prob	Statistic	Prob
Panel v-statistic	−0.853733	0.8034	−1.432547	0.9240
Panel rho-statistic	0.860235	0.8052	−2.942216	0.0016
Panel PP-statistic	−2.905671	0.0018	−7.481367	0.0000
Panel ADF-statistic	0.524965	0.7002	−2.862655	0.0021
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob		
Group rho-statistic	−1.653915	0.0491		
Group PP-statistic	−8.909619	0.0000		
Group ADF-statistic	−4.253716	0.0000		

Results and Discussions

Compared to traditional fixed-effects and random-effects models, the AMG model is often more efficient in estimating parameters. This is because it accounts for both time-invariant and time-varying individual effects, which can reduce the bias in the estimates. In addition, the AMG model can also lead to improved predictive power compared to other panel data models. This is because it allows for more flexibility in modeling the individual effects, which can improve the accuracy of the predictions. Furthermore, the AMG model is particularly useful when there is significant heterogeneity across individuals in the panel. By allowing for both time-invariant and time-varying individual effects, the model can better capture this heterogeneity and provide more accurate estimates of the underlying parameters.

The outcomes of AMG and CCEMG models are presented in Table 6. The value of GDP shows a positive and significant association with CO_2 emissions for both the AMG and CCEMG models, indicating that a 1% increase in GDP will raise CO_2 emissions by 0.054% and 0.321%, respectively. Similar outcomes are confirmed by the study of Al-mulali et al. (2013). Lastly, we revealed a long-run two-way causal connection between CO_2 emissions and economic growth and vice versa. Likewise, energy depletion (ED) also shows a positive and significant link with CO_2 emissions indicating that a 1% increase in energy depletion with increase the level of CO_2 emissions by 0.26% and 0.30%, respectively. Interestingly, energy imports can help reduce emissions by providing access to lower-carbon energy sources and technologies, reducing reliance on high-carbon sources and promoting global cooperation to address climate change. However, it is important to consider the emissions associated with the transportation of energy and the potential for carbon leakage, where reductions in emissions in one country are offset by increases in emissions in another country. Our study found a negative and significant association between energy import and CO_2 emissions, indicating that a 1% increase in energy import can reduce CO_2 emissions in Belt and Road countries by 0.029% and 0.03%, respectively.

Table 6 The outputs of AMG and CCEMG models

Variables	AMG model	CCEMG model
GDP	0.054*** (5.52) [0.172]	0.321*** (3.83) [0.021]
ED	0.262** (2.86) [0.092]	0.303*** (3.45) [0.088]
Energy import	−0.029** (−1.98) [0.015]	−0.03* (−1.95) [0.015]
Constant	−0.380* (−0.44) [0.874]	−1.596* (−0.79) [2.012]

*; ** and *** represent the level of significance at 10%, 5%, and, 1%, respectively

Table 7 Robustness check

Variables	FMOLS	DOLS
GDP	0.154*** (5.749) [0.026]	0.161*** (5.891) [0.027]
Energy depletion	−0.089*** (6.068) [0.014]	−0.077*** (5.041) [0.015]
Energy import	0.038** (−2.187) [0.017]	0.037 (−1.873) [0.019]*

*; ** and *** represent the level of significance at 10%, 5%, and, 1%, respectively

The outcomes of the robustness test are presented in Table 7. The purpose of a robustness check is to evaluate the stability and reliability of a statistical model or analytical result under different conditions, assumptions, and specifications. Robustness checks are performed to test the sensitivity of the results to changes in the model's inputs, parameters, or assumptions. They are important because statistical models and analytical results are often based on simplifying assumptions and idealized scenarios that may not hold in real-world situations.

T values are reported in brackets, while *Z* values are presented in parentheses.

The outcomes of the causality test are presented in Table 8. The purpose of the panel Granger causality test is to determine whether there is a causal relationship between two variables in a panel data set while taking into account the potential effects of other variables. This test is particularly useful in econometric analysis, where researchers often need to understand the causal relationships between economic variables. The panel Granger causality test can help researchers identify the direction of causality between two variables and can be used to test economic theories and can make predictions about future economic trends. It is also useful for

Table 8 Panel Granger causality test

Null hypothesis	Obs	F-statistic	Prob
ED ≠ CO_2	2298	1.15	0.2828
CO_2 → ED		4.49	0.0341
EI → CO_2	2300	5.26	0.0219
CO_2 ≠ EI		0.98	0.3221
GDP ≠ CO_2	2304	1.17	0.2776
CO_2 → GDP		42.7	7.E-11
EI → ED	2294	5.97	0.0145
ED → EI		2.91	0.0880
GDP → ED	2298	4.27	0.0388
ED ≠ GDP		2.06	0.1511
GDP ≠ EI	2300	0.02	0.8649
EI ≠ GDP		0.61	0.4323

policymakers who need to understand how changes in one variable may affect other variables in the economy.

We found a one-way causality running from CO_2 emission to energy depletion, indicating that energy depletion negatively affects CO_2 emissions in BRICS economies. In addition, a two-way causality was found between energy import and energy depletion, indicating that the two variables affect each other. Further, a one-way causal link was found between energy import and CO_2 emissions, it shows that energy import positively affects CO_2 emissions. Finally, no causal association was found between energy import and GDP.

Further Discussion

According to various studies, Belt and Road countries contribute significantly to global carbon dioxide emissions, with China being the largest contributor. Several factors are responsible for these emissions, including energy depletion and energy import. In this paper, we assess the role of energy depletion and energy import on carbon dioxide emissions in Belt and Road countries.

Firstly, energy depletion plays a significant role in carbon dioxide emissions in Belt and Road countries. These countries are home to vast reserves of fossil fuels, including coal, oil, and gas. The extraction and burning of these fossil fuels are major contributors to carbon dioxide emissions in these countries. For example, China, the largest Belt and Road country, relies heavily on coal for electricity generation, which leads to significant carbon dioxide emissions. Secondly, energy imports also play a critical role in carbon dioxide emissions in Belt and Road countries. Many of these countries are heavily dependent on energy imports from other countries, primarily from the Middle East. These imports include oil and gas, which are major contributors to carbon dioxide emissions. For example, Pakistan, a Belt and Road country, imports more than 80% of its oil and gas requirements, leading to significant carbon dioxide emissions. Furthermore, Belt and Road countries' rapid economic growth and industrialization have also contributed to increased carbon dioxide emissions. These countries are investing heavily in infrastructure development, such as power plants, highways, and ports, which requires significant energy consumption, leading to increased carbon dioxide emissions.

In conclusion, energy depletion and energy import are significant contributors to carbon dioxide emissions in Belt and Road countries. These countries must take urgent steps to reduce their reliance on fossil fuels, promote renewable energy sources, and increase energy efficiency to mitigate the impact of carbon dioxide emissions on the environment.

Conclusions and Policy Recommendations

In the current study, we focused on the association between CO_2 emissions, economic growth, energy depletion, and oil imports of Belt and Road countries. Therefore, this study is interesting and makes a significant contribution to the current literature and scientific research. Based on the available research on Belt and Road countries, it can be concluded that energy depletion and energy import have played a significant role in carbon dioxide emissions in these countries. In conclusion, this empirical investigation sheds light on the relationship between carbon emissions, economic growth, energy depletion, and energy import in the Belt and Road Initiatives. The results confirm that there is a co-integrating relationship among the variables and support the causal linkage among the study variables in Belt and Road countries. Specifically, the findings suggest that energy depletion and energy import are significant drivers of CO_2 emissions in Belt and Road countries. These results have important implications for policymakers and stakeholders involved in the Belt and Road countries. The study highlights the need for sustainable energy policies and investments that reduce energy depletion and promote renewable energy use. These findings are in line with the study of Liu et al. (2023). Governments and policymakers need to restructure their policies to contain the consequences of carbon emissions and curb energy utilization for the everlasting environment to its primary level. Overall, this study contributes to the literature on energy, the environment, and economic growth in the context of Belt and Road countries. It provides useful insights for policymakers and stakeholders to design and implement sustainable energy policies to mitigate the impact of carbon emissions on the environment and promote sustainable economic growth.

Moreover, many Belt and Road countries are rich in natural resources, such as oil, gas, and coal, which has led to high levels of energy production and consumption. However, the excessive exploitation of these resources has led to depletion and increased carbon dioxide emissions. Additionally, some Belt and Road countries rely heavily on energy imports to meet their energy needs, which can lead to increased carbon dioxide emissions. For example, China, a major Belt and Road country, has increased its coal imports in recent years, leading to an increase in carbon dioxide emissions. Furthermore, many Belt and Road countries are investing in large-scale infrastructure projects, such as power plants and transportation networks, which require significant amounts of energy and contribute to carbon dioxide emissions. To address these issues, Belt and Road countries need to develop more sustainable energy policies and reduce their reliance on fossil fuels. This could involve investing in renewable energy sources, improving energy efficiency, and promoting the use of low-carbon technologies. Overall, energy depletion and energy import have contributed significantly to carbon dioxide emissions in Belt and Road countries. These countries need to address these issues and transition to more sustainable energy systems to mitigate the effects of climate change.

In conclusion, this study proposes that countries involved in the Belt and Road Initiative (BRI) should collaborate to develop effective clean and green energy strategies to reduce CO2 emissions. All countries and regions need to take responsibility for mitigating carbon emissions to ensure economic and social development in their respective nations. Therefore, governments and policymakers should consider the significance of these critical factors to effectively address the issue of rising carbon emissions in these regions caused by economic growth and development. Furthermore, the findings of this study indicate the crucial need for policymakers in Belt and Road countries to reduce their heavy reliance on conventional energy imports. The utilization of CO_2 emissions and energy consumption has notably surged in these countries over the past two decades. As a result, the following policy implications are suggested based on the conclusions drawn from this study after evaluating the impact of energy depletion and energy imports on carbon dioxide emissions in Belt and Road countries, the following policy recommendations are proposed:

Belt and Road countries should invest more in the development and deployment of renewable energy sources such as solar, wind, and hydropower. Governments could provide incentives and subsidies to promote the use of renewable energy and encourage private investment in these sectors.

- Governments should promote energy efficiency measures such as building insulation, efficient appliances, and transportation networks. This can help to reduce energy consumption and carbon dioxide emissions.
- Governments could implement carbon pricing mechanisms such as carbon taxes or emissions trading schemes to incentivize the reduction of carbon dioxide emissions. This can provide an economic incentive for businesses to invest in low-carbon technologies and reduce their carbon footprint.
- Belt and Road countries should work together to share knowledge and technology to support the transition to low-carbon energy systems. This could include joint research and development programs and knowledge-sharing initiatives.
- Governments should prioritize the development of sustainable infrastructure projects that use low-carbon technologies and promote energy efficiency. This can help to reduce the carbon footprint of infrastructure projects and support the transition to a low-carbon economy.
- Overall, these policy recommendations could help Belt and Road countries to address the role of energy depletion and energy import with carbon dioxide emissions and support the transition to more sustainable energy systems.

Author Contribution Y. K wrote the introduction, literature review and data collection and the main idea of the original draft. He designed the empirical analysis, methodology, and revised the final draft and supervision. While, H. O data collection. T. H supervision, editing and review.

Funding The 2021 Anhui provincial university science and Research project (Grant No. SK2021A0290). This study is financially supported by the Research Program of Social Science and Humanities, Ministry of Higher Education (Grant No.21YJA790081). Foundation of Anhui Natural Science project number (Grant No.2108085MG245). The postdoctoral research fund of Anhui Polytechnic University, Wuhu (Grant No. S022023005/S022023004).

Data Availability The datasets analysed for this study can be found in the World Bank Database, here is the website reference https://databank.worldbank.org/reports.aspx?source=world-development-indicators.

Declarations

Ethics Approval We acknowledged that this paper has not been published elsewhere and is not under consideration by another journal. Ethical approval and informed consent do not apply to this study.

Consent to Participate Not applicable.

Consent for Publication Not applicable.

Conflict of Interest The authors declare no competing interests.

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