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RESEARCH ARTICLE

Carbon neutrality challenges in Belt and Road countries: what factors can contribute to CO_2 emissions mitigation?

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Abstract
As climate warming is intensifying, CO_2 emission reduction has aroused the great attention of many governments and scholars. Compared with traditional industrial times, the influencing system of CO_2 emission in modern society has taken great changes due to technological advancement, improvement in energy efficiency, and the popularity of the internet. But the current literature has not reached a consensus on this theme. Our study tends to investigate the nexus between international trade, international trade taxes, energy intensity, internet usage, renewable energy, and CO_2 emission while incorporating income levels by using the data from Belt and Road countries in the 2008–2020 period. For this purpose, we applied the unit root test, CSD, Granger causality test, AMG, CCMG, and CS-ARDL methods. The results show that energy efficiency, GDP, and internet use have significantly negative effects on CO_2 emission, while GDP has significant positive impacts on CO_2 emission. By classifying 65 countries along Belt and Road into four groups of low-income level, low-middle income level, upper-middle income level, and a high-income level, the regional heterogeneities of influencing factors of CO_2 emission is confirmed. Furthermore, this empirical study provides new insights to policymakers to reduce CO_2 emissions through technology innovation, international cooperation, and human capital investment without deteriorating economic growth.

Keywords CO_2 emissions · International trade taxes · Energy intensity · Internet users · Belt and Road

Abbreviations

BRI	Belt and Road Initiatives
CO_2	Carbon dioxide emissions
OECD	Organization of Economic Cooperation and Development
LI	Lower income
LMI	Lower-middle income
UMI	Upper-middle income
HI	High income
AMG	Augmented mean group
CCEMG	Common correlated effect mean group
FMOLS	Fully modified ordinary least square
DOLS	Dynamic ordinary least square

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Introduction

Environmental pollution is a worldwide severe concern and "Belt and Road" economies are no exception. In 2015, about 200 countries around the world signed the historic "Paris Agreement" and decide to mitigate the rise in average temperature around the globe to less than 2 °C in comparison with pre-industrialization data. The "Belt and Road Initiatives" introduced by Chinese President Xi Jinping in 2013 in Kazakhstan is one of the largest infrastructure development projects in human history (China National Development And Reform Commission 2015). The main purpose of BRI is to promote economic growth including trade exchanges, regional integration, infrastructure development, connectivity, business cooperation, financial investment, people-to-people communication, and cultural exchanges. The GDP of the "Belt and Road Initiatives" countries surpassed US$ 13.77 trillion in 2017, accounting for 16.93% of the total world's GDP (Bank 2019).

Due to the deep cooperation of BRI development, China's foreign capital investment in "Belt and Road" countries has grown year by year. Based on the statistical data from 2013 to 2019, China's cumulative direct investment in countries along the route was US$117.31 billion. As shown in Figure 1, Asia continued to receive the largest share of Chinese BRI investments (about 54% in 2020), while Africa received about 27% of BRI investments. Investments into European countries BRI countries were least affected by COVID-19, declining by 36% only (BRI investments in North America only include investments into Mexico, which tend to be low and thus are not as volatile). In contrast, investments in African regions (Sub-Saharan Africa, Arab, and the Middle East) were most heavily impacted by COVID-19 and declined by 69% and 66%, respectively, from 2019 to 2020. Among them, China's investment flow and stock in Singapore ranked first among countries along the "Belt and Road," reaching US$4.83 billion and US$52.64 billion, respectively, accounting for 25.8% and 29.3% of China's investment in countries along the "Belt and Road" (Yidaiyilu 2019). In addition, China's foreign investments enhance the economic growth of the Belt and Road through investment-driven impacts such as promoting the people's life quality and transportation conditions through infrastructure development.

Climate change and environmental pollution are serious concerns facing today's world. According to the UN World Meteorological Organization, the global average temperature CO_2 emissions density crossed 405 ppm in 2017 (UN 2019), which lead the way to persistent floods, drought, hunger, poverty, rising sea level, melting glaciers, and economic losses. Backdate in 2015, more than 200 countries all over the world signed the promising agreement called "The Paris Accord" which aims to intent circumscribe the increase in average global temperature to less than 2 °C associated with pre-industrialization (Cai et al. 2021). In developing countries such as the "Belt and Road" is necessary to increase their economic growth which will consequently increase

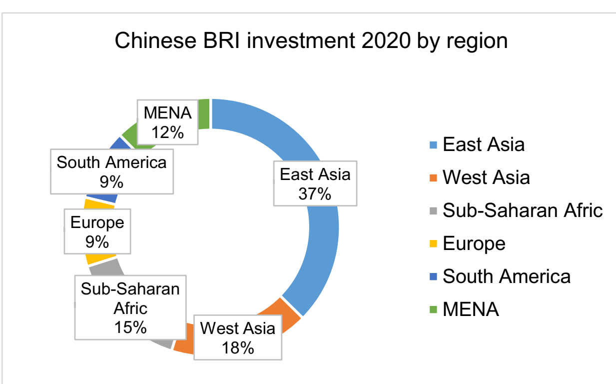

Fig. 1 Chinese BRI investment 2020 by region. Source: Green BRI center, (https://greenfdc.org/china-belt-and-road-initiative-bri-investment-report-2020/)

CO_2 emissions in the BRI countries. Based on the statistical data from the international energy agency (IEA), CO_2 emissions are substantially increased with a rapid speed in Belt and Road countries due to industrialization and an increase in international trade. In 2017, statistical data shows that CO_2 emissions of the Belt and Road countries passed 11.76 billion tons, estimating 35.81% of the total global CO_2 emissions which will significantly affect global climate change and environmental damages (IEA 2019). The Belt and Road economies' GDP is estimated for approximately 17% of the total world economy; however, these countries are also accountable for over one-third of global CO_2 emissions. Because of increased global warming, Belt and Road economies are struggling to steer the association between CO_2 emissions and economic growth, while perpetual to increase opportunities for stable and consolidate economic prosperity. Therefore, it is essential to mitigate CO_2 emissions and develop the Belt and Road economies without the climate damages.

The aim of the "Belt and Road Initiative" is to promote international trade activities and counter trade restrictions among the Belt and Road member countries, which will enhance international trade among the partner countries (Li and Jin 2018). Figure 2 illustrates the Belt and Road Initiatives connectivity map along with the Belt and Road countries and regions. Additionally, China's strategy is to increase foreign investment in Belt and Road countries for the development of economic corridors to promote trade, economic growth, connectivity, energy, and other infrastructure development. The study of Khan and Bin (2020) found a positive and significant linkage between trade and CO_2 emissions in the Belt and Road countries from 1985 to 2017 by employing the CCMG and AMG estimations. In the latest report by the Chinese Ministry of Commerce, the Chinese government spent US$29 billion on Belt and Road economies in the year 2016 and 2017 ("Ministry of commerce," 2017). Consequently, this raise in international trade activities will have a direct influence on the Belt and Road country's economic growth, which resultantly will affect the environment. Hence, it is essential to examine the environmental pollution impact of international trade along the "Belt and Road" countries.

In the previous literature, most of the studies explore the trade-environment linkage by utilizing variables of total trade or trade openness such as Hossain (2011), Ohlan (2015), and Shahbaz et al. (2013a), while there is no study analyzing the impact of international trade taxes on the environment, specifically based on different income levels. Apart from that, the present study also investigated the relationship between CO_2 emissions, internet, and energy intensity in Belt and Road countries. Thus, this study's objective is to fill the existing gap by exploring the impact of international trade taxes, internet usage, and energy intensity

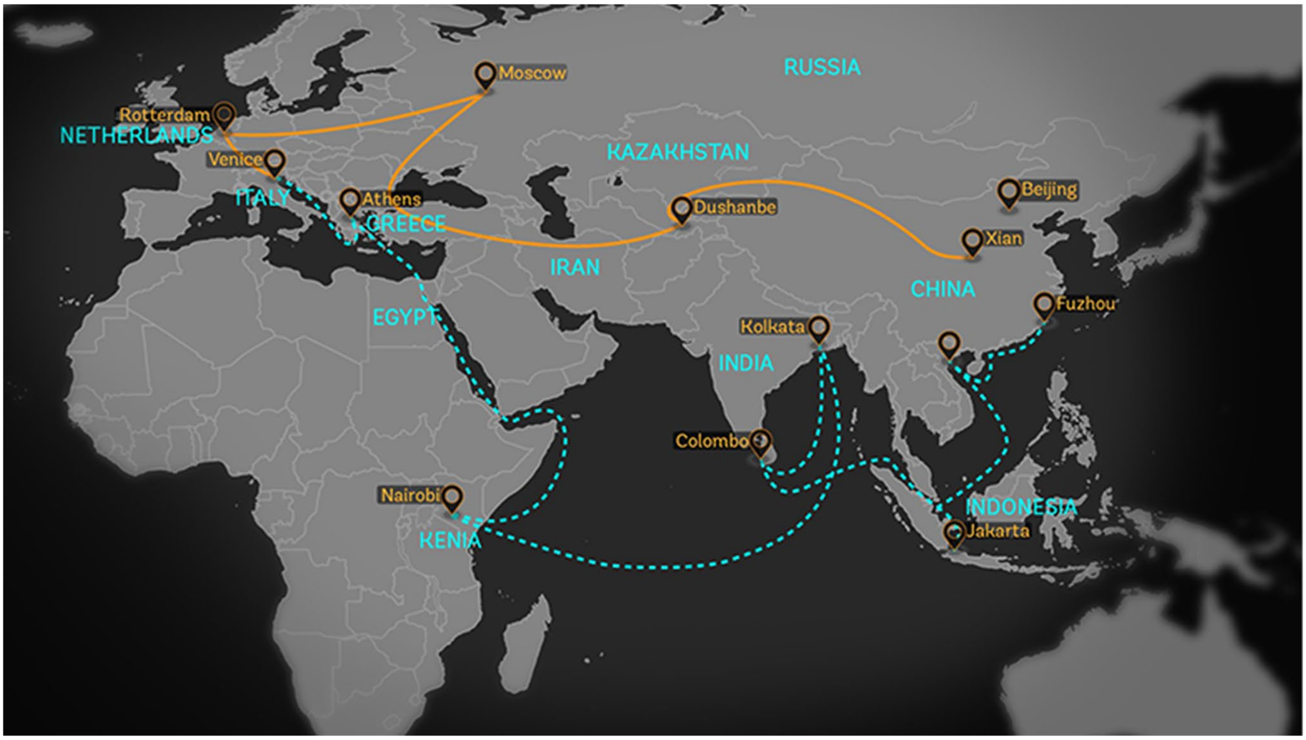

Fig. 2 Map of Belt and Road connectivity

on CO_2 emissions on the basis of various income level countries under the Belt and Road. Regarding the usage of the internet which is believed as an important factor for environmental quality and economic growth, there is still mixed literature on the relationship between ICT goods and services and CO_2 emissions. A recent study by (Khan et al. 2022a) proposed that ICT goods and services play a substantial role in abating CO_2 emissions in Morocco. Regarding the energy intensity and CO_2 emissions nexus, the study of Shahbaz et al. (2015) found that energy intensity has a positive and significant association with CO_2 emission in the long run.

The present study has the following motivations: First, what is the impact of international trade taxes on CO_2 emissions? Second, does internet usage have a negative relationship with CO_2 emissions? Third, what is the role of energy intensity with CO_2 emissions, and how does energy intensity influence CO_2 emissions across various levels of development? Based on the empirical analysis, this study aims to propose specific and scientific policy implications for abating CO_2 emissions and providing sustainable development in Belt and Road economies. The present paper's objectives are as follows. (1) To investigate whether international trade taxes will increase or reduce CO_2 emissions in Belt and Road countries specifically because of different income levels? (2) To study the role of international trade on CO_2 emissions. (3) Up to what extent internet usage can assist the adverse effect of environmental pollution in Belt and Road countries? Finally, this study will investigate the role of energy intensity for the first time in the case of Belt and Road Initiatives countries.

The remainder of the paper is arranged as follows: the study has considered the literature review on the linkage between CO_2 emissions, international trade, international trade taxes, internet usage, and energy intensity. We discuss the theoretical framework of the study variables. The methodology section describes the model specification, data source, and econometric analysis. The results and discussions section highlights the empirical outcomes of the present study. Finally, the paper discusses the conclusion, policy recommendations, and future work.

Literature review on CO_2 emissions, international trade taxes, energy intensity, and internet

***Hypothesis 1**. International trade increases CO_2 emissions*

The environmental impacts of trade liberalization have been discussed for a period of time in scientific research; however, a precise agreement has not yet been carried out so far (Wang et al. 2020). International trade accelerates the utilization of resources by enlarging economic activities, therefore devastating the environmental quality. In addition, countries are focusing on the production of pollution-intensive commodities in the foreign division of labor (Hu et al. 2018) and the rise in export trade affects domestic carbon emissions. Moreover, international trade flow, specifically the rise in import trade flow, gives importing economies knowledge and development of advanced clean and green technology (Wiedmann and Lenzen 2018), also importing median accretions that fulfil the protection of environmental requirements (Ji et al. 2020). The empirical study proposed by Topcu and Payne (2018) urged that trade on the production structure is different from country to country taking the OECD economies between 2000 and 2016. Their study indicates international trade adversely affects environmental pollution by affecting income and production. Another study developed by Wang and Yang (2016) revealed that China's aggregate CO_2 emissions were generated by 17% for exports to the USA between 1997 and 2013. They also examine that in case the USA produced these goods by itself, the USA would have raised its CO_2 emissions by 13% and 16%, respectively (Bildirici 2019). Numerous current studies connected international trade climate and environmental pollution. The work of Peters et al. (2012) proposed that government planning and policies play an important role in shaping climate change. On top of that, countries are free to sell their products to international markets, thereby economic development and openness bring advantages to every nation's economy (Shahbaz et al. 2013b). Climate change has significantly affects agriculture export trade from Pakistan (Khan et al. 2019). A recent study proposed by Liguo et al. (2022) found that trade openness is positively associated with CO_2 emissions in the case of OECD countries between 1990 and 2018. Moreover, Yunfeng and Laike (2010) found that China's export trade is the main driver behind the increasing level of environmental pollution. Researchers such as Wyckoff and Roop (1994) determined that in the largest OECD economies such as Japan, Germany, the USA, France, Canada, and the UK, import of production commodities generates around 13% of the total CO_2 emissions. Asongu et al. (2016) investigated the connection between energy consumption (EC), CO_2 emissions (CE), and economic growth (GDP; gross domestic product) in 24 African countries employing a panel autoregressive distributed lag (ARDL) approach. The findings revealed that there is a long-run relationship between EC, CE, and GDP (Toumi and Toumi 2019). The asymmetric causal relationship from carbon dioxide emissions to REC is neutral in the long term. Both positive and negative shocks to REC consistently had an adverse effect on CE in the long term. Mehmood (2022) found that a 1% increase in renewable energy is lowering CO_2 emissions by 13.95%. Moreover, 1% increase in governance is reducing carbon emissions by 7.68%. Aljadani et al. (2021) found that oil price strengthens the relationship of level, quadratic and cubic of economic growth, and environmental quality while oil rent weakens this relationship. Additionally, the long-term incidences of positive shocks on oil price in the presence of COVID-19 outbreak are not similar to the negative shock to CO2 emissions, implying the existence of asymmetric impacts on carbon dioxide emissions in long-term forms.

Hypothesis 2. *International trade taxes would abate CO_2 emissions in the OECD countries*

The impact of international trade taxes on CO_2 emissions is very rare in the previous literature. Research scholars have not focused on the relationship between international trade taxes and CO_2 emissions in the OECD countries. The study of Ahmad and Zheng (2021) found that export trade increases the level of CO_2 emissions while export taxes are the key factor to reduce environmental pollution in the BRICS economies. In contrast, Michieka et al. (2013) found a Granger causality association running from exports to CO_2 emissions by employing the Granger causality test introduced by Toda and Yamamoto (1995) for China between 1970 and 2010. The latest research suggests that approximately a third of overall Chinese CO_2 emissions are the output of manufacturing products for export to developed and developing countries. The work of Weber et al. (2008) revealed that about one-third of CO_2 emissions were generated by China due to the substantial output of goods for export trade. Therefore, the present study fills the research gap on the impact of international trade taxes on CO_2 emissions in Belt and Road countries.

Hypothesis 3. *Energy intensity would help to abate CO_2 emissions*

The role of energy intensity is inevitable to discuss in the present work. Energy intensity is described as an estimate of the energy inefficiency of an economy. It is measured as units of energy per unit of GDP. In addition, higher energy intensities specify a high cost or price of transforming energy into GDP. The relationship between energy intensity and CO_2 emissions was investigated by Danish et al. (2020), where they found that the consumption of higher energy intensity contributes to environmental pollution by employing time series data for the USA between 1985 and 2017. The latest study proposed by Hassan et al. (2022a) found that energy efficiency is a key factor for environmental pollution mitigation strategy in OECD countries. In addition, lower energy poverty and income are expensive to adopt environmental-related clean technology in developing countries. From this perspective, in rich and developed economies, the transition of energy from carbon-intensive origin to renewable sources is uncomplicated, quick, and affordable as different from lower- income countries. Specifically, efficient technological development in the energy sector abates environmental deterioration by raising the share of renewable energy and energy efficiency (Vukina et al. (1999). The energy efficiency performance was explored by Li and Lin (2015) who found that the eastern region of China achieved substantial progress in inefficiency compared to the meta-frontier, including central and western China. In another case, the study developed by Wu et al. (2012) examined the performance of energy efficiency of various provinces across China over time; their empirical analysis found that the energy efficiency enhancement in China's industrial sector was primarily driven by improvements in technological advancement. Similarly, Pardo and Moya (2013) analyzed the perspective for the enhancement of the energy intensity and CO_2 emission mitigation for the steel sector up to 2030. They suggested that improvement in energy consumption can lead to producing less CO_2 emissions in the steel industry. Recent study proposed by Hassan et al. (2022b) suggests that a unit improvement in political risk and its interaction with environmental policy stringency give rise to 0.231 MtCO2 of CBCE in the long run.

Hypothesis 4. *Internet usage can mitigate CO_2 emissions*

The present study investigates the impact of internet usage on CO_2 emissions in Belt and Road countries. Internet usage is a key variable in the energy-environment literature that is not yet addressed in the case of Belt and Road countries. The work of Salahuddin et al. (2016) supports the hypothesis of internet usage can help abate CO_2 emissions in OECD countries. Similarly, Wang and Xu (2021) found that internet usage is an essential key driver of low-carbon economy development, indicating that internet usage is detrimental to abating CO_2 emissions in China. The nexus between ICT goods and services are discussed by Erdmann and Hilty (2010), who provided a significant policy implication of the adaptation of ICT technology to reduce the level of environmental pollution. Likewise, Khan et al. (2022c) stressed the importance of private partnership in ICT goods and services for the purpose to tackle climate change severity in Morocco. In addition, Ishida (2015) found that ICT can benefit in two ways such as minimizing the level of energy consumption and increase in economic growth in the case of Japan. A study (Toffel and Horvath 2004) proposed that ICT technologies can contribute to mitigating overall societal environmental impacts. In another study, Salahuddin and Alam (2015) explored that the increasing growth in ICT technology utilization, particularly the usage of the internet, creates momentum in domestic demand for the consumption of electricity. In contrast, some studies such as those Fettweis and Zimmermann (2008) and SI and BCG, I (2012) found that ICT goods and services are significantly responsible for about 2% of the total CO_2 emissions around the globe. Aljadani (2022) attempts to test the technology effect hypothesis on environmental mitigation in the case of Saudi Arabia between 1970 and 2016 and the STIRPAT and (ARDL) model was used for empirical inquest. The empirical findings show that financial development and technology have a negative and significant impact on environmental degradation.

Theoretical framework

The present study investigates the relationship between CO_2 emissions, international trade, international trade taxes, internet usage, and energy intensity in Belt and Road countries by utilizing the AMG, CCEMG, and CS-ARDL models from 2008 to 2020. The increasing global environmental challenges and climate change stress finding new directions for a thriving transformation of energy and restricting the pollution caused by energy utilization. Thereby, tax on trade is considered to be one of the key elements liable for abating CO_2 emissions in Belt and Road countries. Most advanced economies are engaged to minimize their role in environmental pollution effectively with the help of robust environmental measures and policies. On the other hand, developing economies are liable for most of the world's emissions because of substantial dependency on conventional energy sources such as fossil fuels, coal, natural gas, and oil to attain blistering economic growth and development, which poses difficulties for environmental sustainability and thus, a meaningful transformation of energy is not fluid to obtain due to low per-capita income and energy poverty of Belt and Road countries. In addition, energy generation and energy utilization from conventional sources (i.e., coal, gas, and oil) have an adverse environmental impact on the air, water, and human health (Popp et al. 2010; Yi et al. 2007). The impact of terrorism on CO_2 emissions in the case of Pakistan was explored by Khan et al. (2022b) by employing the ARDL model over the period of 1990 to 2017. The uncertainty in economic policy and CO_2 emissions nexus was investigated by Khan et al. (2022c) and found that higher economic policy uncertainty can lead to an increase in the level of CO_2 emissions in the East Asian economies, namely China, Singapore, Japan, and South Korea.

In the previous literature, numerous studies have investigated that economic growth is a key factor in affecting climate change and environmental pollution across the countries because of the heterogeneous structure of the economy. From this perspective, it is found that economic growth is linked with environmental mitigation until a threshold level is obtained; it is also confirmed by the environmental Kuznets curve (EKC) hypothesis. Thus, the selected countries in the present study are characterized by different income levels (i.e., low- income, upper- low income, upper- middle income, and high- income) economies. In addition, these Belt and Road countries are still dependent on a huge portion of non-renewable energy consumption, as the present renewable sources of energy consumption are not adequate to achieve the energy demand in Belt and Road initiative countries. Furthermore, environmental-friendly innovation in clean technology is a significant driver of productivity and growth, whereas it maintains the quality of the environment and gains the growth goals at a minimum cost by using fewer energy units and consequently leads to less carbon footprint.

The theoretical framework of the present study is illustrated in Figure 3. The theoretical framework was designed to elaborate on the dependent variable association with other independent variables. It is believable that the relationship between CO_2 emissions and international trade is positive and significant, indicating that international trade is detrimental to CO_2 emissions. This assumption was supported by the work of Jiang and Guan (2017), who revealed that after the great financial recession of 2007 to 2011, the countries accelerated to increase their economic growth by exporting goods to the international market led, which to an increase in global CO_2 emissions to an unprecedented level. Similarly, the study by Essandoh et al. (2020) found a long-run association between CO_2 emissions, international trade, and FDI inflow in 52 developing and developed economies by employing the PMG-ARDL models over the period of 1991 to 2014. Their study revealed that international trade has a long-run negative association with CO_2 emissions exclusively solely for developed economies. On the other hand, our study found that international trade taxes can effectively mitigate CO_2 emissions in Belt and Road countries. A negative and significant connection was found between CO_2 emissions and international trade taxes by utilizing the AMG, CCEMG, and CS-ARDL models. So far, this hypothesis was ignored by researchers to identify the significance of international trade on CO_2 emissions; therefore, this is the first study to examine the nexus between CO_2 emissions and international trade taxes for Belt and Road countries. To our understanding, the relationship between export trade, export taxes, and CO_2 emissions was explored by Liguo et al. (2022), who found that export trade can increase CO_2 emissions while export taxes is a key factor to mitigate CO_2 emissions in the USA.

Moreover, the present study found mixed results between CO_2 emissions and energy intensity in different income-level countries. It is confirmed that higher energy intensity will lead to an increase in the level of CO_2 emissions, while a low energy intensity would help to mitigate CO_2 emissions effectively and efficiently. Similar findings were proposed by Wu et al. (2016), where developing countries' consumption of higher energy intensity led to substantial concerns of increasing greenhouse gas (GHG) emissions (primary CO_2 emissions) and deteriorating energy shortage. They suggested that to tackle this problem, it is necessary to decrease intense energy consumption by adopting renewable energy sources. Moreover, this study also highlights the significance of internet usage in Belt and Road countries. Our study revealed a negative and significant connection between internet usage and CO_2 emissions, indicating that internet users can sustainably reduce CO_2 emissions in Belt and Road countries. The latest study proposed by Salahuddin et al. (2016) suggested that OECD countries can promote their internet usage without taking concern about environmental consequences. Other studies (Ahmed and Le 2021; Altinoz et al. 2021; Faisal et al. 2020; Raheem et al. 2020) support the similar hypothesis.

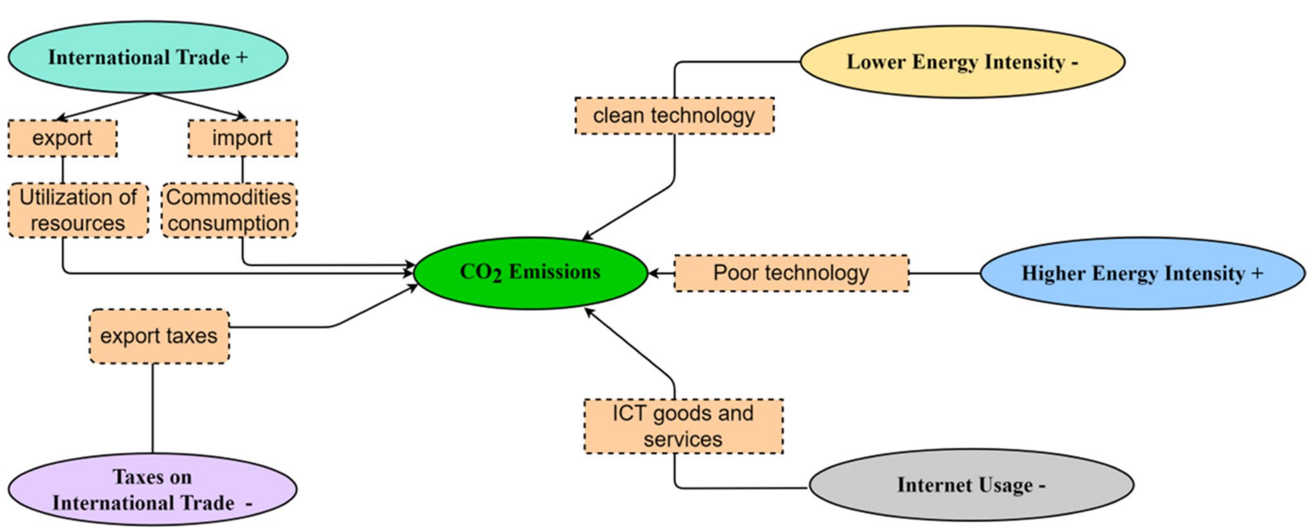

Fig. 3 The theoretical framework of the study

Model specification and econometric strategy

Data source

Table 1 presents the study variable description. CO_2 emissions are described as CO_2 emissions (metric tons per capita); taxes on international trade are defined as taxes on international trade (current LCU); trade is the country's trade in % of GDP; internet service is described as secure internet servers (per 1 million people); renewable electricity is the renewable electricity output (% of total electricity output); energy intensity is defined as the energy intensity level of primary energy (MJ/$2011 PPP GDP). GDP is the gross domestic product per capita current in US$. The data obtained for this study are from the World Bank Indicator (WDI) from 2008 to 2020. All the variables were converted into logarithm form for the purpose to tackle the issue of heteroscedasticity and suppress the coefficients of the study variables. Finally, Figure 4 represents the flowchart of the econometric methodology

Panel unit root tests

It addresses the null hypothesis and is designed for the null hypothesis of a unit root for each series in a panel. Using panel unit root is significantly dynamic compared to the standard time series (Pesaran 2012).

$$CI\hat{P}S = N^{-1} \sum_{i=0}^{n} CDF \tag{4}$$

Cross-sectional dependence test

The present study used CSD estimation by employing the Lagrange multiplier (LM) method suggested by Breusch and Pagan (1980) and (CD) test introduced by Pesaran et al. (2008) to explore the following model:

$$y_{it} = a_i \beta'_{it} x_{it} + \varepsilon_{it} \forall_i = 1, 2 \ldots N = 1, 2 \ldots T \tag{4}$$

where T in Eq. (4) represents the time series magnitude, i signifies the (CS) dimension, y_{it} indicates the dependent variable, x_{it} illustrates the $I \times k$ vector of observation on the independent variables, a_i designates the individual intercepts, while β_i signifies the slope of coefficients collectively. In addition, $I \times k$ and $I \times I$ describe the vectors of parameters to be calculated on the dependent variables that are different across i (cross-sectional) and t (time series). Considerably, for every i, ϵ_{it} is independently error terms that could be correlated across the cross-section.

Thus, we used the LM which is presented in Equation (5) as follows:

$$LM = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N-1} P\hat{ij}^2 \tag{5}$$

The Pij^2 in Eq. (5) defines the simple measurement of the pair-wise correlation of the residual in Eq. (1). Before examining and estimating any panel data series, it is essential to investigate the existence of cross-sectional dependence (CSD) in data. The present paper adopted the methods of bias-corrected scaled LM estimation proposed by Baltagi et al. (2012), CD estimation introduced by Pesaran et al. (2004), and LM method developed by Breusch and Pagan (1980) to investigate the residual (CD) in selected variables. In addition, the null hypothesis of no cross-sectional dependence is found in the residual data series. Thus, we design the equations of Pesaran et al. (2004) and Breusch and Pagan (1980) as follows:

$$CD_1 = \sqrt{\left(\frac{1}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N-1} \left(T\hat{P}_{ij}^2 - 1 \right) \right.} \tag{6}$$

From Eq. (6), null hypothesis H:0 with $T \underset{\infty}{\rightarrow}$ and $N \underset{\infty}{\rightarrow}$, the cross-sectional (CD) test converts to the standard normal distribution.

Panel co-integration test

To investigate the co-integration among all variables, we used three different statistical approaches: (1) Pedroni integration estimation (Pedroni 2004); (2) Kao co-integration approach (Kao 1999); (3) Westerlund (Westerlund 2007)

Table 1 Variable's description

Variables	Description	Period	Source
CO_2 emissions	CO_2 emissions (metric tons per capita)	2008–2020	WDI
TIT	Taxes on international trade (current LCU)	2008–2020	WDI
Trade	Trade in % of GDP	2008–2020	WDI
IU	Secure Internet servers (per 1 million people)	2008–2020	WDI
RE	Renewable electricity output (% of total electricity output)	2008–2020	WDI
EI	The energy intensity level of primary energy (MJ/$2011 PPP GDP)	2008–2020	WDI
GDP	Gross domestic product per capita is current in US$	2008–2020	WDI

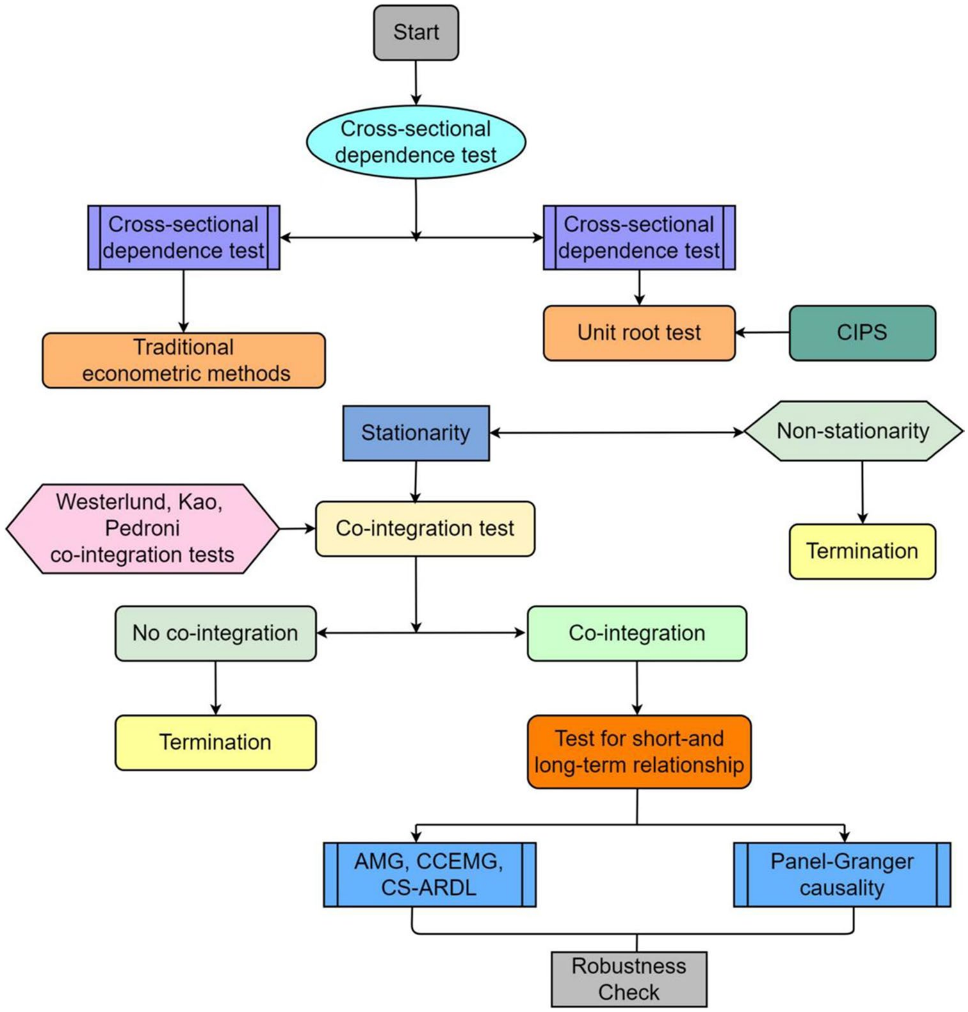

Fig. 4 The flowchart of econometric methodology

which proposes an error correction-based panel co-integration technique.

$$G_t = \frac{1}{N}\sum_{i=1}^{N}\frac{'\alpha_i}{SE('\alpha_i)} \tag{7}$$

$$G_\alpha = \frac{1}{N}\sum_{i=1}^{N}\frac{T'^{\alpha_i}}{'\alpha_i(1)} \tag{8}$$

$$P_t = \frac{T'^{\alpha_i}}{SE('\alpha_i)} \tag{9}$$

$$P_\alpha = T'\alpha \tag{10}$$

Panel causality test

In order to evaluate the causal links among the variables, we employed (Dumitrescu and Hurlin 2012) a revised form of the non-causality (Granger 1969). The panel causality test is an effective econometric technique; it offers consistent outcomes nonetheless of $T > N$ or $T < N$, and (b) it is consistent for both sorts of data heterogeneous or unbalances (Dumitrescu and Hurlin 2012; Gorus and Aydin 2019). This estimation is assumed from Z-bar and W-bar statistics, such as follows:

$$Z_{i,t} = \alpha_{i,t} + \sum_{j=1}^{P}\gamma_t^j Z_{i,t-j}\sum_{j}^{P}\gamma_t^j T_{i,t-j} \tag{11}$$

γ_t^j signifies autoregressive parameters and j is the lag length.

Results and discussions

Table 2 represents the summary statistics of all the panels such as the full sample, lower income, lower-middle income, upper-middle income, and high-income countries under the

Belt and Road Initiatives. The average mean value of CO_2 emission in the full sample is accounted for 0.542 and the standard deviation value is 0.520. The average mean value of international trade is 1.909, while the standard deviation value is 0.325. The average mean value of international trade taxes is accounted for 6.785 and the standard deviation is 4.987. The internet users' average mean value is 1.882, while the standard deviation is accounted for 1.285. Further, the average mean value of renewable energy is accounted for 0.892 and the standard deviation is 0.938. In addition, the average mean value of energy intensity is 0.708, while the standard deviation is 0.184. The average mean value of GDP is reported as .768 and the standard deviation is 0.523. The number of total observations is 858 in the full sample.

Table 2 Summary statistics

Different groups	Statistics	CO_2	IT	ITT	IU	RE	EI	GDP
	Mean	0.542	1.909	6.785	1.882	0.892	0.708	3.768
	Median	0.602	1.947	9.162	1.900	1.057	0.702	3.764
	Max	1.584	2.640	13.79	5.108	0.000	1.336	5.091
Full sample	Min	− 0.950	0.000	0.000	− 1.707	− 3.529	0.299	2.561
	Std. dev.	0.520	0.325	4.987	1.285	0.938	0.184	0.523
	Skewness	− 0.520	− 2.919	− 0.439	0.049	− 1.753	0.434	0.140
	Kurtosis	2.801	18.70	1.507	2.636	8.350	3.096	2.555
	Obs.	858	858	858	858	858	858	858
	Mean	0.128	1.724	0.561	1.057	1.188	0.727	3.289
	Median	0.114	1.785	0.531	1.012	1.409	0.708	3.232
	Max	1.112	2.325	1.424	3.951	2.000	1.336	4.100
Low income	Min	− 0.950	0.000	− 0.266	− 1.707	0.000	0.299	2.561
	Std. dev.	0.509	0.452	0.518	1.217	0.665	0.247	0.355
	Skewness	0.005	− 2.643	0.182	0.315	− 0.462	0.341	0.371
	Kurtosis	1.994	10.80	1.479	2.609	1.900	2.204	2.357
	Obs.	260	260	260	260	260	260	260
	Mean	0.426	1.894	0.344	1.828	1.189	0.702	3.653
	Median	0.502	1.919	0.529	1.723	1.208	0.691	3.653
	Max	1.177	2.247	1.423	4.673	2.000	1.134	4.306
Low-middle income	Min	− 0.950	1.480	− 3.370	− 0.318	− 0.441	0.311	2.672
	Std. dev.	0.431	0.179	0.778	1.118	0.599	0.159	0.356
	Skewness	− 0.816	− 0.213	− 1.816	0.397	− 0.681	0.314	− 0.410
	Kurtosis	3.632	1.982	7.303	2.469	3.122	2.751	2.641
	Obs.	286	286	286	286	286	286	286
	Mean	0.802	2.058	− 0.282	2.512	0.621	0.700	4.081
	Median	0.798	2.050	0.000	2.502	1.019	0.706	4.114
	Max	1.343	2.640	1.518	5.108	2.000	0.948	4.823
Upper-middle income	Min	0.150	1.537	− 4.860	0.049	− 3.529	0.379	3.540
	Std. dev.	0.261	0.198	1.292	1.164	1.252	0.135	0.306
	Skewness	− 0.090	0.183	− 1.608	0.114	− 1.866	− 0.228	0.356
	Kurtosis	2.870	3.793	5.570	2.615	6.757	2.451	2.435
	Obs.	234	234	234	234	234	234	234
	Mean	1.268	2.075	1.573	2.790	− 0.033	0.712	4.652
	Median	1.308	1.998	0.000	2.601	0.000	0.710	4.598
	Max	1.584	2.579	9.517	4.651	1.510	1.046	5.091
High income	Min	0.843	1.711	0.000	1.614	− 1.352	0.458	4.286
	Std. dev.	0.191	0.231	3.540	0.756	0.771	0.161	0.240
	Skewness	− 0.717	0.888	1.788	0.872	− 0.026	0.579	0.477
	Kurtosis	2.818	2.846	4.200	3.06	2.880	2.452	2.000
	Obs.	78	78	78	78	78	78	78

The table presents descriptive statistics of all variables used in the regression models of the study. The sample period is between 2008 and 2020. The std. is the standard deviation. Min and max are the minimum and maximum values of each variable, respectively. The *N* is the number of bank-year observations.

Table 3 Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
CO_2	1.00						
Trade	0.48*	1.00					
Taxes	− 0.29*	− 0.34*	1.00				
EI	0.36*	0.16*	0.02	1.00			
IU	0.50*	0.41*	− 0.20*	− 0.04	1.00		
REC	− 0.48*	− 0.19*	0.12*	− 0.05	− 0.05	1.00	
GDP	0.87*	0.52*	− 0.36*	0.02	0.62*	− 0.41*	1.00

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 3 illustrates the outputs of pairwise correlation statistics between the study variables. Based on the correlation's statistics outcomes, we found a positive and significant correlation between international trade and CO_2 emissions at a 1% significance level ($r = 0.48$; $p < 0.1$), indicating that an increase in international trade in the Belt and Road selected countries led to a rise in CO_2 emissions for all the Belt and Road countries from 2008 to 2020. In contrast, a decrease in international trade consequently decrease in CO_2 emissions and vice versa. Further, a negative and significant association was found between trade taxes and CO_2 emissions at a 1% level of significance ($r = -0.29$; $p < 0.1$), indicating that trade taxes are an important tool in decarburization in the Belt and Road countries. The linkage between energy intensity and CO_2 emissions is positive and significant at a 1% level of significance ($r = 0.36$; $p < 0.1$). This means that a higher energy intensity level leads to an increase in CO_2 emissions. Similarly, the relationship between GDP and CO_2 emissions is positive and significant at a 1% level of significance ($r = 0.87$; $p < 0.1$), suggesting that the rise in GDP growth will lead to an upsurge in CO_2 emissions in all the Belt and Road member countries. Moreover, we found a negative and positive relationship between renewable energy utilization and CO_2 emissions at a 1% level of significance ($r = -0.48$; $p < 0.1$), indicating that the higher dependency on the utilization of renewable energy sources will reduce CO_2 emissions at a substantial level. Finally, the association between internet users and CO_2 emissions is negative and significant at a 1% level of significance ($r = -0.20$; $p < 0.1$). This means that the adaptation and usage of the internet can significantly reduce CO_2 emissions in the Belt and Road countries.

The outputs of Westerlund (2005) co-integration tests are presented in Table 4. The purpose of employing the Westerlund (2005) co-integration test is to examine the different levels of co-integration among the study variables as well as provide more robust and precise results. Therefore, the Westerlund co-integration test allows large N (number of observations) and T (number of time periods) to investigate the co-integration association among CO_2 emissions, international trade, trade taxes, energy intensity, internet users, renewable electricity consumption, and GDP over the period 2008 to 2020. Moreover, the outcomes from Westerlund estimation are divided into two groups: "Gt" and "Ga" define as cluster groups, while "Pt" and "Pa" describe as panel statistics.

Table 4 Westerlund co-integration test

Statistics	Value	*Z*-statistics	*P*-value
Gt	− 3.250	− 13.31***	0.000
Ga	− 3.990	4.704	1.000
Pt	− 14.79	− 3.048**	0.001
Pa	− 6.031	− 3.296**	0.001

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 5 Cross-sectional dependence

Test	Statistic	d.f.	Prob.
Breusch-Pagan LM	6345.22***	2145	0.000
Pesaran scaled LM	64.1274***		0.000
Pesaran CD	26.2901***		0.000

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 5 illustrates the outputs of CSD estimation. The CSD estimation runs for a total of 65 Belt and Road countries; the test validates the rejection of the null-hypothesis of no cross-sectional dependence at a 1% level of significance, which suggests that the panel data of the BRI is significantly cross-sectionally dependent.

Table 6 illustrates the reports of the unit root test. The panel unit root test is an important tool to investigate any spurious outcomes and probe the stationarity characteristics of the observed variables in the study model. In our study, we employ three different forms of unit root tests, i.e., ADF, LLC, and PP, to investigate whether our study variables are stationary at levels 1(0) or the first different 1(1). In general, our null hypothesis of all the three-unit root tests is that (H0) there is a unit root in all the panels. While the alternative hypothesis is that (H1) there is no unit root in all the selected panels. Finally, all the selected variables in our study are stationary at first difference 1(1). The following equations explain the interpretation of the unit root test.

Table 6 Unit root tests

Panel		CO_2	IT	ITT	IU	RE	EI	GDP
	LLC	– 0.277	2.854	1.358	9.128	– 1.346***	– 5.18***	5.602
FS	ADF	118.30	99.70	25.61	17.90	74.88	158.7	39.62
	PP	191.3***	219.15	30.42	9.242	111.8	229.5***	56.01
	LLC	0.211	1.115	– 0.668	3.228	0.540	– 3.897	3.088
LI	ADF	60.64**	30.7	21.42	10.71	19.83	50.8	12.05
	PP	88.20***	56.8	46.78***	8.225	29.08	80.39	12.50
	LLC	0.991	– 0.098	– 3.284	6.19	– 1.36	– 2.562	3.709
LMI	ADF	33.8	39.72	63.52***	3.61	27.86	55.45	12.04
	PP	60.61	89.81	109.31**	0.425	33.09	72.24	10.38
	LLC	0.564	1.502	1.295**	5.675	0.249	– 2.683***	2.802
UMI	ADF	14.6	25.28	24.85	3.326	23.45	42.44	10.84
	PP	25.67	60.26	32.65**	0.463	33.45	66.83***	19.30
	LLC	– 2.408***	3.302	0.606	3.202	0.77	– 1.516	1.645
HI	ADF	18.30	5.343	0.385	0.795	4.13	13.06	4.785
	PP	32.39***	14.11	0.071	0.218	16.43**	20.11***	13.82
At first difference								
	LLC	– 19.35***	– 6.599***	– 320.17***	– 28.94***	– 22.53***	– 17.92***	– 8.367***
FS	ADF	541.44***	299.6***	268.59***	470.2***	494.9***	423.23***	276.06***
	PP	804.39***	504.0***	549.16***	307.06***	861.2***	741.08***	451.14***
	LLC	– 4.659***	– 7.103***	– 5.843***	– 15.51***	– 18.08***	– 6.711***	– 4.172***
LI	ADF	73.86***	104.1***	73.12***	139.9***	185.07***	104.7***	64.45***
	PP	131.4***	155.4***	205.5***	101.5***	314.6***	223.1***	72.46***
	LLC	– 6.941***	– 2.384[a]	– 6.382***	– 18.11***	– 13.10***	– 12.31***	– 4.535***
LMI	ADF	109.08***	94.37***	105.7***	164.5***	173.8***	157.8***	90.68***
	PP	242.1***	163.7***	234.8***	102.5***	315.9***	229.6***	161.01***
	LLC	– 8.063***	– 2.489***	– 1267.5***	– 15.06***	– 11.01***	– 11.56***	– 5.799***
UMI	ADF	104.5***	73.84***	76.69***	135.06***	138.6***	137.5***	89.68***
	PP	207.1***	135.3***	120.7***	72.86***	221.1***	239.8***	162.3***
	LLC	– 1.853***	– 2.489***	– 2.884***	– 6.87***	– 1.625***	– 4.235***	– 3.117***
HI	ADF	22.31***	32.04***	5.764***	35.08***	10.03***	29.88***	35.52***
	PP	43.83***	52.22***	11.06***	32.93***	24.76***	63.48***	59.42***

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 7 illustrates the outcomes of AMG estimation. To comprehensively understand the effect of international trade, international trade taxes, internet users, energy intensity, renewable energy, and GDP on CO_2 emissions, this study was divided into different groups in terms of income level. Based on the findings, international trade adversity affects CO_2 emissions in Belt and Road countries in the full sample including lower-income and upper-middle income. The coefficient value of trade was reported for both full-sample and UMI (β = 0.180, $p < 0.01$) and (β = 0.190, $p < 0.01$), respectively. The results did not find any association between lower middle-income and high-income countries. Trade-related taxes are considered to be an important tool for the reduction of CO_2 emissions in the BRI countries. We found a negative and significant association between trade-related taxes and CO_2 emission for the full-sample and lower-income countries where (β = 0.008, $p < 0.01$) and (β = – 0.119, $p < 0.01$), respectively. In addition, the outcomes did not show any effects for LMI, UMI, and HI regions. Moreover, the relationship between energy intensity and CO_2 emissions is positive and significant for all selected panels, indicating that higher energy intensity will lead to a rise in CO_2 emissions in BRI countries. The regression coefficient for FS (β = 0.776, $p < 0.01$), LI (β = 0.481, $p < 0.01$), LMI (β = 0.624, $p < 0.01$), UMI (β = 0.317, $p < 0.1$), and HI (β = 0.427, $p < 0.01$), respectively. Furthermore, the variable internet users show a negative and significant connection with CO_2 emissions for full sample (β = – 0.016, $p < 0.1$), lower income (β = – 0.018, $p < 0.05$), and high income (β = – 0.020, $p < 0.1$), respectively. This means that the higher the number of internet subscribers, the lower CO_2 emissions will be in the BRI counties. In contrast, the study did not reveal any linkage between internet users and CO_2 emissions for LMI and UMI regions. On the other hand, renewable electricity shows a negative and significant

Table 7 Results of AMG model

Variables	FS	LI	LMI	UMI	HI
Trade	0.180***	0.359***	– 0.136	0.190***	– 0.029
	(15.02)	(15.39)	(– 1.59)	(3.68)	(-0.26)
Taxes	0.008***	– 0.119***	– 0.050	0.120	0.052
	(16.70)	(– 18.94)	(– 1.02)	(1.12)	(1.00)
Energy intensity	0.776***	0.481***	0.624***	0.317*	0.427***
	(10.84)	(10.45)	(2.99)	(1.87)	(3.33)
Internet Users	– 0.016*	– 0.018**	– 0.012	0.016	– 0.020*
	(1.71)	(– 2.31)	(– 1.32)	(1.54)	(– 1.71)
Renewable electricity	– 0.043***	– 0.030**	– 1.050**	– 0.518**	– 0.010**
	(– 10.18)	(– 1.40)	(– 1.00)	(– 1.21)	(– 0.30)
GDP	0.386***	0.380***	0.257***	0.215***	0.022***
	(33.46)	(8.36)	(4.03)	(3.78)	(0.44)
Constant	– 1.991***	– 1.685***	2.511	0.079	0.523
	(– 5.28)	(– 10.21)	(0.90)	(0.10)	(0.85)
N	858	260	286	234	78

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

connection with CO_2 emissions for the BRI regions, indicating that the adaptation and utilization of renewable electricity can play a substantial role in the process of decarbonization. The regression coefficient values are reported as follows; for FS ($\beta = - 0.043$, $p < 0.1$), LI ($\beta = - 0.030$, $p < 0.05$), LMI ($\beta = - 1.050$, $p < 0.05$), UMI ($\beta = - 0.518$, $p < 0.05$), and HI ($\beta = - 0.010$, $p < 0.05$), respectively. Finally, the relationship between GDP and CO2 emission was found positive and significant for all the BRI regions, indicating the GDP is a contributor to CO_2 emissions in the long run. The coefficients of FS ($\beta = 0.386$, $p < 0.1$), LI ($\beta = 0.380$, $p < 0.01$), LMI ($\beta = 0.257$, $p < 0.01$), UMI ($\beta = 0.215$, $p < 0.01$), and HI ($\beta = - 0.022$, $p < 0.01$), respectively.

Table 8 illustrates the outputs of the CCEMG model. The coefficient of international trade is positive and significant indicating that a 1% increase in international trade will lead to a 0.209% increase in CO_2 emissions in the BRI countries. Likewise, a positive and significant association was found between international trade and CO_2 emissions in the lower-income countries, showing that a 1% growth in trade will increase CO_2 emissions to 0.242%, respectively. The study by Hassan et al. (2022c) found that consumption-based CO_2 emissions have a positive and significant effect on international trade. In contrast, a negative and significant linkage was found between international trade and CO_2 emissions in the high-income BRI countries, indicating

Table 8 Results of CCEMG model

	FS	LI	LMI	UMI	HI
Trade	0.209***	0.242***	0.167	1.693	– 0.237*
	(6.61)	(3.17)	(0.53)	(0.62)	(– 0.69)
Taxes	– 0.007*	0.094	0.185	– 0.017**	– 0.132**
	(1.66)	(0.57)	(1.30)	(– 0.56)	(1.00)
Energy intensity	1.019***	– 0.369*	1.113***	– 1.814**	1.225***
	(9.51)	(– 0.73)	(2.74)	(– 0.58)	(3.23)
Internet Users	– 0.023***	0.014	– 0.071*	0.069	0.080
	(4.46)	(0.61)	(– 1.33)	(0.67)	(1.61)
Renewable electricity	– 0.034***	– 0.003**	– 3.618**	– 0.226*	– 0.027***
	(– 3.47)	(– 0.06)	(– 1.03)	(– 0.76)	(– 0.19)
GDP	0.345***	0.501***	0.882*	0.435**	– 0.347
	(7.88)	(4.82)	(1.60)	(0.27)	(– 1.23)
Constant	– 0.001	0.132	7.466	– 4.324*	– 0.080
	(– 0.01)	(0.49)	(0.94)	(– 1.72)	(– 0.02)
N	858	260	286	234	78

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

that a 1% increase in trade will mitigate CO_2 emissions by − 0.237%. The results did not find any relationship between CO_2 emissions and international trade for LMI and UMI BRI regions. The study adopted international trade-related taxes to support the hypothesis of the trade-CO2 emission. Therefore, a negative and significant connection was found between trade taxes and CO_2 emissions for the full sample of BRI, UMI, and HI regions. The results show that a 1% rise in trade taxes will mitigate CO_2 emissions − 0.007% in all the BRI countries, − 0.017% in the UMI, and − 0.132% in the HI regions. Moreover, a mixed relationship was found between energy intensity and CO_2 emissions in the BRI counties. The coefficient value of energy intensity and CO_2 emission is positive and significant for all the BRI countries and regions; a 1% increase in energy intensity will raise CO_2 emission by 1.019% in all BRI countries. In contrast, a negative and significant association was found between energy intensity and CO_2 emission, illustrating that a 1% growth in energy intensity will help to abate CO_2 emissions by − 0.369% and − 1.814% in UMI regions. In addition, a 1% growth in energy intensity will increase CO_2 emissions by 1.113% in LMI and 1.225% in HI regions. A fair reason is that the higher energy intensity will consequently increase the level of CO_2 emission, while a lower-energy intensity will decrease CO_2 emissions in the BRI countries. Likewise, Emir and Bekun (2019) explored the linkage between CO_2 emissions and energy intensity where they found that energy intensity affects CO_2 emissions. A negative and significant connection was found between internet users and CO_2 emissions, indicating that a 1% increase in internet subscribers will assist to mitigate CO_2 emissions by − 0.023% in the BRI countries as well as − 0.071% in the LMI region. In contrast, the results did not show any sort of connection between internet users and CO_2 emissions in LI, UMI, and HI regions. Similarly, the findings proposed by Khan et al. (2022b) and Salahuddin et al. (2016) revealed that the internet and ICT can promote and consolidate environmental sustainability. Furthermore, the relationship between renewable energy utilization and CO_2 emissions was found negative and significant for all the BRI counties and regions. A 1% increase in renewable energy utilization will decrease CO_2 emissions by − 0.034% in all the BRI countries, − 0.003% in the LI, − 3.618 in LMI, − 0.226 in UMI, and − 0.027% in the HI region. These findings are supported by the latest study by Khan et al. (2022c). Lastly, a positive and significant association was found between GDP and CO_2 emissions, indicating that a 1% growth in GDP will increase CO_2 emission level by 0.345 in all the BRI counties including 0.501% in LI, 0.882 in LMI, and 0.435% in UMI regions. In addition, the total number of observations accounted for 858.

Tables 9 and 10 both illustrate the outcomes of the robustness test. The present study utilized the fully modified (OLS) and dynamic (OLS) methods to cross-check the coefficient values obtained from the main models. FMOLS and DOLS confirm both the short- and long-run robustness checks. The robustness check verified that there is no variation and alternation in the coefficients of the selected variables. Therefore, our study confirmed that all the outcomes obtained from the main models are robust and consolidated.

Table 11 shows the outcomes of the panel Granger causality test. Based on the Granger causality test, there is a two-way causal association between energy intensity and CO_2 emissions in the Belt and Road Initiatives countries. This indicates that higher energy intensity can lead to a rise in CO_2 emissions, while an increased level of CO_2 emissions is caused by higher energy intensity. In addition, a one-way causal connection was found between GDP and CO_2 emissions, indicating that GDP is a key factor contributing

Table 9 Robustness check

Panel fully modified least squares (FMOLS)					
	FS	LI	LMI	UMI	HI
Trade	0.325 ***	0.502 ***	0.168	− 0.144	0.507
	(3.97)	(3.78)	(1.46)	(− 1.51)	(1.33)
Taxes	0.011	0.137	0.065**	0.008	0.266
	(1.56)	(1.08)	(2.36)	(0.83)	(0.66)
Energy intensity	1.232***	0.851**	1.296***	0.574 ***	0.346
	(5.41)	(2.09)	(3.84)	(2.98)	(0.98)
Internet users	0.026***	0.032 *	0.027***	0.017 **	0.045
	(3.69)	(1.93)	(3.24)	(2.87)	(0.14)
Renewable electricity	-0.035	0.061	− 0.088	0.002	− 0.688 **
	(-0.71)	(0.68)	(− 1.02)	(0.05)	(− 1.97)
GDP	0.565 ***	0.587 ***	0.647***	0.145 **	1.387 **
	(7.49)	(4.33)	(6.56)	(2.08)	(2.06)
N	516	156	228	132	54

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 10 Robustness check

Panel dynamic least squares (DOLS)					
	Full sample	LI	LMI	UMI	HI
Trade	0.125 **	0.328 ***	0.039	− 0.025	− 0.060
	(2.56)	(4.11)	(0.44)	(− 0.45)	(− 0.64)
Taxes	0.008	0.033	0.040	0.008	0.100
	(1.44)	(0.36)	(1.56)	(1.10)	(0.38)
Energy intensity	0.749 ***	0.605 ***	1.264 ***	0.211 ***	0.261 **
	(7.76)	(3.23)	(6.89)	(2.51)	(2.02)
Internet users	0.031 ***	0.045 ***	0.031 ***	0.009 **	− 0.036 ***
	(6.71)	(4.61)	(4.03)	(2.72)	(− 3.82)
Renewable electricity	− 0.044	0.056	− 0.002	− 0.051 **	− 0.061 **
	(− 1.57)	(0.94)	(− 0.02)	(− 2.07)	(− 2.29)
GDP	0.405 ***	0.367 ***	0.720 ***	0.172***	0.075
	(11.46)	(6.67)	(9.47)	(4.96)	(1.27)
N	858	260	286	234	78

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 11 Results of panel Granger causality test

Null hypothesis	Obs	*F*-Statistic	Prob.	Causality
Energy intensity ↔ CO_2	660	4.123**	0.006	Two-way
CO_2 ↔ Energy intensity	2.830**	0.037		
GDP → CO_2	660	2.728	0.043	One-way
CO_2 ≠ GDP	0.764	0.514		
Renewable electricity ≠ CO_2	660	0.894	0.443	No causality
CO_2 ≠ Renewable electricity	0.328	0.804		
Internet users → CO_2	660	0.367	0.776	One-way
CO_2 ≠ Internet users	2.511**	0.057		
Trade taxes → CO_2	660	0.019**	0.096	One-way
CO_2 ≠ Trade taxes	0.521	0.667		
Trade ↔ CO_2	660	5.534***	0.000	Two-way
CO_2 ↔ Trade	5.102**	0.001		

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

to CO_2 emissions. In contrast, we did not find any causal linkage between renewable electricity and CO_2 emissions. Moreover, a one-way causality was running from trade taxes to CO_2 emissions, indicating that taxes on international trade can play a significant role in reducing CO_2 emissions. On the other hand, a two-way causality was found between international trade and CO_2 emissions, suggesting that an increase in CO_2 emissions will rise international trade because the manufacturing industry substantially increases the level of CO_2 emissions. A one-way casual connection was found between internet users and CO_2 emissions, indicating a higher number of internet users can reduce CO_2 emissions. Internet users can play a role in mitigating their ecological footprint by reducing CO_2 emissions.

The relationship between CO_2 emissions and international trade can be justified through the following theories such as the composition effect, scale effect, and technique effect. Based on the composition effect, international trade flows at the initial stages of development damage climate change due to fragile environmental pollution regulations. Nevertheless, with strong environmental strategies at later stages of development, international trade activities tend to decrease environmental pollution. Scale effect determines that the rise in international trade flows expedites industrial activities and economic growth which is directed to raise environmental pollution. Second, technique effects suggest that trade liberalization accommodates the export of the latest and clean environmental technologies, which enhances the quality of the environment and decreases pollution (Antweiler et al. 2001). The outputs illustrate a negative and significant association between trade tax and CO_2 emissions. A comprehensive interpretation is that governments consistently raise taxes on trade to raise their aggregate domestic utilization or to accommodate fiscal deficits. In case, if there is an increase in trade tax, industries are not ready to export their surplus production, and as a result of that, industries will decrease unnecessary production. Hence, the concluding remark is that diminution of manufacturing output not only reduces the production of exportable commodities but also mitigate the consumption of CO_2, and fossil fuels produced by industry.

Further discussion

Our empirical findings suggest several policy implications for BRI countries to mitigate CO_2 emissions without sacrificing economic growth and further boosting urbanization, environmental-friendly technology innovation, and adopting lower energy intensity by the amount of energy used in producing a given level of output or activity.

Firstly, each country should take consumption- and production-based carbon emission commodities into account when promoting carbon emission reduction. It is recommended to incorporate trade considerations into the top-level design, preparation, and implementation of the CO_2 peaking action plan. Meanwhile, it is significant to implement low-carbon product certification for export products in order to improve the trade facilitation of carbon-friendly products and because low-carbon product certification can encourage enterprises to adopt clean production technology. Furthermore, it is necessary to find a reasonable approach to measure the CO_2 emissions caused by international trade among BRI countries and developed economies in view of equitable distribution of the CO_2 emission reduction responsibilities

Secondly, although the international trade tax helps to abate CO_2 emissions in Belt and Road countries, it does not mean the higher the trade taxes are, the better the effect of environmental protection is. Internal trade contributes to resource allocation among countries and economic prosperity. Therefore, on one hand, moderate international trade taxes can constrain enterprises to avoid excessive resource utilization and environmental pollution. Therefore, it is important to design a reasonable trade tax policy which should be careful consideration for each country in balancing CO_2 reduction and promoting international trade growth.

Thirdly, the policy tools for restraining high energy intensity need to be designed in order to reduce carbon emissions and improve air quality in BRI countries. For instance, the European Union has continuously adjusted its energy policies emphasizing energy conservation and renewable energy use since 1991. It successively issued a series of laws and regulations such as the EU Green Paper on Energy Policy, EU Future Energy: Renewable Energy Paper, and the Development Directive of Renewable Energy. As a result, the consumption of renewable energy in the EU has increased from 6 in 1998 to 19.7% in 2019, while the CO_2 emissions have decreased by 22% in the same period. Evidently, the demand for nonrenewable energy is still increasing in most BRI countries with the promotion of urbanization. The feasible measures may be to improve energy efficiency by optimizing the production technology as well as adjust the energy consumption structure by increasing the application of solar energy, wind energy, and biomass energy.

Fourthly, Internet usage can promote online activities which will consequently reduce the ecological footprint, thereby contributing to a decrease in energy consumption in public transportation and reduction of CO_2 emissions. The policy must be designed to encourage the popularity of internet usage. For the low-income and middle-income BRI countries, the local government is supposed to increase the investment in ICT to provide people with more opportunities of using the Internet (Khan et al. 2022d).

Fifth, the different approaches to CO_2 emission reduction strategies need to be developed according to the average income level per capita in BRI countries. These countries are in different stages of economic growth, which indicates that they have different governance abilities in coordinating economic, social, and environmentally sustainable development. In addition, fair and reasonable CO_2 emission reduction task sharing is demanding, thereby contributing to the achievement of various developing goals in each country. In addition, each BRI country should accelerate technological innovation and promote the transformation and upgrading of the energy sector. The government should encourage the energy sector to conduct independent research and development, adjust the production structure, and improve the efficiency of energy utilization, thereby reducing the carbon emission intensity and scale of the energy industry.

Conclusion and recommendations

The primary reason for conducting this research is to investigate the impacts of energy intensity, Internet usage, international trade, international trade tax, renewable energy, and GDP on CO_2 emissions in Belt and Road countries based on the dataset spanning from 2008 to 2020. The empirical findings of our study revealed that international trade is a source of increasing the level of CO_2 emissions. The present study suggests that implementing international trade taxes can significantly reduce environmental pollution. A fair reason is that manufacturing industries are competing with each other in the international market. Consequently, they produce surplus commodities which lead to extensive use of non-renewable energies. Policymakers should implement taxes on producing surplus products which can restrict industries to minimize their outputs. Energy intensity and Internet users are positively linked with CO_2 emissions, indicating that lower-energy intensity and a higher number of internet users are the main sources of abating environmental pollution in BRI countries. Further, renewable energy is confirmed to be a source of low carbon emissions in BRI since it is acknowledged by many research scholars in the previous literature. Therefore, renewable energy conversion should be an utmost priority for the BRI countries to adopt and depend on renewable energy consumption. Finally, GDP has a negative influence on CO_2 emissions in all the BRI countries.

Based on the present findings, this study suggests the following policy recommendations. First, the Belt and Road economies need to design policies that encourage economic and environmentally friendly related activity during the export and import trade of commodities. For instance, the government or policymakers can stimulate green innovation during industrial manufacturing by developing a sustainable green research and development policy in the manufacturing sector. Secondly, green energy utilization and reduction of carbon emissions, especially their intensity-constrained policies, can significantly reduce air pollution concentrations and improve regional air quality. A reasonable energy structure can promote economic development and ecological environment improvement to a certain extent. For industries with high energy consumption and high emissions, all these countries should strengthen supervision, reduce energy dependence, and steadily implement energy taxes. Third, deepening international and inter-regional economic and trade cooperation is an effective way to improve CO_2 emission reduction mechanisms and upgrade green technologies. Maintaining the multilateral trading system, upgrading free trade agreements, and deeply integrating into international and regional economic and trade cooperation can not only contribute to the development of the world economy but also help improve the level of its foreign trade development. There may be certain technical trade barriers in the introduction of low-carbon technologies. Finally, it is necessary to carry out friendly international cooperation in the green and low-carbon fields. CO_2 emission reduction and carbon neutrality are the common challenges of all mankind. Trade in services should be supported by free trade and cross-border investment. Explore the establishment of "common but differentiated" CO_2 emission standards and rules for international trade through cooperative negotiation of bilateral and multilateral trade agreements. Through green investment, zero-carbon and low-carbon technology trade, etc., expand cooperation with BRI countries in terms of green production capacity, green capital, and green trade.

In this respect, future research studies are expected to explore innovation in eco-technologies in sectors, including energy, manufacturing, and information, and communications. Secondly, this research has adopted a novel approach to two key areas such as international trade and international trade tax which both are inclusive and examines the environmental impact of these positive and negative shocks separately through econometric modeling. Therefore, the current econometric models should be tested by adding energy productivity, R&D, as well as trade bodies such as WTO, FTA, and RCEP as control variables to measure the consistency of current findings. Third, authors are encouraged to apply the current framework in the context of the European Union, RCEP, SAARC, or G-7 nations. Fourth, the difference in difference (DID) model can be used to explore the current stud. Finally, this work examined the association between international trade, trade tax, energy intensity, internet utilization, renewable energy GDP, and carbon dioxide emissions using the CCEMG and AMG approaches. Researchers are encouraged to examine the exports and imports of environmental friendly products and service on carbon dioxide emissions using difference and difference (DID) approach.

Author contribution Fang Liu wrote the introduction, literature review, and data collection. The main idea of the original draft belongs to Yasir Khan. He designed the empirical analysis, methodology, and revised the final draft and supervision. While, Mohamed Meri used the software and data analysis.

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Data availability The datasets analyzed 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.

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Conflict of interest The authors declare no competing interests.

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