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Bridging trade, finance, and the environment: the mediating role of growth in the belt and road countries

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Recent empirical research investigates the relationship between economic growth and environmental quality, focusing on global trade, foreign direct investment, financial development, and energy consumption. However, much of the existing literature does not distinguish between the direct and indirect effects of these macroeconomic variables on environmental quality. Therefore, this study uses economic growth as a mediating variable to separate the direct and indirect impacts of foreign direct investment, financial development, trade, and renewable energy consumption on environmental outcomes. Using a panel dataset of 26 Belt and Road Initiative countries from 1995 to 2020, the research estimates three econometric models employing the Feasible Generalized Least Squares method with Panel-Corrected Standard Errors to obtain robust estimates despite heteroskedasticity and cross-sectional dependence. The results reveal significant changes in both the signs and magnitudes of the estimated coefficients when economic growth is included as a mediating factor. Notably, the direct impact of trade becomes negative, while the effects of foreign direct investment and financial development diminish, suggesting that their environmental influence is transmitted mainly through economic growth. In contrast, the impact of renewable energy consumption remains unchanged. These findings emphasize the importance of accounting for economic activity in understanding how macroeconomic variables affect the environment. These findings further underline the need for policies that support low carbon technologies within trade and investment frameworks, and promote financial instruments that support sustainable growth to ensure that economic expansion does not cause CO_2 emissions.

KEYWORDS

BRI countries, CO2 emissions, environmental degradation, financial development, foreign direct investment, international trade

1 Introduction

The Belt and Road Initiative (BRI) was introduced by the Chinese President Xi Jinping in 2013 to revive the historic Silk Road. At its launch, 65 countries joined the initiative, and by 2022, this number had grown to 138 countries (Hussain and Zhou, 2022). Recently, 150 countries have signed a memorandum of understanding with China, making the BRI one of the most significant global infrastructure and economic development projects. The primary goal of the BRI is to enhance regional connectivity across Africa, Asia, and Europe by promoting economic development, infrastructure connectivity, and trade integration. Additionally, the initiative aims to lower tariff barriers, improve technological transfer, and foster financial integration and international cooperation.

Two years after the launch of BRI, global foreign trade experienced significant growth, rising from $38 billion in 1980 (Wang et al., 2017) to $24.59 trillion in 2015 (Du and Lu, 2018). Trade between BRI partner countries and China has also expanded, reaching a cumulative volume of $19.1 trillion, with an average annual growth rate of 6.4% between 2013 and 2022. Moreover, two-way investments between China and BRI countries have exceeded $380 billion (State Council, 2023). Despite these economic gains, concerns have been raised regarding the environmental impact of the BRI. No doubt, increased trade and investment can drive economic expansion, but if not managed effectively, they may also pose serious environmental risks (Zhou et al., 2024). As a result, the BRI has attracted global attention, making its long-term sustainability a critical area of discussion.

Foreign direct investment (FDI), a core channel of economic integration, generally brings threefold advantages for the host country: it generates employment, improves the effective use of natural resources, and enables the transfer of advanced technologies that are often inaccessible through trade or financial flows alone (Loungani and Razin, 2001). Many BRI member countries, primarily developing nations, actively seek FDI to expand economic activities and boost economic growth. However, studies show that countries with flexible environmental regulations are more likely to attract pollution-intensive FDI. As a result, economic progress may be achieved at the cost of environmental deterioration (Zhou et al., 2024; Mehmood, 2022b). Conversely, other studies suggest that FDI can introduce efficient technologies that drive industrialization and economic growth while maintaining a clean environment (Dilanchiev et al., 2024; Voumik and Ridwan, 2023). Given these contrasting perspectives, this study aims to examine whether FDI ultimately benefits or harms host BRI countries.

Furthermore, many countries overuse natural resources to produce goods for trade and stimulate economic growth, often surpassing the Earth's capacity for natural replenishment. This excessive resource use leads to environmental degradation, such as loss of biodiversity, land degradation, deforestation, and pollution of water and air (Zhou et al., 2024). Research also shows that international trade positively affects carbon emissions, leading to increased environmental harm (Khan et al., 2022b; Jebli and Youssef, 2017). However, it can also enhance production efficiency by enabling countries to specialize based on comparative advantage (Tawiah et al., 2021; Suresh and Tiwari, 2018). Therefore, the effects of trade on the environment are complex and require further investigation.

Financial development is another key driver of economic growth that can expand economic activities (Nuță et al., 2024) and facilitate investments in renewable energy sources. However, like other developments, financial development is a Faustian bargain, and the threat it poses to the environment should not be ignored (Liu and Chen, 2024; Hussain and Zhou, 2022). Financial development improves economic growth by easing consumer credit, allowing people to increase their demand for automobiles, household gadgets, and other technological products (Hussain and Zhou, 2022). This, in turn, stimulates growth in the transport and manufacturing sectors, leading to higher energy consumption and increased environmental pollution (Shahzad et al., 2017).

The growth strategies of most developing and emerging economies concentrate on infrastructure, construction, and manufacturing. For example, the BRI partner economies, which rely heavily on coal-based technologies for their growth trajectories, are projected to account for half of the global GDP by 2030 (Anwar et al., 2021). Such rapid industrial expansion is expected to drive up coal-based energy demand, with potentially serious consequences for the global environment (Lu et al., 2022). One way to safeguard the global environment, without compromising economic growth, is to invest in renewable energy sources (Lee et al., 2022).

Considered together, the aforementioned discussions make BRI recipient countries ideal for studying the relationship between economic growth, investment, and environmental sustainability. Although previous research has advanced our understanding of the connections among FDI, trade, and financial development and environmental quality, most studies have examined these factors separately. Although helpful, this fragmented approach leaves important gaps in the literature. This study aims to fill those gaps in four keyways. First, it offers a detailed multi-factor analysis of how FDI, trade, financial development, and renewable energy consumption influence environmental outcomes, particularly within the unique economic and policy contexts of BRI countries. Second, to the best of our knowledge, no previous study has attempted to differentiate between the direct and indirect effects of these macroeconomic variables on environmental quality. This paper addresses that gap by using economic growth as a natural framework to disentangle such effects. Third, unlike other recent studies, this paper employs advanced second-generation econometric models, including panel corrected standard errors (PCSE) and feasible generalized least squares (FGLS) models that account for serial correlation, heterogeneity, and cross-sectional dependence in the panel data, thereby providing more consistent and reliable results compared to the first-generation models. Lastly, the study proposes policy implications based on its empirical findings, which can inform effective policies to promote sustainable economic development and reduce carbon emissions within BRI nations. The rest of the paper is organized as follows: Section 2 reviews the relevant literature. Section 3 provides the theoretical foundation, data, and methodology, while Section 4 discusses the empirical results, and Section 5 concludes the study with policy implications.

2 Review of the literature

In this section, we briefly outline the theoretical relationships between economic growth, FDI, trade, FD, and environmental quality, along with summarizing the associated empirical studies under separate titles.

2.1 Economic growth and environmental quality

Economic activities are increasingly shifting from an agriculture-driven growth economy to an industry-led growth worldwide. This transition has significantly increased energy demand, primarily of fossil fuels, which, in turn, contributes to the degradation of environmental quality (Shahzad et al., 2017). Consequently, the IPCC (2014) reported that the rapid increase in economic activities constitute the primary driver of GHG emissions. Similarly, Wang et al. (2024) argue that countries with the highest total emissions are those possessing a strong economic activity base. No doubt, the rapid economic growth can foster industrialization and improve living conditions, but it also places increased demand on natural systems (Hassan et al., 2023). The extensive utilization of natural resources during development, through industrialization, mining, agriculture, and deforestation, can lead to severe environmental degradation (Georgescu et al., 2025b; Danish et al., 2019).

Since the seminal work (Grossman and Krueger, 1995; Grossman and Krueger, 1991) on economic growth and environmental degradation, numerous studies have shown that economic growth has a positive impact on CO_2 emissions (e.g., Al-Zubairi et al., 2024; Wang et al., 2024; Yasin et al., 2024; Deka et al., 2023; Khan et al., 2022b; Jijian et al., 2021; Nawaz et al., 2020). More recently, Al-Zubairi et al. (2024) examined Arab countries from 2000 to 2020 and found that economic growth significantly contributed to higher CO_2 emissions, whereas renewable energy was negatively associated with CO_2 emissions. Employing fixed effects and generalized method of moments models for 39 BRI countries, Khan et al. (2022b) found that economic growth is associated with increased CO_2 emissions. In another study, Jijian et al. (2021) examined 53 BRI countries using the common correlated effects mean group (CCEMG) method and found that economic growth is associated with increased consumption-based emissions *per capita*. Nawaz et al. (2020) further confirmed that higher economic growth is associated with increased CO_2 emissions in BRICS and OECD economies. Based on these findings, we propose the following hypothesis.

Hypothesis 1. Economic growth has a significant impact on environmental quality.

2.2 Foreign direct investment and environmental quality

The influence of FDI on environmental quality has remained a subject of debate in the literature over the past decade. One set of literature suggests that FDI helps countries to receive highly skilled workers, advanced technologies, and financial resources (Lasbrey et al., 2018). On the other hand, several studies argue that FDI may contribute to environmental degradation by shifting pollution-intensive industries to developing countries with less stringent environmental regulations (e.g., Sreenu, 2025; Mehmood, 2022b). In the context of Pakistan, Jan et al. (2023) found that FDI reduces CO_2 emissions, while Yi et al. (2023) found a negative correlation between FDI in manufacturing sector and CO_2 emissions for China. Jahanger and Usman (2022) provided support for the pollution halo hypothesis in 44 subregional BRI countries, showing that FDI reduces environmental pollution. In contrast, Haug and Ucal (2019), using a non-linear autoregressive distributed lag for Turkey, found that FDI does not have a significant impact on CO_2 emissions. On the other hand, Zhou et al. (2024) employed the CCEMD method and concluded that an increase in FDI is associated with a rise in the ecological footprint in 53 BRI countries. Georgescu et al. (2025a) demonstrated that investment efficiency influence environmental outcomes. In another study, Shinwari et al. (2024) found that FDI, particularly China's Overseas FDI in 29 BRI countries, increases energy consumption. Furthermore, Mehmood (2022b) for South Asian countries, Khan et al. (2022a) for BRI countries, and Wang and Huang (2022) for East Asian countries confirm that FDI tend to increase CO_2 emissions. Based on these studies, we hypothesize as follows.

Hypothesis 2. Foreign direct investment has a significant impact on environmental quality.

2.3 International trade and environmental quality

Previous literature on the nexus between international trade and environmental quality presents conflicting results. Some studies found that international trade boosts economic growth through achieving efficiency in the allocation of resources in sectors where a country has a comparative advantage (e.g., Tawiah et al., 2021; Suresh and Tiwari, 2018), while other suggests that international trade encourages CO_2 emissions, leading to environmental degradation by overexploitation of resources in production to serve the global market demands (e.g., Khan et al., 2022b; Kanemoto et al., 2014). According to Kurramovich et al. (2022), countries that rely on fossil fuels tend to specialize in the production of pollution-intensive commodities and usually export those goods. Consequently, when trade barriers are removed, these dirty industries tend to grow in these nations, leading to higher CO_2 emissions. Conversely, when international trade promotes specialization in and the expansion of cleaner industries, it can also contribute to a reduction in CO_2 emissions. Zhou et al. (2024) employed the CCEMD method and concluded that increases in exports and imports are associated with a rise in the ecological footprint in 53 BRI countries. Similarly, Anwar et al. (2021) concluded that trade stimulates CO_2 emissions in BRI countries. These authors further emphasized that trade openness can boost economic growth, but this growth will come at the cost of environmental quality by increasing production-related emissions. On the other hand, Khan et al. (2022a) reported that international trade reduces CO_2 emissions in BRI countries. Further, Liu and Chen (2024) found a negative relationship between digital trade and ecological footprint for MINT countries. Based on these findings, we propose the following hypothesis.

Hypothesis 3. International trade has a significant impact on environmental quality.

2.4 Financial development and environmental quality

Financial development is yet another vital source influencing environmental quality. Zhao and Yang (2020) argue that a robust financial system facilitates the adoption of energy-efficient technologies, thereby improving environmental quality. Hence, an improved financial sector can play a crucial role in environmental sustainability through facilitating investments in environmentally friendly technologies and supporting green initiatives (Al-Zubairi et al., 2024). Empirical evidence from Shen et al. (2021) suggests that investing in clean technologies is crucial for reducing carbon emissions, even when financial development is not environmentally friendly. In other words, investing in green and environmentally friendly technologies is a crucial option for addressing environmental degradation (Georgescu et al., 2025c).

However, previous literature provides equivocal findings on the environmental impacts of financial development. More recently, Liu and Chen (2024) analyzed MINT countries from 2005 to 2022 using the Augmented Mean Group (AMG) method and found that financial development positively impacts the material footprint. Similarly, Yousaf et al. (2024), employing the Pooled Mean Group (PMG) method with panel data from 1990 to 2022, demonstrated that financial development is associated with a higher ecological footprint in Asian Emerging Economies. In addition, studies by Hussain and Zhou (2022) for 92 BRI countries and Shahzad et al. (2017) for Pakistan have concluded that financial development is associated with increased CO_2 emissions. In contrast, Al-Zubairi et al. (2024) for Arab countries, Nuță et al. (2024) for eight emerging economies from Europe and 7 emerging economies from Asia, and Yasin et al. (2024) for BRICS economies find that financial development is reducing CO_2 emissions. Moreover, Mehmood (2022a) reported that financial development reduces the ecological footprint in South Asian countries. Based on these findings, we propose the following hypothesis.

Hypothesis 4. Financial development has a significant impact on environmental quality.

2.5 Research gap from the literature

The literature reveals numerous studies investigating the relationships among economic growth, FDI, international trade, and financial development with CO_2 emissions, but significant gaps still remain unaddressed. First, most existing studies (e.g., Sreenu, 2025; Wang et al., 2024; Zhou et al., 2024; Mehmood, 2022a) primarily explored the direct effects of FDI, trade, and FD on CO_2 emissions, treating economic growth as an explanatory variable. Second, the current literature also presents inconsistent and contradictory findings. For instance, some studies support the pollution haven hypothesis (e.g., Zhou et al., 2024; Mehmood, 2022b; Wang and Huang, 2022), indicating that increased FDI and trade exacerbate environmental degradation, while others aligned with the pollution halo hypothesis, suggesting that FDI and trade facilitate technology transfer and cleaner production (e.g., Khan et al., 2022a; Jahanger and Usman, 2022; Lasbrey et al., 2018). Furthermore, the environment related role of financial development also remains inconclusive, as some studies linking it to improved environmental quality (e.g., Al-Zubairi et al., 2024; Mehmood, 2022a), while others find evidence that financial development results in increase of CO_2 emissions (e.g., Yousaf et al., 2024; Hussain and Zhou, 2022). Hence, the existing literature indicates mixed findings on the impacts of FDI, trade, and FD on CO_2 emissions, which warrant further investigation. In fact, it also shows no evidence of whether these factors affect CO_2 emissions through their influence on economic growth. Instead, it focuses mainly on direct relationships only. Consequently, the potential mediating role of economic growth in linking FDI, trade, and FD variables to environmental quality is missing. As a result, the transmission mechanism between global economic integration and environmental outcomes remains primarily underexplored in empirical research. To address these gaps, we will employ a mediation analysis in this study to examine whether economic growth mediates the effects of FDI, trade, and FD on CO_2 emissions. This approach allows for a clearer distinction between direct and indirect effects. It contributes to a more nuanced understanding of the growth-environment nexus. Moreover, this study offers valuable empirical insights for designing sustainable economic policies, particularly in rapidly developing and emerging economies, such as BRI countries.

3 Model, data, and methods

3.1 Theoretical framework and model development

This research draws on the Environmental Kuznets Curve (EKC) hypothesis, the Pollution Haven, and the Halo hypothesis to achieve its objectives. The EKC hypothesis posits an inverted U-shape relationship between economic growth and environmental degradation. In their pioneering work, Grossman and Krueger (1991) proposed that developing nations may prioritize industrialization and production over environmental quality, resulting in a negative relationship between environmental degradation and economic growth. However, once an economy reaches a certain level of prosperity, further economic growth results in improved environmental quality, mainly due to the adoption of environmentally friendly technologies (Stern, 2004). Panayotou (1993) later coined the term "Environmental Kuznets Curve" after Simon, (1955), who initially examined the relationship between income inequality and economic growth. Since then, numerous studies have investigated the EKC hypothesis (see, for example, Haciimamoglu, 2025; Nuță et al., 2024; Yousaf et al., 2024; Majeed et al., 2022), mostly finding an inverted U-shape relationship between environmental degradation and economic growth.

Meanwhile, the Pollution Haven Hypothesis (Phav-H) posits that, in developed countries with stricter environmental laws and regulations, industries that produce pollution relocate their operations to developing countries with less stringent environmental regulations to reduce their production costs. This relocation results in an influx of pollution-intensive FDI, effectively turning developing countries into hubs for pollution-intensive industries and causing significant environmental degradation. The Pollution Halo Hypothesis (Phal-H), in contrast, asserts that FDI can bring more advanced, environmentally friendly technologies from developed countries that do not degrade the environment. Numerous empirical studies support the "Phav-H″, indicating that higher levels of FDI can lead to environmental degradation (see, for instance, Zhou et al., 2024; Mehmood, 2022b). Conversely, other studies supported the Phal-H by demonstrating that FDI can improve environmental quality (Liu et al., 2024; Jan et al., 2023; Jahanger and Usman, 2022).

Based on these theoretical perspectives, this study uses a panel-adapted mediation framework grounded in the classical approach of Baron and Kenny (1986) to investigate whether economic growth acts as a transmission channel through which FDI, trade openness, and financial development influence CO_2 emissions. Consistent with the procedure outlined by Hsu (2020), the analysis is structured to test the direct and indirect effects transmitted through the economic growth channel. This approach is consistent with recent advances on mediation in macro panel environments and provides statistically valid findings on the transmission mechanism that acts through economic growth. While prior studies have predominantly focused on the direct relationship between these financial and trade-related forces and environmental degradation, as noted in previous studies (e.g., Haciimamoglu, 2025; Sreenu, 2025; Wang et al., 2024; Yousaf et al., 2024; Zhou et al., 2024; Mehmood, 2022a; Hussain and Zhou, 2022; Jijian et al., 2021; Nawaz et al., 2020). The analytical approach adopted in this study provides a more comprehensive causal mechanism and can allow for a more nuanced assessment of how financial and trade-related factors influence environmental quality, with a focus on their impact on economic growth.

Following the studies of Hsu (2020) and Baron and Kenny (1986), this study's empirical investigation is structured in four core steps. In Step 1, we regress economic growth on FDI, international trade, financial development, and renewable energy consumption to estimate their impact on growth in Model 1. This step verifies that the explanatory variables exert a meaningful influence on economic growth, which is the first stage of the mediated effect. Therefore, significant coefficients in Model 1 for FDI, trade, financial development, and renewable energy would confirm that the mediator is responsive to these variables. In Step 2, we regress CO_2 emissions on the same independent variables (FDI, international trade, financial development, and renewable energy consumption) to estimate their total effects in Model 2. This step assesses whether the explanatory variables are significantly associated with CO_2 emissions. This establishes the baseline association between each explanatory variable and CO_2 emissions. In Step 3, we further regress CO_2 emissions on both the primary independent variables and economic growth to determine the direct effects in Model 3. This step examines whether the mediator, economic growth, contributes to variations in the dependent variable. A statistically significant coefficient for economic growth in Model 3 would confirm the second stage of the mediation effects. In Step 4, the impact of each independent variable on CO_2 emissions should diminish or disappear once the mediator variable is included in the specification. This outcome indicates that the previously observed relationship between the independent variables and CO_2 emissions is absorbed by the mediator, implying that the environmental impact operates entirely through the economic growth channel. If all four steps are satisfied, the results will provide evidence of complete mediation. However, if only the first three steps hold but the coefficients of independent variables remain significant, albeit smaller in magnitude, the findings would indicate partial mediation. The three models, specified below, are developed as modifications of prior studies (Tripathy et al., 2025; Hsu, 2020; Baron and Kenny, 1986) for the empirical analysis.

Model 1:

$$lnEG_{it} = \varphi_o + \varphi_1 lnFDI_{it} + \varphi_2 TR_{it} + \varphi_3 FD_{it} + \varphi_4 REC_{it} + \mu_{it} \quad (1)$$

Model 2:

$$lnCE_{it} = \varphi_o + \varphi_1 lnFDI_{it} + \varphi_2 TR_{it} + \varphi_3 FD_{it} + \varphi_4 REC_{it} + \mu_{it} \quad (2)$$

Model 3:

$$lnCE_{it} = \varphi_o + \varphi_1 lnFDI_{it} + \varphi_2 TR_{it} + \varphi_3 FD_{it} + \varphi_4 REC_{it} + \varphi_5 lnEG_{it} + \mu_{it} \quad (3)$$

Where i and t represents the country (26 BRI countries) and the specified year (1995–2020), respectively. *CE* represents CO_2 emissions, *EG* denotes economic growth, *TR* denotes the volume of international trade, *FDI* is the net inflow of foreign direct investment, *FD* is the level of financial development, and *REC* is the percentage of renewable energy consumption. The ln (.) notation represents the natural logarithm of the variables, which helps reduce data skewness and facilitates the interpretation of the slope coefficients as elasticities. The φ_o is the intercept while φ_k (k = 1–6) are the slope coefficients, and μ_{it} defines the error structure.

3.2 Data and measures of variables

This study focused on evaluating the dynamic relationship between, FDI, international trade, financial development, renewable energy consumption, and CO_2 emissions for 26 BRI countries (Argentina, Bangladesh, Bulgaria, Chile, China, Czechia, Iran, Jamaica, Jordan, Kenya, South Korea, Madagascar, Malaysia, Pakistan, Peru, Philippines, Poland, Portugal, Romania, Russian Federation, Singapore, South Africa, Sri Lanka, Sudan, Tunisia, and Vietnam), using panel data from 1995 to 2020. This study aims to provide new insights into how these forces affect environmental quality, particularly by exploring the mediating role of economic growth. Data on the variables of interest is obtained from the World Bank and the International Monetary Fund databases, and are outlined in Table 1. In line with the recent studies (Tabash et al., 2025; Zhou et al., 2024; Nyeadi, 2023; Hussain and Zhou, 2022; Anwar et al., 2021; Nawaz et al., 2020; Shahzad et al., 2017), we use CO_2 emissions as the dependent variable, serving as a proxy for environmental degradation. Foreign direct investment (FDI) is measured as the net inflow of FDI, capturing the direct investment flow from foreign entities into the domestic economy. International trade is defined as the total trade volume of goods and services with the rest of the world, and is expressed as a percentage of GDP, indicating the degree of trade openness. Financial development measures the level of a country's financial sector by assessing the depth, access, and efficiency of its financial institutions and markets. The index ranges from 0 to 1, with a value closer to 1 indicating a higher level of financial development in a country. Additionally, renewable energy consumption is measured as the percentage share of renewable energy use in total energy consumption, serving as an indicator of sustainable energy

TABLE 1 List of variables and their measures.

Variables	Symbols	Measure	Source	Expected sign
Carbon dioxide emissions	CE	CO_2 emissions measured in metric tons *per capita*	World bank	NA
Foreign direct investment	FDI	Net FDI inflows expressed in current UD dollars	World bank	Positive
International trade	TR	Total trade volume as percentage of GDP	World bank	Positive
Financial development	FD	Financial development index, composite measure of financial institutions and markets	IMF	Negative
Renewable energy consumption	REC	Percentage share of renewable energy in total final energy consumption	World bank	Negative
Economic growth	EG	GDP *per capita* in constant 2015 US dollars	World bank	Positive

TABLE 2 Summary of descriptive statistics.

Variable	Obs	Mean	Std. Dev	Min	Max
CE	676	4.486,601	3.507,263	0.0651,833	15.34125
FDI	676	1.14E+10	3.35E + 10	1,896,372	2.91E + 11
TR	676	83.56884	65.94421	19.77142	437.3267
FD	676	0.3,679,064	0.1,841,545	0.0799,443	0.8,528,287
REC	676	24.03991	23.10641	0.33	87.23
EG	676	8,250.318	9,610.315	414.6873	61,386.24

adoption. These four variables constitute the primary independent variables in the study. While economic growth is represented by GDP *per capita*, acting as mediator channel in this study. The summary statistics of the variables are presented in Table 2.

3.3 Method of analysis

In the pre-estimation analysis, we conducted a series of preliminary diagnostic tests essential for identifying and addressing potential issues in panel data at early stages. This enhances the accuracy and reliability of the model estimation. Therefore, we first thoroughly checked cross-sectional dependence (CD) in panel data, using the test proposed by Pesaran (2004) to ensure the consistency of our estimations. Since the presence of CD in the data can lead to spurious results, it is crucial to select an estimation technique that allows for cross-sectional dependence. The Pesaran (2004)'s test is effective in detecting CD which could arise from economic, social, and cultural interdependencies in the panel countries, and the equation to estimate the test is given in Equation 4.

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

The CD test results, given in Table 3, suggest that CE, FD, FDI, TR, and, EG are interdependent, as the alternative hypothesis is significant at a 1% level. However, REC is independent, and the null hypothesis is accepted. These results indicate that economic fluctuations in one BRI country can spill over to other panel members due to economic dependency, reflecting strong economic and financial linkages. In isolation, this result

TABLE 3 Cross-sectional dependence analysis.

Variable	CD-test	P-value
Pesaran. (2004)		
lnCE	15.955***	0.000
lnFDI	46.603***	0.000
TR	16.604***	0.000
FD	36.228***	0.000
REC	0.365	0.715
lnEG	73.32***	0.000
Model 1: lnEG is DV		
Pesaran (2015)	16.468***	0.000
Friedman (1937)	133.127***	0.000
Frees (1995)	7.743*	
Model 2: lnCE is DV		
Pesaran (2015)	3.375***	0.001
Friedman (1937)	45.796***	0.007
Frees (1995)	3.693*	
Model 3: lnCE is DV		
Pesaran (2015)	−0.663	0.5072
Friedman (1937)	13.507	0.9697
Frees (1995)	4.265*	

*** is $p < 0.01$, ** is $p < 0.05$, and * is $p < 0.10$.

highlights the need for coordinated policies in trade, investment, and economic integration to achieve more favorable environmental outcomes. Table 3 also contains the results of Pesaran (Pesaran, 2015), Friedman (Friedman, 1937), and Frees (Frees, 1995) tests to check weak CD in the specified research models. The findings show that the research models have a significant weak CD. Therefore, this research employs second-generation (SG) methods for empirical estimation to address this problem.

Furthermore, given the evidence of CD, it is essential to check for the stationarity of the variables. Assuming stationarity without proper testing can lead to biased and false results. To address stationarity, we

TABLE 4 CADF unit root analysis.

Variables	Level		1st difference	
	Statistic	P-value	Statistic	P-value
lnCE	−2.009	0.950	−3.231***	0.000
lnFDI	−3.100***	0.000		
TR	−2.137	0.829	−2.954***	0.000
FD	−2.523	0.122	−3.657***	0.000
REC	2.167	0.783	−3.645***	0.000
lnEG	−1.582	1.000	−2.774***	0.005

*** is p < 0.01.

TABLE 5 VIF analysis.

Variable	VIF	1/VIF	VIF	1/VIF
	Model 1: lnEG is DV		Model 3: lnCE is DV	
lnEG			4.21	0.2374
FD	2.17	0.4608	2.92	0.3427
lnFDI	1.79	0.5572	1.90	0.5274
REC	1.46	0.6866	2.20	0.4547
TR	1.30	0.7701	1.32	0.7585
Mean VIF	1.68		2.51	

employed Cross-Sectional Augmented Dickey-Fuller (CADF) panel unit root test to determine the order of integration of each variable. This SG test, proposed by Pesaran (2007), account for CD, making it preferable to first-generation panel unit root test. The equation for the CADF test is defined in Equation 5.

$$CADF = a_i + b_i Y_{i,t-1} + c_i \bar{Y}_{t-1} + d_i \Delta \bar{Y}_t + \varepsilon_{i,t} \tag{5}$$

The results of the CADF test are reported in Table 4, indicating that CE, FDI, TR, FD, REC, and, EG are not stationary at the level, except for FDI. After taking the first difference, all variables become stationary. Hence, CADF test confirms that the first difference eliminates the problem of the unit root from the data. Since estimating variables in the presence of a unit root can produce inaccurate results (Nuță et al., 2024), the data were integrated to I (1) before the estimation.

We also assessed multicollinearity in this research using the Variance Inflation Factor (VIF) method, and the results are presented in Table 5. The VIF values of all variables employed are less than 10, indicating no multicollinearity issues in the data. In general, multicollinearity arises when VIF values exceed 10; in such cases, the variables exhibiting multicollinearity should be dropped from the empirical analysis.

Another pertinent issue in panel data is slope heterogeneity (SH). If slopes differ across countries but are assumed homogeneous, the results may be biased. Therefore, evaluating the slope heterogeneity is an essential part in the panel data estimation. For this purpose, this study employed the second-generation slope homogeneity test developed by Pesaran and Yamagata (2008) to examine the slope homogeneity. The equations utilized for conducting SH test are given below in Equations 6, 7.

$$\tilde{\Delta}_{slope\,homogeneity} = \sqrt{N}\,(2K)^{-\frac{1}{2}}\left(N^{-1}\tilde{S} - k\right) \tag{6}$$

$$\tilde{\Delta}_{adjusted\,slope\,homogeneity} = \sqrt{N}\left(\frac{2k\,(T-k-1)}{T+1}\right)^{-\frac{1}{2}}\left(N^{-1}\tilde{S} - k\right) \tag{7}$$

The SH test results are presented in Table 6. The results provide evidence to reject the null hypothesis of homogeneity, confirming that the panel consists of heterogeneous countries. Consequently, the study employs SG heterogeneous panel methods that allow parameters to differ across individual cross-sections. Table D also contains the results of the Wooldridge test for autocorrelation (Drukker, 2003; Wooldridge, 2002) and the Modified Wald test for groupwise heteroscedasticity (Baum, 2001). The results confirm the existence of first-order autocorrelation and significant heteroscedasticity in the panel data.

After testing CD, slope heterogeneity, and unit roots, the study proceeds to examine cointegration using Pedroni cointegration test. Pedroni is employed because it allows for time-demeaning of the panel series, which is essential given the strong cross-sectional dependence detected in the data. Demeaning ensures that the test statistics remain unbiased and robust, providing reliable results. The results are reported in Table 7. The Pedroni test statistics (MPP, PP, and ADF) are significant, rejecting the null hypotheses of no cointegration. Hence, we concluded that the specified models in the study exhibit a long-run relationship, and methods that provide long-run estimates can be employed for estimation.

After completing the essential diagnostic tests of the panel data, this study employs the Feasible Generalized Least Squares (FGLS) model by Parks (1967) alongside the Panel Corrected Standard Errors (PCSE) model by Beck and Katz (1995) for the estimation of Equations 1–3. These techniques are preferred for several reasons. First, considering BRI countries, which predominantly are emerging and developing economies and share common economic, cultural, and institutional characteristics. Country-level data from countries sharing similar characteristics could result in cross sectional dependence, autocorrelation, and heteroscedasticity. Addressing these issues is essential to ensure the robustness and validity of the empirical estimation. In such cases, FGLS and PCSE techniques provide a more accurate estimation of the model parameters (Hoechle, 2007; De Hoyos and Sarafidis, 2006). Second, these techniques effectively address serial correlation and panel-specific autocorrelation. Ignoring these issues could lead to inconsistent and biased results. Third, if the panel data exhibits CD, heteroskedasticity, and first-order autocorrelation, with the number of cross sections greater than or equal to the number of periods, PCSE regression produces efficient results (Nuță et al., 2024). Conversely, when the number of periods exceeds or equals to number of cross sections, FGLS regression is more appropriate for achieving accurate results (Hoechle, 2007). Furthermore, several studies have recommended the use of FGLS and PCSE to overcome issues of autocorrelation and heteroscedasticity in panel data (e.g., Kashyap and Hussain, 2025; Soto et al., 2025; Nuță et al., 2024; Shinwari et al., 2024; Kongkuah et al., 2021). Hence, we used both PCSE and FGLS models to ensure the accuracy and reliability of our empirical analysis, providing

TABLE 6 Slope homogeneity, serial correlation and heteroskedascticity analysis.

Test	Test statistic	P-value
Model 1: lnEG is DV		
Delta	27.861***	0.000
Adjusted delta	31.767***	0.000
Wooldridge test for autocorrelation in panel data (F-statistics)	153.084***	0.000
Modified Wald test for groupwise heteroskedasticity (χ^2)	817.36***	0.000
Model 2: lnCE is DV		
Delta	20.817***	0.000
Adjusted delta	23.735***	0.000
Wooldridge test for autocorrelation in panel data (F-statistics)	46.536***	0.000
Modified Wald test for groupwise heteroskedasticity (χ^2)	2650.43***	0.000
Model 3: lnCE is DV		
Delta	20.020***	0.000
Adjusted delta	23.420***	0.000
Wooldridge test for autocorrelation in panel data (F-statistics)	78.553***	0.000
Modified Wald test for groupwise heteroskedasticity (χ^2)	4,908.70***	0.000

*** is p < 0.01.

TABLE 7 Pedroni cointegration analysis.

	Statistic	P-value
Model 1: lnEG is DV		
Modified PP	2.571***	0.0051
PP	−2.1836**	0.0145
ADF	−1.4976*	0.0671
Model 2: lnCE is DV		
Modified PP	2.0372**	0.0208
PP	−3.6043***	0.0002
ADF	−3.2828***	0.0005
Model 3: lnCE is DV		
Modified PP	3.8602***	0.0001
PP	−1.8566**	0.0317
ADF	−1.4137*	0.0787

The subtraction of cross-sectional means (demean) is included in order to overcome CD. PP, is Phillips Peron; ADF, is Augmented Dickey Fuller; Note: *** is p < 0.01, ** is p < 0.05, and * is p < 0.10.

strong support for the robustness and validity of the overall estimations.

4 Empirical results and discussion

The deterioration of environmental quality is a pressing global concern, and the world must address its causes and consequences. Environmental degradation threatens not only the ecological balance but also poses significant risks to human wellbeing and economic stability. While the drivers of environmental degradation vary across countries and regions–ranging from unsustainable resource exploitation to rapid economic expansion and weak environmental regulations–however, its impacts are universal and long-term. Many countries and regions have committed to achieve specific carbon emissions reduction targets. For example, the

TABLE 8 FGLS and PCSE panel estimation regression results.

Regressors	FGLS estimation			PCSE estimation		
	Coefficients	Std. Err	P-value	Coefficients	Std. Err	P-value
	Model 1: DV is Economic Growth					
lnFDI	0.0172***	0.0002	0.000	0.0882***	0.0079835	0.000
TR	0.0009***	0.00004	0.000	0.0011***	0.0001576	0.000
FD	0.6093***	0.0065	0.000	2.4423***	0.0939,938	0.000
REC	−0.0163***	0.0001	0.000	−0.0194***	0.000605	0.000
Constant	8.2202***	0.0118	0.000	6.0633***	0.1,426,789	0.000
R-squared				0.7626		
No. of Obs	676			676		
No. of groups	26			26		
Wald chi2(4)	33,890.85			11,946.74		
Prob > chi2	0.000			0.000		
Regressors	*Model 2: DV is CO_2 emissions*					
	Coefficients	Std. Err	P-value	Coefficients	Std. Err	P-value
lnFDI	0.0159***	0.0002	0.000	0.0706***	0.0076	0.000
TR	0.0003***	0.00004	0.000	−0.0007***	0.00008	0.000
FD	0.4279***	0.0091	0.000	1.1063***	0.0842	0.000
REC	−0.0382***	0.0001	0.000	−0.0434***	0.0006	0.000
Constant	1.3832***	0.0117	0.000	0.1563	0.1460	0.284
R-squared				0.8882		
No. of Obs	676			676		
No. of groups	26			26		
Wald chi2(4)	133,523.70			54,156.47		
Prob > chi2	0.000			0.000		
Regressors	*Model 3: DV is CO_2 emissions*					
	Coefficients	Std. Err	P-value	Coefficients	Std. Err	P-value
lnFDI	0.0061***	0.0002	0.000	0.0320***	0.0069312	0.000
TR	−0.0004***	0.00003	0.000	−0.0012***	0.0000836	0.000
FD	0.0273***	0.0059	0.000	0.0377	0.0629,868	0.550
REC	−0.0294***	0.0001	0.000	−0.0349***	0.0004715	0.000
lnEG	0.5228***	0.0045	0.000	0.4376***	0.010840	0.000
Constant	−2.8584***	0.0401	0.000	−2.4967***	0.1,446,575	0.000
R-squared				0.9211		
No. of Obs	676			676		
No. of groups	26			26		
Wald chi2(4)	349,774.86			133,552.04		
Prob > chi2	0.000			0.000		

*** is $p < 0.01$, ** is $p < 0.05$, and * is $p < 0.10$.

United Kingdom seeks to achieve net-zero carbon emissions by 2050, while China has set a goal of reaching carbon neutrality by 2060 (Akpanke et al., 2023). On the other hand, the European Green Deal projects a 55% decrease in carbon emissions by 2050. Additionally, the Paris Climate Agreement aims to decrease global warming to 2 ˚C or below, while the United Nations has called for a 7.6% carbon emissions reduction per annum between 2020 and 2030 (Akpanke et al., 2023). In the present study, we adopted a comprehensive mediating analysis approach to examine the relationship between FDI, trade, financial development, renewable energy consumption, and CO_2 emissions with economic growth acting as the mediating factor for the 26 BRI countries from 1995 to 2020. We used CO_2 emissions as a proxy for environmental degradation. Variables in absolute values are transformed into natural logarithms to reduce skewness and facilitate interpretation of the estimated coefficients as elasticities. We employed both FGLS and PCSEs methods to analyze the panel data, as these techniques yield robust results even in the presence of cross-sectional dependence, autocorrelation, and heteroscedasticity. We now proceed to interpret the empirical results and to make sure that the empirical findings are reliable and support the formulation of well-informed policy implications.

As illustrated in Table 8, the results from Model 1 revealed that FDI, TR and FD have a positive and statistically significant influence on economic growth across both FGLS and PCSE estimators. The coefficient for FDI indicates that a one percent increase in FDI boosted economic growth by 0.0172%–0.0882% at a 1% significance level, holding other variables constant. While the coefficient of FD shows that a one unit increase in FD leads to a 0.6093%–2.4423% increase in economic growth, holding other variables constant. Our findings are consistent with recent studies that suggest increased capital inflows and a well-functioning financial sector play a pivotal role in promoting economic growth (Solaymani and Montes, 2024; Nabi et al., 2023; Nguyen, 2022).

The estimated coefficient of TR is also positively associated with economic growth across both FGLS and PCSE regressions, reflecting that a 1% increase in trade openness raises economic growth by 0.001%–0011%, holding other variables constant. This result indicates that greater integration into global markets enhances economic activity in BRI countries by fostering exports opportunities and facilitating access to foreign markets. The result is consistent with Tawiah et al. (2021) and Suresh and Tiwari (2018) studies that suggest trade openness fosters efficiency gains and capital accumulation, thereby accelerating economic growth. Moreover, similar evidence from Nabi et al. (2023) confirms that trade openness supports economic growth by strengthening comparative advantage and expanding production capacity. Overall, the positive coefficient for trade in Model 1 underscores its role as a critical driver of economic growth in the BRI countries.

In contrast, the coefficient of REC is negative and significant at the 1% level, indicating that a percentage increase in renewable energy use results in between 0.0163% and 0.0194% decrease in economic growth, holding other variables constant. This finding may reflect transitional inefficiencies within the energy sectors of BRI countries. Several recent studies have evidenced similar findings that renewable energy consumption can hinder economic growth, especially when economies are undergoing a transition from fossil fuels consumption to renewable energy sources (Umar et al., 2024; Altıner and Şimşek, 2022; Feng and Zhao, 2022). Maji et al. (2019) argue that renewable energy use lowers total factor productivity, thereby slowing economic growth. Similarly, Solaymani and Montes (2024) attributed this negative relationship between economic growth and renewable energy to the fact that economic growth has been primarily driven by increased reliance on fossil fuel consumption. Additionally, fossil fuels, as conventional energy sources, are less compatible with the integration of renewable technologies. This structural dependence restricts the ability of renewables to contribute meaningfully to economic growth in the short term. Furthermore, the high installation and maintenance costs, along with the limited scalability of renewable energy technologies can also constrain its potential to create economic growth benefits (Dirma et al., 2024). The significant coefficient for FDI, TR, FD, and REC in Model 1 establishes the first stage of the mediated effect.

Considering the estimates from Models 2 and 3 in Table 8, the findings indicate a positive and statistically significant impact of FDI on CO_2 emissions in Model 2. According to the findings, a 1% increase in FDI results in a 0.0159%–0.0706% rise in CO_2 emissions at a 1% significance level, holding other variables constant. However, the coefficient of FDI significantly declines from 0.0159% to 0.0706% (Model 2) to 0.0061%–0.0320% (Model 3) when economic growth is introduced in Model 3, indicating a partial mediation. These results imply that FDI affects CO_2 emissions both directly and indirectly through economic growth, suggesting that as FDI inflow increases in BRI countries, so will carbon emissions. The findings are consistent with Model 1, which shows that FDI significantly stimulates economic growth. Our findings further highlight the dual nature of FDI in BRI countries. First, FDI may help these countries by bringing in capital that boosts output and infrastructure, thereby promoting economic growth. Second, due to flexible environmental rules and regulations aimed at attracting greater FDI, these countries may also facilitate the relocation of pollution-intensive industries. Consequently, our findings support the pollution-haven hypothesis in the context of BRI countries, suggesting that these countries may require stronger environmental regulations to attract more sustainable FDI. Our results are also consistent with other recent studies (Sreenu, 2025; Yousaf et al., 2024; Zhou et al., 2024; Khan et al., 2022a).

In the case of TR, it shows interesting findings across both Model 2 and 3. In Model 2 under FGLS, the coefficient is positive and statistically significant at 1% significance level. The coefficients indicate that a 1% increase in TR would lead to a 0.0003% increase in CO_2 emissions. However, while statistically significant, its sign changes in PCSE estimation. These findings are noteworthy, given that the environmental impacts of trade openness may operate through three core channels: scale effect, technology effect, and composition effect (Shahzad et al., 2017; Antweiler et al., 2001). The positive coefficient under FGLS suggests a scale effect: higher trade volumes expand production and energy consumption, thereby increasing CO_2 emissions. This aligns with the arguments that greater integration into global markets initially intensifies resource exploitation and industrial output (Khan et al., 2022b; Anwar et al., 2021). In contrast, the negative coefficient under PCSE indicates the possible presence of a technology effect, in which trade facilitates the transfer of cleaner technologies and efficiency gains that mitigate environmental harms (Khan et al., 2022a). In Model 3, when economic growth is introduced as a mediator, trade consistently shows a significant negative relationship with CO_2 emissions across both regressions. Since Model 2 captures the total effects of trade, whereas Model 3 separates the direct effect from the total effects that are mediated by economic growth. The positive scale-related impact of trade is transmitted through its growth-enhancing effect, and this part of the relationship becomes absorbed by the mediator. Consequently, the direct effect of trade represents the technology and composite channels, which contribute to lower emissions by supporting cleaner production processes and encouraging shifts toward less carbon-intensive sectors. This mediated formulation reveals why the coefficient in Model 3 becomes negative and stable under both FGLS and PCSE regressions and indicates that the environmental burden of trade declines when the growth-caused scale effects are separated. In other words, the technology and composition effects dominate the scale effect of trade volume when the growth pathway is controlled for. This highlights that trade openness not only fosters access to environmentally efficient technologies but may also encourage structural reallocation toward less carbon-intensive sectors. Thus, we concluded that trade openness negatively contributes to CO_2 emissions and improves environmental quality in BRI countries. Our findings are consistent with the studies by Zhou et al. (2024) and Tawiah et al. (2021), who reported that trade can help countries achieve efficiency in production by focusing on their comparative advantage, while, at the same time, they can also benefit from green technological transfers to mitigate environmental risks.

Financial development also shows a statistically significant positive impact on CO_2 emissions across both Model 2 and 3. According to Model 2's findings, a unit increase in FD results in 0.4279%–1.1063% rise in CO_2 emissions ($p < 0.01$). However, once economic growth is introduced as a mediator in Model 3, the relationship between FD and CO_2 emissions weakens considerably. Under FGLS estimation, the FD coefficient remains positive, but its magnitude significantly declines, while under PCSE the coefficient becomes statistically insignificant, indicating partial mediation. These results further imply that FD affects CO_2 emissions both directly and indirectly through economic growth, suggesting that as FD increases in BRI countries, so will carbon emissions. This finding is supported by the results in Model 1, where FD has a positive impact on economic growth across both estimations. Hence, these findings underscore the dual nature of financial development. It catalyzes economic growth, but may also lead to environmental degradation. These findings further highlight that, in BRI countries with weak environmental regulations and poor enforcement, financial resources are often channeled into pollution-intensive sectors such as manufacturing, construction, and fossil-fuel-based energy production. Several previous studies, including Teklie and Yağmur (2024) for African countries, Shahzad et al. (2023) for the Association of Southeast Asia Nations, and Hussain and Zhou (2022) for BRI countries, have found similar results and concluded significant financial development impacts on CO_2 emissions.

Renewable energy consumption, on the other hand, shows a consistently negative and significant correlation with CO_2 emissions in both the total-effect analysis (Model 2) and mediation analysis (Model 3). It remains a highly significant mitigator of CO_2 emissions across all estimations. Given its negative impact on economic growth (Model 1), the effect of renewable energy on CO_2 emissions appears to be largely direct and independent, even after accounting for economic growth. The estimated coefficient for REC indicates that a 1% increase in renewable energy consumption reduces CO_2 emissions by 0.0382%–0.0434% in Model 2. The result is consistent with Model 3 estimations, indicating that the environmental benefits of renewable energy are structural and not mediated through economic growth. Furthermore, this finding suggests that shifting towards renewable energy sources can significantly reduce CO_2 emissions. Our findings are in line with several recent studies (Al-Zubairi et al., 2024; Yasin et al., 2024; Deka et al., 2023; Khan et al., 2022a), which suggest that renewable energy use can play a crucial role in reducing carbon emissions.

Regarding the impact of economic growth on CO_2 emissions in Model 3, the results demonstrated a positive and statistically significant relationship between economic growth and CO_2 emissions, confirming its role as a key mediator. This result establishes the second stage of the mediated effect. This condition indicates that the relationship between CO_2 emissions and the explanatory variables diminishes once economic growth is controlled for. The reduction in magnitude, rather than the complete disappearance, of the coefficients implies that economic growth absorbs part of the environmental impact of the explanatory variables. Therefore, satisfying the first three conditions provides evidence of partial mediation, suggesting the coexistence of both direct and growth mediated effects on CO_2 emissions. The significant coefficient of lnEG shows that a 1% increase in economic growth corresponds to a 0.4376%–0.5228% rise in CO_2 emissions, holding other variables constant. Thus, economic growth is the primary driver of CO_2 emissions in the sample of BRI countries, suggesting that the panel countries may not adequately consider their environmental quality in their growth strategies. Hence, the finding underscores the urgent need for policy initiatives to decouple economic growth from environmental degradation, thereby pursuing sustainable economic development and addressing environmental issues. The result is in line with the other recent studies (Al-Zubairi et al., 2024; Wang et al., 2024; Khan et al., 2022b; Nawaz et al., 2020) that also found a similar positive relationship between economic growth and CO_2 emissions. We also assessed the robustness of our results by re-estimating the empirical findings using Dynamic Ordinary Least Squares (DOLS) and Fully Modified Ordinary Least Squares (FMOLS), given in Table 9. All the results generally matched the FGLS and PCSE estimations in Table 8. Although there might be slight variations in the magnitude and statistical significance of the coefficients, the overall trends and implications remain consistent. Overall, our results underscore the urgent need for policy measures to decouple economic growth from environmental degradation, ensuring that economic progress in the panel BRI countries is not achieved at the expense of environmental quality.

Finally, we employed the Dumitrescu and Hurlin (2012) test to test the short-run association among variables. This approach comprises Z-bar and W-bar statistics. Table 10 presents the results of the Dumitrescu and Hurlin (D-H) causality test. The results show that bidirectional D-H causality runs between lnFDI

TABLE 9 Results from DOLS and FMOLS estimators for Robustness check.

Regressors	DOLS estimation			FMOLS estimation		
	Coefficients	Std. Error	P-value	Coefficients	Std. Error	P-value
	Model 1: DV is Economic Growth					
lnFDI	0.0994***	0.015853	0.000	0.0260***	0.002482	0.000
TR	0.0026**	0.001018	0.011	0.0004*	0.000244	0.085
FD	1.3025***	0.215,107	0.000	0.2250***	0.069267	0.001
REC	0.0196**	0.007901	0.014	−0.0176***	0.003229	0.000
Regressors	*Model 2: DV is CO_2 emissions*					
	Coefficients	Std. Error	P-value	Coefficients	Std. Error	P-value
lnFDI	0.0780***	0.004778	0.000	0.0710***	0.002271	0.000
TR	−0.0011*	0.000616	0.078	0.0001	0.000381	0.785
FD	1.4520***	0.221,257	0.000	0.8348***	0.135,874	0.000
REC	−0.0675***	0.019802	0.001	−0.0573***	0.009981	0.000
Regressors	*Model 3: DV is CO_2 emissions*					
	Coefficients	Std. Error	P-value	Coefficients	Std. Error	P-value
lnFDI	−0.0409**	0.016924	0.017	−0.0010	0.004147	0.809
TR	0.0011	0.000937	0.229	0.0003	0.00029	0.380
FD	0.3457	0.503,241	0.493	0.3878***	0.098246	0.000
REC	−0.0387***	0.008503	0.000	−0.0671***	0.007187	0.000
lnEG	0.3084***	0.055957	0.000	0.2305***	0.012329	0.000

*** is $p < 0.01$, ** is $p < 0.05$, and * is $p < 0.10$.

and lnEG, between TR and lnEG, between FD and lnEG, between REC and lnEG. Similarly, a bidirectional D-H causality association is found between lnFDI and lnCE, between TR and lnCE, between FD and lnCE, between REC and lnCE, and between lnEG and lnCE. These significant relationships observed for lnFDI, TR, FD, and REC with respect to both lnEG and lnCE, suggesting that FDI, international trade, financial development, and renewable energy consumption contribute to the changes in economic growth and CO_2 emissions. Hence, these findings highlight a strong interdependence among economic, energy, and environmental indicators.

5 Conclusion and policy implications

Global commerce (FDI and trade) and local financial development, when handled carefully, have been the primary drivers of economic growth in recent history. However, because most developing countries may not be sufficiently cautious about their environments, both global commerce and local financial development, if driven by profit maximizers, may lead to deteriorating environmental quality in such countries. Most BRI countries have experienced a surge in both FDI and trade flows recently, and, being predominantly developing and emerging economies that rely on coal-based technologies, their environmental sustainability may be at risk. Hence, this study examined how economic growth mediates the effects of financial and trade-related macroeconomic variables on CO_2 emissions in 26 BRI countries from 1995 to 2020. The primary contribution of this study lies in its mediation framework, as it introduces economic growth as an endogenous channel. This approach is grounded in the EKC and the pollution haven–halo hypotheses.

Employing robust FGLS and PCSE estimators, the findings revealed interesting and complex results. These findings provide policymakers in BRI countries with important insights. They highlight the need for a multidimensional policy approach that considers both the direct and indirect effects of macroeconomic variables on environmental quality. First, this study found significant cross-sectional dependence amongst the sample BRI countries. This indicates strong economic and environmental interdependence. Being tied to one another, BRI countries could benefit from improved environmental quality if cooperation to share best environmentally friendly practices is enhanced and cross-border environmental issues are jointly resolved. Second, FDI increases CO_2 emissions both directly and indirectly. This evidence supports the pollution haven hypothesis for the host BRI countries, suggesting that investment inflows may contribute to environmental degradation. Therefore, BRI countries need to

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TABLE 10 Dumitrescu and Hurlin panel causality test results (Lag 1).

Null hypothesis (H_0)	W Bar	Z bar	P-value	Decision	Conclusion
lnFDI does not granger cause lnEG	1.6288**	2.2671	0.023	Reject H_0	Bidirectional causality (lnFDI↔lnEG)
lnEG does not granger cause lnFDI	3.2567***	8.1365	0.000	Reject H_0	
TR does not granger cause lnEG	4.4707***	12.5136	0.000	Reject H_0	Bidirectional causality (TR↔lnEG)
lnEG does not granger cause TR	3.5276***	9.1134	0.000	Reject H_0	
FD does not granger cause lnEG	2.7525***	6.3188	0.000	Reject H_0	Bidirectional causality (FD↔lnEG)
lnEG does not granger cause FD	3.6012***	9.3789	0.000	Reject H_0	
REC does not granger cause lnEG	3.2845***	8.2368	0.000	Reject H_0	Bidirectional causality (REC↔lnEG)
lnEG does not granger cause REC	3.8495***	10.2742	0.000	Reject H_0	
lnFDI does not granger cause lnCE	1.9332***	3.3647	0.001	Reject H_0	Bidirectional causality (lnFDI↔lnCE)
lnCE does not granger cause lnFDI	2.1707***	4.2211	0.000	Reject H_0	
TR does not granger cause lnCE	2.9531***	7.0421	0.000	Reject H_0	Bidirectional causality (TR↔lnCE)
lnCE does not granger cause TR	2.1468***	4.1348	0.000	Reject H_0	
FD does not granger cause lnCE	2.6287***	5.8722	0.000	Reject H_0	Bidirectional causality (FD↔lnCE)
lnCE does not granger cause FD	2.575***	5.6788	0.000	Reject H_0	
REC does not granger cause lnCE	2.1302***	4.075	0.000	Reject H_0	Bidirectional causality (REC↔lnCE)
lnCE does not granger cause REC	3.3787***	8.5766	0.000	Reject H_0	
lnEG does not granger cause lnCE	4.1596***	11.392	0.000	Reject H_0	Bidirectional causality (lnEG↔lnCE)
lnCE does not granger cause lnEG	2.8108***	6.5289	0.000	Reject H_0	

*** is $p < 0.01$, ** is $p < 0.05$, and * is $p < 0.10$, and ↔ represents two-way causality association.

consider environmental quality when evaluating long-term investments. This could include a proper mechanism to ensure that investment inflows align with their environmental goals.

Third, our findings indicate that FD indirectly drives CO_2 emissions through its impact on economic growth. This finding highlights the need to align financial sector expansion with environmental objectives. Governments and financial institutions should strengthen green financial architecture. Mechanisms such as green bonds, environment quality-linked lending, and climate risk assessments are essential. Further, redirecting capital toward sustainable investments requires a well-regulated and climate-conscious financial system. Hence, regulatory reforms aimed at enhancing the environmental accountability of financial flows are essential to shift capital flow toward sustainable investments projects.

Fourth, empirical evidence on trade suggests that trade openness does not directly influence CO_2 emissions. Instead, its effect is transmitted indirectly through economic growth. This suggests that the environmental benefits of trade are not inherent but contingent upon structural and policy factors. Therefore, policy interventions should not aim to restrict trade. Rather, they should focus on managing the nature and quality of trade-led growth. Furthermore, trade policy should be restructured to align with national climate goals by incorporating environmental impact assessments of trade flows. By managing the composition and quality of trade-driven growth, BRI countries can ensure that economic integration contributes to long-term environmental preservation and sustainable development.

Fifth, the brighter side of our study is that renewable energy consumption reduces CO_2 emissions, independent of the economic growth pathway. This indicates that increased use of renewable energy plays a significant role in reducing environmental degradation in BRI countries. Policymakers should foster both public and private investment in renewable energy infrastructure, to achieve a low-carbon future and promote environmental sustainability. Although the short-term impact of renewable energy on economic growth may appear negative, the long-term benefits are substantial. These include environmental protection, energy security, and sustainable development. Therefore, renewable energy should remain a strategic priority in the policy agendas of BRI countries.

Sixth, the findings confirmed that economic growth plays a significant mediating role in the relationship between FDI, FD, trade, and CO_2 emissions. Economic growth acts as a transmission mechanism through which these macroeconomic variables indirectly affect environmental quality. While economic progress is vital for development, its environmental cost–manifested through increased CO_2 emissions–must not be overlooked. Therefore, BRI countries must shift toward sustainable growth models that minimize environmental harm while sustaining developmental momentum. This includes integrating environmental criteria into macroeconomic planning, incentivizing resource-efficient industries, and promoting the adoption of low-emission technologies. Growth strategies should be supported by robust institutional frameworks that align investments and production with long-term environmental goals. By addressing the indirect environmental impacts of macroeconomic expansion, policymakers can decouple economic growth from CO_2 emissions. This can foster a development path that is both economically inclusive and environmentally sustainable.

Several limitations in this study may be addressed in future research. First, the study is limited to 26 BRI countries. Although these countries represent key emerging and transition economies from BRI partners, excluding other BRI participants may limit the generalizability of the results. In addition, the dataset covers data from 1995 period up to 2020, which is determined based on the availability of consistent data for the variables of interest across the selected BRI member countries. While the latest data is available for a few individual countries, post-2020 data for certain variables remains unavailable or incomplete for most BRI economies. This limits our ability to construct a balanced, methodologically reliable panel dataset beyond 2020. Given the substantial variation in economic structures, policy frameworks, and environmental regulations across the BRI countries, future research should expand both the dataset to include a broader range of BRI countries and the time period once harmonized post-2020 data become accessible. This would enhance empirical robustness and allow for more generalizability of the findings, while also capturing post-2020 developments. Second, the current study does not account for key structural and institutional variables. Factors such as technological innovation, institutional quality, and regulatory enforcement are not included. These may influence how FDI, trade, and financial development affect CO_2 emissions through economic growth. Their absence limits the study's explanatory power. Including such moderating or control variables would strengthen the analytical depth of future studies and provide more targeted policy implications in BRI countries.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://databank.worldbank.org/source/world-development-indicators and https://data.imf.org/.

Author contributions

AK: Conceptualization, Data curation, Formal Analysis, Methodology, Software, Writing – original draft. TG: Conceptualization, Methodology, Supervision, Writing – review and editing. IU: Data curation, Formal Analysis, Writing – review and editing. AD: Data curation, Formal Analysis, Writing – review and editing. TM: Formal Analysis, Validation, Writing – review and editing.

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