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Assessing the impact of inbound tourism on carbon emissions: Evidence from the Belt and Road Initiative countries

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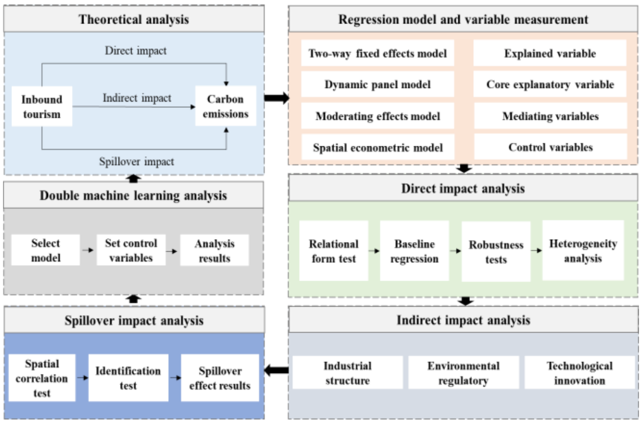
Graphical abstract



Abstract

As an important vehicle for implementing the Belt and Road Initiative (BRI), inbound tourism not only promotes economic growth among participating countries but also plays a significant role in optimizing the flow of production factors and enhancing green low-carbon cooperation. Based on the panel data encompassing 66 countries along the BRI from 2009 to 2019, we use the two-way fixed effects model, dynamic panel model, panel threshold model, instrumental variable model, moderating effects model, spatial econometric model, and double machine learning model to investigate the nonlinear impact, mediating mechanism, and spatial spillover effect of inbound tourism on carbon emissions. Results indicate that the development of inbound tourism has an inverse U-shaped nonlinear influence on carbon emissions, and this influence remains credible after robustness testing and endogenous control. Moreover, this effect varies significantly across countries with different geographical conditions and economic development levels. Mechanism analysis indicates that inbound tourism can reduce carbon emissions by upgrading industrial structure, enhancing environmental regulatory, and fostering technological innovation. The application of spatial durbin model reveals the spatial spillover effect of inbound tourism on carbon emissions of neighboring countries. Based on the above conclusions, this paper argues that it is necessary to consider the differences in economic development stages and location characteristics among countries, formulate targeted tourism development policy systems, and establish a cross-border collaborative governance framework for tourism-related carbon emissions. This will promote the synergistic advancement of high-quality tourism economic development and low-carbon emission reduction in the BRI countries.

Keywords: inbound tourism; carbon emissions; nonlinear impact; spillover effect

1. Introduction

Inbound tourism, a pivotal segment of the tourism industry, is indicative of the international tourism competitiveness and degree of global engagement of nations and regions (Chiu *et al*., 2021; Xu *et al*., 2023). The hypothesis of tourism-driven economic growth underscores the indispensable role of inbound tourism in fostering national economic growth, creating job opportunities, reducing poverty, and enhancing people's well-being (Lagos and Wang, 2023; Wang and Tziamalis, 2023; Wong *et al*., 2024).

The advent of the COVID-19 pandemic has had a profound and unparalleled influence on inbound tourism (Allan *et al*., 2022). However, as the pandemic recedes and countries ease their entry restrictions, inbound tourism begins to show signs of recovery. The January 2024 edition of World Tourism Barometer, released by the United Nations World Tourism Organization (UNWTO), illustrated that international tourist arrivals reached 1.3 billion in 2023, representing a 34% increase from 2022 and a recovery to 88% of pre-pandemic levels. Amid a resurgence in cross-border tourism demand, ongoing enhancements in international air routes, and increasing entry convenience, the inbound tourism market is expected to sustain its positive development trajectory. Nonetheless, scholars have voiced concerns regarding the environmental challenges that accompany the swift development of inbound tourism. For example, according to Lenzen *et al*. (2018), the global tourism-related carbon emissions experienced a substantial increase, rising from 3.9 billion to 4.5 billion tons during the 2009-2013 period. The UNWTO predicts that carbon emissions from tourism-related transportation will surge significantly, projected to rise from 697 million tons in 2016 to 1.998 billion tons in 2030, with an average annual growth rate of nearly 8% (UNWTO, 2019). In this context, a clean understanding of the relationship between inbound tourism and carbon emissions is essential for advancing energy efficiency, reducing emissions, and ensuring the sustainable development of tourism industry.

Currently, the academic community has conducted extensive research on the environmental effects of inbound tourism, with a primary focus on its impacts on water resources, atmospheric environment, carbon emissions, and ecological footprint (Miralles *et al*., 2023; Pásková *et al*., 2024). In terms of research scope, studies have covered global, continental, multinational, and single-country scales. Methodologically, models such as the autoregressive distributed lag model (Wang *et al*., 2022), vector autoregressive model (Gedikli *et al*., 2022), two-way fixed effects model (Qureshi *et al*., 2019), dynamic panel threshold model (Li *et al*., 2022a), and coupling coordination degree model (Liu *et al*., 2025) have been employed to analyze the relationship between the two. Regarding mechanisms, some studies have found that inbound tourism can influence the environment through pathways such as promoting industrial upgrading (Geng *et al*., 2021), driving green innovation (Zhao *et al*., 2022), and optimizing energy structure (Zhang *et al*., 2024).

Table 1. Review of the published research

Authors	Regions	Time periods	Econometric models	Main findings
Jebli *et al*. (2019)	22 Central and South American countries	1995-2010	ARDL, VECM	Reduce carbon emissions
Eyuboglu and Uzar (2020)	Turkey	1960-2014	ARDL, VECM	Promote carbon emissions
Ehigiamusoe (2020)	31 African countries	1995-2016	FMOLS, GMM	U-shaped relationship
Yue *et al*. (2021)	Thailand	2004-1999	Boostrap ARDL	Reduce carbon emissions
Le and Nguyen (2021)	95 countries	1998-2014	Double fixed model	Promote carbon emissions
Yıldırım *et al*. (2021)	15 Mediterranean countries	2001-2017	Panel threshold model	Inverted U-shaped relationship
Ahmad and Ma (2022)	Asian Tigers countries	2000-2016	FMOLS, DOLS	Reduce carbon emissions
Salahodjaev *et al*. (2022)	45 Europe and Central Asia countries	1990-2105	Two-step GMM	Promote carbon emissions
Liu *et al*. (2022)	70 countries	2000-2017	Spatial econometric model	Inverted U-shaped relationship
Ullah *et al*. (2023)	BRICS countries	1995-2018	CS-ARDL	Reduce carbon emissions
Adjei-Mantey *et al*. (2023)	7 African countries	1995-2021	Quantile regression, FMOLS	Reduce carbon emissions
Voumik *et al*. (2024)	40 Asian countres	1995-2019	CS-ARDL	Reduce carbon emissions
Odhiambo (2024)	29 Sub-Saharan African countries	1995-2019	DCCE-MG, Driscoll-Kraay, FMOLS	Inverted U-shaped relationship
Purwono *et al*. (2024)	77 countries	2008-2019	Quantile regression	Inverted N-shaped relationship

Regarding the relationship between inbound tourism and carbon emissions, existing research mainly includes the following three viewpoints: (1) The development of inbound tourism is associated with a rise in carbon emissions. The growth of tourist infrastructure directly escalates energy consumption, consequently driving up carbon emissions. Moreover, the boom in inbound tourism spurs development in related industries — including transportation, accommodation, and catering— whose operations further contribute to the carbon footprint. Eyuboglu and Uzar (2020) conducted a study in Turkey and reported a long-term equilibrium relationship among inbound tourism, economic growth, energy consumption, and carbon emissions, with inbound tourism having a considerable positive influence on carbon emissions. Using panel data from 95 countries from 1998 to 2014, Le and Nguyen (2021) found that inbound tourism significantly increases carbon emissions in the transportation sector. Using panel data from European and Central Asian countries from 1990 to 2015, Salahodjaev *et al*. (2022) concluded that inbound tourism exacerbates the growth of carbon emissions. (2) The expansion of inbound tourism can play a role in mitigating carbon emissions. Jebli *et al*. (2019) analyzed panel data from 22 Central and South American countries over the period from 1995 to 2010 and discovered that an increase in inbound tourist numbers is associated with a reduction in carbon emissions. Studies focusing on Thailand (Yue *et al*., 2021), the Asian Tigers (Ahmad and Ma, 2022), BRICS countries (Ullah *et al*., 2023), the African region (Adjei-Mantey *et al*., 2023), and the Asian region (Voumik *et al*., 2024) have reached similar conclusions. (3) A complex nonlinear relationship. For instance, studies from 70 countries worldwide (Liu *et al*., 2022), Mediterranean countries (Yıldırım *et al*., 2021), and Sub-Saharan African countries (Odhiambo, 2024) have indicated an inverted U-shaped relationship between inbound tourism and carbon emissions. Concurrently, some scholars have identified U-shaped (Ehigiamusoe, 2020) and inverted N-shaped relationships (Purwono *et al*., 2024) between the two.

Overall, the impact of inbound tourism on carbon emissions has not yet reached a consensus, with results varying substantially across regions, time periods, and econometric models (**Table 1**).

Since the launch of the Belt and Road Initiative (BRI) in 2013, tourism exchanges between countries along the route have become increasingly close, making this region a significant global inbound tourism market. It attracts approximately 582 million inbound tourists annually, accounting for 44.02% of the global share (Chen *et al*., 2021). The BRI spans a vast territory, covering 39% of the global land area, 30% of the global GDP, and 60% of the global population (Huang, 2016). However, most countries along the route have a more extensive economic development model, along with high levels of resource and energy consumption and significant pressures to reduce carbon emissions (Dong *et al*., 2024). Therefore, several questions arise: Can the development of inbound tourism reduce carbon emissions of countries along the BRI? If a carbon-reducing effect exists, what are the mechanisms at play? Does the development of inbound tourism have a spillover effect on neighboring countries? The scientific answers to these questions have significant implications for advancing the high-quality development of the BRI.

The distinctive contributions of this work are notably evident in three areas. Firstly, existing studies pay close attention to the quantitative relationship between inbound tourism and carbon emissions, but they lack of theoretical disclosure of the relationship. Building upon the investigation into the nonlinear relationship between the two variables, this study further explores the transmission mechanisms, examining the influences of industrial structure, environmental regulatory, and technological innovation. Secondly, by integrating traditional econometric methods such as two-way fixed effects, dynamic panel, and panel threshold models, along with machine learning models such as double machine learning (DML), this study delves into the nonlinear effect of inbound tourism on carbon emissions from a multidimensional methodological perspective, thereby enhancing the credibility of the empirical results. Thirdly, the development of inbound tourism has facilitated the flow of production factors, and information exchange, thereby enhancing the level of interconnectivity between countries. This study employs the spatial econometric model to further investigate spatial spillover effect of inbound tourism on carbon emissions at the country level from both theoretical and empirical dimensions.

2. Theoretical analysis and research hypothesis

2.1. Direct impact of inbound tourism on carbon emissions

The development of inbound tourism is a dynamic evolutionary process that transitions from a lower to a higher stage, with its impact on carbon emissions obviously varies across different stages. In the early stages, substantial investments in capital, labor, and infrastructure lead to a rapid increase in inbound tourists. However, because of the complexity of visa and customs clearance procedures, inadequate transportation facilities, and imperfect management of tourist attractions, the contradiction between the supply of tourist attractions and the demand for inbound tourists intensifies, putting pressure on the ecological environment of tourist areas (Pásková *et al*., 2021). In addition, insufficient synergies among industries related to inbound tourism, such as transportation, accommodation, catering, and shopping, result in severe resource wastage and increase carbon emissions. However, in the later stages of development, the construction and management of visitor attractions are greatly enhanced and optimized with the prevalence of low-carbon tourism policy and improved facilities (Zhang *et al*., 2023). The integration of all parties involved in tourism supply and demand increases notably, effectively addressing the issue of improper allocation of tourism resources and promoting the rational allocation of labor, technology, and material resources (Li *et al*., 2024). Consequently, carbon emissions begin to decline. Considering this process, we propose Hypothesis 1:

Hypothesis 1: Inbound tourism and carbon emissions exhibit an inverted U-shaped nonlinear relationship.

2.2. Indirect impact of inbound tourism on carbon emissions

As a form of service export, inbound tourism can generate substantial foreign exchange earnings for national development. The augmentation of foreign exchange earnings not only bolsters economic prowess but also facilitates the importation of production materials, technological equipment and so on, thereby supporting domestic industrial upgrading and development. Furthermore, the development of inbound tourism transcends the tourism industry itself as it stimulates the growth of related industries (Elgin and Elveren, 2024). The progression of related industries contributes to the formation of a more comprehensive industrial chain, enhances inter-industry coordination efficiency and overall competitiveness, and subsequently promotes the refinement and enhancement of the industrial structure. Finally, inbound tourism provides more employment for residents in tourist destinations and improves their lives (Li *et al*., 2022b), thereby stimulating consumption and domestic demand growth and offering a broader market for industrial structure upgrading.

Industrial structure upgrading serves as a potent strategy for mitigating carbon emissions. For one thing, the secondary industry encompasses numerous sectors characterized by high energy usage, severe pollution, and considerable emissions. As the industrial structure shifts towards a service-oriented economy, economic growth increasingly reduce dependence on resource and energy, contributing to a decrease in regional carbon emissions (Zheng *et al*., 2020). For another, industrial restructuring and upgrading promote the mobility and redistribution of production factors, such as capital and labor, across various industries, significantly enhancing the productivity and efficiency of energy use while curbing the growth of carbon emissions. Consequently, Hypothesis 2 is expressed as:

Hypothesis 2: The development of inbound tourism reduces carbon emissions by upgrading industrial structure.

The development of inbound tourism relies on a sound ecological environment. However, as the number of inbound tourists increases, they adversely influence the environmental and carrying capacities of tourist destinations. This effect forces local tourism authorities to formulate corresponding environmental regulation policies, effectively supervise all parties involved in tourism activities, and promote environmental improvement. Foreign tourists' environmental concerns and protection awareness can, to a certain extent, drive domestic residents' attention to environmental issues (Bilynets and Cvelbar, 2022). Such focus helps enhance the effectiveness and sustainability of a country's environmental regulatory.

Environmental regulatory is crucial in reducing carbon emissions. On the one hand, environmental regulatory imposes strict external costs (e.g., levying high carbon and energy taxes), forcing high energy-intensive enterprises to reduce energy demand and switch to clean or renewable energy sources (Zhao *et al*., 2022), thereby directly suppressing carbon emissions. On the other hand, environmental regulatory can incentivize enterprises to innovate and upgrade their environmental protection technologies, thereby generating a "technology innovation compensation effect," (Zhang *et al*., 2025). This effect helps offset the additional costs associated the regulatory compliance while simultaneously achieving the indirect reduction of carbon emissions. Following the analysis, Hypothesis 3 can be stated as:

Hypothesis 3: The development of inbound tourism reduces carbon emissions by enhancing environmental regulatory.

As a significant form of "people-to-people diplomacy," inbound tourism provides opportunities for face-to-face exchanges among individuals from different countries and regions. This exchange is not limited to tourism activities, but may also involve multiple fields, such as science, technology, culture, and economy. Therefore, it helps to stimulate innovative thinking and promote the dissemination and sharing of technological information (Liu and Nijkamp, 2019). Certainly, the development of inbound tourism often relies on advanced tourism facilities and services. For instance, with the help of digital technology, tourists can enjoy more convenient and personalized travel experiences (Sustacha *et al*., 2023). This strategy will encourage relevant enterprises and institutions to continuously improve their technological capabilities and service quality. In this process, a series of technological innovations and improvements may emerge, particularly in the fields of tourism informatization and intelligent services.

Numerous studies have shown that technological innovation is pivotal in enhancing production efficiency, restructuring industries, and fostering low-carbon sectors, thereby serving as a fundamental way to reduce carbon emissions. For example, Cheng *et al*. (2021) conducted a study using panel data from 35 OECD countries spanning the years 1996 to 2015. Their findings indicated that technological innovation can decrease total carbon emissions. Similar conclusions have been drawn in studies on the construction (Erdogan, 2021), transportation (Awan *et al*., 2022), and steel industries (Wang *et al*., 2022a). Consequently, Hypothesis 4 is illustrated as:

Hypothesis 4: The development of inbound tourism reduces carbon emissions by fostering technological innovation.

2.3. Spillover impact of inbound tourism on carbon emissions

With the continuous development of inbound tourism, border restrictions between countries have gradually broken down, and the spatial interaction effect has become increasingly significant. This interaction is reflected not only in traditional areas such as transportation, human mobility, and capital but also information, technology, culture, and other dimensions, thereby exerting a notable spatial spillover effect on carbon emissions in neighboring countries. The spatial spillover effect manifests in three key dimensions.

The first one is the demonstration effect. On the one hand, a country emphasizes environmental protection and low carbon in the development of inbound tourism and formulates and implements strict green tourism standards, which will provide a reference model for neighboring countries. On the other hand, the country's technological innovation and management experience in green tourism may significantly drive the green tourism development of neighboring countries through the knowledge spillover effect and technology transfer mechanism.

The second aspect is the competitive effect. To attract more tourists, neighboring countries continuously optimize tourism resource allocation and increase investments in green tourism, thereby improving resource utilization efficiency and reducing carbon emissions. However, if neighboring countries compete for tourists, they may also over-develop tourism resources and practice poor management. This has resulted in the degradation of ecosystems within tourist destinations and a corresponding rise in carbon emissions.

The last is the mobility effect. During the cross-border travel, inbound tourists facilitate the bidirectional exchange of environmental protection concepts and low-carbon technologies between their countries of origin and destination. Through their sustainable consumption behaviors, these tourists actively promote the optimization of environmental governance in host destinations. This dynamic interaction fosters the development of an evolving low-carbon symbiotic system between source and destination regions. Therefore, Hypothesis 5 is depicted as:

Hypothesis 5: The development of inbound tourism has spatial spillover impact on carbon emissions in neighboring countries.

To conclude, **Figure 1** illustrates the theoretical framework of the impact of inbound tourism on carbon emissions.

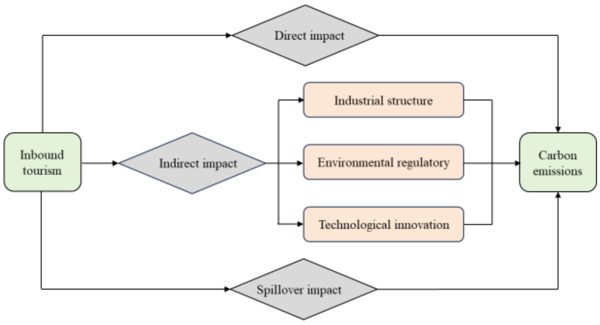


Figure 1. Theoretical framework of the impact of inbound tourism on carbon emissions in the BRI

3. Research design

3.1. Data resources

Given the data availability and to avoid the interference of major international events such as financial crises and the COVID-19 pandemic, this paper focuses on a time frame ranging from 2009 to 2019 for its sample. In conjunction with the key regional directions indicated in plans such as "Vision and Actions on Jointly Building Silk Road Economic Belt and 21st - Century Maritime Silk Road" and "Building the Belt and Road: Concepts, Practices, and China's Contributions," this paper ultimately identifies 66 countries along the BRI (Figure 2).

The data in this paper come from several sources, including the World Bank, the United Nations Conference on Trade and Development, the Energy Institute, the Global Carbon Budget, the International Monetary Fund (IMF), the Penn World Table (PWT) version 10.01, and UN Comtrade Database

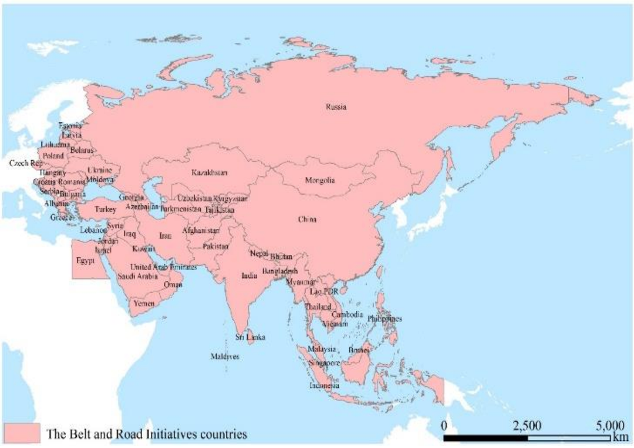


Figure 2. Map of the BRI countries

3.2. Regression model design

3.2.1. Baseline model

To verify Hypothesis 1, we adopt the model specification from Zheng *et al*. (2023) by incorporating both inbound tourism and its quadratic term into a two-way fixed effects model. The baseline model is delineated below:

$$\ln C_{it} = \alpha_0 + \alpha_1 \ln Int_{it} + \alpha_2 \left(\ln Int_{it}\right)^2 + \gamma \ln X_{it} + \mu_i + \tau_t + \varepsilon_{it} \tag{1}$$

In Equation (1): C_{it} and Int_{it} represent the carbon emission level and inbound tourism level of country i in year t, respectively; X_{it} denotes all control variables; μ_i and τ_t represent the country fixed effect and the time fixed effect, respectively; ε_{it} refers to the random error term. All variables are transformed using logarithms to reduce potential errors caused by heteroscedasticity.

Given the potential path dependency in carbon emissions across countries (Zuo *et al*., 2024), we introduce the first-order lagged term of carbon emissions to construct a dynamic panel model and employ the system generalized method of moments (SYS-GMM) for the regression analysis. The model is presented below:

$$\begin{aligned} \ln C_{it} = {} & \alpha_0 + \alpha_1 \ln Int_{it} + \alpha_2 \left(\ln Int_{it}\right)^2 + \alpha_3 \ln C_{it-1} + \gamma \ln X_{it} \\ & + \mu_i + \tau_t + \varepsilon_{it} \end{aligned} \tag{2}$$

In Equation (2): C_{it-1} represents the first-order lagged term of carbon emissions.

3.2.2. Moderating effects model

To verify Hypotheses 2-4, we apply the mediation framework proposed by Baron and Kenny (1986) to explore the underlying mechanism. The specific model setup is as follows:

$$\ln M_{it} = \beta_0 + \beta_1 \ln Int_{it} + \beta_2 \left(\ln Int_{it}\right)^2 + \gamma \ln X_{it} + \mu_i + \tau_t + \varepsilon_{it} \tag{3}$$

$$\begin{aligned} \ln C_{it} = {} & \varphi_0 + \varphi_1 \ln Int_{it} + \varphi_2 \left(\ln Int_{it}\right)^2 + \varphi_3 \ln M_{it} + \gamma \ln X_{it} \\ & + \mu_i + \tau_t + \varepsilon_{it} \end{aligned} \qquad (3)$$

In Equation (3): M_{it} denotes the mediating variable, while other variables are explained in the same way as in Equation (1). Equation (3) represents the impact of inbound tourism on the mediation variable, while Equation (4) represents the combined effects of inbound tourism and the mediating variable on carbon emissions.

3.2.3. Spatial econometric model

To test Hypothesis 5, this paper incorporates a spatial weight matrix (LeSage and Pace, 2009) into Equation (1), and constructs the spatial durbin model (SDM). SDM is set up as follows:

$$\begin{aligned} \ln C_{it} = {} & \rho W_{ij} \ln C_{it} + \alpha_0 + \alpha_1 \ln Int_{it} + \alpha_2 \left(\ln Int_{it}\right)^2 + \gamma \ln X_{it} \\ & + \beta_1 W_{ij} \ln Int_{it} + \beta_2 W_{ij} \left(\ln Int_{it}\right)^2 + \theta W_{ij} \ln X_{it} + \mu_i + \tau_t + \varepsilon_{it} \end{aligned} \tag{5}$$

In Equations (5): ρ represents the spatial autoregressive coefficient. W_{ij} represents the spatial weight matrix, and in this paper, we construct adjacent matrix (W_1) and economic linkage matrix (W_2). W_1 is set in Equation (6)

$$W_1 = \begin{cases} 1, \text{when country } i \text{ is adjacent to country } j \\ 0, \text{when country } i \text{ is not adjacent to country } j \end{cases} \tag{6}$$

Bilateral trade is an important reflection of economic ties between countries. Due to the significant difference in bilateral trade volume, referring to the treatment of Zhou et al. (2025), we construct a directed unweighted trade network with a threshold of $ 100 million to represent W_2. W_2 is set in Equation (7):

$$W_2 = \begin{cases} 1, & when\,\overline{\text{Trade}_{ij}} > U.S.\ \$100\,million \\ & 0, other \end{cases} \tag{7}$$

In Equation (7): $\overline{Trade_{ij}}$ represents the average export trade volume from country *i* to *j* from 2009 to 2019.

3.3. Variable measurement

3.3.1. Explained variable

Refer to existing relevant studies (Bhattacharya *et al*., 2020; Yi *et al*., 2022), this paper uses carbon emission intensity (*Cei*), measured as the proportion of total carbon emissions to GDP (in 2017 constant U.S. dollars), to measure a country's carbon emission level. As shown in **Figure 3**, the total carbon emissions in the BRI increase from 16.31 billion tons in 2009 to 21.825 billion tons in 2019, representing a 33.81% growth. However, carbon emission intensity has shown a significant declining trend since 2012, with an overall decrease of 14.01%. **Figure 4** illustrates the spatial distribution of total carbon emissions and carbon emission intensity along the BRI. This distribution indicates that both total carbon emissions and carbon emission intensity exhibit notable spatial variations across the BRI countries.

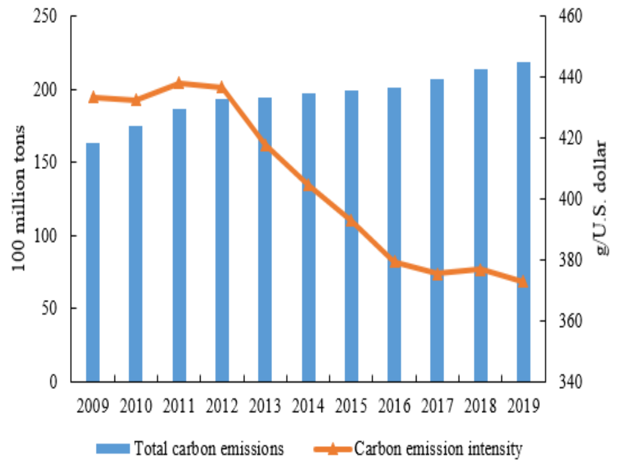


Figure 3. Evolution trends of total carbon emissions and carbon emission intensity along the BRI

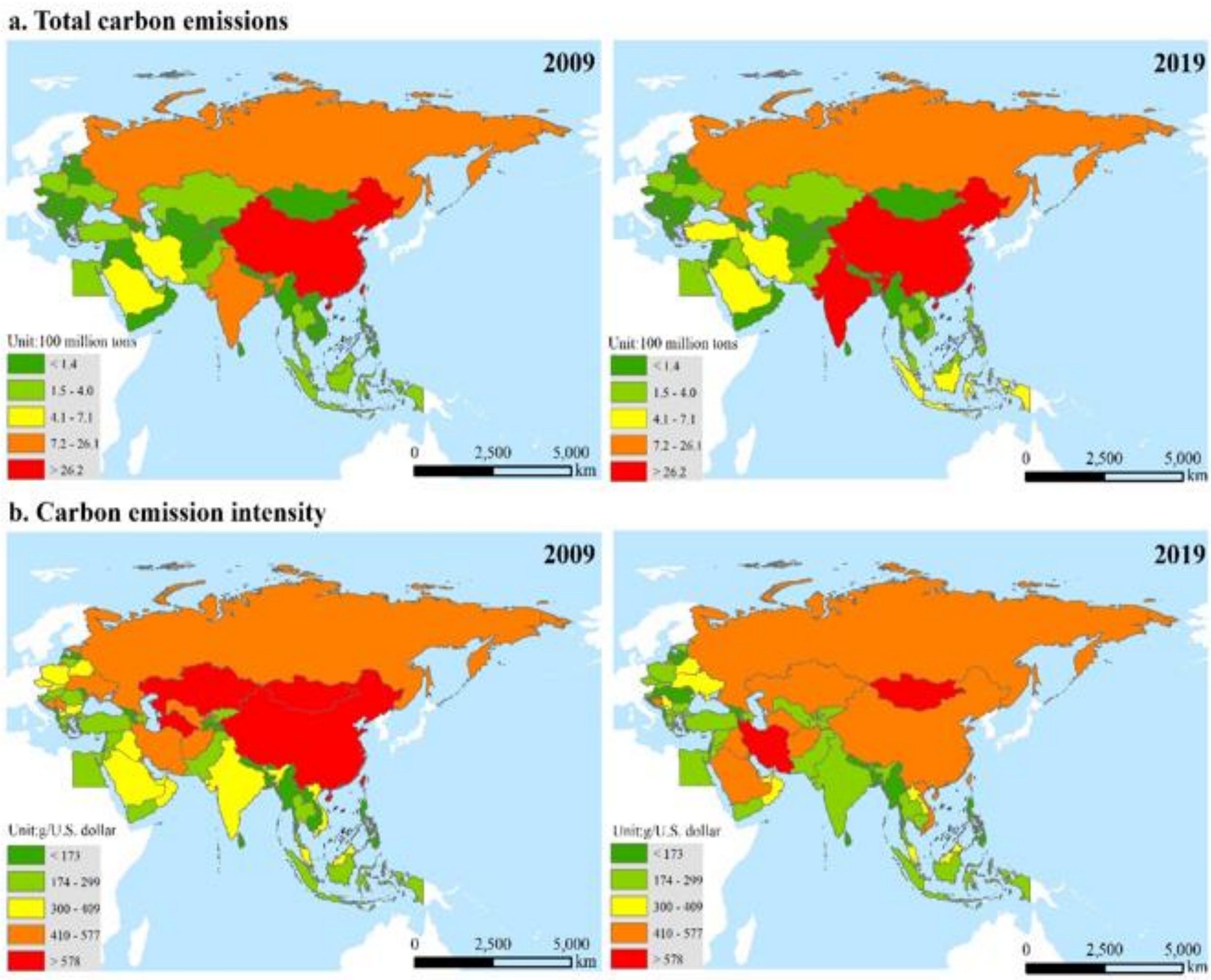


Figure 4. Spatial distributions of total carbon emissions and carbon emission intensity along the BRI

Table 2. The input-output index system of the GML

System	Subsystem	Index	Source
Input	Labor input	Total larbor (Million people)	World Bank
	Capital input	Capital stock (U.S. $10 billion at constant 2017 price)	PWT 10.01
Output		GDP (U.S. $10 billion at constant 2017 price)	PWT 10.01

Table 3. Descriptive statistics

Variables	Units	Obs	Mean	Max	Min	Std. Dev.
Cei	g/U.S. $	726	298.138	1583.145	64.277	174.762
Int	%	726	5.888	76.027	0.075	8.856
Edl	U.S. $	726	20900.640	120748.400	488.300	19653.788
Pz	Million people	726	68.880	1410.000	0.353	228.707
Ul	%	726	58.836	100.000	16.434	20.672
Fd	-	682	0.330	0.760	0.070	0.159
Hc	-	726	2.706	4.352	1.388	0.609
Is	-	726	2.437	10.738	0.332	1.548
Er	-	726	57.619	88.980	21.570	12.963
Ti·	-	726	0.663	1.000	0.081	0.226

Table 4. Coefficient matrix and VIF of main explanatory variables

	ln*Int*	(ln*Int*)^2	ln*Edl*	ln*Pz*	ln*UL*	ln*Fd*	ln*Fd*	VIF
ln*Int*	1.000							2.70
(ln*Int*)^2	0.722***	1.000						2.31
ln*Edl*	0.265***	0.051	1.000					4.59
ln*Pz*	-0.557***	-0.413***	-0.391***	1.000				2.67
ln*Ul*	0.136***	-0.018	0.783***	-0.285***	1.000			3.13
ln*Fd*	0.056	-0.010	0.627***	0.1420***	0.598***	1.000		2.87
ln*Hc*	0.268***	0.012	0.587***	-0.249***	0.560***	0.437***	1.000	1.61

*Note: *, ** and *** indicate that statistics are significant at the 10%, 5% and 1% level of significance, respective.*

3.3.2. Core explanatory variable

Drawing on existing research (Wang *et al*., 2022b; Dandy and Zhao, 2023), this paper measures *Int* using the proportion of inbound tourism revenue to GDP. A higher value of the indicator signifies a more advanced level of inbound tourism and a higher degree of tourism openness in the country.

3.3.3. Mediating variables

Based on the indirect impact analyzed above, inbound tourism can suppress the growth of carbon emissions through three mediating variables: Industrial structure, environmental regulatory, and technological innovation. (1) Industrial structure (*Is*), expressed as the proportion of the value added by the tertiary sector to that of the secondary sector. (2) Environmental regulatory (*Er*), expressed as the Environmental Performance Index (EPI), a joint publication from Yale and Columbia universities. The EPI includes two dimensions: environmental health and ecosystem vitality. The former reflects the impact of environmental stress on human health, while the latter measures the level of ecosystem health and management of natural resources. (3) Technological innovation (*Ti*), expressed as the total factor productivity (TFP). Following the methodology of Oh (2010), this paper employs a global Malmquist-Luenberger (GML) productivity index with a directional distance function to measure the TFP of countries along the BRI. **Table 2** shows the input-output indicators for the GML.

3.3.4. Control variables

In this paper, we draw on relevant studies (Haini, 2021; Ren *et al*., 2023; Zhou *et al*., 2024) to establish a set of control variables, which cover economic development level, population size, urbanization level, financial development, and human capital. (1) Economic development level (*Edl*), expressed as the per capita GDP (in 2017 constant U.S. $). (2) Population size (*Pz*), expressed as the total population. (3) Urbanization level (*Ul*), expressed as the proportion of urban population to the total population; (4) Financial development (*Fd*), expressed as the financial development index released by the IMF, which summarizes the development of financial institutions and markets in various countries. (5) Human capital (*Hc*), expressed as the human capital index published by the PWT 10.01, which is calculated based on years of education and education return rate. Table 3 provides a summary of the descriptive statistics of all variables.

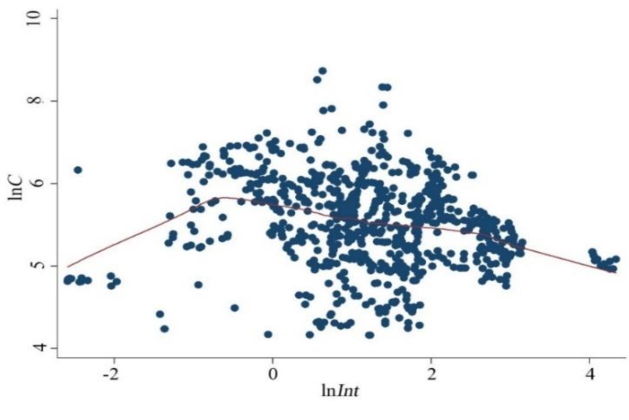


Figure 5. Scatter diagram of inbound tourism and carbon emissions

4. Results analysis

4.1. Variable correlation and relational form test

Table 4 displays the correlation outcomes among the variables. The correlation coefficients of all independent variables are relatively low, none surpassing the threshold of 0.8, which suggests that there are no substantial multicollinearity concerns. The variance inflation factors (VIF) of the independent variables are measured, and the results show a maximum VIF of 4.59, minimum VIF of

1.61, and mean of only 2.84. Overall, the control variables selected in this paper have a certain degree of rationality.

Before using the econometric regression models to explore the impact of inbound tourism on carbon emissions, we plot a scatter diagram of the relationship to verify the rationality of the model setup. As depicted in **Figure 5**, a nonlinear relationship may exist between inbound tourism and carbon emissions, preliminarily validating the Hypothesis 1 and the usability and rationality of the baseline model.

Table 5. Baseline regression results

Variables	FE			SYS-GMM
	(1)	(2)	(3)	(4)
ln*Int*	0.045**	0.055**	0.055**	0.113***
	(2.03)	(2.50)	(2.50)	(5.79)
(ln*Int*)^2	-0.037***	-0.024**	-0.024**	-0.027*
	(-3.83)	(-2.45)	(-2.45)	(-1.91)
lnC_{t-1}				0.448***
				(9.21)
ln*Edl*	-0.189***	-0.077	-0.077	-0.146**
	(-3.45)	(-1.33)	(-1.33)	(-2.43)
ln*Pz*	0.270**	0.440***	0.440***	0.021
	(2.45)	(3.93)	(3.93)	(0.07)
ln*Ul*	1.937***	2.436***	2.436***	3.177***
	(7.72)	(9.34)	(9.34)	(5.38)
ln*Fd*	0.368***	0.312***	0.312***	0.004
	(5.83)	(4.91)	(4.91)	(0.04)
ln*Hc*	-1.344***	-0.815***	-0.815***	-0.574***
	(-7.50)	(-4.12)	(-4.12)	(-3.06)
Constant	0.772	-3.286***	-3.286***	-7.777***
	(0.88)	(-2.93)	(-2.93)	(-3.62)
Country-FE	Yes	No	Yes	Yes
Time-FE	No	Yes	Yes	Yes
AR(1)				-2.310**
				[0.02]
AR(2)				-1.530
				[0.13]
Hansen				34.330
				[0.93]
R^2	0.200	0.248	0.248	

*Note: *, ** and *** indicate that statistics are significant at the 10%, 5% and 1% level of significance, respective. The figures in () are t statistics, and in [] are P statistics of AR(1) , AR(2), and Hansen.*

4.2. Baseline regression results

The baseline regression results are reported using both fixed effects (FE) and SYS-GMM estimates (Table 5). The first three Columns consider the country-FE, time-FE, and double-FE. The regression coefficient of ln*Int* is significantly positive, and that of (ln*Int*)^2 is significantly negative. These results indicate that the impact of inbound tourism on carbon emissions follows an inverted U-shaped curve relationship. When the inbound tourism level is low, it significantly increases carbon emissions; however, when the inbound tourism level exceeds a critical value (the proportion of inbound tourism revenue to GDP is 3.145%), the inhibitory effect of inbound tourism on carbon emissions gradually strengthens. Therefore, Hypothesis 1 is supported.

In terms of the control variables, the regression coefficient for economic development is not obvious. Specifically, the regression coefficients for population size and financial development are both significantly positive, suggesting that promoting population growth and financial development will increase carbon emissions. The regression coefficient for urbanization level is also significantly positive, thereby indicating that urbanization is not conducive to reducing carbon emissions. The reason may be that most of the countries along the BRI are still in the primary stage of urbanization development, and the urban economic development is dominated by the secondary industry, with high energy consumption, high pollution and high emission industries in the majority. By contrast, the regression coefficient for human capital is significantly negative, indicating that the enhancement of human capital can help restrain carbon emissions.

Column (4) provides the SYS-GMM estimation results. According to the test criteria of Hansen (1982) and Arellano and Bond (1991), the AR(1) test is significant, whereas the AR(2) and Hansen tests are not, indicating that the SYS-GMM is valid. Furthermore, the coefficient of lnC_{t-1} is 0.448 and significant at the 1% level, suggesting a "carbon lock-in" effect in the BRI countries. This finding aligns with the conclusions of Wu *et al*. (2021) and Khan *et al*. (2024) regarding carbon emissions in the BRI. Moreover, the coefficient of ln*Int* is significantly negative, and its quadratic term is significantly positive. This result further corroborates Hypothesis 1.

4.3. Robustness tests

4.3.1. Replace the variables

In this paper, per capita carbon emissions and the proportion of inbound tourism arrivals to the total population are used to replace the explained and core explanatory variables, respectively. Columns (1) and (2) of **Table 6** presents the results. Both ln*Int* and (ln*Int*)^2 pass the significance test at the 5% level, further supporting Hypothesis 1.

Table 6. Replacing variables results

Variables	(1)	(2)
ln*Int*	0.054**	0.089**
	(2.50)	(2.19)
(ln*Int*)^2	-0.024**	-0.016***
	(-2.45)	(-2.74)
Constant	-17.102***	-3.559***
	(-15.25)	(-2.91)
Control variables	Yes	Yes
Country-FE	Yes	Yes
Time-FE	Yes	Yes
R^2	0.553	0.260

*Note: *, ** and *** indicate that statistics are significant at the 10%, 5% and 1% level of significance, respective. The figures in () are t statistics.*

Table 7. Threshold effect test results

Test parameter	Threshold	Fstat	Prob	Crit10	Crit5	Crit1
ln*Int*	Single	41.190	0.093	39.793	49.410	85.118
	Double	14.500	0.583	39.057	50.178	99.545

Table 8. Threshold regression results

Variables	Coefficients	Variables	Coefficients
ln*Int*＜-0.900	0.201***	ln*Int* ≥ -0.900	-0.062***
	(5.35)		(-2.91)
Constant	0.205		
	(0.24)		
Control variables	Yes		
Country-FE	Yes		
Time-FE	Yes		
R^2	0.228		

*Note: *, ** and *** indicate that statistics are significant at the 10%, 5% and 1% level of significance, respective. The figures in () are t statistics.*

4.3.2. Change the model

Before using the panel threshold model for the estimation, we adopt the bootstrap method with 300 automatic resamples to ascertain the asymptotic distribution of the F-value and construct the corresponding p-value. The results are summarized in **Table 7**. The single threshold for inbound tourism is found to be significant at the 10% level, yet it does not meet the criteria for a double threshold. This suggests that the appropriate number of thresholds for inbound tourism should be set to 1.

After determining the number of thresholds, we continue to estimate the influence of inbound tourism on carbon emissions, with the findings detailed in **Table 8**. When ln*Int* is less than -0.900, which corresponds to *Int* being less than 0.407, the effect of inbound tourism on carbon emissions is significantly positive at the 1% level. Conversely, when *Int* is greater than 0.407, the effect becomes significantly negative at the 1% level. These outcomes reinforce the validity of Hypothesis 1.

4.3.3. Instrumental variable method

To address potential endogeneity concerns within the baseline regression model, this paper employs the air connectivity index in 2007 (Arvis and Shepherd, 2011) as an instrumental variable (IV) for endogeneity discussion. There are two main reasons for this. On the one hand, air connectivity index is an important metric for measuring the connectivity of air transport network. The higher the index, the more convenient the flights and the denser the routes in that country, which attracts more inbound tourists. On the other hand, the impact air connectivity index in 2007 on current carbon emissions is relatively small, meeting the requirement of exogeneity. It should be noted that IV is cross-sectional data, and time-series data must be chosen as an interaction term with the cross-sectional data to be appropriate for the panel data in this paper. In specific application, we construct the logarithm of the interaction term between the air connectivity index in 2007 and inbound tourism level in the previous year as IV. **Table 9** reports the endogeneity regression results. Specifically, Column (1) shows the impact of IV and its quadratic term on inbound tourism, indicating a linear relationship between the two. Column (2) shows the impact of IV and its quadratic term on quadratic term of inbound tourism, indicating a U-shaped relationship between the two. In Column (3), the Kleibergen-Paap rk LM test passes the significance test at the 1% level, and the Cragg-Donald Wald F statistic is far greater than the critical value, indicating that the IV passes the identification and weak IV tests and that the constructed IV is valid. Additionally, ln*Int* and $(\ln Int)^2$ pass the significance test at the 1% level. The above analysis suggests that after addressing potential endogeneity issues, the conclusion of an inverted U-shaped relationship between inbound tourism and carbon emissions remains valid.

Table 9. Instrumental variable test

Variables	(1)	(2)	(3)
IV	0.615***	-1.364***	
	(4.32)	(-8.77)	
IV^2	0.010	0.625***	
	(0.41)	(17.75)	
ln*Int*			0.116**
			(2.58)
$(\ln Int)^2$			-0.042***
			(-2.94)
Constant	3.823**	6.552	-3.601*
	(2.19)	(1.62)	(-1.87)
Control variables	Yes	Yes	Yes
Country-FE	Yes	Yes	Yes
Time-FE	Yes	Yes	Yes
Kleibergen-Paap rk LM statistic	27.61		
	[0.00]		
Cragg-Donald Wald F statistic	233.081		
	{7.03}		
R^2	0.976	0.986	0.943

*Note: *, ** and *** indicate that statistics are significant at the 10%, 5% and 1% level of significance, respective. The figures in () are t statistics, and in [] is P statistic of Kleibergen-Paap rk LM. The figure in {} is the critical value at the 10% level of Stock-Yogo weak instrumental variable identification test.*

4.4. Intermediary mechanism tests

Table 10 presents the empirical results for the three mechanisms. Column (1) shows the impact of inbound tourism on industrial structure. The regression coefficients of ln*Int* and $(\ln Int)^2$ are both significantly positive, indicating that inbound tourism has a positive effect on promoting related service industries, such as transportation, accommodation, catering, and business logistics, and is conducive to optimizing and upgrading the national industrial structure. Compared with that of ln*Int*, the significance (p-value < 0.01) of $(\ln Int)^2$ is more pronounced, suggesting that after inbound tourism reaches a certain scale, its promotional effect on industrial structure upgrading increases. Columns (3) and (5) represent the impact of inbound tourism on environmental regulatory and technological innovation, respectively. The regression coefficients of ln*Int* and $(\ln Int)^2$ are negative and positive, respectively, and they pass the significance test at the 1% level, indicating the U-shaped nonlinear effect of inbound tourism on environmental regulatory and technological innovation. Columns (2), (4), and (6) present the regression results of incorporating industrial structure, environmental regulatory, and technological innovation, respectively, into Equation (4). The regression coefficients of ln*Is*, ln*Er*, and ln*Ti* are all significantly negative, indicating that these factors play an intermediary role in the process of inbound tourism affecting carbon emissions. Therefore, Hypotheses 2-4 are supported.

4.5. Heterogeneity analysis

This paper investigates the heterogeneous differences based on the geographical locations and economic development levels of countries along the BRI (Table 11). Initially, geographical locations are categorized according to whether a country is landlocked or coastal, with the results shown in Columns (1) and (2). Inbound tourism has a significant nonlinear influence on carbon emissions in coastal countries, whereas it has no significant impact in inland countries. Possible reasons include the fact that compared with coastal countries, landlocked countries are constrained by geographical environments and lagging transportation infrastructure, both of which raise the difficulty and cost for international tourists to reach these destinations. By contrast, some coastal countries that benefit from favorable geographic locations actively improve their transportation conditions, enhance the accessibility of tourist attractions, and bolster support services to cater to the diverse preferences of international tourists. Consequently, coastal countries are becoming more closely integrated with inbound tourism and socio-economic development, resulting in a heightened influence on carbon emissions.

Table 10. Mechanism tests

Variables	ln*Is*		ln*Er*		ln*Ti*	
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
ln*Is*		-0.146***				
		(-3.47)				
ln*Er*				-0.332***		
				(-5.80)		
ln*Ti*						-0.169**
						(-2.34)
ln*Int*	0.036*	0.060***	-0.053***	0.037*	-0.090***	0.039*
	(1.73)	(2.76)	(-3.50)	(1.72)	(-7.38)	(1.72)
(ln*Int*)^2	0.035***	-0.019*	0.020***	-0.017*	0.029***	-0.019*
	(3.70)	(-1.93)	(2.97)	(-1.80)	(5.34)	(-1.91)
Constant	1.541	-3.062***	11.207***	-17.987	-2.992***	-3.792***
	(1.43)	(-2.75)	(-14.43)	(-14.20)	(-4.76)	(-3.33)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Country-FE	Yes	Yes	Yes	Yes	Yes	Yes
Time-FE	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.304	0.262	0.635	0.288	0.652	0.254

*Note: *, ** and *** indicate that statistics are significant at the 10%, 5% and 1% level of significance, respective. The figures in () are t statistics.*

Table 11. Heterogeneity analysis results

Variables	Geographical conditions		Economic development levels	
	(1)	**(2)**	**(3)**	**(4)**
ln*Int*	-0.059	0.098***	-0.034	0.076***
	(-0.77)	(5.63)	(-0.84)	(2.96)
(ln*Int*)^2	-0.007	-0.019**	0.009	-0.018**
	(-0.19)	(-2.60)	(0.39)	(-2.03)
Constant	-19.474***	2.921***	-2.693	7.545***
	(-6.85)	(3.06)	(-1.40)	(5.98)
Control variables	Yes	Yes	Yes	Yes
Country-FE	Yes	Yes	Yes	Yes
Time-FE	Yes	Yes	Yes	Yes
R^2	0.532	0.296	0.443	0.482

*Note: *, ** and *** indicate that statistics are significant at the 10%, 5% and 1% level of significance, respective. The figures in () are t statistics.*

In addition, economic development levels may also influence the carbon reduction effect of inbound tourism. Based on the World Bank's 2023 classification standard, the samples are divided into lower-middle and low-income countries, and upper-middle and high-income countries for grouped analysis, with the results shown in Columns (3) and (4). Inbound tourism has a significant inverted U-shaped influence on carbon emissions in upper-middle and high-income countries, but it has no substantial impact in lower-middle and low-income countries. Possible reasons include the fact that countries with higher economic development levels are more capable of seizing the opportunities presented by the growth of inbound tourism. During the development of inbound tourism, these countries continuously drive the low-carbon transformation of their industrial structures, promote the enhancement of human capital, and foster advancements in technological innovation. Consequently, the carbon emission reduction effect of inbound tourism becomes increasingly pronounced.

4.6. Spillover effect analysis

When conducting the SDM analysis, it is essential to examine the spatial correlation between inbound tourism and carbon emissions. In this paper, the Stata software is used to compute the Global Moran's I for both variables, employing the following formula:

$$\text{Global Moran's I} = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}\left(x_i-\overline{x}\right)\left(x_j-\overline{x}\right)}{\left(\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}\right)\sum_{i=1}^{n}\left(x_i-\overline{x}\right)^2} \quad (8)$$

In equation (8): x_i represents the inbound tourism level or carbon emission level of country *i*; *n* denotes the number of countries, which is 66; W_{ij} represents the spatial weight matrix, consistent with the previous text; $\bar{x}$ stands for the average level of inbound tourism or carbon emissions among the BRI countries.

Table 12 shows the Global Moran's I values for both inbound tourism and carbon emissions under W_1 and W_2. Overall, both inbound tourism and carbon emissions have evidence spatial agglomeration characteristics, and the significance in W_1 is better than in W_2. Therefore, when studying the relationship between inbound tourism and carbon emissions, spatial factors cannot be ignored.

Table 12. Spatial correlation test

Year	W_1		W_2	
	ln*Int*	ln*C*	ln*Int*	ln*C*
2009	0.266***	0.119*	0.035**	0.048***
2010	0.244***	0.141**	0.041**	0.043**
2011	0.244***	0.132**	0.043**	0.030**
2012	0.215***	0.133**	0.043**	0.028**
2013	0.213***	0.117*	0.038**	0.018*
2014	0.241***	0.138**	0.039**	0.011
2015	0.264***	0.130**	0.039**	0.015
2016	0.262***	0.129**	0.040**	0.005
2017	0.309***	0.145**	0.041**	0.001
2018	0.303***	0.174**	0.036**	0.000
2019	0.285***	0.183***	0.022*	-0.003

*Note: *, ** and *** indicate that statistics are significant at the 10%, 5% and 1% level of significance, respective.*

Table 13. Identification test of the SDM

	SAR			SEM		
	LM lag	Robust LM lag	Wald test lag	LM error	Robust LM error	Wald test error
W_1	47.128***	34.125***	115.100***	62.410***	49.407***	28.020***
W_2	28.642***	28.162***	120.230***	0.642	0.212	148.57***

*Note: *, ** and *** indicate that statistics are significant at the 10%, 5% and 1% level of significance, respective.*

Table 14. Regression results of the SDM

Variables	W_1		W_2
	SDM	SDM	SEM
ρ		0.310***	0.231**
		(98.64)	(2.18)
λ			0.237***
			(2.71)
ln*Int*	0.052**	0.037**	0.045**
	(2.54)	(2.23)	(2.47)
(ln*Int*)^2	-0.034***	-0.031***	-0.033***
	(-3.67)	(-4.05)	(-4.03)
*W*ln*Int*	-0.056***	0.315***	
	(-4.87)	(4.61)	
*W*ln*Int*^{2}	0.025***	-0.164***	
	(5.23)	(-4.92)	
Control variables	Yes	Yes	Yes
Country-FE	Yes	Yes	Yes
Time-FE	Yes	Yes	Yes
R^2	0.075	0.331	0.190
ln*Int* (Direct effect)	0.097***	0.042**	
	(3.54)	(2.43)	
ln*Int* (Spillover effect)	0.252***	0.416***	
	(3.22)	(4.31)	
(ln*Int*)^2 (Direct effect)	-0.051***	-0.033***	
	(-4.58)	(-4.41)	
(ln*Int*)^2 (Spillover effect)	-0.095***	-0.217***	
	(-2.79)	(-4.41)	

*Note: *, ** and *** indicate that statistics are significant at the 10%, 5% and 1% level of significance, respective. The figures in () are z statistics.*

Prior to engaging in spatial regression analysis, this paper employs the LM and Wald tests to ascertain the suitability of the SDM over the spatial autoregressive (SAR) model and the spatial error model (SEM). As shown in **Table 13**, choosing SDM under W_1 is the most appropriate. However, the LM and Wald test results under W_2 are contradictory, so choosing SDM and SEM is acceptable.

Table 14 presents the estimation results of the spatial effect of inbound tourism on carbon emissions. Whether choosing W_1 or W_2, ln*Int* and $(lnInt)^2$ both pass the 5% significance test, demonstrating the robustness of Hypothesis 1. This paper further employs partial derivatives to analyze the spatial effect. The direct coefficients of ln*Int* and $(lnInt)^2$ on carbon emissions are positive and negative, respectively, and both are significant at the 5% level, indicating the inverted U-shaped impact of inbound tourism on domestic carbon emissions. The estimated coefficients for the spillover effect are also significant at the 1% level, suggesting the inverted U-shaped impact of inbound tourism on carbon emissions in neighboring countries, with a notable spatial spillover effect. This result indicates that in the early stages of inbound tourism development, neighboring countries primarily experience negative externalities in the form of competitive effect. However, as inbound tourism matures and technological spillovers occur, neighboring countries gradually benefit from demonstration and mobility effects. Thus, Hypothesis 5 is supported.

4.7. Double machine learning analysis

Based on traditional causal reasoning models, the previous section verifies the nonlinear impact of inbound tourism on carbon emissions. However, the numerous limitations and flaws of traditional models may compromise the accuracy of conclusions. By integrating traditional regression models with modern machine learning techniques, the DML approach enhances the precision of estimating causal relationships (Chernozhukov *et al*., 2018). Its advantages are as follows: Firstly, DML can adapt to more complex nonlinear relationships, thereby providing a reliable basis for the estimation of causal effects. Secondly, it can handle high-dimensional control variables; hence, it not only mitigates issues such as multicollinearity but also alleviates the estimation bias resulting from limited control variables. The constructed DML model is as follows:

$$\ln C_{it+1} = \theta_0 \ln Int_{it} + \pi_0 \left(\ln Int_{it}\right)^2 + \varphi\left(X_{it}\right) + U_{it} \quad (9)$$

$$E\left(U_{it} \mid \ln Int_{it}, X_{it}\right) = 0 \quad (10)$$

In Equation (9) and (10): θ_0, π_0 are the regression coefficients of primary interest. If both are significantly positive, it further supports Hypothesis 1; Consistent with the previous setup, X_{it} denotes the control variables, and their specific form is estimated using machine learning algorithms; U_{it} is the error term.

If estimates are made directly on Equation (9) and (10), θ_0 may be biased. To address the issue of convergence difficulty in machine learning methods, this paper further constructs auxiliary regression models as follows:

$$\ln Int_{it} = m\left(X_{it}\right) + V_{it} \quad (11)$$

$$E\left(V_{it} \mid X_{it}\right) = 0 \quad (12)$$

In equation (11) and (12): $m(X_{it})$ denotes the regression function of the high-dimensional control variables needs to be estimated through machine learning algorithms, and V_{it} is the error term.

This paper selects the lasso and gradient boosting models as the estimation models within the DML framework. The number of cross-validation folds (k) is set to 5. For the control variables, to maintain consistency, the same five variables as in the previous section are selected, and their quadratic terms are included to capture the nonlinear relationships among the variables. As shown in **Table 15**, Columns (1) and (3) only consider the control variables, while Columns (2) and (4) also consider their quadratic terms. The results show that regardless of whether the lasso model or gradient boosting model is used and whether the quadratic terms of control variables are included, Hypothesis 1 is robust.

Table 15. Regression results of the DML

Variables	Lasso model		Gradient boosting model	
	(1)	(2)	(3)	(4)
ln*Int*	0.074***	0.063***	0.060**	0.055*
	(3.65)	(3.20)	(2.01)	(1.85)
$(\ln Int)^2$	-0.028***	-0.025***	-0.068***	-0.066***
	(-2.98)	(-2.72)	(-5.73)	(-5.62)
Constant	-0.001	-0.001	0.003	0.000
	(-0.22)	(-0.21)	(0.40)	(0.05)
Control variables	Yes	Yes	Yes	Yes
Control variables with quadratic terms	No	Yes	No	Yes
Country-FE	Yes	Yes	Yes	Yes
Time-FE	Yes	Yes	Yes	Yes

*Note: *, ** and *** indicate that statistics are significant at the 10%, 5% and 1% level of significance, respective. The figures in () are z statistics.*

5. Conclusions and policy recommendations

The nonlinear impact, mediating mechanism, and spatial spillover effect of inbound tourism on carbon emissions in the BRI countries are empirically investigated in this study. The main results can be summarized as follows: (1) From 2009 to 2019, the total carbon emissions show an upward trend, while carbon emission intensity tends to decline, with a decrease of 14.01%. In addition, they all exhibit distinct differentiation characteristics. (2) Overall, inbound tourism exerts a complex influence on carbon emissions, following an inverted U-shaped curve. This finding remains robust after replacing the dependent and core independent variables and applying the panel threshold, IV, and DML models. (3) Industrial structure, environmental regulatory, and technological innovation play partial mediating roles in the carbon-reducing effect of inbound tourism. Furthermore, inbound tourism exhibits an U-shaped influence on environmental regulatory and technological innovation. (4) Compared with the landlocked countries and lower-middle and low-income countries, Inbound tourism has a more significant impact on carbon emissions in coastal countries and upper-middle and high-income countries. (5) Spatially, inbound tourism exerts a notable impact on carbon emissions of neighboring countries.

Drawing from the empirical results, we put forward relevant policy insights:

(1). Accelerate the transition to low-carbon tourism. On one hand, efforts should be made to advance the green transformation of tourism-related industries (such as hotels, transportation, and catering), encouraging the adoption of clean energy and low-carbon technologies. On the other hand, new tourism formats such as ecotourism and cultural tourism should be developed, shifting toward intensive, high-quality, and innovative models to reduce reliance on high-energy-consumption tourism practices.

(2). Implement differentiated regional tourism development strategies. For coastal countries and upper-middle and high-income countries, where inbound tourism has a significant impact on carbon emissions, it is essential to continue strengthening environmental regulations. Measures such as introducing tourism carbon taxes and establishing low-carbon tourism certification systems should be implemented to effectively enhance the high-quality service standards of inbound tourism. For landlocked countries and lower-middle and low-income countries, where inbound tourism does not significantly affect carbon emissions, the focus should be on capacity building and technical support. This includes investments in green tourism infrastructure and the promotion of ecotourism models to prevent these countries from falling into a "high-carbon lock-in" effect due to tourism expansion.

(3). Establish a cross-border collaborative carbon emission monitoring mechanism for tourism. On one hand, the Belt and Road Green Tourism Alliance should be established to facilitate real-time data sharing and coordinated supervision of major emission sources such as transportation and accommodation. On the other hand, a cross-border green technology innovation fund should be created to support the research, development, and application of low-carbon tourism technologies, as well as to facilitate technology sharing.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors have no conflicts of interest to declare.

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References

Adjei-Mantey K., Adusah-Poku F. and Kwakwa P.A. (2023). International tourism, exchange rate, and renewable energy: Do they boost or burden efforts towards a low carbon economy in selected African countries? *Cogent Economics & Finance*, **11**(2), 2245258. https://doi.org/10.1080/23322039.2023.2245258.

Ahmad N. and Ma X. (2022). How does tourism development affect environmental pollution? *Tourism Economics*, **28**(6), 1453–1479. https://doi.org/ 10.1177/13548166211000480.

Allan G., Connolly K., Figus G. and Maurya A. (2022). Economic impacts of COVID-19 on inbound and domestic tourism. *Annals of Tourism Research Empirical Insights*, **3**(2), 100075. https://doi.org/10.1016/j.annale.2022.100075.

Arellano M. and Bond S. (1991). Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations. *Review of Economic Studies*, **58**(2), 277–297. https://doi.org/10.2307/2297968.

Arvis J.F. and Shepherd B. (2011). The Air Connectivity Index: Measuring Integration in the Global Air Transport Network (No. WPS 5722). *Policy Research Working Paper*. The World Bank. https://doi.org/10.1596/1813–9450-5722.

Awan A., Alnour M., Jahanger A. and Onwe J. (2022). Do technological innovation and urbanization mitigate carbon dioxide emissions from the transport sector? *Technology in Society*, **71**, 102128. https://doi.org/10.1016/j.techsoc.2022.102128.

Baron P.M. and Kenny D.A. (1986). The moderator-mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology*, **51**(6), 1173–1182. https://doi.org/10.1037//0022-3514.51.6.1173.

Bhattacharya M., Inekwe J.N. and Sadorsky P. (2020). Consumption-based and territory-based carbon emission intensity: Determinants and forecasting using club convergence across countries. *Energy Economics*, **86**, 104632. https://doi.org/10.1016/j.eneco.2019.104632.

Bilynets I. and Cvelbar L.K. (2022). Tourist pro-environmental behaviour: The role of environmental image of destination and daily behaviour. *Annals of Tourism Research Empirical Insights*, **3**(2), 100070. https://doi.org/10.1016/j.annale.2022.100070.

Chernozhukov V., Chetverikov D., Demirer M., Duflo E., Hansen C., Newey W. and Robins J. (2018). Double/debiased machine learning for treatment and structural parameters.

The Econometrics Journal, **21**(1), 1–68. https://doi.org/10.1111/ectj.12097.

Chen J., Cui F., Balezentis T., Streimikiene D. and Jin H. (2021). What drives international tourism development in the Belt and Road Initiative? *Journal of Destination Marketing & Management*, **19**, 100544. https://doi.org/10.1016/j.jdmm.2020.100544.

Cheng C., Ren X., Dong K., Dong X. and Wang Z. (2021). How does technological innovation mitigate CO_2 emissions in OECD countries? Heterogeneous analysis using panel quantile regression. *Journal of Environmental Management*, **280**, 111818. https://doi.org/10.1016/j.jenvman.2020.111818.

Chiu Y.B., Zhang W. and Ding, K. (2021). Does Globalization Influence Inbound Tourism? Evidence from a Dynamic Panel Threshold Analysis. *Journal of Travel Research*, **60**(5), 1074–1084. https://doi.org/10.1177/0047287520919514.

Dandy B. and Zhao Y. (2023). The relationship between inbound tourism and economic growth: Case of Botswana. *Natural Resources Forum*, **48**(1), 16–34. https://doi.org/10.1111/1477–8947.12290.

Dong H., Tao M., Wen L., Poletti S. and Sheng M.S. (2024). Does natural resource dependence restrict green development? An investigation from the Belt and road countries. *Environmental Research*, **255**, 119108. https://doi.org/10.1016/j.envres.2024.119108.

Ehigiamusoe K.U. (2020). Tourism, growth and environment: analysis of non-linear and moderating effects. *Journal of Sustainable Tourism*, **28**(8), 1174–1192. https://doi.org/10.1080/09669582.2020.1729164.

Elgin C. and Elveren A.Y. (2024). Unpacking the economic impact of tourism: A multidimensional approach to sustainable development. *Journal of Cleaner Production*, **478**, 143947. https://doi.org/10.1016/j.jclepro.2024.143947.

Erdogan S. (2021). Dynamic Nexus between Technological Innovation and Building Sector Carbon Emissions in the BRICS Countries. *Journal of Environmental Management*, **293**, 112780. https://doi.org/10.1016/j.jenvman.2021.112780.

Eyuboglu K. and Uzar U. (2020). The impact of tourism on CO_2 emissions in Turkey. *Current Issues in Tourism*, **23**(13), 1631–1645. https://doi.org/10.1080/13683500.2019.1636006.

Gedikli A., Erdoğan S., Çevik E.I, Çevik E., Castanho R.A. and Couto G. (2022). Dynamic relationship between international tourism, economic growth and environmental pollution in the OECD countries: evidence from panel VAR model. *Economic Research-Ekonomska Istraživanja*, **35**(1), 5907–5923. https://doi.org/10.1080/1331677X.2022.2041063.

Geng Y., Wang R., Wei Z. and Zhai Q. (2021). Temporal-spatial measurement and prediction between air environment and inbound tourism: Case of China. *Journal of Cleaner Production*, **287**, 125486. https://doi.org/10.1016/j.jclepro.2020.125486.

Hansen L.P. (1982). Large Sample Properties of Generalized Method of Moments Estimators. *Econometrica*, **50**(4), 1029–1054. https://www.jstor.org/stable/1912775.

Haini H. (2021). Examining the impact of ICT, human capital and carbon emissions: Evidence from the ASEAN economies. *International Economics*, **166**, 116–125. https://doi.org/10.1016/j.inteco.2021.03.003.

Huang Y. (2016). Understanding China's Belt & Road Initiative: Motivation, framework and assessment. *China Economic Review*, **40**, 314–321. https://doi.org/10.1016/j.chieco.2016.07.007.

Jebli M.B., Youssef S.B. and Apergis, N. (2019). The dynamic linkage between renewable energy, tourism, CO_2 emissions, economic growth, foreign direct investment, and trade. *Latin American Economic Review*, **28**, 1–19. https://doi.org/10.1186/s40503-019-0063-7.

Khan I., Zhong R., Khan H., Dong Y. and Nuţă F.M. (2024). Examining the relationship between technological innovation, economic growth and carbon dioxide emission: dynamic panel data evidence. *Environment, Development and Sustainability*, **26**, 18161–18180. https://doi.org/10.1007/s10668-023-03384-w.

Lagos K. and Wang Y. (2023). International Tourism and Poverty Alleviation: Cross-Country Evidence Using Panel Quantile Fixed Effects Approach. *Journal of Travel Research*, **62**(6), 1347–1371. https://doi.org/10.1177/00472875221119978.

Le T.H. and Nguyen C.P. (2021). The impact of tourism on carbon dioxide emissions: insights from 95 countries. *Applied Economics*, **53**(2), 235–261. https://doi.org/10.1080/00036846.2020.1804051.

Lenzen M., Sun Y.Y., Faturay F., Ting Y.P., Geschke A. and Malik A. (2018). The carbon footprint of global tourism. *Natural Climate Change*, **8**, 522–528. https://doi.org/10.1038/s41558-018-0141-x.

LeSage J. and Pace P.K. (2009). Introduction to spatial Econometric. CRC Press, New York. https://doi.org/10.1201/9781420064254.

Li X., Meo M.S., Aziz N., Aziz M., Arain H. and Ferraz D. (2022a). Effects of inbound Tourism on the Ecological Footprint. An Application of an Innovative Dynamic Panel Threshold Model. *Frontiers in Environmental Science*, **10**, 910999. https://doi.org/10.3389/fenvs.2022.910999.

Li J., Ridderstaat J. and Yost E. (2022b). Tourism development and quality of life interdependence with evolving age-cohort-based population. *Tourism Management*, **93**, 104621. https://doi.org/10.1016/j.tourman.2022.104621.

Li L., Feng R., Hou G., Xi J., Gao P. and Jiang X. (2024). Integrating tourism supply-demand and environmental sensitivity into the tourism network identification of ecological functional zone. *Ecological Indicators*, **158**, 111505. https://doi.org/10.1016/j.ecolind.2023.111505.

Liu J. and Nijkamp P. (2019). Inbound Tourism as a Driving Force for Regional Innovation: A Spatial Impact Study on China. *Journal of Travel Research*, **58**(4), 594–607. https://doi.org/10.1177/0047287518771223.

Liu Z., Lan J., Chien F., Sadiq M. and Nawaz M.A. (2022). Role of tourism development in environmental degradation: A step towards emission reduction. *Journal of Environmental Management*, **303**, 114078. https://doi.org/10.1016/j.jenvman.2021.114078.

Liu Y., Li J., Zhan X., Zhao H., Wang L. and Suk S. (2025). Exploring the interactive coercing relationship between tourism and ecological environment: a case study in Kanto region, Japan. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-025-05980-4.

Miralles C.C., Barioni D., Mancini M.S., Jordà J.C., Roura M.B., Salas S.P., Argelaguet L.L. and Galli A. (2023). The Footprint of tourism: a review of Water, Carbon, and Ecological Footprint applications to the tourism sector. *Journal of Cleaner Production*, **42**, 138568. https://doi.org/10.1016/j.jclepro.2023.138568.

Odhiambo N.M. (2024). Tourism development and carbon emissions in sub-Saharan African countries: Is there an inverted U-shaped relationship? *Development Studies Research*, **11**(1), 2360986. https://doi.org/10.1080/21665095.2024.2360986.

Oh D. (2010). A global Malmquist-Luenberger productivity index. *Journal of Productivity Analysis*, **34**(3), 183–197. https://doi.org/10.1007/s11123-010-0178-y.

Pásková M., Wall G., Zejda D. and Zelenka J. (2021). Tourism carrying capacity reconceptualization: Modelling and management of destinations. *Journal of Destination Marketing & Management*, **21**, 100638. https://doi.org/10.1016/j.jdmm.2021.100638.

Pásková M., Štekerová K., Zanker M., Lasisi T.T. and Zelenka J. (2024). Water pollution generated by tourism: Review of system dynamics models. *Heliyon*, **10**(1), e23824. https://doi.org/10.1016/j.heliyon.2023.e23824.

Purwono R., Sugiharti L., Esquivias M.A., Fadliyanti L., Rahmawati Y. and Wijimulawiani B. (2024). The impact of tourism, urbanization, globalization, and renewable energy on carbon emissions: Testing the inverted N-shape environmental Kuznets curve. *Social Sciences & Humanities Open*, **10**, 100917. https://doi.org/10.1016/j.ssaho.2024.100917.

Qureshi M.I., Elashkar E.E., Shoukry A.M., Aamir A., Mahmood N.N., Rasli A.M. and Zaman K. (2019). Measuring the ecological footprint of inbound and outbound tourists: evidence from a panel of 35 countries. *Clean Technologies and Environmental Policy*, **21**, 1949–1967. https://doi.org/10.1007/s10098-019-01720-1.

Ren X., Zhao M., Yuan R. and Li N. (2023). Influence mechanism of financial development on carbon emissions from multiple perspectives. *Sustainable Production and Consumption*, **39**, 357–372. https://doi.org/10.1016/j.spc.2023.05.009.

Salahodjaev R., Sharipov K., Rakhmanov N. and Khabirov D. (2022). Tourism, renewable energy and CO2 emissions: evidence from Europe and Central Asia. *Environment, Development and Sustainability*, **24**, 13282–13293. https://doi.org/10.1007/s10668-021-01993-x.

Sustacha I., Baños-Pino J.F. and Valle E.D. (2023). The role of technology in enhancing the tourism experience in smart destinations: A meta-analysis. *Journal of Destination Marketing & Management*, **30**, 100817. https://doi.org/10.1016/j.jdmm.2023.100817.

Ullah A., Raza K. and Mehmood U. (2023). The impact of economic growth, tourism, natural resources, technological innovation on carbon dioxide emission: evidence from BRICS countries. *Environmental Science and Pollution Research*, **30**, 78825–78838. https://doi.org/10.1007/s11356-023-27903-4.

UNWTO. (2019). *Transport-related CO_2 emissions of the tourism sector–Modelling results*. UNWTO, Madrid. https://doi.org/10.18111/9789284416660.

Voumik L.C., Islam M.A. and Nafi S.M. (2024). Does tourism have an impact on carbon emissions in Asia? An application of fresh panel methodology. *Environment, Development and Sustainability*, **26**, 9481–9499. https://doi.org/10.1007/s10668-023-03104-4.

Wang C.M. and Wu T.P. (2022). Does tourism promote or reduce environmental pollution? Evidence from major tourism arrival countries. *Environment, Development and Sustainability*, **24**, 3334–3355. https://doi.org/10.1007/s10668-021-01568-w

Wang X., Zhang T., Nathwani J., Yang F. and Shao Q. (2022a). Environmental regulation, technology innovation, and low carbon development: Revisiting the EKC Hypothesis, Porter Hypothesis, and Jevons' Paradox in China's iron & steel industry. *Technological Forecasting and Social Change*, **176**, 121471. https://doi.org/10.1016/j.techfore.2022.121471.

Wang Y., Han L. and Ma X. (2022b). International tourism and economic vulnerability. *Annals of Tourism Research*, **94**, 103388. https://doi.org/10.1016/j.annals.2022.103388.

Wang Y. and Tziamalis A. (2023). International tourism and income inequality: The role of economic and financial development. *Tourism Economics*, **29**(7), 1836–1864. https://doi.org/10.1177/13548166231177106.

Wong D.W.H., Tai A.C.L., Chan D.Y.T. and Lee H.F. (2024). Can tourism development and economic growth mutually reinforce in small countries? Evidence from Singapore. *Current Issues in Tourism*, **27**(8), 1316–1331. https://doi.org/10.1080/13683500.2023.2213879.

Wu Y., Shi X. and Hu C. (2021). Per capita CO_2 emissions divergence influenced by bilateral trade with China under the belt and road initiative. *Sustainable Production and Consumption*, **27**, 1589–1601. https://doi.org/10.1016/j.spc.2021.04.005.

Xu Y., Zheng Q., Yang Y. and Li W. (2023). The impact of UNESCO world heritage sites on the origin distribution of inbound tourist flows from the global perspective. *Tourism Review*, **78**(3), 794–807. https://doi.org/10.1108/TR-05-2022-0209.Yi M., Liu Y., Sheng M.S. and Wen L. (2022). Effects of digital economy on carbon emission reduction: New evidence from China. *Energy Policy*, **171**, 113271. https://doi.org/10.1016/j.enpol.2022.113271.

Yi M., Liu Y., Sheng M.S and When L. (2022). Effects of digital economy on carbon emission reduction: New evidence from China. *Energy Policy*, **171**, 113271. https://doi.org/10.1016/j.enpol.2022.113271.

Yıldırım S., Yıldırım D.Ç., Aydın K. and Erdoğan F. (2021). Regime-dependent effect of tourism on carbon emissions in the Mediterranean countries. *Environmental Science and Pollution Research*, **28**, 54766–54780. https://doi.org/10.1007/s11356-021-14391-7.

Yue X.G., Liao Y., Zheng S. Shao X. and Gao J. (2021). The role of green innovation and tourism towards carbon neutrality in Thailand: Evidence from bootstrap ADRL approach. *Journal of Environmental Management*, **292**, 112778. https://doi.org/10.1016/j.jenvman.2021.112778.

Zhang M., Huang Y., Shen S., Ye Y., Liao Q., Wang W., Liu L., Zhu X. and Guo J. (2023). Study on the protection and sustainable development of scenic resources–a case study of Qingxiushan scenic spot in Nanning city. *Journal for Nature Conservation*, **72**, 126348. https://doi.org/10.1016/j.jnc.2023.126348.

Zhang W., Jia C., Liu Z., He P. and Enle W (2024). Examining the impact of tourism on carbon neutrality and environmental sustainability in China: The role of renewable energy. *Energy Strategy Reviews*, **56**:101579. https://doi.org/10.1016/j.esr.2024.101579.

Zhang Z., Shi K., Gao Y. and Feng Y. (2025). How does environmental regulation promote green technology innovation in enterprises? A policy simulation approach with an evolutionary game. *Journal of Environmental Planning and Management*, **68**(5), 979–1008. https://doi.org/10.1080/09640568.2023.2276064.

Zhao L, Xu L, Li L, Hu J. and Mu L. (2022). Can Inbound Tourism Improve Regional Ecological Efficiency? An Empirical Analysis from China. *International Journal of Environmental Research and Public Health*, **19**, 12282. https://doi.org/10.3390/ijerph191912282.

Zhao X., Mahendru M., Ma X., Rao A. and Shang Y. (2022). Impacts of environmental regulations on green economic growth in China: New guidelines regarding renewable energy and energy efficiency. *Renewable Energy*, **187**, 728–742. https://doi.org/10.1016/j.renene.2022.01.076.

Zheng X., Wang R. and Du Q. (2020). How does industrial restructuring influence carbon emissions: City-level evidence from China. *Journal of Environmental Management*, **276**, 111093. https://doi.org/10.1016/j.jenvman.2020.111093.

Zheng R., Wu G., Cheng Y., Liu H., Wang Y. and Wang X. (2023). How does digitalization drive carbon emissions? The inverted U-shaped effect in China. *Environmental Impact Assessment Review*, **102**, 107203. https://doi.org/10.1016/j.eiar.2023.107203.

Zhou B., Wang Y.L. and Hu B. (2024). The nonlinear effects of digital finance on carbon performance: Evidence from China. *Journal of Innovation & Knowledge*, **9**, 100484. https://doi.org/10.1016/j.jik.2024.100484.

Zuo S., Zhao Y., Zheng L., Zhao Z., Fan S. and Wang J. (2024). Assessing the influence of the digital economy on carbon emissions: Evidence at the global level. *Science of The Total Environment*, **10**, 174242. https://doi.org/10.1016/j.scitotenv.2024.174242.