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# International tourism carbon footprint and carbon transfer along the belt and road regions

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It is increasingly urgent to constantly monitor and analyze the carbon emission of international tourism activities. This paper focuses on countries and regions along the Belt and Road (B&R), utilizes the MRIO model to approximate international tourism carbon footprint (ITCT), and analyzes the patterns of carbon transfer. Panel model is further applied to discuss the effects of various influencing factors. The results show that: 1) in 2015, ITCT along the B&R accounts for approximately 40.74% of global carbon emission of the year; 2) ITCT along the B&R experienced continuous growth from 2005 to 2015, with an annual growth rate of 3.22%; 3) individual income level, urbanization, and air passenger volume in the countries along the B&R has positive impact on ITCT, which varies according to the income level of the country. The results are of significance for countries and regions along the B&R to formulate future policies for tourism development.

## KEYWORDS

the belt and road, MRIO model, international tourism carbon footprint, tourism development, global carbon emission

## 1 Introduction

In September and October 2013, Chinese President Xi Jinping put forward the cooperation initiative of the New Silk Road Economic Belt and the 21st Century Maritime Silk Road respectively, which is called the Belt and Road (B&R) for short (Zhang, 2019). The Belt and Road Initiative (BRI) aims to achieve win-win cooperations and common prosperities between China and other Asian, African and European countries (Li et al., 2020; Zhai, 2018). Against the backdrop of the current global economic downturn, BRI stimulates demand and employment, encourages investment and consumption, explores the development potential of regions along the B&R, and ultimately provides markets and impetus for global economic development by enhancing the flow of economic factors, promoting connectivity among countries and integrating markets (Irshad, 2015; O'Trakoun, 2018; Pacheco Pardo, 2018). To date, China has signed visa waiver agreements with 57 countries along the B&R, jointly celebrated the "Year of Tourism" with several countries, and established tourism cooperation initiatives such as the Silk Road Tourism Marketing Alliance, the Maritime Silk Road Tourism Promotion Alliance, and the Great Tea Road International Tourism Alliance. This corresponds to the

fact that almost all countries along the B&R see tourism as a pillar sector to their economies (Li et al., 2020; Torres-Delgado et al., 2024).

According to the China Tourism Academy, the number of tourists from China alone to other countries along the B&R has been increasing steadily year by year, from 15.49 million in 2013 to 27.41 million in 2017. Clearly, as a driving factor for regional economic expansion within the region (Zhai, 2018), tourism activities on this scale have a significant impact on the environment (Gössling, 2002) as increase energy demand (Selvanathan et al., 2021) and thus are responsible for the increasing CO<sub>2</sub> emission (Dogan et al., 2020; Inglesi-Lotz and Dogan, 2018; Moutinho et al., 2018; Wen and Shao, 2019; Yamano and Ahmad, 2006; Zameer and Wang, 2018). Tourism's global carbon footprint, which are mainly contributed by transport, shopping and food, accounts for around 8% of global greenhouse gas emissions (2009-2013) (Lenzen et al., 2018). Given the commitment of countries associated with the United Nations Framework Convention on Climate Change (UNFCCC) to achieve a net zero increase in carbon emissions, and the distinct Sustainable Development Goal of combating climate change ratified by the UN (2017) and future projections of an unabated tourism growth, continuous monitoring and analysis of tourism-related carbon emissions is becoming increasingly urgent (Lenzen et al., 2018).

Research on tourism carbon footprint has increased significantly focuses on the urban tourism carbon footprint (Yang and Guo, 2024), the impact of tourism on CO<sub>2</sub> emission (Gössling et al., 2011; Le and Nguyen, 2021), namely, the causality between tourism, economic growth and CO<sub>2</sub> emissions (Adedoyin and Bekun, 2020; Selvanathan et al., 2021), the inter-relationship between tourist arrivals, energy consumption and pollutant emissions (Nepal et al., 2019), as well as energy consumption and carbon emission for tourism transport (Tang et al., 2015; Xiao et al., 2022; Zaman et al., 2017; Q; Zhang, 2022). With the concern of environmental protection and low carbon, the concept of low-carbon tourism is beginning to take hold (Changbo and Jingjing, 2011; Zha et al., 2019). Some studies began to use econometric models such as linear model, life cycle model (LCA) and input-output model to estimate tourism carbon footprint. In which, input-output model overcomes the limitations of linear model and the practical difficulties of LCA model and becomes the mainstream of research (Zhang, 2017).

In summary, current studies on international tourism carbon footprint mostly take countries (Le and Nguyen, 2021), regions (Liu et al., 2011; Selvanathan et al., 2021; Zhao et al., 2019), destinations (Cheng et al., 2013; Tang et al., 2015) as the subjects to discuss the legal development regarding tourism carbon emissions (TCEs). Although Lenzen et al. (2018) discussed global TCEs from 2009 to 2013, there has been a lack of discussion on the transfer rules of TCEs from the global or large regional scale in the past decade. However, there is relatively little research in this area at present, especially in the aspects of quantitative analysis, case studies and policy response. To sum up, there are many gaps and challenges in the research field of carbon footprint of international tourism and carbon transfer along the Belt and Road. To fill these gaps, this paper takes countries along the B&R as the research contexts and highlights the importance of tourism carbon footprint issues with respect to multiple influencing factors at multi-region scales. There are two innovations in this paper. Firstly, this paper introduces

MRIO model to evaluate the carbon footprint of international tourism along the B&R, which enriches the literature on international tourism carbon footprint research. Secondly, this paper discusses the transfer mode of international tourism carbon footprint, analyzes the influencing factors of international tourism carbon footprint, and clarifies the transfer mechanism and influence mechanism of international tourism carbon footprint. It specifically adopts the input-output model, and uses multi-regional trade data from Eora global supply chain database (Lenzen et al., 2013), which contains the environmental and social Satellite accounts of 190 countries, to assess the international tourism carbon footprint and explore the tourism carbon footprint transfer. The following session reviews the existing research studies on carbon emissions and TCEs in the B&R regions, and followed by the methods and data collection details. The next section illustrates the results and analysis, and concludes with implications and policy recommendations.

## 2 Literature review

### 2.1 Carbon emissions in the B&R regions

China and the countries along the B&R are richly endowed with proven reserves of energy and resources, among which their carbon reserves accounted for 52.27% of the world's standard coal in 2005 (Zhao et al., 2019). Rich energy reserves contribute to regional and even global prosperity by providing energy security for infrastructure construction which require substantial energy consumption (Zhang et al., 2017). However, many B&R countries lack renewable energy facilities, energy demands are largely met by fossil fuels. As one of the most carbon-intensive economies worldwide, China accounts for about 25% of global greenhouse gas emissions (GHGEs) (Dargusch, 2017) and the B&R regions account for 95% of the world's net carbon exports (Han et al., 2018). In recent years, the geography of Global Supply Chains are shifting from China to successor developing countries in South Asia, Africa and Latin America by streamlining exports (Jiang and Green, 2017), which also indicates that the GHGEs generated in the production process are also shifting to less developing economies (Lambin et al., 2018; Mi et al., 2017; Pendrill et al., 2019). While the current embodied carbon flows are virtually all from BR regions to developed economies (Han et al., 2018). Thus, the operation and maintenance of the infrastructure in the B&R countries, the growth of energy-intensive industries under spatial shift of industrial capacity finally contribute to the considerable global carbon emissions (Zhang et al., 2017).

Some studies have evaluated the impact of BRI infrastructure projects on CO<sub>2</sub> emissions, and specifically relevant studies show that investment in infrastructure in the B&R regions is beneficial to reduce transportation time and cost, and reduce CO<sub>2</sub> emissions (De Soyres et al., 2019). 36 renewable energy projects in the B&R regions may reduce CO<sub>2</sub> emissions by 240 Mt by 2030 (Gu and Zhou, 2020). For every 1% increase in Chinese investment in the region, CO<sub>2</sub> emissions along the B&R regions will decrease by 0.04% in high-income countries and 0.02% in low-income countries (Su et al., 2022). In general, existing studies have evaluated the impact of infrastructure on CO<sub>2</sub> emissions along the B&R countries and

regions (De Soyres et al., 2020; Wang et al., 2020), in terms of CO<sub>2</sub> emissions from power generation (Gu and Zhou, 2020), industrial carbon efficiency (Lu and Li, 2020), and the dynamic process of logistics efficiency (Zheng et al., 2020). Additionally, the changing trends of consumption and embodied emissions are also calculated in terms of consumption (Han et al., 2020; Hou et al., 2020). Methodologically speaking, majority studies estimated carbon emissions with the production-based accounting (PBA) analysis and consumption-based accounting (CBA) analysis (Chen et al., 2019; Chen et al., 2018; Kanemoto et al., 2016; Xu et al., 2020).

## 2.2 Tourism carbon emissions assessment

Tourism carbon emissions are usually studied in terms of tourism carbon footprint (TCF), and most of these studies focus on the carbon directly emitted from tourism activities and the carbon contained in the commodities purchased by tourists (Lenzen et al., 2018; Rosselló et al., 2024). The three most widely applied models to evaluate the carbon emissions of tourism industry are linear model (Kannan et al., 2012; Sun, 2016), life cycle model (LCA) (Cederberg et al., 2011; Jones and Kammen, 2011; Tang and Ge, 2018), and input-output model (Lenzen et al., 2018).

Linear model refers to a statistical model that connects all links related to the tourism industry through a certain process to calculate the carbon emissions of the tourism industry (Cooper and McCullough, 2021). Cooper and McCullough (2021) proposed a statistical model through stadium operation and travel, food, waste, and lodging of fans and teams, and believed that travel accounts for nearly 80% of the total carbon footprint. Zhiyong et al. (2021) discussed the carbon footprint of China's inbound tourism, and concluded that the carbon footprint of inbound tourism in China increased from 5.623 million tons in 2007 to 10.8809 million tons in 2017, among which transportation, post, and telecommunications are the most significant contributors. Huang and Tang (2021) estimated the TCF of Heilongjiang Province from 2009 to 2018 by using TCF and the tourism carbon capacity model, and believed that the *per capita* TCF increased from 53.9 kg in 2009 to 116.0 kg in 2018.

Life cycle model uses LCA as a tool to evaluate energy consumption, which runs through the whole life cycle process of goods and services, that is, the emissions are allocated to the production of capital goods required in an industry (Cadarso et al., 2016). Tang et al. (2018) proposed a measurement model for energy and carbon emission efficiency of the destination tourism industry by combining the life cycle assessment theory and material flow analysis, and measured the energy efficiency and carbon emission efficiency of the tourism industry in Wulingyuan Scenic area from 1979 to 2015. They believed that with the evolution of the tourism life cycle stage, energy and carbon efficiency is improving in the tourism sector.

Input-output model (IOA) was proposed and refined by economist Leontief (1986), and has been widely used in resources and environment research since the 1970s (Kitzes, 2013). The essence of IOA method is to interconnect resource flows and environmental impacts to categories of intermediate use and final demand (Chen and Chen, 2011a; Chen and Chen, 2011b). As a well-established macro-level statistical method of TCF, it has been widely

used in the study of TCF. For example, Sun (2016) proposed an analytical framework for national TCF and discussed its dynamic relationship with economic growth. Lenzen et al. (2018) used the input-output model to measure TCF of 160 countries in the world, and explored its transfer rule. They believed that, from 2009 to 2013, tourism global carbon footprint has increased from 3.9 to 4.5 GtCO<sub>2</sub>e. Tang and Ge, (2018) estimated that TCF in Shanghai accounted for 20.45% of the total carbon emission in 2012, indicating that tourism industry in Shanghai is not a low-carbon industry. There are also some derived input-output model, such as the Economic Input-Output Life Cycle Assessment (EIO-LCA) model (Suh, 2009), which uses a top-down economy-wide approach (Jones and Kammen, 2011), the life cycle assessment input-output (LCA-IO) model (Cadarso et al., 2016), the input-output life cycle model (Jones and Kammen, 2011), and the multi-regional input-output (MRIO) model (Davis and Caldeira, 2010; Han et al., 2018; Lin and Sun, 2010). The MRIO model has been employed to compute the spatial distribution of carbon intensities (Han et al., 2018) and the embodied regional carbon emission flows (Chen and Han, 2015), including embodied carbon flows along the B&R regions (Han et al., 2018). In general, input-output model has become a new macro method to compile TCF inventory. Relative to traditional bottom-up approaches, input-output models can improve the consistency of applications with the Tourism Satellite Accounts (TSAs) and the treatment of embedded emissions from imports, and contribute to the implementation of the Sustainable Development Goals (Sun et al., 2020). Given the vision of a community with a shared future for mankind and the complexity of regional tourism economies, MRIO analysis is implied to determine ITCF of countries in the B&R regions.

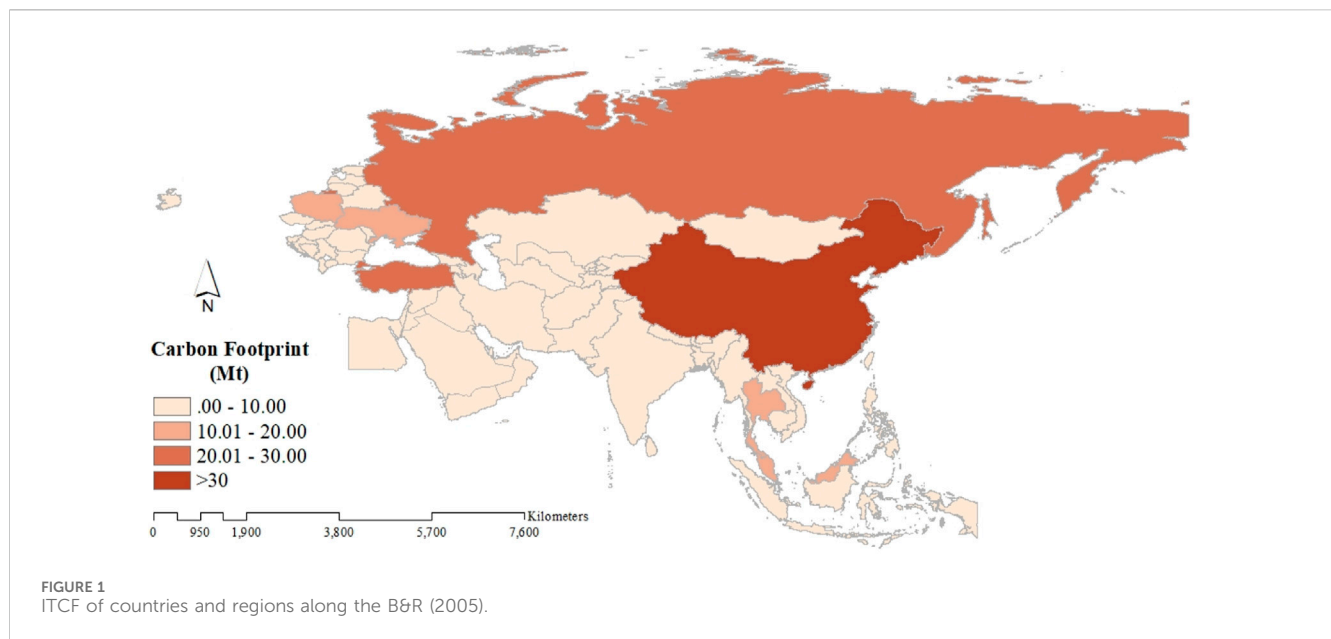
## 3 Methods and data

### 3.1 Multi-regional input–output model

Based on the MRIO model, detailed TSAs and CO<sub>2</sub> emission data, this paper calculated the carbon footprint of international tourism along the B&R regions. The MRIO model use the multi-regional trade transfer matrix to calculate the CO<sub>2</sub> emitted by tourists in the process of transportation and consumption of goods. The key to the MRIO model is the input-output table and major databases (Kitzes, 2013; Minx et al., 2009; Tukker and Dietzenbacher, 2013), including OECD (19 countries) (Yamano and Ahmad, 2006), WIOD (43 countries) (Dietzenbacher et al., 2013), EORA (190 countries) (Lenzen et al., 2012a; Lenzen et al., 2012b), GTAP (140 countries) (Narayanan, 2008), and EXIOPOL (43 countries) (Tukker et al., 2009). EORA database which features continuous time series and data reliability (Lenzen et al., 2013) is selected for this study. The input-output model can be expressed by the following Equation 1 (Chen and Han, 2015):

$$X = T + Y \quad (1)$$

Where  $X = [x_i^r]$  represents output from Sector  $i$  in Region  $r$ ,  $T = [z_{ij}^{rs}]$  represents output from Sector  $i$  in Region  $r$  for intermediate input to Sector  $j$  in Region  $s$ ,  $Y = [y_i^{rs}]$  represents output from Sector  $i$  in Region  $r$  for final demand of Sector  $i$  in Region  $s$ .



Matrix T represents the absolute value of supply and demand between different sectors in each region. Since CO<sub>2</sub> emission intensity between countries and sectors cannot be accurately compared, it is necessary to introduce direct consumption coefficient A, which is also known as direct consumption coefficient. Subsequently, the above equation can be converted [Equation 2](#):

$$X = A \times X + Y \tag{2}$$

Here  $A = T/X = [a_{ij}^{rs}]$  represents the input of Sector i in region r to meet the needs of Sector j in region s to produce products with unit value added. Thus, the above form can be expressed as [Equation 3](#):

$$X = (I - A)^{-1} \times Y \tag{3}$$

Where I is the identity matrix,  $(I - A)^{-1} = [b_{ij}^{rs}]$  is the Leontief inverse matrix. It represents the total input of Sector i in Region r to meet the final demand of Sector j in Region s with one monetary unit. In linking economic activities with CO<sub>2</sub> emissions, the carbon emission intensity coefficient matrix f is introduced by [Equation 4](#):

$$f = Q/X \tag{4}$$

Where f is the CO<sub>2</sub> emission generated by the production of a monetary unit product in the sector and represents CO<sub>2</sub> emission intensity, Q = [q<sub>j</sub><sup>s</sup>] is the CO<sub>2</sub> emission of Sector j in region s.

Therefore, the ITCF can be calculated by the following [Equation 5](#):

$$E = f \times (I - A)^{-1} \times Y \tag{5}$$

Where, E represents ITCF. Due to the lack of data, CO<sub>2</sub> emissions caused by tourism and non-tourism related activities are not distinguished in the calculation of Q and f in this paper. The 39 products in the original TSAs data are classified according to the sections in the database EORA26, and the TSAs data is converted into the matrix Y in the input-output model, which is used as the final demand of tourism consumers in the input-output model.

### 3.2 Data collection

By March 2022, 149 countries had signed agreements with China on B&R Cooperation. A number of 65 countries are selected in this research, with total population of 4.4 billion, land area of about 50.7 million km<sup>2</sup>, and economy accounting for nearly 30% of global GDP.

## 4 Results and analysis

### 4.1 International tourism carbon footprint along the belt and road

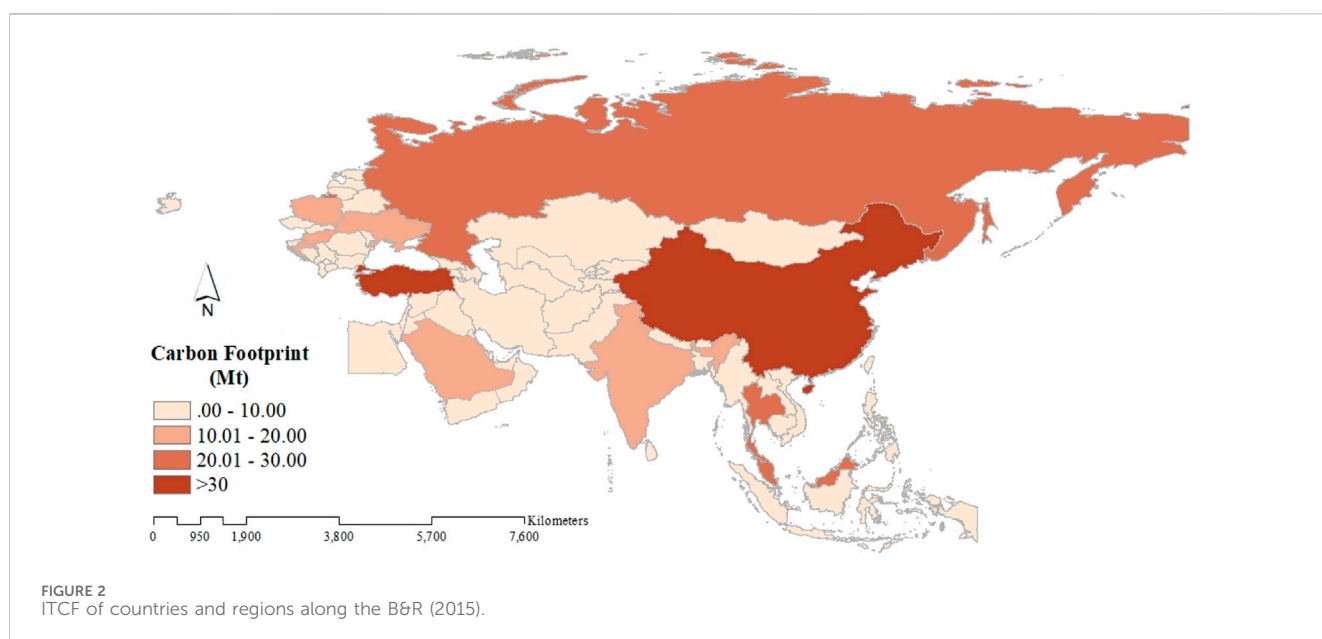
The carbon footprint of international tourism in countries and regions along the B&R increased from 295.65 Mt in 2005 ([Figure 1](#)), namely, 37.82% of the world's total, to 390.89 Mt in 2015, accounting for 40.74% of the world's total, with an average annual growth rate of 3.22% ([Table 1](#)). In 2015, the top five countries (regions) along the B&R were China, Turkey, Russia, Thailand, and Hong Kong. China, were with their ITCF of 35.67, 32.79, 26.93, 24.74, and 21.98 Mt respectively ([Figure 2](#)). Ukraine and Malaysia were among the top five countries and regions along the B&R in terms of ITCF in 2005, and were replaced by Hong Kong, China and Thailand in 2015. The five countries and regions along the B&R with the smallest ITCF are Bhutan, Bangladesh, Moldova, Turkmenistan, and Tajikistan ([Figure 2](#)).

From 2005 to 2015, Bhutan, Kyrgyzstan, Myanmar, Vietnam, and Laos experienced the fastest growth in ITCF, with an annual growth rate of 85.88%, 70.42%, 49.67%, 42.22%, and 34.32%, respectively. In 2005, ITCF of China (43.52 Mt), Russia (20.62 Mt), and Turkey (20.01 Mt) were greater than 20 Mt. In 2015, ITCF of China (35.67 Mt), Turkey (32.79 Mt), Russia (26.93 Mt), Thailand (24.74 Mt), Hong Kong, China (21.98 Mt), and Malaysia (21.21 Mt) were greater than 20 Mt. Results show that the BRI has changed the tourism development distribution of the countries along the B&R regions ([Table 2](#)).

TABLE 1 Distribution of countries and regions along the B&R.

Region	Country	Number
Mongolia and Russia	Mongolia, Russia	2
Central Asia	Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan, Turkmenistan	5
Southeast Asia	Vietnam, Laos, Cambodia, Thailand, Malaysia, Singapore, Indonesia, Brunei, Philippines, Myanmar, Timor-Leste	12
South Asia	India, Pakistan, Bangladesh, Afghanistan, Nepal, Bhutan, Sri Lanka, Maldives	8
Central and Eastern Europe	Poland, Czech Republic, Slovakia, Hungary, Slovenia, Croatia, Romania, Bulgaria, Serbia, Montenegro, Macedonia, Bosnia and Herzegovina, Albania, Estonia, Lithuania, Latvia, Ukraine, Belarus, Moldova	19
West Asia and the Middle East	Turkey, Iran, the Syrian Republic, Iraq, the United Arab Emirates, Saudi Arabia, Qatar, Bahrain, Kuwait, Lebanon, Oman, Yemen, Jordan, Israel, Palestine, Armenia, Georgia, Azerbaijan and Egypt	19

Note: Information was gathered from <https://www.yidaiyilu.gov.cn/>, which is the Chinese government official website for the BRI.



### 4.2 The inflow and outflow of international tourism carbon footprint along the B&R regions

From 2005 to 2015, the net outflow of ITCF along the B&R decreased from 0 to -0.08 Mt, and tourism carbon footprint of countries along the B&R was transferred to other countries and regions in the world. In 2005, the top five countries and regions with net inflow were Poland, Macao, Malaysia, Hong Kong, China, and Turkey respectively, which changed to Macao, Malaysia, Thailand, Hong Kong, China, and Turkey in 2015. These countries and regions received travel carbon transfers from the rest of the world (Table 2).

In 2005, China, Russia, Moldova, Belarus, India, and Iran were the top five countries in terms of ITCF outflow under the BRI, with the outflow volume of 21.57, 19.53, 11.83, 9.53, 6.07, and 5.88 Mt, respectively, accounting for 53.55% of the total outflow volume from countries and regions along the B&R. By 2015, the carbon footprint outflow of international tourism from China, Russia, India, Saudi Arabia and Belarus was 92.6, 17.52, 11.56, 11.13, and 8.97 Mt,

respectively, accounting for 64.88% of the total outflow from countries along the B&R (Table 3). In general, the outflow of ITCF along the B&R regions was highly concentrated.

In 2005, China, Turkey, Russia, Ukraine, and Malaysia were the top five countries along the B&R regions in terms of ITCF inflow, which were 16.8, 8.95, 8.25, 7.51, and 7.15 Mt, respectively, accounting for 38.01% of the total inflow of countries along the B&R regions. By 2015, Turkey, China, Russia, Thailand, and Hong Kong, China ranked among top five in terms of ITCF inflows, which were 18.92, 14.89, 14.89, 14.21, and 12.65 Mt, respectively, accounting for 34.57% of the total outflow of countries along the B&R regions (Table 3). In general, the inflow of ITCF along the B&R regions was relatively dispersed.

### 4.3 Factors influencing international tourism carbon footprint along the B&R regions

To further examine the influencing factors of ITCF along the B&R regions, a panel model is adopted in this paper. According to

TABLE 2 ITCF in countries and regions along the B&amp;R (Mt).

Country/region	2005		2015		Change in rank	Growth rate (%)
	ITCF	Rank	ITCF	Rank		
Global	781.70	-	959.59	-	-	2.28
B&R countries	295.65	—	390.89	—	—	3.22
China	43.52	1	35.67	1	0	-1.80
Russia	20.62	2	26.93	3	-1	3.06
Turkey	20.01	3	32.79	2	1	6.38
Ukraine	17.18	4	10.26	13	-9	-4.03
Malaysia	16.13	5	21.21	6	-1	3.14
Poland	14.91	6	13.85	8	-2	-0.71
Hong Kong, China	14.45	7	21.98	5	2	5.21
Thailand	11.36	8	24.74	4	4	11.77
Hungary	9.85	9	11.91	10	-1	2.09
Czech Republic	9.28	10	9.65	15	-5	0.40
Macau, China	8.92	11	11.91	9	2	3.35
Egypt	8.11	12	7.57	19	-7	-0.66
Saudi Arabia	7.82	13	14.58	7	6	8.64
Croatia	7.66	14	10.56	12	2	3.79
The United Arab Emirates	7.00	15	5.49	22	-7	-2.16
Singapore	6.95	16	9.94	14	2	4.31
Slovakia	6.11	17	5.01	23	-6	-1.81
Romania	5.77	18	7.76	18	0	3.45
Indonesia	4.91	19	8.61	16	3	7.54
Bulgaria	4.77	20	5.90	21	-1	2.38
Bahrain	3.87	21	3.30	30	-9	-1.48
India	3.81	22	10.80	11	11	18.33
The Syrian Arab Republic	3.53	23	4.22	26	-3	1.96
Taiwan, China	3.30	24	8.54	17	7	15.90
Kazakhstan	3.10	25	3.79	29	-4	2.22
Bhutan	2.95	26	3.13	32	-6	0.60
The Philippines	2.58	27	4.42	24	3	7.12
Albania	2.40	28	3.15	31	-3	3.14
Republic of Lithuania	1.98	29	1.72	40	-11	-1.29
Estonia	1.90	30	2.49	35	-5	3.11
Israel and Palestine	1.88	31	2.32	37	-6	2.39
Iran	1.84	32	4.28	25	7	13.30
Georgia	1.77	33	1.90	39	-6	0.71
Slovenia	1.54	34	2.25	38	-4	4.65
Cambodia	1.41	35	3.98	27	8	18.24

(Continued on following page)

TABLE 2 (Continued) ITCF in countries and regions along the B&amp;R (Mt).

Country/region	2005		2015		Change in rank	Growth rate (%)
	ITCF	Rank	ITCF	Rank		
Vietnam	1.19	36	6.23	20	16	42.22
Lebanon	1.12	37	1.26	45	-8	1.23
Latvia	1.10	38	1.69	41	-3	5.26
Qatar	0.90	39	2.43	36	3	16.96
Oman	0.88	40	1.59	43	-3	8.00
Pakistan	0.79	41	0.80	49	-8	0.19
Azerbaijan	0.69	42	1.60	42	0	13.30
Laos	0.67	43	2.95	33	10	34.32
Myanmar	0.65	44	3.90	28	16	49.67
Sri Lanka	0.54	45	1.50	44	1	17.54
Serbia and the Republic of Montenegro	0.45	46	0.94	48	-2	11.00
The Republic of Maldives	0.39	47	1.03	46	1	16.28
Nepal	0.37	48	0.45	54	-6	2.09
Mongolia	0.33	49	0.32	56	-7	-0.39
Yemen	0.33	50	0.31	57	-7	-0.81
Armenia	0.32	51	0.99	47	4	21.41
Kyrgyzstan	0.32	52	2.54	34	18	70.42
Belarus	0.24	53	0.79	50	3	22.43
Uzbekistan	0.24	54	0.62	52	2	15.95
Bosnia and Herzegovina	0.21	55	0.56	53	2	16.29
Bangladesh	0.21	56	0.10	61	-5	-4.94
Macedonia	0.19	57	0.40	55	2	10.75
Brunei	0.12	58	0.18	58	0	4.56
Kuwait	0.10	59	0.15	59	0	4.68
Moldova	0.06	60	0.08	62	-2	2.32
Bhutan	0.01	61	0.13	60	1	85.88
Turkmenistan	0.01	62	0.01	63	-1	-2.75
Tajikistan	0.00	63	0.00	64	-1	-1.59
Iraq	—	64	0.74	51	13	—

Note: ITCF, stands for international tourism carbon footprint, '-' means there is no data, among which, there is no data for Afghanistan and East Timor.

the report of the World Bank's national income data, the samples are divided into the overall sample, the sample of low- and middle-income countries, high- and middle-income countries, and high-income countries. Low-income samples were not included in the analysis due to lack of data.

The results show that ITCF along the B&R regions is affected by *per capita* income. Despite the heterogeneity of *per capita* income among countries, the influence coefficient of *per capita* income of countries and regions along the B&R regions on the ITCF is maintained between 0.307 and 0.387. The influence coefficient of

urbanization rate on the ITCF is 0.439, and the impact on low- and middle-income countries is the largest (0.820). For high-income countries, there is a negative effect, with an influence coefficient of 0.401. The influence coefficient of the number of tourists on the ITCF is maintained between 0.373 and 0.606, and the impact on high-income countries is the largest (0.606). The influence coefficient of air passenger volume on the ITCF is 0.118, among which the influence of air passenger volume on high- and middle-income countries is not significant, and its influence on low-income countries is the largest, with an impact coefficient of 0.318 (Table 4).

TABLE 3 The inflow and outflow of ITCF in countries and regions along the B&amp;R.

Country/region	Outflow volume (Mt)		Inflow volume (Mt)		Net outflow volume (Mt)	
	2005	2015	2005	2015	2005	2015
China	21.57	92.60	16.80	14.89	4.76	77.71
Belarus	9.53	8.97	0.10	0.45	9.43	8.52
Iran	5.88	8.23	0.80	2.43	5.08	5.80
India	6.07	11.56	1.66	6.07	4.41	5.49
Iraq	0.88	3.94	0.00	0.42	0.88	3.52
Kuwait	1.79	3.42	0.05	0.09	1.74	3.33
Saudi Arabia	5.36	11.13	3.42	8.23	1.94	2.90
Russia	19.53	17.52	8.25	14.89	11.28	2.62
Taiwan, China	4.22	7.03	1.45	4.87	2.77	2.15
Qatar	0.76	3.10	0.40	1.40	0.36	1.71
The Philippines	1.44	3.57	1.15	2.54	0.29	1.03
The United Arab Emirates	2.14	4.00	3.11	3.15	-0.97	0.85
Pakistan	1.21	1.28	0.35	0.46	0.86	0.82
Lebanon	1.71	1.53	0.50	0.73	1.21	0.81
Vietnam	1.37	4.23	0.53	3.57	0.84	0.65
Moldova	11.83	0.44	0.03	0.05	11.80	0.40
Turkmenistan	0.11	0.25	0.01	0.00	0.11	0.24
Oman	0.42	1.14	0.39	0.92	0.03	0.22
Bangladesh	0.15	0.25	0.09	0.06	0.05	0.19
Serbia and Montenegro	0.27	0.71	0.20	0.54	0.07	0.16
Mongolia	0.15	0.26	0.15	0.19	0.00	0.07
Tajikistan	0.02	0.03	0.00	0.00	0.02	0.03
Brunei	0.10	0.12	0.06	0.11	0.04	0.02
Azerbaijan	0.31	0.92	0.31	0.92	0.00	-0.01
Yemen	0.25	0.14	0.15	0.18	0.10	-0.04
Bhutan	0.00	0.02	0.01	0.07	0.00	-0.05
Nepal	0.06	0.16	0.17	0.26	-0.11	-0.10
Armenia	0.11	0.46	0.14	0.57	-0.03	-0.11
Uzbekistan	0.30	0.21	0.11	0.36	0.19	-0.15
Macedonia	0.07	0.08	0.09	0.23	-0.02	-0.16
Bosnia and Herzegovina	0.11	0.12	0.10	0.33	0.01	-0.20
Israel and Palestine	1.00	1.02	0.84	1.34	0.16	-0.32
Sri Lanka	0.30	0.47	0.24	0.86	0.05	-0.40
Maldives	0.03	0.09	0.18	0.59	-0.14	-0.51
Kazakhstan	1.37	1.57	1.38	2.18	-0.02	-0.62
Republic of Lithuania	0.22	0.21	0.89	1.00	-0.67	-0.78
Latvia	0.15	0.12	0.50	0.98	-0.34	-0.85

(Continued on following page)



TABLE 3 (Continued) The inflow and outflow of ITCF in countries and regions along the B&amp;R.

Country/region	Outflow volume (Mt)		Inflow volume (Mt)		Net outflow volume (Mt)	
	2005	2015	2005	2015	2005	2015
Georgia	0.09	0.17	0.80	1.10	-0.70	-0.92
Estonia	0.23	0.50	0.85	1.44	-0.62	-0.94
Slovenia	0.30	0.21	0.69	1.30	-0.39	-1.10
Kyrgyzstan	0.09	0.23	0.14	1.47	-0.06	-1.24
Bhutan	0.53	0.51	1.32	1.81	-0.79	-1.30
Laos	0.01	0.26	0.30	1.71	-0.29	-1.45
Indonesia	3.29	3.49	2.17	4.94	1.13	-1.45
Albania	0.28	0.27	1.08	1.82	-0.79	-1.55
Bahrain	0.32	0.35	1.74	1.91	-1.42	-1.56
The Syrian Republic	0.82	0.56	1.58	2.44	-0.76	-1.88
Cambodia	0.04	0.11	0.63	2.30	-0.59	-2.19
Egypt	1.86	2.16	3.61	4.36	-1.75	-2.21
Myanmar	0.04	0.04	0.29	2.26	-0.25	-2.21
Ukraine	5.00	3.35	7.51	5.89	-2.51	-2.54
Slovakia	0.35	0.32	2.74	2.89	-2.39	-2.57
Bulgaria	1.33	0.72	2.13	3.41	-0.79	-2.69
Romania	0.51	0.46	2.58	4.49	-2.08	-4.03
Czech Republic	1.07	1.06	4.14	5.57	-3.08	-4.52
Singapore	0.74	1.02	3.10	5.73	-2.36	-4.72
Poland	2.79	2.47	6.60	7.97	-3.81	-5.50
Croatia	0.26	0.18	3.43	6.11	-3.17	-5.93
Hungary	0.84	0.57	4.40	6.88	-3.56	-6.31
Macau, China	0.04	0.05	4.01	6.90	-3.96	-6.84
Malaysia	2.38	3.75	7.15	12.16	-4.77	-8.41
Thailand	2.41	3.03	5.04	14.21	-2.62	-11.18
Hong Kong, China	0.76	0.70	6.42	12.65	-5.66	-11.95
Turkey	0.81	1.10	8.95	18.92	-8.14	-17.83
Total	127.98	218.54	128.01	218.57	0.00	-0.08

#### 4.4 The transfer of international tourism carbon footprint along the B&R regions

From 2005 to 2015, the carbon emission structure of China's international tourism became more diversified. In 2005, China's ITCF was mainly transferred from Russia, accounting for 33.56% of the top six countries in China's international tourism carbon emissions. In 2015, the carbon footprint of China's international tourism was mainly transferred from Russia, India, Iran, Saudi Arabia and Albania, accounting for 12.06%–27.01%. Russia accounted for 27.01%, with a decrease of 6.55%. This suggests China's international tourism carbon emissions more diversified among countries along the B&R (Figure 3).

## 5 Discussion

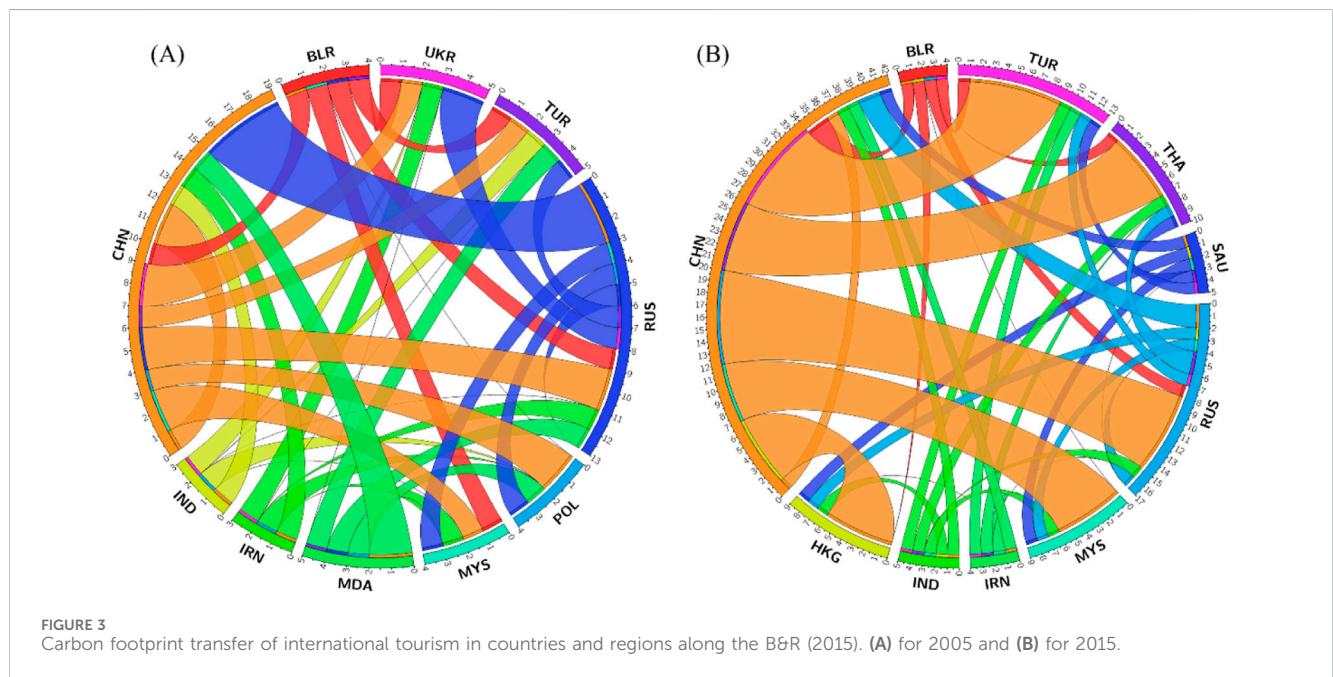
The results of the study show that the BRI has significantly increased the number of inbound tourists from countries along the route, which has been confirmed by Li et al. (2020). Results also show that the tourism carbon footprint has shifted to the rest of the world, which can be attributed to three reasons.

First, tourism cooperation between countries has increased. After the BRI was put forward, countries adopted visa-free (Han et al., 2018), jointly held tourism years, established tourism promotion alliances and other measures (Rosselló et al., 2024; Wang et al., 2020), which enhanced the visibility and accessibility of countries along the B&R, attracted more international tourists, and promoted the transfer of international tourism

TABLE 4 Panel model of ITCF in countries and regions along the B&R.

Variable	lnITCF	lnITCF	lnITCF	lnITCF
	BRI	Lower middle income	Upper middle income	High income
lnpgdp	0.375*** (0.0358)	0.316*** (0.0757)	0.387*** (0.0645)	0.307*** (0.0414)
lnurban	0.439*** (0.253)	0.820* (0.477)	0.057*** (0.527)	-0.401* (0.725)
lnpop	0.507*** (0.0768)	0.391** (0.180)	0.373** (0.146)	0.606*** (0.0849)
lnair	0.118*** (0.0302)	0.318*** (0.0812)	0.0886 (0.0602)	0.108*** (0.0261)
_cons	-18.26*** (1.519)	-16.49*** (3.107)	-18.27*** (2.518)	-6.855** (3.112)
N	849	284	269	264
R <sup>2</sup>	0.49	0.49	0.52	0.59
F	609.25***	242.57***	173.60***	251.53***

Standard errors in parentheses \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$  Random-effects GLS, regression. There are only two low-income samples.



carbon footprint to other parts of the world. For example, China has reached visa-free agreements with 57 countries to jointly build the B&R, jointly host the Tourism Year, and established cooperative alliance with many other B&R countries, such as the New Silk Road Economic Belt and the 21st Century Maritime Silk Road and the Silk Road Tourism Marketing Alliance, the Maritime Silk Road Tourism Promotion Alliance, and the Great Tea Road International Tourism Alliance.

Second, infrastructure connectivity is a top priority for the BRI. A series of economic corridors have been built along the route, such

as New Eurasian Land Bridge, China-Mongolia-Russia, China-Central Asia-West Asia, China-Indochina Peninsula, China-Pakistan, and Bangladesh-China-India-Myanmar economic corridors (Li et al., 2020). These economic corridors have boosted cultural exchanges and incomes, stimulating trade and tourism between countries (Irshad, 2015).

Third, the BRI has increased investment and reduced poverty in countries along the route. According to a World Bank study, B&R investments could help lift more than 34 million people out of

moderate poverty, 29.4 million of whom live in countries and regions along the routes. Driven by the BRI, foreign economic and trade cooperation among countries along the B&R has continued to grow, and the scale of Chinese investment has increased year by year, employing hundreds of thousands of local workers (Li et al., 2020). With the support of Chinese capital and technology, the industrial structure of the countries along the route has become more complete, and the advantageous production capacity has been shown. At the same time, the digital B&R cooperation has also blossomed in the countries along the route, and the digital trade dominated by e-commerce has been booming, promoting the development of business tourism in various countries (De Soyres et al., 2019).

## 6 Conclusion

In this study, the MRIO model (Chen and Han, 2015) is used to estimate the ITCF along the B&R, its inflow and outflow rule and transfer rule are also analyzed, and the panel model is used to discuss the influencing factors of the ITCF. Results show that the ITCF along the B&R region accounted for 37.82%–40.74% of the global total between 2005 and 2015.

Results show that the BRI has changed the ITCF along the B&R regions and the ITCF increased continuously from 2005 to 2015, with an average annual growth rate of 3.22%, indicating the pressure of tourism development on climate change mitigation. Tourism development distribution of the countries along the B&R region has also been changed with China (35.67 Mt), Turkey (32.79 Mt), Russia (26.93 Mt), Thailand (24.74 Mt) and Hong Kong, China (21.98 Mt) being the top five countries (regions) along the B&R in terms of ITCF in 2015. In general, the inflow of ITCF along the B&R regions was relatively dispersed, the outflow of ITCF along the B&R regions was highly concentrated. Macao, Malaysia, Thailand, Hong Kong, China and Turkey were the countries/regions with net ITCF inflows in 2015.

There is little difference in the impact of income level on ITCF among countries/regions along the B&R, ranging from 0.307 to 0.387. Urbanization rate is an important factor affecting the ITCF (0.439), especially in low-income countries, which is as high as 0.820, indicating that the higher the urbanization rate of countries, the larger the ITCF and the higher the carbon emissions of tourism industry. The influence coefficient of air passenger volume on ITCF is 0.118.

The research reveals that countries and regions along the B&R should consider the carbon burden brought by the development of the tourism industry when formulating tourism industry development strategies. In order to meet the challenge of climate change mitigation brought by carbon emissions from the tourism industry, tourists should be encouraged to choose more environmentally friendly ways to travel. Tourist destinations are advised to increase green public transport systems. In addition, referring to some international deals, such as the European Green Deal (Rosselló et al., 2024), relevant countries and regions are encouraged to take an active role in the tourism carbon footprint transfer in the B&R region, and jointly promote the development of green and low-carbon tourism by formulating policies, providing financial support, strengthening publicity and education, developing international tourism carbon tax and tourism carbon trading

systems and promoting international cooperation to limit the future growth of tourism-related carbon emissions in the B&R region.

Generally speaking, most of these regions are developing countries, the analysis of the carbon emission rules of tourism industry in this region is of great significance for understanding the mitigation of climate change in the tourism industry. However, due to the time-lag of input-output table, this paper only focused on the carbon footprint of international tourism along the B&R regions from 2005 to 2015. How to simulate the future carbon footprint of international tourism through historical rules becomes the focus of future research. The MRIO model in this study also has some limitations. First, there is a time lag of EORA database generated by MRIO model; Second, the MRIO model is still a statistical model that complies with accounting standards, and is mostly used for macro-scale research. In the future, mixed experiments should be adopted to explore the scientific issues of the carbon footprint of international tourism. In addition, this paper mainly focuses on the carbon footprint of international tourists, and the carbon footprint of domestic tourists has not been studied due to the missing data. Relevant scientific issues and rules of domestic tourism carbon footprint should be explored from the perspective of domestic tourists.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

## Author contributions

HS: Conceptualization, Data curation, Funding acquisition, Methodology, Supervision, Writing–original draft, Writing–review and editing. QL: Methodology, Formal analysis, Resources, Writing–review and editing. RY: Data curation, Formal Analysis, Software, Writing–original draft. TL: Formal Analysis, Supervision, Visualization, Writing–review and editing. NC: Conceptualization, Project administration, Supervision, Writing–review and editing. YR: Supervision, Visualization, Writing–review and editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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