



Characteristics, decoupling effect, and driving factors of regional tourism's carbon emissions in China

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Abstract

By revealing the temporal and spatial differentiation of China's regional tourism carbon emissions and its decoupling relationship with tourism economic growth and identifying the key factors affecting tourism carbon emissions, this paper is expected to provide a reference for the formulation and implementation of China's regional tourism industry emission reduction policies and measures. Using the tourism's carbon emission data of 30 provinces (cities) in China from 2007 to 2019, we have established a logarithmic mean Divisia index (LMDI) model to identify the main driving factors of carbon emissions related to tourism and a Tapio decoupling model to analyze the decoupling relationship between tourism's carbon emissions and tourism-driven economic growth. Our analysis suggests that China's regional tourism's carbon emissions are growing significantly with marked differences across its regions. Although there are observed fluctuations in the decoupling relationship between regional tourism's carbon emissions and tourism-driven economic growth in China, the data exhibit a primary characteristic of weak decoupling. Nonetheless, the degree of decoupling is rising to various extents across regions. Three of the five driving factors investigated are also found to affect emissions. Both tourism scale and tourism consumption lead to the growth of tourism's carbon emissions, while energy intensity has a significant effect on reducing emissions. These effects differ across regions.

Keywords Tourism · Carbon emission · Decoupling effect · Factor decomposition · LMDI model · China

Introduction

The rise in carbon emissions is a major contributor to global climate change. It is expected that global tourism's carbon emissions will continue to grow at a rate of 2.5% per year until 2035 (Castellani and Sala 2010). As one of the most resilient economic sectors in the world, tourism also exacerbates environmental pressure. Statistics show that this sector has contributed 8% to the total global greenhouse gas emissions in 2013. As a major contributor to the world economy,

China occupies a pivotal position in the global tourism market. In 2019, China's tourism revenue reached 6.63 trillion-yuan, accounting for 11.05% of its GDP. The resulting energy consumption and the carbon emissions generated to meet the needs of tourists, however, cannot be ignored. Due to this presence, China naturally becomes an integral part of achieving global carbon reduction targets. Low-carbon developments within China's tourism industry are not only instrumental for achieving high-quality economic development, but also an inevitable path for China as it seeks to achieve the goals of "carbon peak" and "carbon neutrality". To realize these goals, it will be imperative to have a better understanding of the driving factors of tourism's carbon emissions in China, and how these factors impact tourism-driven economic growth.

Based on the above background, this paper uses the bottom-up method to measure the carbon emissions of tourism in 30 provinces (cities) in China from 2007 to 2019. The LMDI model is introduced to identify the main driving factors of tourism's carbon emissions and the Tapio decoupling

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model is applied to analyze the decoupling relationship between tourism's carbon emissions and tourism-driven economic growth. It aims to provide a reference for the formulation and promotion of regional tourism emission reduction policies and measures in China. The specific research objectives are: (1) measure the carbon emissions of China's regional tourism and reveal its temporal and spatial differentiation laws; (2) analyze the decoupling relationship between China's regional tourism carbon emissions and tourism economic growth; (3) explore in-depth the key factors affecting carbon emissions of China's regional tourism.

Literature review

With the increasing global environmental crisis, society and academia have paid great attention to the issue of carbon emissions. Once referred to as the 'smoke-free industry', tourism is an essential engine of global economic growth; however, as the industry continues to expand in size, the 'smoke-free' characteristics gradually become less apparent and the negative environmental impacts progressively expand. Determining the characteristics of tourism carbon emissions and their relationship with tourism economic development and exploring the related factors that affect them have become a research focus.

The literature on tourism's carbon emissions assessment can be traced back to the preliminary studies of Carlsson-Kanyama and Lindén (1999) and Schafer and Victor (1999) on energy consumption and carbon emissions generated in tourism. The last two decades have seen more in-depth research on this field, with an expansion in the research scope. Overall, most scholars use the top-down and bottom-up methods (Gössling et al. 2004) to measure carbon emissions in tourism from different scales. For example, Lenzen et al. (2018) and Balsalobre-Lorente et al. (2020) evaluated tourism carbon emissions from a global perspective. They proposed that there is an inverted U-shaped relationship between international tourism and carbon emissions, and most of the global tourism carbon emissions are mainly generated by high-income countries. Katircioglu et al. (2014), Liu et al. (2019), and Meng et al. (2017) explored the tourism carbon emissions at the national scale and confirmed that the tourism carbon emissions are increasing year by year. Huang et al. (2019) and Tian and Ding (2018) studied the tourism carbon emissions at the provincial scale and analyzed their temporal and spatial characteristics. Some scholars also evaluated the related carbon emissions of tourist attractions (He et al. 2021), tourist transportation (Ma et al. 2019), and tourist accommodation (Liu et al. 2017) at the departmental scale.

Based on the evaluation results of tourism carbon emissions, some scholars further explore the relationship between tourism carbon emissions and tourism economic growth. Among them, the decoupling model has been widely used as it can measure the relationship between economic development and environmental stress in a more scientific manner. For example, Huang et al. (2021) and Hu and Hu (2019) conducted an in-depth analysis of the decoupling state of tourism carbon emissions in the Yellow River Basin and Tibet based on the Tapio decoupling model, respectively. Weng et al. (2021) used the Tapio decoupling model to study the decoupling characteristics of China's tourism carbon emissions and found that the tourism industry's carbon emissions are generally featured by weak decoupling. In contrast, Li et al. (2021) and Cheng et al. (2020) found that the decoupling of China's carbon emissions was dominated by expansive coupling. Besides, different attempts have also been made (Zhang and Liu 2015; Ma and Qing 2021; Sun and Yang 2020) to construct the decoupling model.

With increasing research, studies on the factors affecting tourism carbon emissions have gradually become the research focus. For example, Robaina-Alves et al. (2016) and Qiu et al. (2017) examined the factors affecting carbon emission in Portuguese and China tourism separately by exponential decomposition, and found that tourism scale is a key factor in driving the growth of carbon emissions in the tourism industry. Tang et al. (2017) found that energy structure and output scale are important contributors to curb the growth of tourism carbon emissions. Zha et al. (2018) and Sun and Yang (2020) identified that elements such as energy intensity, tourism added value, sector structure, and technology effects were also dominant factors in promoting and suppressing overall tourism carbon emissions in China. And based on the Geodetector model, Pan et al. (2021) explored the influencing factors of tourism carbon emissions. They found that the core influencing factors were technological innovation, economic development, urbanization, environmental pollution control, and industrial structure, in descending order of importance.

The advancement of research in this field has laid a strong foundation for the study of tourism's carbon emissions in China. However, in the existing research literature, the studies exploring the effects of tourism carbon emission decoupling based on tourism carbon emission computation are mostly limited to specific regional levels, with relatively few and less complete studies of various provinces across the country. The focus should also be put on the impact of different factors at the provincial levels rather than the China tourism market as a whole. This paper will address these research gaps by using a decoupling model and LMDI method to carry out a systematic study on China's regional tourism's carbon emissions.

Methods and data

Data collection

This study uses panel data from 30 provinces in China in the period from 2007 to 2019. Data of Hong Kong, Macao, Taiwan and Tibet are excluded due to missing observations. Statistics on the number of Chinese and foreign tourists, tourism income, passenger turnover of all means of traffic come from *China Statistical Yearbooks*, the statistical yearbooks and bulletins of each province; the number of beds and rental rate of star-rated hotels come from *China Tourism Statistical Yearbook*, *China Tourism Statistical Bulletin*, *China Urban Statistical Yearbook*; the proportion of tourists participating in various tourism activities comes from the *Sample Survey Report of Inbound Tourists* and *Sample Survey Report of Domestic Tourists*.

Methods

Estimation of tourism's carbon emissions and energy consumption

At present, the measurement methods of tourism carbon emissions mainly include the top-down method and the bottom-up method. The top-down approach is primarily estimated with the help of tourist satellite accounts, which are difficult to calculate directly owing to missing data on China's tourist satellite accounts. In contrast, the bottom-up method (Shi and Wu 2011) can not only better compensate for the difficult access to data, but also accurately reflect the contributions of various major sectors to tourism carbon emissions, leading to the development of more targeted abatement measures. Therefore, this paper will use the bottom-up method to estimate tourism's carbon emissions in China. Based on the existing literature, three key areas of tourism's carbon emissions are identified, namely tourism transportation, tourism activities, and tourism accommodation. In this study, carbon emissions and energy consumption of tourism will be constructed through a composite measure consisting of these three components. The formulas are as follows:

$$C = C_1 + C_2 + C_3 \quad (1)$$

Where C is the total carbon emissions and energy consumption of tourism; C_1 , C_2 , and C_3 are respectively the carbon emission and energy consumption of tourism transportation, tourism accommodation, and tourism activities.

$$C_1 = \sum_{i=1}^{30} \sum_{x=1}^4 R_{xi}^t \cdot f_x \cdot \alpha_x \quad (2)$$

Where C_1 is the total carbon emissions/energy consumption of tourism transportation; x represents four modes of transportation, namely railway, highway, air, and water transportation; R_{xi}^t is the passenger turnover of various modes of transportation in each province; α_x denotes the carbon emissions and energy consumption coefficient of type x transportation modes; f_x represents the proportion of tourists in all types of passenger traffic. According to the actual situation of China's tourism industry and the existing research results, the carbon emissions coefficient of railway, highway, air, and water transportation is 27 gCO₂/pkm, 133 gCO₂/pkm, 137 gCO₂/pkm, 106 gCO₂/pkm, and the energy consumption coefficient is 1 MJ/pkm, 1.8 MJ/pkm, 2 MJ/pkm, 0.9 MJ/pkm, respectively (Kuo and Chen 2009; Shi and Wu 2011); the tourist proportion of railway, highway, air, and water transportation is 31.6%, 13.8%, 64.7%, and 10.6%, respectively (Wei et al. 2012).

$$C_2 = \sum_{i=1}^{30} N_i^t \cdot l_i^t \cdot \delta \cdot n \quad (3)$$

Where C_2 is the total carbon emission and energy consumption of tourism accommodation; N_i^t is the number of beds in star-rated hotels in each province; l_i^t is the average room occupancy rate of each province; δ represents the carbon emission/energy consumption coefficient per bed per night, the carbon emission coefficient was 2.458, the energy consumption coefficient is 155 MJ per bed per night (Shi and Wu 2011); n is the number of days the hotel operates, which is set to 365 days.

$$C_3 = \sum_{i=1}^{30} \sum_{m=1}^5 Q_{im}^t \cdot \gamma_m \quad (4)$$

Where C_3 is the total carbon emissions and energy consumption of tourism activities; m refers to five types of tourism activities, namely leisure vacation, sightseeing, business trip, visiting relatives and friends, etc.; Q_{im}^t is the number of tourists participating in various activities in each province; γ_m is the carbon emissions and energy consumption coefficient of various tourism activities. According to research (Shi and Wu 2011), the carbon emission coefficient of the above-mentioned activities is 1670 gCO₂/per, 417 gCO₂/per, 786 gCO₂/per, 591 gCO₂/per, 172 gCO₂/per, and the energy consumption coefficient is 26.5 MJ/per, 8.5 MJ/per, 16 MJ/per, 12 MJ/per and 3.5 MJ/per, respectively.

Tapio decoupling model

The concept of "decoupling" was first proposed in the 1960s and has been widely used in agricultural policy, economics, and other research fields. Currently, the relatively widely

used analytical decoupling models in academia mainly include the OECD model and the Tapio model. Among them, the calculation results of the OECD model would be considerably biased under the influence of different time base period choices. And the Tapio model can improve the stability and accuracy of the calculation results by dimensionless data processing. Therefore, this paper chose the Tapio model to measure the relationship between tourism carbon emissions and tourism economic growth. According to the value of decoupling elasticity, the decoupling state can be divided into eight types (Tapio 2005), as shown in Table 1.

Based on the Tapio model, this paper analyzes the decoupling relations between regional tourism’s carbon emissions and tourism-driven economic growth in China. The formula is as follows:

$$e = \frac{\Delta C/C}{\Delta G/G} \tag{5}$$

Where e is the elasticity of decoupling; C is tourism's carbon emissions; ΔC is the change in carbon emissions; G is the tourism-driven economic growth, expressed in tourism revenue; ΔG is the change in tourism-driven economic growth.

Factor decomposition of tourism’s carbon emissions

At present, scholars have done a systematic analysis of the factors affecting carbon emissions applying a large number of methods. The commonly used research methods include the Geo detector, the IPAT model, the GMM dynamic regression model, the STIRPAT model, Dee’s exponential decomposition method and others. Among them, Dee’s exponential decomposition method, which allows simultaneous time series analysis and cross-regional comparisons, has been increasingly used (Alajmi 2021; Lisaba and Lopez 2021). Compared with other methods, the LMDI method (Ang and Lee 1994) has a simple calculation process and intuitive decomposition results. It has obvious advantages in adaptability and result display, and is the most widely used. Therefore, this paper adopted the LMDI method to analyze the driving factors of tourism's carbon emissions.

Based on Kaya identity, the LMDI multi-dimensional factor decomposition model is shown as follows:

$$C = \frac{C}{E} \times \frac{E}{G} \times \frac{G}{P} \times \frac{P}{S} \times S = \beta_0 \times \beta_1 \times \beta_2 \times \beta_3 \times \beta_4 \tag{6}$$

Where C is the carbon emission of tourism; E is the energy consumption of tourism; G is the tourism revenue; P is the number of tourists; S is the total population of the region; β_0 is the carbon emission coefficient factor of tourism, expressed as the ratio of tourism’s carbon emissions to energy consumption; β_1 is the tourism energy intensity factor, expressed in energy consumption per unit of tourism income; β_2 is the tourism consumption level factor, expressed in per capita tourism consumption; β_3 is the tourism scale factor, expressed by the ratio of tourist numbers to the total population; β_4 is the regional population factor, expressed by the total population of the region.

Using the LMDI additive decomposition approach, tourism's carbon emission increment C can be decomposed into the sum of carbon emission coefficient effect ($\Delta\beta_0$), tourism energy intensity effect ($\Delta\beta_1$), tourism consumption level effect ($\Delta\beta_2$), tourism scale effect ($\Delta\beta_3$) and regional population effect ($\Delta\beta_4$).

$$\Delta C = \Delta\beta_0 + \Delta\beta_1 + \Delta\beta_2 + \Delta\beta_3 + \Delta\beta_4 \tag{7}$$

In addition, according to the formula of the Tapio decoupling model, the decoupling index of tourism's carbon emissions and tourism-driven economic growth can be decomposed into:

$$e = \Delta C \times \frac{G}{C \times \Delta G} = (\Delta\beta_0 + \Delta\beta_1 + \Delta\beta_2 + \Delta\beta_3 + \Delta\beta_4) \times \frac{G}{C \times \Delta G} = \frac{\Delta\beta_0 \times G}{C \times \Delta G} + \frac{\Delta\beta_1 \times G}{C \times \Delta G} + \frac{\Delta\beta_2 \times G}{C \times \Delta G} + \frac{\Delta\beta_3 \times G}{C \times \Delta G} + \frac{\Delta\beta_4 \times G}{C \times \Delta G} = \epsilon_0 + \epsilon_1 + \epsilon_2 + \epsilon_3 + \epsilon_4 \tag{8}$$

Where ϵ_0 is the decoupling index of tourism's carbon emission coefficient; ϵ_1 is the decoupling index of tourism energy intensity; ϵ_2 is the decoupling index of tourism consumption level; ϵ_3 is the index of tourism scale decoupling; ϵ_4 is the index of regional population decoupling. Due to space limitations, the specific decomposition process is not described here.

Table 1 Decoupling state type

Decoupling state		$\Delta C/C$	$\Delta G/G$	Elasticity e
Negative decoupling	Expansion negative decoupling	+	+	$e > 1.2$
	Strong negative decoupling	+	-	$e < 0$
	Weak negative decoupling	-	-	$0 \leq e < 0.8$
Decoupling	Weak decoupling	+	+	$0 \leq e < 0.8$
	Strong decoupling	-	+	$e < 0$
	Recession decoupling	-	-	$e > 1.2$
Connection	Expansive coupling	+	+	$0.8 \leq e < 1.2$
	Recessive coupling	-	-	$0.8 \leq e < 1.2$

Results

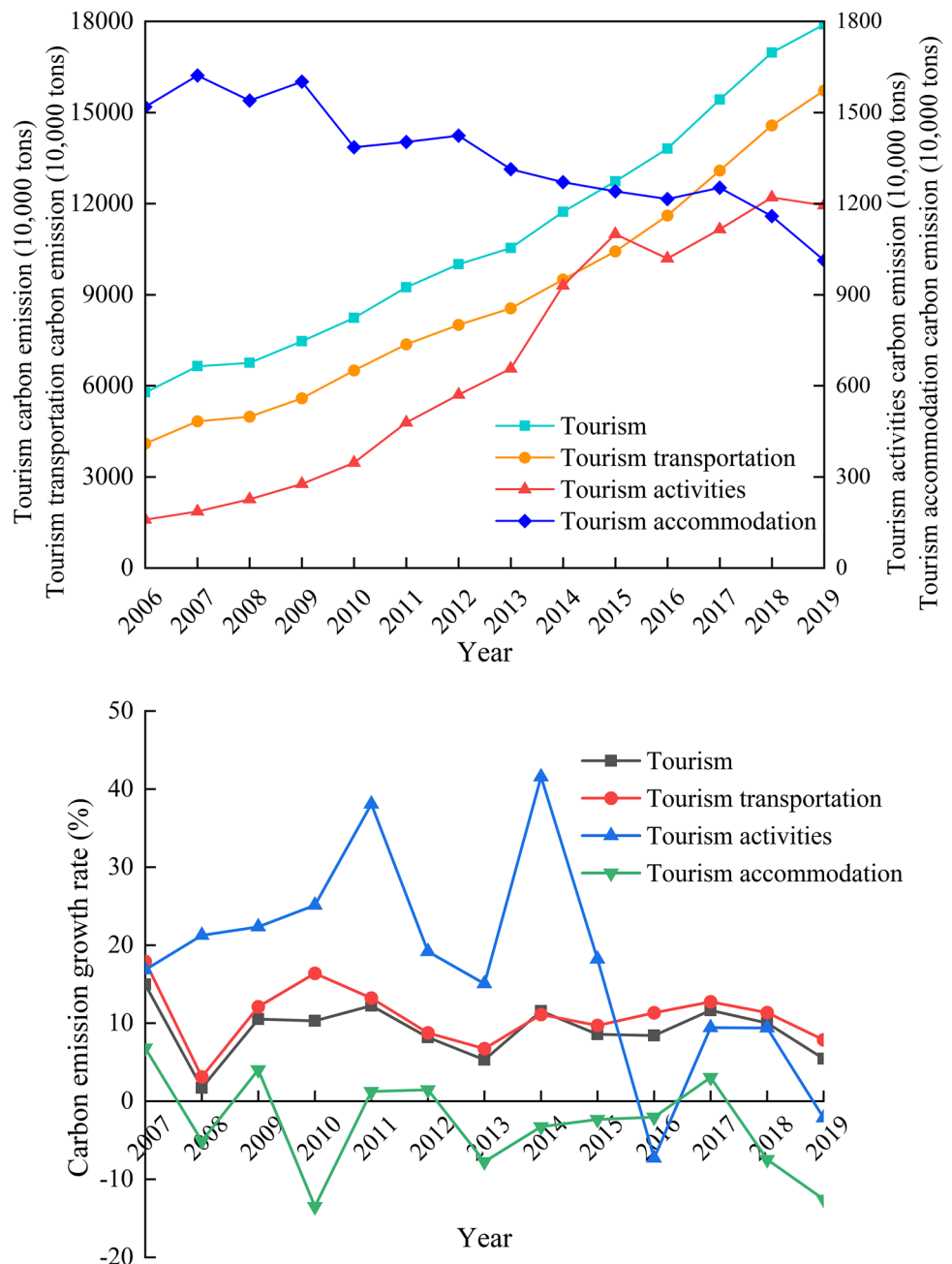
Analysis on the carbon emission situation of China's regional tourism industry

Timing difference in China's regional tourism carbon emissions

Based on formulas (1) to (4), the carbon emissions of China's regional tourism and its various sectors are calculated (see Fig. 1). As the figure suggests, the carbon emissions of tourism in 2019 is 179.31 million tons, 2.7 times over the 2007 figures,

constituting an average annual growth rate of 9.15%. The carbon emissions caused by tourism transportation, tourism accommodation, and tourism activities account for 87.69%, 5.65%, and 6.66% of the total tourism's carbon emissions respectively. From 2007 to 2019, the total carbon emissions of China's regional tourism industry have also been on the rise, as the tourism industry has promoted the development of related industries, intensifying CO₂ emissions. Tourism transportation accounts for 72% to 88% of carbon emissions in the tourism industry across the studied period. Due to this dominant presence, the focus of tourism's carbon emission reduction will likely be focused on tourism transportation in the future. The

Fig. 1 Total carbon emissions of regional tourism and various sectors in China from 2007 to 2019



overall carbon emission of tourism accommodation, however, demonstrates a fluctuating downward trend, accounting for 24.4% at its peak. This is not surprising as there is an increasing acceptance of energy-saving and emission reduction measures in accommodation facilities and an increasing tendency of large-scale operation of the tourism accommodation industry, bringing advances in the efforts of controlling carbon emissions. Tourism activities account for the smallest proportion of carbon emissions and show a fluctuating upward trend during the studied period. This is probably due to the differences in consumption and travel purpose of tourists in different periods. Overall, the factor input and carbon emissions of tourism activities are increasing year by year, suggesting that the environmental problems caused by tourism activities need greater attention.

Spatial difference in China's regional tourism's carbon emissions

As can be seen from Table 2, there are significant differences in tourism's carbon emissions among China's provinces in the year 2019. Among them, tourism's carbon emissions of Guangdong (26.43 million tons), Shanghai (21.53 million tons) and Beijing (19.15 million tons) are much higher than other provinces. Together, they account for 37.42% of the national tourism's carbon emissions. Qinghai has the lowest carbon emissions of 0.73 million tons, equivalent to 0.4% of the nation's total. Carbon emissions in the eastern and western regions account for 89.62% of the total. The high concentration of carbon emissions in these regions is expected as provinces in eastern China are more economically developed while provinces in western China have become attractive tourist destinations due to their enhanced infrastructure and investment in tourism. However, it's shown that the central region has the highest carbon emission intensity, followed by the western region and finally the eastern region. There are also wide-ranging differences among the provinces. For example, Jiangxi has the highest carbon emission intensity of 42.1 tons per 10,000 yuan, while Hainan has the lowest carbon emission intensity of only 1.3 tons per 10,000 yuan.

Decoupling effect and driving factors of China's regional tourism's carbon emissions

Temporal and spatial characteristics of carbon emission decoupling in China's regional tourism industry

Based on the Tapio decoupling model, the carbon emission decoupling index and its temporal changes in China's regional tourism industry from 2007 to 2019 can be calculated, as shown in Table 3. As can be seen, the decoupling index of the regional tourism's carbon emissions fluctuates across the studied period, with the highest being 0.698 and the lowest at -1.606 . The key driving factors of the decoupling elasticity, tourism consumption

Table 2 Carbon emissions and carbon intensity of tourism in 30 provinces (cities) in China in 2019

Region	Province	Carbon emissions (10,000 tons)	Carbon emission intensity (tons/ten thousand yuan)
Eastern	Beijing	1914.6	3.3
	Fujian	652.3	11.7
	Guangdong	2643	5.7
	Hainan	794.1	1.3
	Hebei	338.7	27.5
	Jiangsu	381.7	37.3
	Liaoning	345.4	18
	Shandong	989.2	11.2
	Shanghai	2152.8	2.5
	Tianjin	310.1	13.9
Central	Zhejiang	763.4	14.3
	Anhui	214.8	39.7
	Henan	394.2	24.3
	Heilongjiang	487	7.2
	Hubei	336	20.6
	Hunan	389.1	20.6
	Jilin	117.5	41.9
	Jiangxi	229.4	42.1
	Shanxi	418.6	19.2
	Western	Gansu	116.1
Guangxi		603.3	17
Guizhou		368.4	33.4
Inner Mongol		279.8	16.6
Ningxia		73.4	4.6
Qinghai		73	7.7
Shaanxi		333.5	21.6
Sichuan		1128.9	10.3
Xinjiang		262.9	13.8
Yunnan		300.3	36.7
Chongqing	519.3	11.1	

level, tourism scale, and regional population elasticity all have positive effects on the decoupling index of tourism's carbon emissions. In addition, the tourism consumption level and tourism scale elasticity are higher than the decoupling elasticity of tourism's carbon emissions during the studied period, indicating that these two are the main factors affecting the decoupling state. The overall elasticity of energy intensity and tourism's carbon emission coefficient is negative, playing an important role in curbing tourism's carbon emissions. Overall, tourism's carbon emissions were experiencing weak decoupling. The strong negative decoupling in 2009 was mainly caused by the rapid decline of the tourism industry in these 2 years.

To further illustrate the differences of tourism's carbon emission decoupling effect across regions, we dissected the research period into three sub-stages: 2007–2010, 2010–2015, and 2015–2019, with a view to exploring the changing

Table 3 Decoupling characteristics and driving factors decoupling elastic changes of regional tourism carbon emissions in China from 2007 to 2019

Year	$\Delta C/C$	$\Delta G/G$	e	Decoupling characteristics	$\Delta\beta_0$ Elasticity	$\Delta\beta_1$ Elasticity	$\Delta\beta_2$ Elasticity	$\Delta\beta_3$ Elasticity	$\Delta\beta_4$ Elasticity
2007	0.150	0.223	0.670	Weak decoupling	-0.000	-0.062	0.044	2.468	0.008
2008	0.017	0.464	0.037	Weak decoupling	-0.027	-0.338	0.245	0.129	0.008
2009	0.105	-0.066	-1.606	Strong negative decoupling	-0.007	0.161	-0.263	0.188	0.007
2010	0.103	0.251	0.411	Weak decoupling	-0.024	-0.102	0.052	0.165	0.005
2011	0.122	0.251	0.488	Weak decoupling	-0.005	-0.103	0.002	0.217	0.006
2012	0.082	0.256	0.321	Weak decoupling	-0.002	-0.147	0.142	0.080	0.005
2013	0.053	0.158	0.336	Weak decoupling	0.066	-0.162	-0.040	0.182	0.005
2014	0.113	0.162	0.698	Weak decoupling	-0.001	-0.038	-0.005	0.150	0.006
2015	0.086	0.160	0.537	Weak decoupling	0.019	-0.085	0.035	0.107	0.006
2016	0.085	0.177	0.478	Weak decoupling	0.008	-0.090	0.017	0.140	-0.001
2017	0.117	0.223	0.523	Weak decoupling	0.011	-0.102	0.046	0.156	0.013
2018	0.100	0.190	0.530	Weak decoupling	0.007	-0.085	0.039	0.122	0.005
2019	0.054	0.173	0.315	Weak decoupling	0.001	-0.107	0.031	0.123	0.008

characteristics of tourism's carbon emission decoupling types during the 11th, 12th, and 13th Five-Year Plans in China. According to the experience of developed countries, the decoupling index generally goes through a process of "strong decoupling - weak decoupling - negative decoupling - strong decoupling" (Tang 2015). However, it can be observed that most provinces in China were still in a weak decoupling state from 2007 to 2019.

- (1) From 2007 to 2010, only Hebei, Jiangsu, Sichuan, and Yunnan showed strong decoupling, accounting for 13.3% of the total. This indicates that tourism's carbon emissions and tourism-driven economy in these regions have gradually stepped into the coupling stage. Beijing was in the state of expansive coupling, while other provinces were in a weak decoupling state. Among all provinces, Jiangsu had the highest degree of decoupling, while Beijing had the lowest, with the decoupling elasticity indexes of -0.173 and 1.033 respectively.
- (2) From 2010 to 2015, the provinces with strong decoupling states in the previous stage all transitioned to weak decoupling states. Tianjin, Liaoning, and Shanghai all showed expansive negative decoupling, while Chongqing showed growth and connection. Among all provinces, the highest degree of decoupling was in Xinjiang, and the lowest was in Chongqing, with a decoupling index of 0.112 and 0.838, respectively.
- (3) From 2015 to 2019, only Jilin showed strong decoupling, and its degree of decoupling was the highest, with a decoupling index of -0.007. Beijing, Shanghai, and Shandong showed expansive coupling, while Guangdong turned from a weak decoupling to an expansive negative decoupling, and its degree of decoupling was the lowest, with a decoupling index of 1.243. The remaining provinces were in a weak decoupling state.

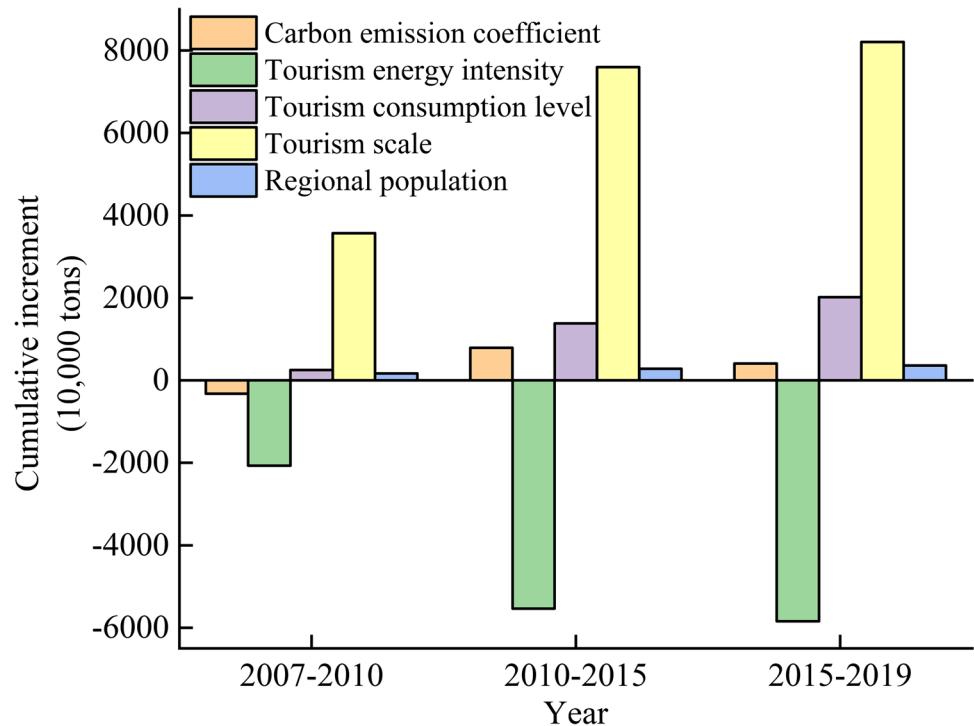
Decomposition of driving factors of regional tourism's carbon emissions in China

Across the country, the tourism scale effect is the main driver of the increasing emissions in tourism. Over the studied period, the figure has increased from 35.67 million tons to 82.08 million tons. The scale of tourism reflects the development level of tourism, and the negative impact on the environment is increasingly evident. Tourism consumption level is closely related to the tourism scale. It can be seen from Fig. 2 that the tourism consumption level effect also has an increasing influence on the change of tourism's carbon emissions, mainly because the increase of per capita consumption level makes people more likely to travel and consume. On the other hand, energy intensity has a significant negative effect on tourism's carbon emissions, with the cumulative change value moving from -20.67 million tons to -58.44 million tons. These observations suggest that the structure of tourism is constantly adjusted and optimized, and the energy efficiency is becoming more manageable. Regional population effect and carbon emission coefficient effect are found to have little effect on the change of tourism's carbon emissions, and similar trends are expected in the future.

To explore the differences in the effects of different factors in various provinces, the decomposition effects of tourism's carbon emission drivers at different periods in 30 provinces (cities) in mainland China were compared. This is shown in Fig. 3. Analysis shows that:

- (1) From 2007 to 2010, the regional tourism's carbon emissions in China increased by 15.94 million tons, of which Guangdong alone contributed 3.20 million tons, followed by Shanghai and Beijing. The key fac-

Fig. 2 Effect decomposition of regional tourism carbon emission change in China from 2007 to 2019



tor of the increased emissions in Guangdong was the tourism scale, while the main factors of the reduced emissions were tourism consumption level and energy consumption intensity. The regional population effect was a major contributor to the increase in tourism in Beijing. In Shanxi, the contribution value of tourism consumption level effect was negative, counteracting the positive effect of tourism scale. Tourism scale and energy intensity were the main factors that affected the carbon emissions of tourism in other provinces.

- (2) From 2010 to 2015, regional tourism's carbon emissions in China increased by 45.27 million tons. Guangdong's tourism's carbon emission increment continued to be at a high level, followed by Sichuan, Beijing, and Shanghai. The tourism consumption level effect strengthened, and the energy intensity had a significant negative effect on carbon emission. The decomposition effect of tourism's carbon emissions in Shanxi experienced significant changes compared to the previous period. The tourism consumption level effect and tourism scale effect, however, changed in the opposite direction. In other provinces, while the effect of each driver on tourism's carbon emissions had changed to some extent, the changing directions were similar to the previous stage.
- (3) From 2015 to 2019, the growth rate of regional tourism's carbon emissions in China slowed down, with an increment of 51.61 million tons. The highest incre-

ments came from Shanghai and Guangdong, reaching 7.76 and 7.46 million tons, respectively. The effects of tourism scale and tourism consumption level on tourism's carbon emission growth in Shanghai had strengthened, while the energy intensity effect on the tourism's carbon emissions in Guangdong had decreased significantly. At this stage, the level of tourism-related consumption played a certain role in promoting the growth of tourism's carbon emissions in Shanxi province, and the inhibiting effect of energy intensity on tourism's carbon emissions in this province had gradually strengthened.

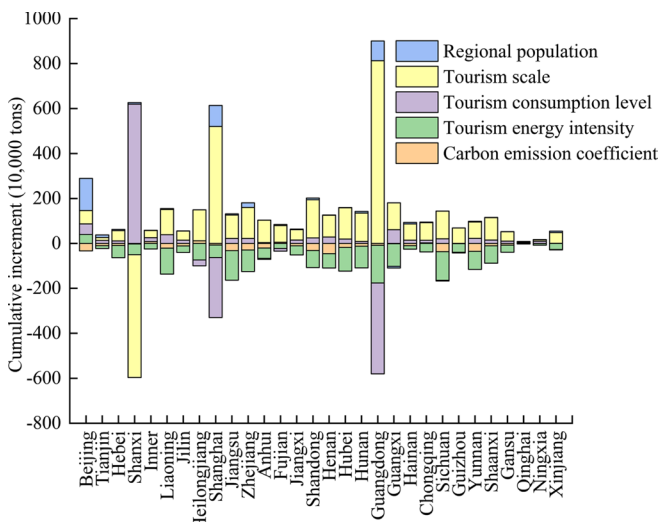
Conclusions and implications

Conclusion

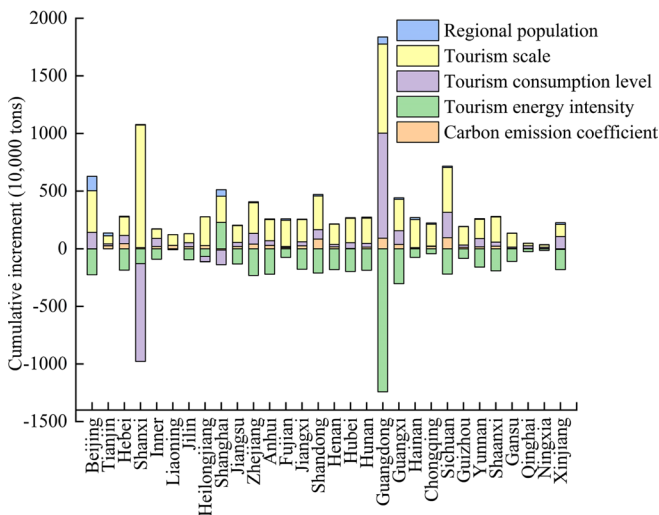
Like other traditional industries, China's tourism industry has experienced extensive development and brought about irreversible damages to the ecological environment. Due to the different resource endowments, economic and technological development levels across the regions of China, the extent of tourism's carbon emissions also differs to some extent. The main conclusions are as follows.

Regional tourism's carbon emissions in China are on the rise, with a large growth rate of 9.13% and marked differences across its regions in our studied period. Although there

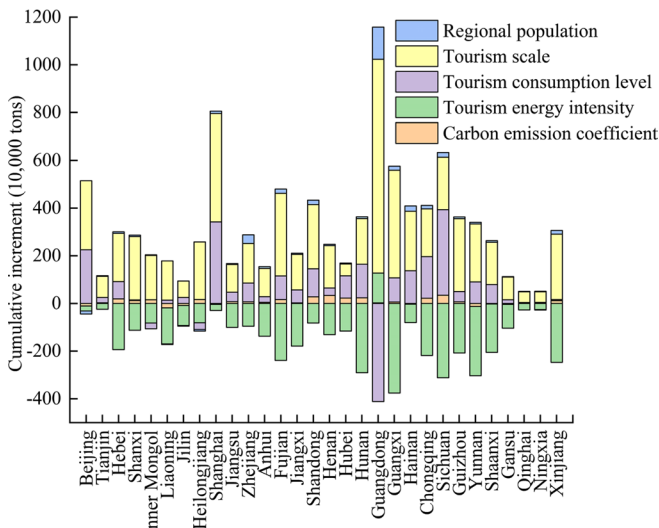
Fig. 3 Decomposition of tourism’s carbon emission drivers in 30 provinces (cities) in China from 2007 to 2019



(a) 2007 ~ 2010



(b) 2010~2015



(c) 2015~2019

are observed fluctuations in the decoupling relationship between regional tourism's carbon emissions and tourism-driven economic growth in China, the data suggest that the overall characteristic is still weak decoupling. Nonetheless, the degree of decoupling is rising to various extents across regions. Three of the five driving factors investigated are also found to affect on emissions. Both tourism scale and tourism consumption lead to the growth of tourism's carbon emissions, while energy intensity has a significant effect on reducing emissions. These effects differ across regions.

The following similarities and differences exist between our conclusions with previous studies. Through the calculation and analysis of China's regional tourism carbon emissions, it is found that of the three main tourism sectors, transportation is the primary source of tourism carbon emissions, accounting for 72–88%. This is consistent with estimates by Gössling et al. (2005) and Liu et al. (2019), who found that tourism transportation carbon emissions account for 60–95% of total tourism carbon emissions. Further, there are significant regional differences observed — some economically developed provinces in eastern China and traditional tourism provinces in western China have much higher carbon emissions from tourism than other provinces. And regional tourism's carbon emission intensity of China is found to be highest in the central region, followed by the western region and finally the eastern region (Zhang and Liu 2015). Tourism scale and energy intensity contribute significantly to changes in tourist carbon emissions. However, we found that although there are observed fluctuations in the decoupling relationship between regional tourism's carbon emissions and tourism-driven economic growth in China, the data suggest a key feature of weak decoupling. This is inconsistent with the research conclusions of Li et al. (2021) and Cheng et al. (2020), who found that China's carbon emissions is predominately featured by expansive coupling. Meanwhile, we also found that there are obvious differences in the extent to which different influencing factors contribute to tourism carbon emissions in various provinces. In particular, the differences in positive and negative driver effects are greater in Beijing, Shanxi, Shanghai and Guangdong. This enriches relevant studies to some extent.

Our study has two limitations. First, due to limited data access, the analysis is only conducted at the provincial level. In the future, with the possibility of data access, we can further analyze at the county and city levels to go deeper to identify the drivers and possible ways of reducing tourism's carbon emissions across China. Second, the content and influencing factors of tourism's carbon emissions are by no means comprehensive in this study. Although the tourism's carbon emission measurement already includes the main areas of the tourism industry, its carbon emissions, and influencing factors are far greater than what we have covered and potentially even more complex at different levels

of analysis within tourism. Nonetheless, we believe we have covered the key factors identified in the literature and thus provide a parsimonious model here. Future research should consider a wider range of aspects of the tourism industry for such investigation.

Implications

Tourism is not a smoke-free industry, and tourism's carbon emissions in China have not yet reached their peak. To achieve the leap from a weak decoupling to a strong decoupling, effective policy measures and joint efforts from multiple parties are needed. Therefore, it is necessary to consider the actual development of tourism in each province and chart the optimal path of low-carbon tourism development according to local conditions.

Optimizing the structure of the tourism industry will provide strong support to achieve low-carbon development for the industry. In recent years, the total carbon emissions of regional tourism in China have increased rapidly. To prevent the aggravation of environmental problems, we must pay attention to the optimization of the layout of tourism. All regions should focus on energy conservation and emissions reduction. Particular attention should be paid to provinces with high total and intensity of tourism's carbon emissions. For example, in the eastern region, Beijing, Shanghai, and Guangdong are the key provinces to focus on carbon emission reduction. Low-carbon tourism economic development should be regarded as an important condition, and the suppressive effect of environmental regulations on tourism carbon emissions should be maximized (Yang and Wang 2021). In western China, tourism's carbon emission reduction is mainly concentrated in Sichuan, Chongqing, Guizhou, and other traditional tourism provinces. For these provinces, the structure of tourism and related industries can be optimized accordingly to the different resource endowments and regional development levels. The central region should improve the utilization efficiency of tourism resources while promoting large-scale and high-quality tourism development.

Accelerating the adjustment of energy structure is the key to realizing the low-carbon development of tourism, as energy intensity has a significant inhibitory effect on tourism's carbon emissions. Creating a clean and efficient environment and improving the efficiency of energy use is crucial to the low-carbon development of the tourism industry. As an important field of energy conservation and emission reduction in tourism, the energy utilization efficiency of passenger transport cannot be ignored. All regions should actively promote the development of low-carbon transportation by reforming the mode of tourism transportation and increasing the use of clean energy vehicles (Wang et al. 2020). For the tourism accommodation

industry, it is necessary to reduce energy consumption by upgrading energy-saving and emission reduction technologies and strengthening the management of the low-carbon accommodation industry. Finally, tourists should be educated to adopt a low-carbon tourism mentality, including guiding them towards low-carbon travel, green consumption, and other behaviors.

Coordinating regional tourism economic development is an important way to achieve low-carbon tourism development. The low-carbon and high-quality development of tourism cannot be achieved only with the efforts of one province. As there are significant differences in resource distribution and economic development across the provinces, it is particularly important to strengthen cooperation and promote the spatial turnover of resources, economy, technology and other elements (Cheng et al. 2020). For example, some provinces with higher tourism development levels in the eastern region can provide leadership to the surrounding provinces using their economic and technological advantages. Provinces in the central region, such as Anhui, Jiangxi, and Hubei, can make use of the policy advantages of the Yangtze River Economic Belt to build a regional tourism economic circle and formulate two-way tourism emission reduction measures. The western region can jointly build a characteristic tourism demonstration area through regional characteristics and advantages to make up for the adverse impacts of distance, transportation, and other factors on tourism development. In addition, attention should be paid to the coordination and cooperation within provinces to achieve an overall high-quality tourism development.

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Declarations

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