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Study on Spatial-Temporal Evolution, Decoupling Effect and Influencing Factors of Tourism Transportation Carbon Emissions: Taking North China as an Example

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Abstract: As global warming intensifies, reducing carbon emissions has become a global common mission. Tourism transportation is one of the important sources of carbon emissions, and reducing its carbon emissions is a key part of achieving China's carbon reduction goals. Based on the panel data of various provinces and cities in North China from 2000 to 2022, this paper calculates the carbon emissions of tourism transportation by using the carbon emission coefficients of different transportation modes in different segments. Moreover, the temporal and spatial evolution of the tourism economy is systematically analyzed. The Tapio decoupling model and LMDI addition decomposition model are used to analyze the relationship between carbon emissions and tourism economic growth and the effects of 11 influencing factors on carbon emissions. The results show that: (1) The carbon emission of tourism transportation in North China has experienced four stages: a steady growth period, a transitional adaptation period, a stable equilibrium period, and a drastic decline period. The overall carbon emission level of tourism transportation is as follows: Hebei Province > Shanxi Province > Inner Mongolia Autonomous Region > Beijing City > Tianjin City. (2) The decoupling coefficient between tourism traffic carbon emissions and economic development fluctuates but mainly shows a weak decoupling state. (3) In terms of influencing factors, passenger size and passenger density have the greatest impact on the carbon emissions of tourism transportation.

Keywords: tourism transportation carbon emissions; North China; space-time evolution; decoupling effect; influencing factor

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Citation: Feng, D.; Li, C.; Li, Y. Study on Spatial-Temporal Evolution, Decoupling Effect and Influencing Factors of Tourism Transportation Carbon Emissions: Taking North China as an Example. *Atmosphere* **2024**, *15*, 720. https://doi.org/10.3390/atmos15060720

Academic Editors: Lei Chen and Linyu Xu

Received: 17 May 2024
Revised: 8 June 2024
Accepted: 12 June 2024
Published: 15 June 2024

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1. Introduction

Unlike in the past, when tourism was a low-carbon and pollution-free industry [1–3], today's tourism industry not only receives a large number of tourists, more than 10 billion tourists but also a comprehensive industry integrating tourism, food, and accommodation [4]. According to the World Tourism Organization, global tourism carbon emissions have accounted for 5–14% of the total human carbon emissions. In tourism, the energy consumption of transportation is as high as 70%, which is the most fundamental source of carbon emissions [5,6]. The tourism system is the product of the interaction of the tourist's origin, destination, and route, while the traffic is the carrier that connects the starting point and the endpoint [7]. Transportation is the foundation of tourism promotion and an important driving force for tourism prosperity [8], with great potential for emission reduction [9,10]. In the low-carbon game and competition pattern, studying how to reduce the carbon emissions of tourism transportation is the fundamental way to achieve the carbon emission reduction of tourism [11], and it has also become an important issue related to environmental sustainability.

At present, there are few research studies on tourism transportation carbon emission, mainly focusing on the following: (1) Tourism carbon emission calculation: these include two calculation methods, the "top-down" method [12–15] and the "bottom-up" method [16,17]. On a national scale, domestic and foreign scholars mostly choose the

"bottom-up" approach (YORUCO [18], 2016; Hu, C. [19], 2022; Li, J.M. [20], 2024; Liu, J.H. [11], 2024) to calculate tourism transportation energy consumption and carbon emissions and research a regional basis, which has strong universality. (2) The influencing factors of tourism and transportation carbon emissions: the main research methods include LMDI model decomposition (Wang, L.G. [21], 2023; Sun, Y.Y. [15], 2020; Zhang, M. [22], 2011; Becken [5], 2003), the Kaya equation (Lin, Y. [23], 2023; Eskander [24], 2021; Ling, L.W. [25], 2017), and the Geographic detector (Wang, W. [26], 2024). (3) The relationship between tourism economic growth and carbon emissions: the decoupling model is mainly used to investigate the relationship between the rate of economic change and the rate of environmental factor change [27]. The decoupling model methods mainly include the OECD decoupling model (Lundquist [28], 2021) and the Tapio decoupling model (Liu, F. [29], 2022; Wang, Z. [30], 2022) [31].

To sum up, the existing research has important theoretical value for exploring the rules of carbon emissions from tourism and transportation, but compared with the research on carbon emissions from transportation, the research on carbon emissions from tourism and transportation is still weak. As an example, consider the following: (1) In terms of research objects, the research on the spatial correlation of tourism carbon emissions across administrative regions needs to be further deepened. (2) In terms of research methods, few papers combine spatial-temporal evolution and the decoupling effect to analyze a certain region. In addition, the research on effectively reducing the carbon emission of tourism transportation through policy and technical means is not deep enough. To sum up, the carbon emission from tourism transportation is an important issue that needs to be solved urgently in the field of tourism and environmental protection. In order to better cope with this challenge, the purpose of this paper is to strengthen further the research on the carbon emission of tourism transportation, in order to provide the scientific basis for policy formulation and industrial sustainable development.

North China, as the third largest region on an economic scale and the leading area for the construction of energy conservation and emission reduction ecological civilization, has a great difference in its development degree from the South. Its area accounts for about 10% of the total area of the country, its GDP accounts for 13.5% of the national GDP, and its carbon emissions account for about 26% of the national carbon emissions. The analysis of the temporal and spatial characteristics, the decoupling effect, and influencing factors in North China will provide important references for the formulation of regional ecological environmental protection and energy conservation and emission reduction policies and is of great significance for promoting the realization of the "dual carbon" goal and high-quality development in the region [10].

In addition, taking North China as the research object is not only to study tourism transportation carbon emissions based on the practical needs of regional characteristics and problems but also to deeply understand the influencing factors and trends of tourism transportation carbon emissions, to provide scientific support for environmental protection and sustainable development. First of all, North China is one of the most densely populated and economically developed regions in China, and the problems of traffic congestion and environmental pollution are more prominent. With the rapid development of tourism, the scale and frequency of tourism traffic are increasing, resulting in an increasingly prominent problem of carbon emissions. Second, the Chinese government has been committed to reducing carbon emissions and achieving carbon neutrality and has stepped up efforts to control carbon emissions. By choosing North China as the research object, we can further study the carbon emission of tourism transportation under the guidance of government policies, and provide a scientific basis for the formulation of carbon emission reduction policies. Most importantly, as the location of China's capital, Beijing, and the surrounding region, North China has a demonstration effect on government planning and policy implementation. The study on the carbon emission of tourism transportation in this region can provide a reference for other regions.

Therefore, this paper selects North China as the research object, sets different carbon emission calculation coefficients at different time points, uses the "bottom-up" proxy coefficient method to more accurately measure the carbon emission of tourism transportation in North China, and then systematically analyzes its spatial-temporal evolution. The Tapio decoupling model is used to verify the relationship between tourism transportation carbon emissions and tourism economic growth. Finally, a driving factor research framework is constructed, and the effects of 11 influencing factors are discussed through the LMDI additive decomposition model (Figure 1). The variables in Figure 1 are explained in Appendix A.

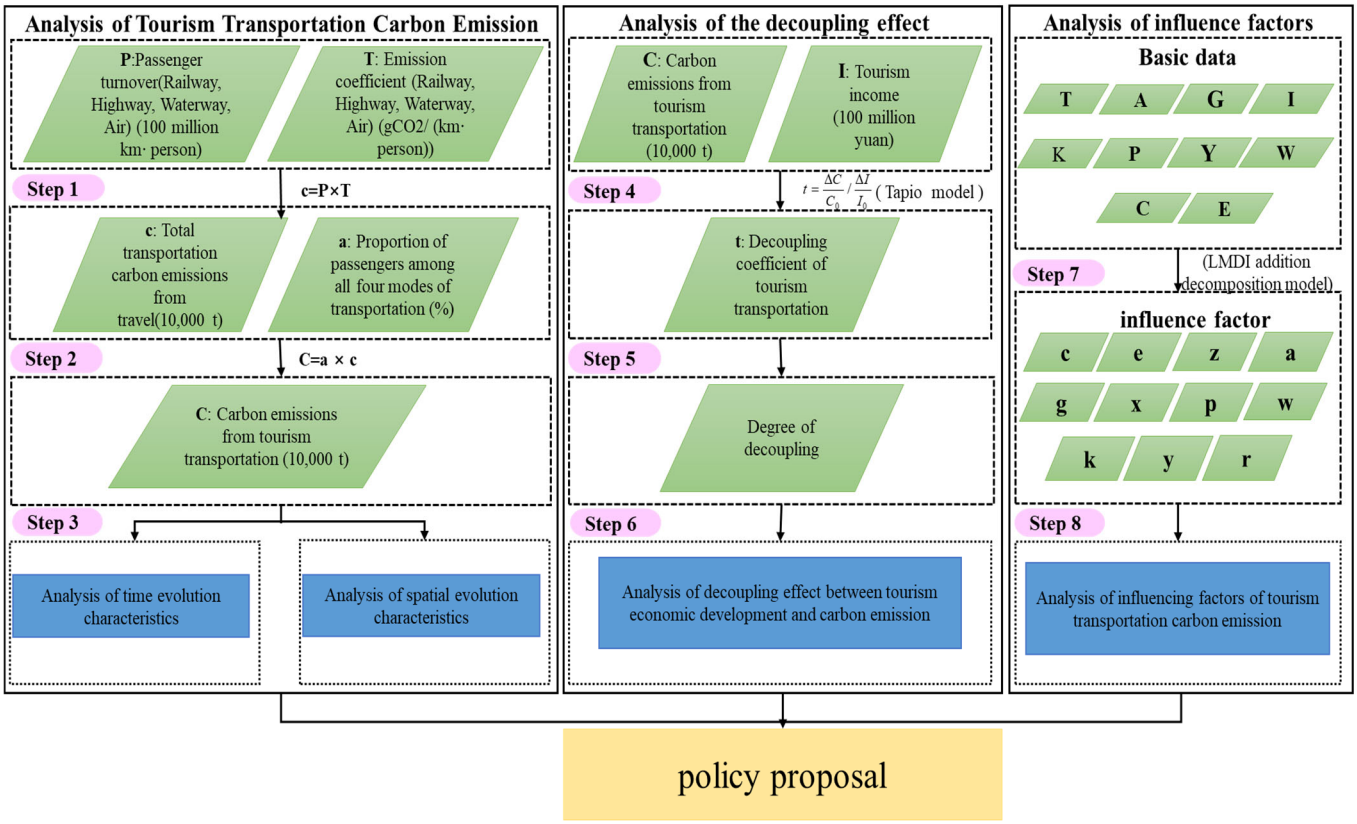


Figure 1. Technology roadmap.

2. Materials and Methods

2.1. Study Area

The northern region of China, encompassing Beijing, Tianjin, Hebei, Shanxi, and the Inner Mongolia Autonomous Region, serves as a significant backdrop for China's historical progression and cultural legacy. It is situated along the border between China and Mongolia to the north, the Qin Ling and Huai Rivers to the south, the Bohai Sea and Yellow Sea to the east, and the Qinghai-Tibet Plateau to the west. The northern region of China encompasses a mere 6.5% of the total land area of the country, although it harbors a substantial population of 320 million individuals, constituting around 25% of the overall population. During the initial six months of 2023, the GDP of the five provinces and municipalities in North China amounted to over 7172 billion, or almost 12% of the nation's overall GDP. North China possesses favorable characteristics, including flat topography and convenient transportation, which facilitates tourism travel. However, this also leads to an increase in carbon emissions. Furthermore, North China serves as a significant hub for China's energy and heavy industry sectors. Consequently, examining carbon emissions resulting from tourism traffic can offer valuable insights for rationalizing the region's energy

consumption and industrial composition. This, in turn, can facilitate the harmonization of economic and environmental development (Figure 2).



Figure 2. Distribution of provinces and cities in North China.

2.2. Data

In this paper, from the perspective of data availability and research cycle, the years 2000–2022 are selected as the research object. The data required for the calculation of carbon emissions from tourism traffic mainly come from the statistical yearbook information of two provinces, two cities, and one region in North China, and the data for other indicators are taken from the Statistical Yearbook (2000–2022) and the Statistical Bulletin of National Economic and Social Development (2000–2022) of the provinces and cities in North China. Data for individual missing years are processed by interpolation to ensure the completeness and accuracy of the calculation data.

2.3. Methods

2.3.1. Carbon Emission Calculation Models for Tourism Traffic

By the recommendations made by the United Nations World Tourism Organisation (UNWTO), the carbon emissions of the four major modes of transportation in the country were measured based on the product of the passenger turnover and the emission factor of the four major modes of transportation in the country [32]. The calculation model is as follows:

$$C_i = T_i \times Q_i \quad (1)$$

where represents the total transportation carbon emissions (gCO_2) of the i type of passenger travel mode, T_i denotes the emission coefficient of the i type of travel mode (gCO_2/(km·person)), and Q_i denotes the passenger turnover of the i type of transportation (km·person). The carbon emission factor for rail passenger transportation is 27 (gCO_2/(km·person)) according to the norms developed by the United Nations World Tourism Organisation (UNWTO) and the United Nations Environment Programme (UNEP). The Organisation for Economic Co-operation and Development (OECD) has set the emission factor for road passenger transportation at 133 (gCO_2/(km·person)). The carbon emission

factors for air and waterborne passenger transportation are 137 and 66 (gCO_2/(km·person)), respectively, drawing on existing research [4,33,34]. (gCO_2 stands for "grams of Carbon Dioxide". This is a unit used to quantify carbon dioxide emissions, often in environmental science and climate change research, to measure the amount of carbon dioxide produced by an individual, organization, or country during a particular activity or period.)

The carbon emission calculation model for tourism transportation is as follows:

$$C = \sum_{i=1}^{4} \alpha_i \times C_i \tag{2}$$

where C denotes the total carbon emissions from tourism transportation (gCO_2), α_i is the proportion of passengers in the four modes of transportation (rail, road, civil aviation, and waterway), and the value of α_i cannot be used accurately due to the lack of clarity of China's Tourism Satellite Account (TSA) system [4]. Referring to previous studies [10,19,34], the setting of α_i (%) for the railway, road, civil aviation, and waterway is shown in Table 1.

Table 1. Share of passengers in the four modes of transportation.

Period	α_i			
	Railways	**Motorway**	**Aeronautical**	**Waterborne**
2000–2008	31.6	13.8	64.7	10.6
2009–2014	36.9	16.7	60.4	7.1
2015–2019	38.7	17.5	59.1	5.8
2020–2022	43.9	21.3	50.6	5.2

2.3.2. Tapio Decoupling Model

Decoupling refers to breaking the link between environmental hazards and economic development [35]. The definition highlights an evolutionary trend of decoupling, also known as "decoupling". The definition highlights an evolving trend of decoupling, also known as "decoupling", which does not refer to random shifts and deviations in energy consumption or carbon emissions in the short term but rather can be separated from the direction of economic development over a period of time [36]. In the existing research on economic decoupling, most scholars use the Tapio model because it contains eight different decoupling criteria, which, compared with the classic OECD model, can more completely portray the conflict between economic development and ecological pressure, effectively overcoming the difficulty of choosing the base period and making the correlation between the country's carbon emissions and the total value of industry more intuitive and accurate. The basis for determining the eight decoupling states and their descriptions is shown in Table 2 [37]. The decoupling coefficients are calculated as follows:

$$t = \frac{\Delta C}{C_0} / \frac{\Delta I}{I_0} \tag{3}$$

where t denotes the decoupling coefficient of tourism traffic; ΔC is the change in carbon emissions in the current year relative to the base year, in tons; C_0 is the carbon emissions in the base year, in tons; ΔI is the change in tourism revenue in the current year relative to the base year, in billions of CNY; I_0 is the tourism revenue in the base year, in billions of CNY.

Table 2. Guidelines for determining the degree of decoupling and descriptions.

Degree of Decoupling		Norm			Descriptions
		%Δ*C*	%Δ*I*	t	
Negative decoupling	Weak-negative decoupling	<0	<0	0 < t < 0.8	Economic downturn, CO_2 emissions decrease, and the economy slows down faster than carbon emissions.
	Strong-negative decoupling	>0	<0	t < 0	Economic downturn and increased CO_2 emissions.
	Expansion negative decoupling	>0	>0	t > 1.2	The economy grows, CO_2 emissions increase, and carbon emissions grow faster than the economy.
Connection	Growing connection	>0	>0	0.8 < t < 1.2	Economic growth, increased CO_2 carbon emissions.
	Recession connection	<0	<0	0.8 < t < 1.2	Economic downturn reduces CO_2 emissions.
Decoupling	Weak decoupling	>0	>0	0 < t < 0.8	Economy grows, CO_2 emissions increase, carbon emissions grow slower than economic growth.
	Strong decoupling	<0	>0	t < 0	Economic growth and reduced CO_2 emissions.
	Recessionary decoupling	<0	<0	t > 1.2	Economic downturn, CO_2 emissions decrease, and economic slowdown is slower than carbon slowdown.

2.3.3. LMDI Decomposition Model

In recent years, with the increasing pressure of carbon emission reduction, the factors affecting carbon emissions have received more and more attention. In existing research, the common methods used to study energy and environmental issues are Index Decomposition Analysis (IDA) and Structural Decomposition Analysis (SDA) [38,39]. Compared with IDA, SDA has higher data requirements and requires input and output data, while Dee's decomposition method (LMDI) in IDA has no residuals and effectively avoids the pseudo-regression problem, making it a more complete decomposition method.

The Logarithmic Mean Divisia Index (LMDI) decomposition model was proposed by Ang in 1998 based on LMDI and further improved by Ang and Liu, which overcame the remaining defects of previous decomposition methods and decomposed the results completely. It is widely used in the fields of energy economics and environmental economics.

LMDI models take the form of both additive and multiplicative models, with additive models usually being more suitable for analyses of quantitative indicators, such as total energy consumption. The multiplicative model is more suitable for the analysis of intensity indicators, such as total energy intensity. The additive model can intuitively reflect the degree of contribution of each factor to the total energy consumption, thus helping decision-makers to understand which factors are the main drivers of energy consumption and then formulate corresponding energy management and emission reduction strategies. This paper analyses the carbon emission characteristics of tourism and transportation in North China by using the "additive decomposition" method. The model is as follows:

$$\begin{aligned} C &= {C}/{E} \times {E}/{T} \times {T}/{A} \times {A}/{G} \times {G}/{I} \times {I}/{P} \times {P}/{W} \times {W}/{K} \times {K}/{Y} \times {Y}/{P} \times P \\ &= \sum_i c_i \cdot e_i \cdot t_i \cdot a_i \cdot g_i \cdot x_i \cdot p_i \cdot w_i \cdot k_i \cdot y_i \cdot r_i \end{aligned} \quad (4)$$

In additive form:

$$C_t - C_0 = \Delta C = \Delta c + \Delta e + \Delta t + \Delta a + \Delta g + \Delta i + \Delta p + \Delta w + \Delta k + \Delta y + \Delta r \quad (5)$$

By referring to studies [12,40–42], the paper selects influential factors such as energy mix, energy intensity, capital input–output ratio, tourism investment rate, tourism intensity, and tourism consumption level and then constructs 11 influencing factor index systems, as shown in Table 3. Among them are carbon emissions of tourism transportation (C, 10,000 tons), total energy consumption (E, 10,000 tons), the added value of the tertiary

industry (T, CNY 100 million), investment in fixed assets (A, CNY 100 million), gross regional product (G, CNY 100 million), tourism income (I, CNY 100 million), tourist number (P, 10,000 people), number of cultural facilities (W, 10,000), tourist turnover (K, 100 million passenger kilometers), and passenger volume (Y, 10,000 people).

Table 3. Indicator system of factors influencing carbon emissions from tourism transportation.

Considerations	Interpretation	Markings	Magnitude of Change
Energy mix	C/E	c	$\Delta c = \sum_i \frac{C_{i,t} - C_{i,0}}{lnC_{i,t} - lnC_{i,0}} \cdot ln\frac{c_{i,t}}{c_{i,0}}$
Energy intensity	E/T	e	$\Delta e = \sum_i \frac{C_{i,t} - C_{i,0}}{lnC_{i,t} - lnC_{i,0}} \cdot ln\frac{e_{i,t}}{e_{i,0}}$
Capital input–output ratio	T/A	z	$\Delta z = \sum_i \frac{C_{i,t} - C_{i,0}}{lnC_{i,t} - lnC_{i,0}} \cdot ln\frac{z_{i,t}}{z_{i,0}}$
Tourism investment rate	A/G	a	$\Delta a = \sum_i \frac{C_{i,t} - C_{i,0}}{lnC_{i,t} - lnC_{i,0}} \cdot ln\frac{a_{i,t}}{a_{i,0}}$
Tourism intensity	G/I	g	$\Delta g = \sum_i \frac{C_{i,t} - C_{i,0}}{lnC_{i,t} - lnC_{i,0}} \cdot ln\frac{g_{i,t}}{g_{i,0}}$
Tourism consumption level	I/P	x	$\Delta x = \sum_i \frac{C_{i,t} - C_{i,0}}{lnC_{i,t} - lnC_{i,0}} \cdot ln\frac{x_{i,t}}{x_{i,0}}$
Visitor Reception of Cultural Facilities	P/W	p	$\Delta p = \sum_i \frac{C_{i,t} - C_{i,0}}{lnC_{i,t} - lnC_{i,0}} \cdot ln\frac{p_{i,t}}{p_{i,0}}$
Utilization of cultural facilities	W/K	w	$\Delta w = \sum_i \frac{C_{i,t} - C_{i,0}}{lnC_{i,t} - lnC_{i,0}} \cdot ln\frac{w_{i,t}}{w_{i,0}}$
Occupancy (i.e., the proportion of passengers traveling on a bus or train)	K/Y	k	$\Delta k = \sum_i \frac{C_{i,t} - C_{i,0}}{lnC_{i,t} - lnC_{i,0}} \cdot ln\frac{k_{i,t}}{k_{i,0}}$
Passenger density	Y/P	y	$\Delta y = \sum_i \frac{C_{i,t} - C_{i,0}}{lnC_{i,t} - lnC_{i,0}} \cdot ln\frac{y_{i,t}}{y_{i,0}}$
Passenger size	P	r	$\Delta r = \sum_i \frac{C_{i,t} - C_{i,0}}{lnC_{i,t} - lnC_{i,0}} \cdot ln\frac{r_{i,t}}{r_{i,0}}$

Note: The number of cultural facilities is represented by the sum of the number of libraries and museums.

3. Result

3.1. Analysis of the Spatial and Temporal Evolution of Carbon Emissions from Tourism Transportation in North China

3.1.1. Analysis of Time Evolution Characteristics

According to its evolutionary characteristics, it can be divided into four phases:

(1) Stable growth period (2000–2012): During this period, tourism was not yet a dominant industry in North China at this stage, which led to a low level of overall carbon emissions and a slow growth rate. While the economy of North China grew steadily, the transportation network became more and more perfect, and its carrying capacity gradually increased. The hosting of the Beijing Olympic Games has boosted the prosperity of tourism in North China and at the same time brought about an increase in carbon emissions. In 2012, carbon emissions from tourism transportation peaked for the first time.

(2) Transitional adaptation period (2013–2015): During this period, the concept of low-carbon tourism gradually took root, the government's attention to environmental protection increased, and the tourism industry began to implement low-carbon development modes such as green tourism within the industry. To reduce carbon emissions, the state has introduced a series of emission reduction policies and the Tourism Law of the People's Republic of China, a special tourism law, that is of great significance to the transformation of China's tourism industry and the optimization of the industrial structure.

(3) Stable equilibrium stage: (2016–2019): Mass tourism, economic development, and transportation infrastructure provide good environmental conditions for its rising carbon emissions, but at the same time, emission reduction driven by the green

economy has become a common concern, so the carbon emissions of the tourism industry in North China have been maintaining a relatively stable equilibrium state.

(4) Dramatic decline phase (2020–2022): In 2020, due to the impact of the COVID-19 pandemic, the tourism industry was hit hard, tourism carbon emissions dropped significantly, and signs of recovery were beginning to emerge in 2021. Then, the second new crown epidemic broke out again in late 2021, restricting the development of the tourism industry, coupled with the target of carbon peaking and carbon neutrality put forward in the "Outline of the Fourteenth Five-Year Plan for the National Economic and Social Development of the People's Republic of China and the Visionary Goals for the Year 2035" in the same year; the carbon emissions from tourism transportation were significantly lower [43] (Figure 3).

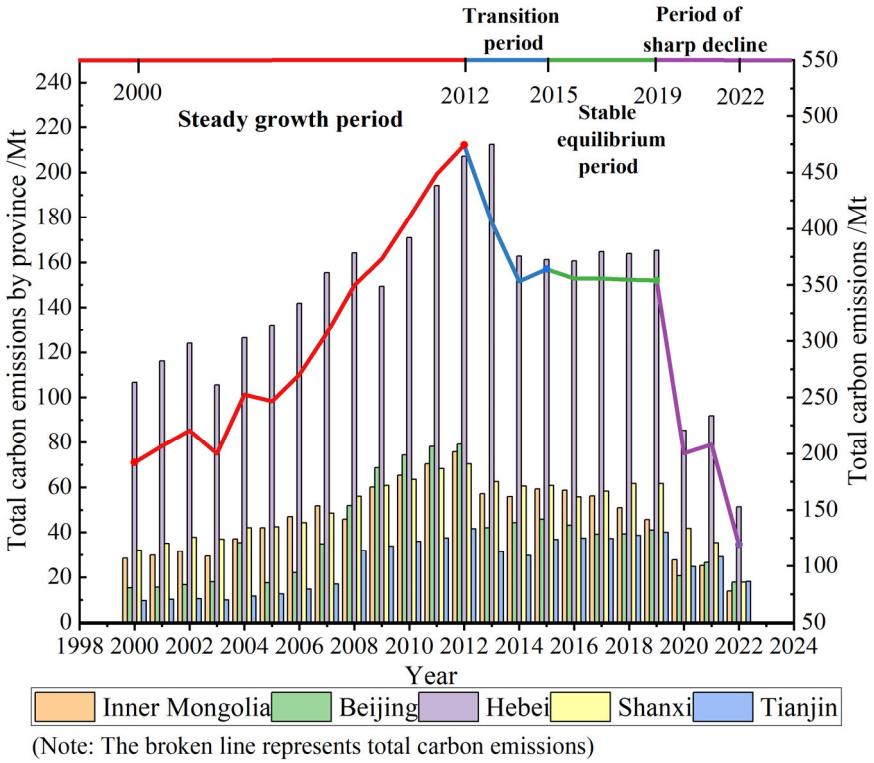


Figure 3. Temporal evolution characteristics of carbon emissions from tourism transportation in provinces and cities in North China (2000–2022).

3.1.2. Analysis of Spatial Evolution Characteristics

Based on ArcGIS10.8, using the natural breakpoint method, the North China region is divided into four levels according to the different carbon emissions from the tourism industry: high-carbon-emission area, slightly high carbon emission area, medium-carbon-emission area, and low-carbon-emission area [19] (Figure 4).

According to Figure 3, the spatial distribution pattern of tourism transportation carbon emissions in North China is "Hebei first, followed by Shanxi and Inner Mongolia", while Beijing and Tianjin are the smallest. Hebei is rich in natural and cultural resources. With the development of tourism, Hebei's transportation infrastructure has also been developed rapidly but mainly by traditional energy transportation such as cars and trains, which have high carbon emissions. In contrast, the application of new energy vehicles is less. At the same time, Hebei's industrial structure is dominated by heavy industry, and energy consumption and carbon emissions are high. Shanxi and Inner Mongolia are both provinces rich in tourism resources, with many natural and cultural landscapes. However, the tourism transportation infrastructure is relatively lagging behind, and the traffic structure is not perfect. Among them, Inner Mongolia traffic is mainly road and air. At the same time, Shanxi's energy consumption and carbon emissions are also high, mainly coal and other

traditional energy sources; Inner Mongolia's industrial structure is dominated by animal husbandry, and energy consumption and carbon emissions are also high. Although Beijing is an important tourist source and destination in the world, its transportation infrastructure is nearly perfect, the transportation network is developed, the transportation efficiency is high, the industrial structure is dominated by the service industry, and the energy consumption and carbon emissions are relatively low. In the "three-region linkage" strategy implemented in the Beijing–Tianjin–Hebei region in 2014, transportation integration is an important part of the Beijing–Tianjin regional economic cooperation and also drives the resource integration among Beijing, Tianjin, and Hebei. In 2015, the Outline of the Beijing–Tianjin–Hebei Coordinated Development Plan listed the Beijing–Tianjin–Hebei region as the three priority development directions. Tianjin is the leading city of low-carbon development in the country, and it is also vigorously promoting energy conservation and consumption reduction. Therefore, the carbon emission from tourism is relatively small. In terms of specific years, the results can be summarized as follows:

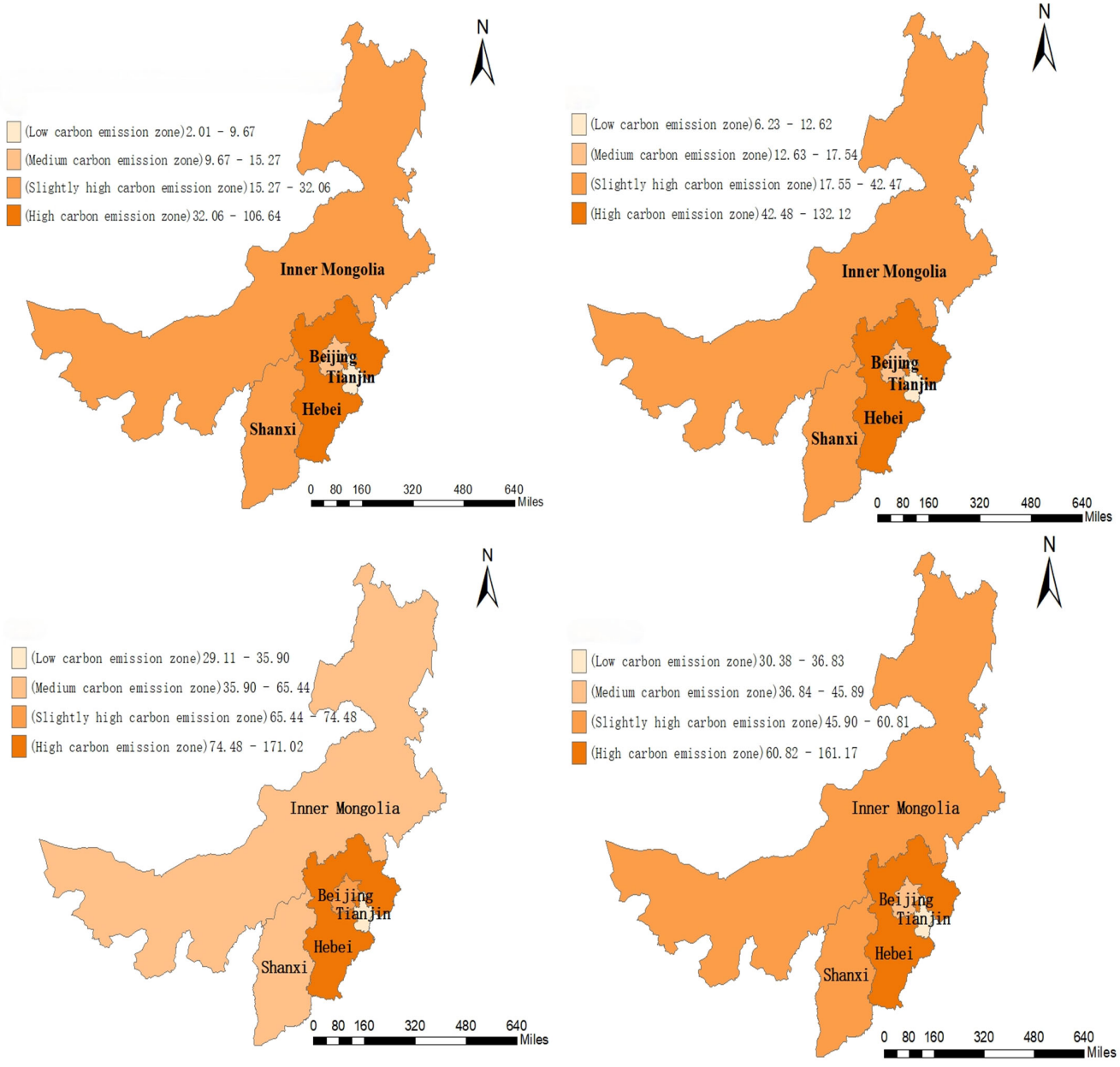


Figure 4. *Cont.*

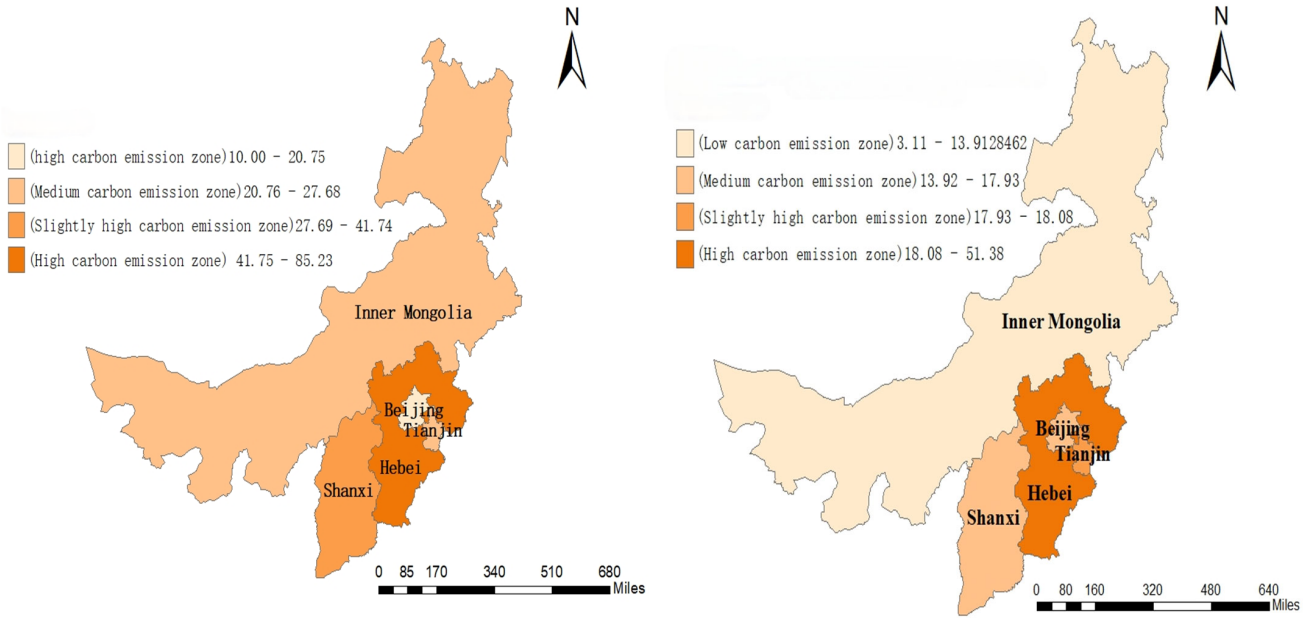


Figure 4. Spatial evolution characteristics of carbon emissions from tourism transportation in North China (2000, 2005, 2010, 2015, 2020, 2022).

(1) In 2000 and 2005, the carbon emissions of transportation activities in different regions are significantly different. The results show that the carbon emissions of the tourism industry in Hebei and Tianjin are significantly different. Hebei is a high-carbon-emission zone, while Tianjin is a low-carbon-emission zone.

(2) In 2010, Hebei was still a high-carbon-emission zone, while Beijing was converted to a high-carbon-emission zone. Other provinces and cities made the transition from high to low, such as Shanxi and Inner Mongolia from high-emission areas to medium-emission areas. The 2008 Beijing Olympics increased the city's popularity, attracted many tourists, and significantly increased carbon emissions. In 2010, the National Development and Reform Commission launched a pilot program for "low-carbon cities", followed by emission reduction measures in Shanxi and Inner Mongolia.

(3) In 2015, the spatial distribution pattern of "Hebei first, followed by Shanxi and Inner Mongolia" was again presented. In 2013, the country introduced a series of policies and policies to mitigate climate change, making Beijing's tourism carbon emission level relatively low.

(4) In 2020 and 2022, Tianjin was planned to be transformed from a low-carbon-emission zone to a high-carbon-emission zone. In order to implement the decision-making and deployment of the Party Central Committee and The State Council on promoting the integration of culture and tourism and the development of all-region tourism and promote the high-quality development of the city's tourism industry, Tianjin has formulated and promulgated the Two-year Action Plan for Promoting the Development of Tourism in Tianjin (2019–2020) [44]. In order to implement the spirit of the Guiding Opinions of The State Council on Accelerating the Establishment and Improvement of the Green, low-carbon and Circular Development Economic System (Guo fa [2021] No. 4), build and improve the economic system of green, low-carbon, and sustainable development in the Inner Mongolia Autonomous Region, and promote high-quality development, a series of measures have been proposed [45]. As a result, Inner Mongolia has been transformed from a medium-carbon-emission area to a low-carbon-emission area.

3.2. North China Tourism Decoupling of Economic Development and Carbon Emissions Effectiveness Analysis

From 2000 to 2022, tourism transportation carbon emissions and tourism income in North China mainly show a weak decoupling state (Figure 5), which indicates that tourism carbon emissions are slower than the economic growth rate of tourism, and tourism is in a sustainable development stage.

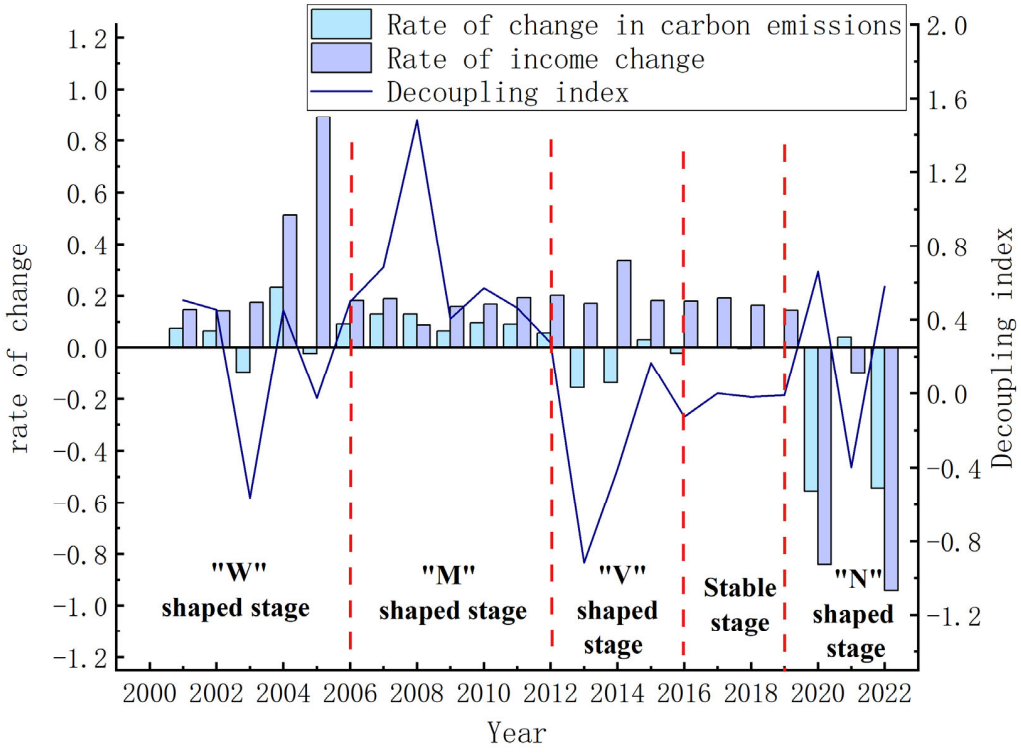


Figure 5. Rate of change in tourism revenue, rate of change in transportation carbon emissions, and decoupling index for North China (2000–2022).

In particular, the steady growth period is divided into the "W" shape (2000–2006) and the "M" shape (2006–2012), which cross through weak decoupling and strong decoupling periods:

(1) The "W-shaped" stage is in the "Tenth Five-Year Plan" planning period. The "Outline of the Tenth Five-Year Plan for National Economic and Social Development of the People's Republic of China" clearly indicates that in the "Tenth Five-Year Plan" period, the overall goals of China's national economic and social development are as follows: ① Continue to develop at high speed; ② optimize the economic structure; and ③ improve the quality and efficiency of economic development [46]. The growth of tourism income, which develops together with the national economy, is more obvious, and its growth rate is faster than the growth rate of tourism and transportation carbon emissions, so this stage is mainly manifested as weak decoupling. The strong decoupling period from 2002 to 2003 and 2004 to 2005 was due to the impact of SARS, the stampede in Beijing, and the large-scale mining accident and air crash in Inner Mongolia and other places, the tourism traffic volume decreased, and correspondingly, carbon emissions decreased.

(2) The "M" shape stage is mainly the weak decoupling stage. This stage is the "eleventh Five-Year" and "Twelfth Five-Year", the national economy is stable and rapidly developing, and tourism income and transportation carbon emissions are steadily increasing. In 2007–2008, due to the economic crisis, the growth rate of tourism income slowed down, the traditional means of tourism transportation were mainly used,

and the carbon emissions increased significantly so that there was expansionary negative decoupling.

The transition adaptation stage is mainly the strong decoupling stage, which is the "V" shape stage. In the latter part of the 12th Five-Year Plan, people's living conditions continued to improve, the national willingness to travel increased significantly, and tourism income also increased. In 2011, The State Council issued the 12th Five-Year Plan for the Control of Greenhouse Gas Emissions [47], led by the National Development and Reform Commission, which put forward the overall requirements and main tasks of China's emission reduction work before 2015 [48] and put forward the main work and countermeasures on how to promote China's low-carbon development.

The stable equilibrium stage is the strong decoupling stage. The 13th Five-Year Plan mentioned that the overall quality of the ecological environment had been improved. The way of production and life had been developed in the direction of green and low-carbon development. It had greatly improved the efficiency of the use of energy resources and had largely controlled energy consumption, water, building land, and carbon emissions [49]. Transportation carbon emissions are reduced, the level of economic development is raised, and the economy enters the optimal state of low-carbon development.

The sharp decline stage is the weak negative decoupling stage, which shows the "N" shape change. During this period, the tourism industry was in a downturn, the revenue of tourism and the carbon emissions of transportation were both declining, and the decline of the former was even greater. The year 2020–2021 was the most serious year of the epidemic, and the negative decoupling state is obvious, which is the stage of strong negative decoupling.

3.3. Analysis of Factors Affecting Carbon Emissions from Tourism Transportation in North China

Based on the year 2000 as the base period, the carbon emissions of tourism transportation in North China from 2000 to 2022 were decomposed, and the LMDI decomposition formula was used to analyze the influencing factors of tourism transportation carbon emissions in North China. The cumulative impact degree of various influencing factors was obtained by calculating according to the formula in Table 3 (see Table 4). Tourism investment rate, tourism consumption level, tourist reception of cultural facilities, the utilization rate of cultural facilities, passenger load factor, and passenger scale are promoting factors, while energy mix, energy intensity, capital input–output ratio, tourism intensity, and passenger transportation density are hindering factors. Among them, the first promoting factor is passenger size, and the first hindering factor is passenger density.

Table 4. The cumulative effect of various factors influencing carbon emissions from tourism traffic in North China (2001–2022).

Factor	Contribution Degree (%)
Energy mix	−17.46
Energy intensity	−22.49
Capital input–output ratio	−6.48
Tourism investment rate	10.30
Tourism intensity	−21.17
Tourism consumption level	11.06
Visitor Reception of Cultural Facilities	33.16
Utilization of cultural facilities	14.38
Occupancy (i.e., the proportion of passengers traveling on a bus or train)	12.96
Passenger density	−60.51
Passenger size	42.92

From the perspective of time, the driving effects of different driving factors on carbon emissions in North China are very different. The driving effects of the influencing factors are described respectively according to the four stages of time evolution (Figure 6).

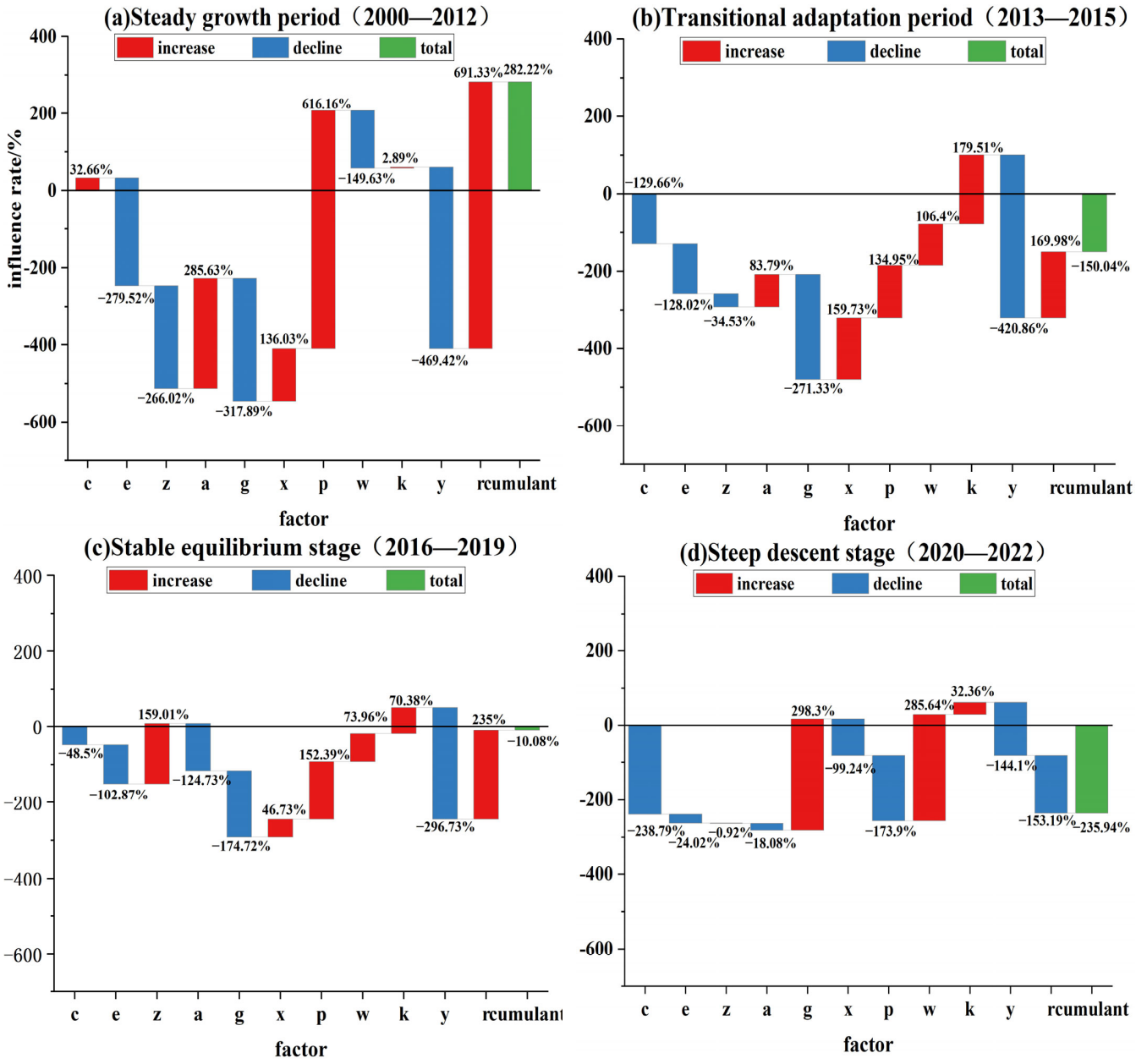


Figure 6. Effects of 11 factors on carbon emissions in four stages during 2000–2022.

From the perspective of the cumulative effect of the overall influencing factors in the four stages, only the value of the stable growth period is positive, showing an increasing effect, and the value is 282.22%, equivalent to nearly three times the promotion effect. It can be seen that the high-carbon situation is unusually significant in the early stage, and the negative value in the last three stages indicates that the government's series of energy conservation and emission reduction measures after the "Twelfth Five-Year Plan" have been highly effective. In terms of the specific development of each influencing factor, consider the following:

(1) In the steady growth period, the energy mix showed a slight increase effect, but the overall performance restrained carbon emissions, and it showed fluctuations under the influence of technological progress, energy optimization, economic growth, policy regulation, market mechanism, and natural emergencies. This trend reflects the complexity and uncertainty of tourism development.
(2) Energy intensity in the four stages showed an inhibition effect, and according to the calculation results of the formula in Table 3, the inhibition effect showed a trend of increasing first and then decreasing and reached the peak of inhibition in 2010–2011. The negative energy intensity reflects the improvement of energy utilization efficiency in North China, which benefits from technological progress and the optimization of energy structure. This reduces energy demand per unit of output, which in turn inhibits carbon emissions from tourist transportation. At the same time, government policies, such as energy conservation and emission reduction and the promotion of new energy vehicles, also significantly affected energy consumption and tourism and transportation carbon emissions in 2010–2011, making this period have the most prominent inhibition effect.
(3) The capital input–output ratio, tourism investment rate, utilization rate of cultural facilities, and patronage rate have all changed by a small margin, with a weak impact effect.
(4) Tourism intensity has changed from the main inhibiting factor to the promoting factor. The reasons include the following: The rapid growth of tourism leads to an increase in transportation demand and carbon emission. The change in tourism consumption structure, such as the increase in self-driving trips and the use of private cars, leads to the rise of carbon emissions. With the improvement of tourism infrastructure construction, energy consumption and carbon emission increase. Changes in policy and market mechanisms, such as prioritizing tourism development policies over economic benefits, may diminish the focus on environmental benefits. This shift reflects the tradeoff between economic and environmental benefits in tourism development.
(5) Tourism consumption level, tourist reception of cultural facilities, and tourist scale reflect the scale, activity, and development level of the tourism market from different angles, all showing the promoting effect. Among them, tourist scale and tourist reception of cultural facilities have the most obvious promoting effect on the carbon emission of tourism transportation in North China. It reflects the importance of cultural factors and the results of the in-depth development of cultural and tourism integration.
(6) Passenger density significantly reduces tourism transportation carbon emissions due to the efficient use of transportation resources to reduce fuel consumption, promoting public transportation use to reduce emissions from private vehicles, optimizing transportation networks to improve public transportation accessibility, and promoting intelligent transportation to reduce congestion. These factors together promote the development of North China's transportation system in an environmentally friendly and sustainable direction.

4. Discussion

Carbon emissions from tourism transportation in North China generally experienced four stages: a stable growth period (2000–2012), a transitional adaptation period (2013–2015), a stable equilibrium period (2016–2019), and a sharp decline period (2020–2022). According to equation (2), carbon emissions peaked in 2012 at 4,743,500 tons. To verify this result, the authors used SPSS software to estimate the linear function curve, quadratic function curve, and cubic function curve of tourism transportation carbon emissions and per capita GDP in North China (Figure 7).

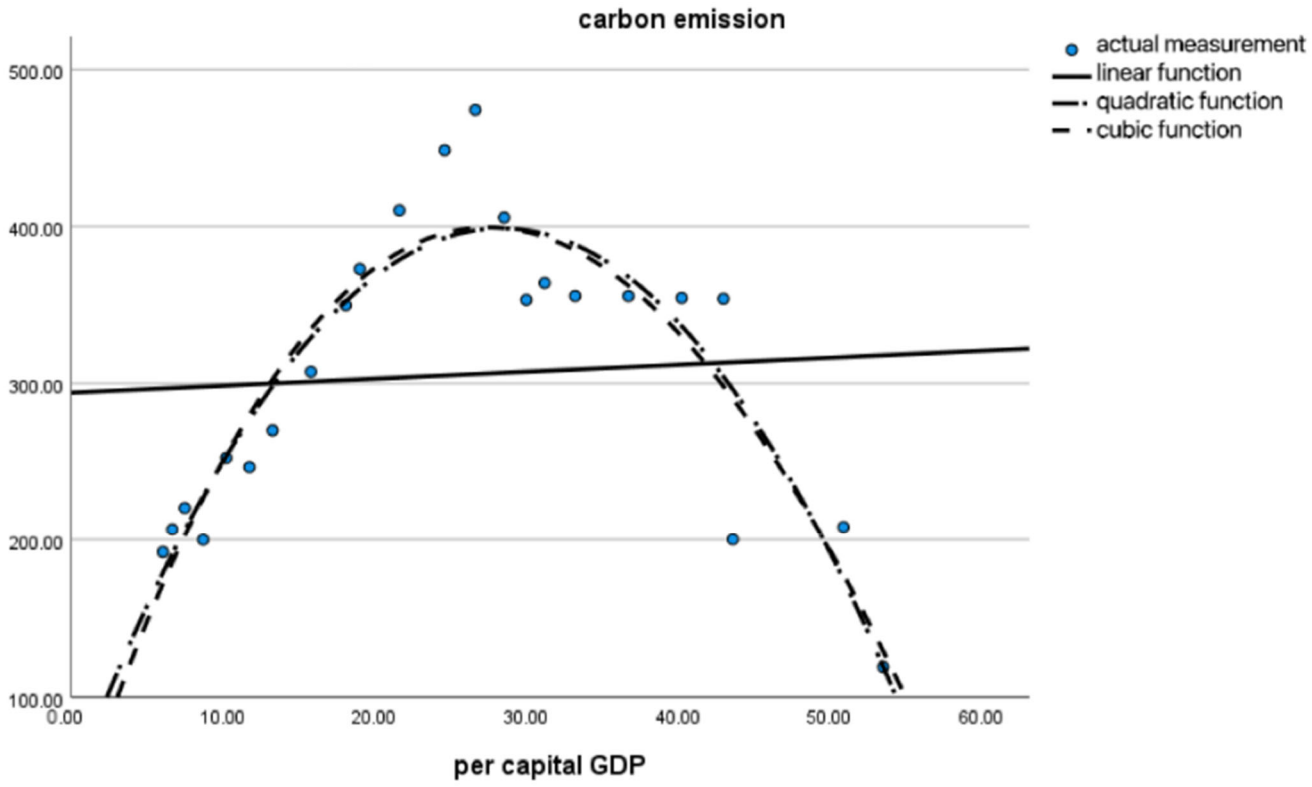


Figure 7. Carbon emission and per capita GDP curve fitting results.

The corresponding parameters are shown in Table 5.

Table 5. The fitting correlation coefficient between tourism and transportation carbon emissions and per capita GDP in North China.

Equation	Model Summary				Coefficient			
	R^2	Adjusted R^2	F	Significance	a_1	a_2	a_3	Constant
Linear function	0.005	−0.043	0.099	0.756	0	0	0.445	294.105
Quadratic function	0.841	0.825	52.891	<0.001	0	−0.441	25.038	43.717
Cubic function	0.844	0.819	34.185	<0.001	0.002	−0.622	29.476	16.07

It can be seen that the fitting effect of the linear curve is the worst, the fitting R values of quadratic function and cubic function curve estimation are close, and the significance values are both less than 0.05, which meets the requirements. Finally, from the quadratic function F value greater than the cubic function, it can be seen that the relationship between the dependent variable carbon emission and the independent variable per capita GDP is more in line with the quadratic curve, and the specific model is as follows:

$$Y = -0.441x^2 + 25.038x + 43.717 \quad (6)$$

When the per capita GDP is 283,880 yuan, the carbon emission reaches the maximum, which is 391.03 million tons. Hebei Province is the region with the largest carbon emission from tourism transportation, reaching 33.1357 million tons.

5. Conclusions

5.1. Conclusion Summary

This paper takes the panel data of North China from 2000 to 2022 as the research object and uses the "bottom-up" method to quantitatively measure the carbon emissions from tourism transportation in North China; on this basis, the decoupling between the economic development of tourism and carbon emissions is empirically examined through the Tapio model, and its influence factors are further investigated through the LMDI model. The following conclusions are drawn:

(1) The characteristics of the spatial and temporal evolution of carbon emissions from tourism transportation. In North China, between 2000 and 2022, carbon emissions from tourism traffic reached the maximum peak at 4,743,500 tons, which can be roughly divided into four phases: a period of steady growth (2000–2012), a period of transitional adaptation (2013–2015), a period of stable equilibrium (2016–2019), and a period of dramatic decline (2020–2022). In 2020, carbon emissions from tourism traffic fell sharply to the starting level of 2000 due to the impact of the new crown epidemic. In the whole study year, the level of carbon emissions from tourism traffic is shown as Hebei Province > Shanxi Province > Inner Mongolia Autonomous Region > Beijing City > Tianjin City.

(2) The decoupling effect of carbon emissions from tourism transportation and economic development. The decoupling coefficient between carbon emissions from tourism traffic and economic development in North China fluctuates but mainly shows a weak decoupling state, which means that carbon emissions from the tourism industry grow at a slower rate than the tourism industry's economic growth rate, reflecting the fact that the tourism industry is in a sustainable development stage.

(3) Analysis of factors affecting carbon emissions from tourism transportation. The first facilitator is the size of the traveling public, with an impact of 42.92 percent, and the first impediment is the density of passenger traffic, with an impact of −60.51 percent. In addition, it can also be seen that the number of tourists received by cultural facilities has a strong driving effect on carbon emissions from tourism transportation. In the context of the rapid development of culture and tourism, it is of great significance to study the mechanism of cultural factors on the carbon emission of tourism.

5.2. Proposal

Based on the results of the above study, targeted proposals for carbon emission reduction countermeasures in North China are put forward:

(1) Fine-tuning and optimizing travel routes. The results show that traveling by rail and road is the mainstay of tourism in North China, with its carbon emissions accounting for about 99.8 percent of total emissions. The reason for this is that the provinces in North China are relatively close to each other, and travelers mostly choose self-driving tours, high-speed railways, and other modes of travel, and the routes of some tourist attractions are not reasonably planned, resulting in unnecessary carbon dioxide emissions. Hence, the government and pertinent departments must undertake comprehensive optimization of tourism routes. To begin with, it is important to employ big data analysis techniques to comprehend tourists' travel behavior patterns and preferences. This will establish a scientific foundation for the creation of more rational and effective tourist routes. Furthermore, it is imperative to enhance collaboration with other regions to foster the development of cross-regional tourism routes, thereby offering travelers more convenient and environmentally sustainable modes of transportation. Furthermore, supplementary points of interest, stations, and attractions, as well as alternative bus and subterranean joint convenient bus routes, can be established to diminish tourists' inclination to opt for taxis or drive themselves.

(2) Formulate carbon emission reduction strategies for tourism transportation according to local conditions. There are obvious regional differences in carbon emissions from tourism transportation among provinces and cities in North China. Hebei's

cumulative carbon emissions from 2000 to 2022 amount to 33,135,700 tons, which is about 5.5 times the total carbon emissions of Tianjin. In order to mitigate the issue of disparities, each province must implement a tailored emission reduction strategy that aligns with its unique circumstances. Beijing and Tianjin hold significant importance as transportation hubs within China. To effectively leverage their social, economic, and technological advantages, it is imperative to enhance research and development efforts in the areas of clean energy and environmental monitoring. This will enable these cities to take the lead in promoting the low-carbon development of the tourism industry in North China. Inner Mongolia should actively encourage the merger of "tourism + ecology", build an ecotourism product system, and adapt the existing tourism business, leveraging its unique characteristics. Shanxi and Hebei provinces ought to consider adapting their economic growth strategies to align with local circumstances, fostering environmentally sustainable development, capitalizing on emerging prospects, initiating the digital economy as a new driving force, and achieving a harmonious integration of economic growth and ecological preservation.

(3) Promote the research, development, and application of new energy transportation. The expansion of carbon emissions from tourism transportation is hindered by energy intensity and passenger density. To achieve a fundamental improvement in energy efficiency and a reasonable increase in passenger density, technical innovation is necessary. The optimization of traffic flow and reduction in ineffective driving can be achieved by the implementation of intelligent transportation systems, which encompass intelligent traffic lights, intelligent navigation, and real-time road condition monitoring. The implementation of sustainable energy sources, such as hydrogen fuel cells and solar energy, in local transportation systems has the potential to mitigate carbon dioxide emissions. The marketing of electric vehicles holds equal significance to the establishment of charging infrastructure, particularly in regions characterized by significant tourism routes and picturesque locations. Autonomous cars have the potential to mitigate human error and enhance traffic efficiency. The utilization of big data and artificial intelligence technologies for the analysis of road traffic data has the potential to establish a scientific foundation for the governance and strategic planning of urban traffic. Furthermore, the utilization of ecologically sustainable construction materials and technology is imperative for the development of tourist attractions and transportation systems. The findings of this study have the potential to offer robust technical assistance for the promotion of low-carbon tourism development in the northern region of China.

(4) Enhance public awareness of environmental protection. The impact of traveler volume and tourist influx at cultural establishments in North China significantly influences the promotion of carbon emissions from tourism and transportation. This highlights the crucial role of public participation and support in effectively reducing emissions. Hence, it is advisable to augment public consciousness regarding environmental preservation by means of publicity, education, and public welfare initiatives. By facilitating environmental protection information lectures, exhibitions, and other related events, the general public can gain a comprehensive understanding of the significance and strategies employed in reducing emissions. Simultaneously, it is possible to initiate publicity efforts focused on low-carbon tourism with the aim of motivating tourists to mitigate carbon emissions during their travels. Furthermore, there is potential for enhancing real-time headcount broadcasting and implementing reservation quota restrictions at certain attractions.

(5) Strengthen regional cooperation and promote coordinated development. There are large regional differences in North China, and the horizontal coordination degree is low, so there is no complete and reasonable carbon emission monitoring mechanism. All provinces and cities should strengthen exchanges and cooperation with local governments, strengthen top-level design, study and formulate corresponding normative measures, and formulate corresponding normative documents. At the same time, it is

necessary to strengthen the cooperation between regions, give play to the correlation role between regions, and realize the balanced development of green transportation between regions [50].

Although this paper makes up for some of the shortcomings of cross-administrative tourism transportation research, analyzes the factors affecting carbon emissions at multiple levels, and puts forward emission reduction strategies, in addition to assessing the carbon emissions of tourism transportation, the study on carbon emission reduction should pay more attention to the overall carbon emissions of tourism. The future research direction should be to subdivide tourism into different regions and then study their carbon emissions separately. On this basis, by analyzing the characteristics and influencing factors of carbon emissions in different regions, the overall situation of carbon emissions from the tourism industry in China can be comprehensively understood, and the corresponding emission reduction countermeasures can be proposed.

Author Contributions: Conceptualization, D.F. and C.L.; methodology, D.F.; software, D.F.; validation, D.F., C.L. and Y.L.; formal analysis, D.F.; investigation, D.F.; resources, C.L.; data curation, D.F.; writing—original draft preparation, D.F. and C.L.; writing—review and editing, D.F. and C.L.; visualization, D.F.; supervision, C.L.; project administration, C.L.; funding acquisition, C.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The datasets generated during this study are available from the authors upon reasonable request. The data are not publicly available due to privacy.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

The variables used in this paper and their explanations are shown in Table A1.

Table A1. Abbreviations, interpretations and units of text variables.

Variate	Interpretation	Unit
T	Added value of the tertiary industry	CNY 100 million
A	Investment in fixed assets	CNY 100 million
G	Gross regional product	CNY 100 million
I	Tourism income	CNY 100 million
K	Tourist turnover	100 million passenger kilometers
P	Tourist number	10,000 people
Y	Passenger volume	10,000 people
W	Number of cultural facilities	10,000
C	Carbon emissions from tourism transportation	10,000 tons
E	Total energy consumption	10,000 tons
c	Energy mix	-
e	Energy intensity	Ton per CNY 10,000
z	Capital input–output ratio	-
a	Tourism investment rate	-
g	Tourism intensity	-
x	Tourism consumption level	CNY 10,000 per person
p	Visitor Reception of Cultural Facilities	Person per facility
w	Utilization of cultural facilities	One per 10,000 person kilometers
k	Occupancy (the proportion of passengers traveling on a bus or train)	10,000 km
y	Passenger density	-
r	Passenger size	10,000 people

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