



Decoupling and decomposition analysis of carbon emissions in Beijing's tourism traffic

Huiqiang Ma¹ · Jiale Liu¹ · Jianchao Xi²

Received: 20 March 2021 / Accepted: 12 July 2021 / Published online: 23 July 2021
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Abstract

Using the calculation method of the United Nations World Tourism Organization (UNWTO), this paper measured the carbon emissions of tourism traffic and their evolution process in Beijing from 2005 to 2017. The Tapio model and Logarithm Mean Divisia Index (LMDI) approach were used to discuss the decoupling relationship between economic development and the change of tourism traffic carbon emissions and the influencing factors. There are six major indicators in our analysis, including (1) tourists scale, (2) per capita tourism consumption level, (3) contribution rate of tourism industry to Gross Domestic Product (GDP), (4) passenger traffic volume per unit GDP, (5) energy consumption per unit passenger traffic volume, and (6) energy structure. The results showed that: the main positive drivers are tourists scale, per capita tourism consumption level and energy consumption per unit of passenger traffic volume. In addition, per unit GDP passenger traffic volume is an effective factor to restrain the growth of carbon emissions. And the economic development of Beijing is developing in step with the change of carbon emissions in Beijing's tourism traffic. The research results have important theoretical and practical significance for Beijing to formulate emission reduction policies and develop low-carbon economy.

Keywords Tourism traffic · Carbon emissions · Tapio model · LMDI approach · Green and low-carbon tourism · Energy conservation

1 Introduction

Global carbon emissions are increasing and keep warming the globe (Intergovernmental Panel Climate Change 2014). In recent years, more attention has been directed to reducing carbon emissions in specific regions and industries. Carbon dioxide emissions have significant implications in climate change, energy saving and emission reduction. How

✉ Jiale Liu
546792398@qq.com; 18235190893@163.com

¹ College of Culture and Tourism, Shanxi University of Finance and Economics, Taiyuan 030006, Shanxi, China

² Institute of Geographic Sciences and Resources, Key Laboratory of Land Surface Patterns and Modeling, Chinese Academy of Sciences, Beijing 100101, China

to increase the energy saving and development emission reduction, therefore, is urgently needed (Fang et al. 2013). The rapid development of China's tourism causes increasing CO₂ emission annually. Globally, tourism is recognized as an important sector of greenhouse gas emissions (Gössling 2013). Carbon emissions resulted by tourism accounted for a growing proportion of total carbon emissions nowadays, and green, low-carbon tourism has become the mainstream trend of future tourism development.

Among all sources of emissions in tourism sector, traffic contributes a significant part. Many researches also reveal this point. For example, Gössling (2002) first pointed out that the portion of emissions from traffic, accommodation, and activity were 94, 4, and 2%, respectively. Also, other studies (BECKEN S 2003; Kuo and Chen 2009; Wu and Shi 2011) argued that traffic is one of the main contributors to tourism-related carbon emissions. Subsequently, further studies have investigated carbon emissions caused by specific traffic methods in tourism. For example, Becken et al. (2003) identified that the main contributor to domestic tourism-related carbon emissions was private car, and Sun (2014) found that international aviation is the main source of outbound tourism-related carbon emissions, accounting for 47%. Guo B et al. (2014) revealed the CO₂ emission pattern of China's transportation industry from the regional and provincial levels, and found that there are obvious regional differences in CO₂ emission of China's transportation industry. Chinese scholars have also tried to do a lot of researches, and the research results involve national, regional, provincial and municipal levels (Wei 2012; Bao et al. 2012; Tao 2015). Nowadays, the growth of economy and population leads to the rapid development of tourism. Under this trend, the traffic energy consumption and carbon emissions caused by tourism will further increase.

In general, two approaches, *top-down* and *bottom-up*, were used to measure carbon emissions in the tourism sector. The former regards tourism sub-sectors as a single department in the national economic system. However, its shortcomings include relying on relatively complete tourism statistics systems and national environmental economic accounting systems; also the estimation is often inaccurate (Nielsen S P et al. 2010). Therefore, this method is suitable for countries or regions with small areas where data can be refined and easily collected (Becken, Frampton et al. 2001). In contrast, the bottom-up approach is more broadly applied. Gössling (2002) used the bottom-up approach to divide global tourism-related carbon emissions into three parts: traffic, accommodation and activities.

Decomposition analysis is the method that analyzes historical changes in economic, environmental, and other socio-economic indicators to trace the underlying factors that contribute to such changes (Sun 2016). The Logarithm Mean Divisia Index (LMDI) has been widely used in energy efficiency and environmental impact decomposition (Ang and Zhang 2000; Ang 2005) and particularly CO₂ decomposition (Wang et al. 2005; Liu et al. 2007; Lin and Long 2016). LMDI approach is applied to industrial CO₂ emissions and employment in 5 European Union countries (Kopidou, Tsakanikas et al. 2016). İpek Tunç et al. (2009) used the LMDI approach to identify the factors that contribute to changes in CO₂ emissions for the Turkish economy. Yang et al. (2016) analyzed several measurement possibilities, present and develop a number of approaches based on the LMDI approach to decompose changes in aggregate CO₂ emissions. Achour and Belloumi (2016) identified the driving factors and measure the corresponding contributions in traffic energy consumption over the period 1985–2014 for Tunisia using LMDI.

On the issue of carbon emissions from tourism traffic, scholars have made significant attempts. The researches mainly focused on the macro-level of the country. Yorucu.V (2016) found that there is a significant relationship between CO₂ emissions and visitor arrivals in Turkey. Ang et al. (2016) used the LMDI approach to analyze the changes

of total carbon intensity of global and national power generation from 1990 to 2013. It was found that the reduction of power generation in the world and most major power generating countries was mainly due to the improvement of thermal efficiency of power generation, not fuel conversion. Most results of using LMDI approach to decompose carbon emissions are the overall carbon emissions, and the research on the decomposition of carbon emissions in tourism and traffic industry has not been sufficiently studied.

Through the previous literature review, we can notice that previous researches involve multi-dimensional space of country, region, province and city, but the case study of Beijing has not appeared. As the political and cultural center of China, Beijing is one of the most developed tourism areas. With the national attention to tourism and environmental protection in recent years, the research on carbon emissions from tourism industry in Beijing has received increasing attentions. And, it lacks a comprehensive and long-term estimation of tourism traffic carbon emissions and its influencing factors. The scientific significance and theoretical value of this project lies in that the research on carbon emissions from tourism traffic is produced under the background of rapid development of tourism industry, and with the in-depth study of carbon emissions from tourism by scholars. Carbon emissions from tourism traffic have also attracted much attention. However, there are few reports on the spatial level of provinces and municipalities, especially Beijing as a case study area. This study uses Beijing as the research object, and employs LMDI approach and Tapio model to decompose and analyze the influencing factors of tourism traffic carbon emissions at the city level, which is conducive to enriching and improving the theoretical system of tourism traffic carbon emissions; furthermore, the current attention on tourism traffic carbon emissions is insufficient, and this study is conducive to expanding the research scope of environment-economic geography.

The research scope of economic geography provides a positive exploration for the theoretical construction of urban tourism traffic carbon emissions from the perspective of geography. Taking Beijing as an example, this paper calculates the carbon emissions of Beijing's tourism traffic from 2005 to 2017. As the political and cultural center of China, Beijing's tourism industry is particularly developed. The task of reducing carbon emissions in tourism industry is arduous and the development of tourism industry is urgent. Based on the calculation of carbon emissions in Beijing's tourism traffic, this paper uses Tapio model and LMDI approach, discusses the relationship between economic development and the change of traffic carbon emissions and its influencing factors in Beijing, so as to provide theoretical basis for the study of Beijing's tourism traffic carbon emissions and provide scientific basis for the formulation of policies related to carbon emissions reduction.

2 Methodology and data source

2.1 Methodology

So far, China still lacks the statistical caliber of tourism traffic data. Based on the collected data of tourism traffic, this study chooses three modes of traffic, railway, highway and civil aviation, calculates the carbon emissions of passenger traffic, and uses its proportion in the carbon emissions of tourism traffic to indirectly estimate the carbon emissions of tourism traffic in Beijing.

2.1.1 Carbon emissions from passenger traffic

The United Nations World Tourism Organization (UNWTO) method for calculating traffic carbon emissions (UNWTO 2008), the specific calculation model could refer to Eq. (1).

$$C = P_i \times Q_i \quad (1)$$

where C represents total emissions of CO₂, P_i refers to the carbon emissions coefficient of traffic type (i), and Q_i denotes passenger volume of the mode of traffic type (i). Table 1 gives the generalized emission factors used for the analyses.

2.1.2 Carbon emissions from tourism traffic

The calculation model of carbon emissions from tourism traffic can be calculated by Eq. (2):

$$C' = \beta \times C \quad (2)$$

where C' refers to the carbon emissions of tourism traffic, C represents the CO₂ emissions of passenger traffic, and β is the proportion of tourism carbon emissions in a particular passenger traffic carbon emissions.

Due to the establishment of China's tourism satellite account system is not perfect, it is impossible to accurately determine the β value. According to the actual situation and referring to the research results of experts and scholars, this paper chooses the β value of highway, civil aviation and railway as 13.8, 64.7 and 31.6%, respectively (Wei et al. 2012).

2.1.3 Decoupling model

The decoupling model is used to verify the relationship between related variables. According to Tapio (2005), the decoupling index between economic activity and carbon emissions is shown as Eq.(3) as follows:

$$DE = \frac{\Delta C/C_0}{\Delta G/G_3}$$

where DE represents the total decoupling index; C represents carbon emissions in Beijing's tourism traffic sector; G represents GDP (gross domestic product); and Δ denotes the change from the base year 0 to year t. Tapio decoupling indicators identify a more comprehensive decoupling state based on DE, as shown in Fig. 1. It should be noted that strong decoupling is the optimal decoupling state, and strong negative decoupling is the case where decoupling is least expected.

Table 1 Generalized emission factors for transport. (source: Peeters et al.2004; Peeters et al.2007; Kuo and Chen 2009; Peeters and Dubois 2010)

Transport mode (gCO_2/pkm)	Emission factor
Rail	27
Car	133
Air (Domestic)	137

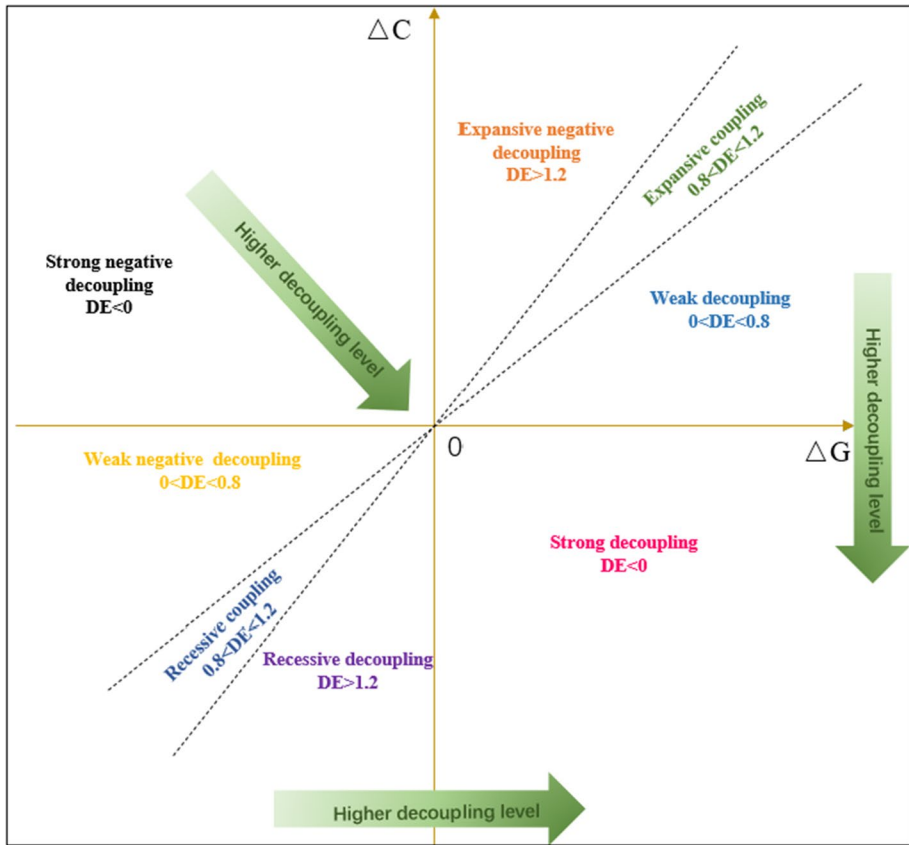


Fig. 1 Decoupling category of economic activity and carbon emissions (adjusted from Tapio P 2005)

2.1.4 LDMI approach for decomposition of influencing factors of carbon emissions

At present, the decomposition methods of influencing factors of carbon emissions are mainly divided into two categories: structural decomposition analysis (SDA) and index decomposition analysis (IDA) (Sun and Ang 2000; Peters 2007; Guan, Hubacek et al. 2008). Structural decomposition analysis (SDA) is an input–output model of econometrics, based on input-output data, to decompose the changes of carbon emissions. This method requires high research data, and the decomposition results can only be in the form of additions, which has become the main obstacle to its extensive application in empirical analysis. Index decomposition analysis (IDA) relatively convenient to calculate, it only needs to use the total data of sectors. It is especially suitable for the model with less factors and time series. In this paper, the index decomposition method (IDA) and Logarithm Mean Divisia Index (LMDI) are used to analyze the decomposition factors of tourism traffic carbon emissions.

LMDI approach is one of the most popular factor decomposition approaches in the field of carbon emissions research. One of the most commonly used methods of exponential decomposition is the logarithmic index decomposition approach proposed by

Ang, D.W. (Ang and Zhang 2000; Ang 2004). This approach has the characteristics of convenient calculation, no residual terms, solid theoretical basis and wide application range. It has great advantages in adaptability, presentation and result display. It is often used by many scholars in the decomposition and analysis of carbon emission factors. Scholar Yoichi Kaya (1989) proposed the Kaya equation in 1989. It is the mainstream analytical model for decomposing the driving factors of carbon dioxide emissions. The specific expressions are as follows:

$$C = P \times (G/P) \times (E/G) \times (C/E) \quad (4)$$

where C represents the total CO_2 emissions; P , G and E denote tourists scale, GDP (Gross Domestic Product) and energy consumption, respectively. The decomposition factors of carbon dioxide emissions by traditional Kaya equation are not comprehensive enough. According to existing researches, the main factors affecting carbon dioxide emissions of tourism traffic include economic development, tourists scale, energy structure, industrial structure, etc. Due to Beijing's special political and cultural status, rapid development of tourism industry and increasing number of tourists, this paper chooses the number of tourists as the scale effect of tourists, and the level of per capita tourism consumption and the contribution of tourism industry to GDP as the scale effect of economy, which can reflect both the scale of tourists and the number of tourists. The close relationship between the development of tourism environment can also measure the overall economic development of Beijing. According to the different energy sources used by traffic modes and means of traffic, the energy intensity and energy structure effects are selected to reflect the development level and energy consumption mode of Beijing's traffic sector, and the energy consumption structure of traffic is adopted. To change analysis of the composition of energy consumption system, mining the emission reduction mechanism of the traffic sector, predicting the future structure of traffic consumption better, we choose the specific selection factors and expanded expressions are as follows (Eq. (5)) (Wang 2016):

$$C = \sum_j P \times \frac{R}{P} \times \frac{GDP}{R} \times \frac{T}{GDP} \times \frac{E}{T} \times \frac{E_j}{E} \times \frac{CO_2}{E_j} \quad (5)$$

where C represents the total CO_2 emissions, P represents the number of tourists in Beijing, R represents the tourism income of Beijing, GDP represents the gross domestic product of Beijing, T represents the volume of passenger traffic in Beijing, E represents the traffic energy consumption in Beijing, and E_j represents energy consumption from fuel type j in Beijing; P reflects the scale effect of tourists; R/P represents the level of per capita tourism consumption, GDP/R can be used to represent the reciprocal contribution of tourism industry to GDP and economic scale effect; T/GDP represents the passenger traffic volume per unit GDP, E/T represents the energy consumption per unit passenger traffic volume, and the combination of the two reflects the energy intensity effect; E_j/E represents the ratio of fuel type j to the total energy consumption of traffic, reflecting the energy structure effect. Changes in carbon emissions during base year 0 and year t can be expressed as the following additive models (Wang 2016):

$$\Delta CO_2 = C^t - C^0 = \Delta C_p + \Delta C_a + \Delta C_r + \Delta C_g + \Delta C_q + \Delta C_s + \Delta C_a \quad (6)$$

where ΔCO_2 represents the change of traffic carbon emissions from base year 0 to final year t (10,000 tons); ΔC_p represents the tourists scale; ΔC_a represents the level of per capita tourism consumption; ΔC_r represents the contribution of tourism industry to GDP;

ΔCg represents the passenger traffic volume per unit GDP; ΔCq represents the energy consumption per unit passenger traffic volume; ΔCs represents energy structure; ΔCk represent carbon emission coefficients. It is known in the calculation that the carbon emission coefficients of each energy source do not change, so the value of ΔCk is zero.

Ang, B. W. (2005) solved the problem that LMDI method could not deal with zero and negative values of data by using the technique of “analytical limit.” In practical problems, for the value of 0, an arbitrary small number can be used to replace (for example, 10^{-10} – 10^{-20} power), so that the calculation results are not affected. Refer to the LMDI decomposition approach (detailed derivation of the calculation process can refer to Ang B. W. (2005)), under the additive decomposition mode, the specific expressions of each variable are as follows:

$$\Delta Ca = \ln \left[\frac{a^t}{a^0} \right] \cdot \sum_{j=1} \frac{C_j^t - C_j^0}{\ln C_j^t - \ln C_j^0} \quad (7)$$

$$\Delta Cp = \ln \left[\frac{p^t}{p^0} \right] \cdot \sum_{j=1} \frac{C_j^t - C_j^0}{\ln C_j^t - \ln C_j^0} \quad (8)$$

$$\Delta Cr = \ln \left[\frac{r^t}{r^0} \right] \cdot \sum_{j=1} \frac{C_j^t - C_j^0}{\ln C_j^t - \ln C_j^0} \quad (9)$$

$$\Delta Cg = \ln \left[\frac{g^t}{g^0} \right] \cdot \sum_{j=1} \frac{C_j^t - C_j^0}{\ln C_j^t - \ln C_j^0} \quad (10)$$

$$\Delta Cq = \ln \left[\frac{q^t}{q^0} \right] \cdot \sum_{j=1} \frac{C_j^t - C_j^0}{\ln C_j^t - \ln C_j^0} \quad (11)$$

$$\Delta Cs = \ln \left[\frac{s^t}{s^0} \right] \cdot \sum_{j=1} \frac{C_j^t - C_j^0}{\ln C_j^t - \ln C_j^0} \quad (12)$$

In the formula, $p=POP$, $a=R/P$, $r=GDP/R$, $g=T/GDP$, $q=E/T$, $s=E_j/E$. If the calculation result is greater than zero, it means that this factor promotes carbon dioxide emissions; if the calculation result is less than zero, it means that this factor inhibits carbon dioxide emissions.

2.2 Data sources

In order to better explain the trends of carbon emissions in Beijing’s tourism traffic and analyze the composition of influencing factors, the analysis was based on limited data from 2005–2017. The data in this paper mainly come from Beijing Statistical Yearbook (2006–2018), and the specific data are shown in Table 2.

The passenger volume of each traffic during the period of study is presented in Fig. 2.

Table 2 Passenger volume in Beijing from 2005 to 2017 (Unit: 100 million kilometers) *Source:* Beijing Statistical Yearbook (2006, 2018)

Year	Passenger volume			Total
	Railway	Highway	Civil Aviation	
2005	776.03	1873.75	5731.00	8380.78
2006	890.69	791.95	6571.90	8254.54
2007	908.44	1474.25	7220.78	9603.46
2008	902.28	2409.60	7108.09	10419.98
2009	935.60	2677.14	7852.02	11464.76
2010	995.51	2906.49	10093.41	13995.40
2011	1086.61	3036.66	11163.24	15286.50
2012	1163.83	3047.76	11746.29	15957.88
2013	1179.56	1360.83	12447.33	14987.72
2014	1356.31	1382.97	13287.97	16027.25
2015	1493.11	1301.21	14682.46	17476.78
2016	1508.20	1176.74	16208.19	18893.13
2017	1537.63	993.97	18026.86	20558.45

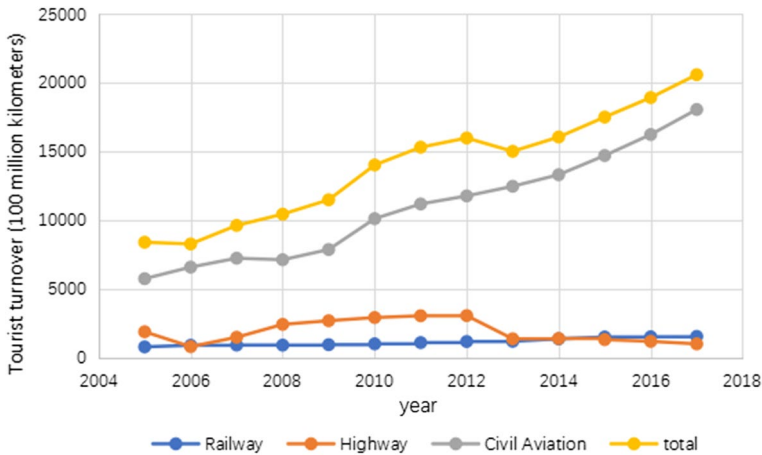


Fig. 2 Passenger volume in Beijing from 2005 to 2017

3 Result analysis

3.1 Carbon emissions and dynamic evolution of tourism traffic

Using Eqs. 1 and 2, we calculated the carbon emissions of railway, highway and civil aviation tourism traffic from 2005 to 2017, as shown in Table 3.

From 2005 to 2017, the passenger volume of different modes of traffic in Beijing showed an increasing trend (Table 2). The passenger volume of civil aviation is significantly higher than that of railway and highway. As the political and cultural center, Beijing has convenient traffic, developed traffic network system, rapid development of civil aviation traffic, and

Table 3 Carbon emissions of tourism traffic in Beijing from 2005 to 2017 *Source:* Based on Beijing Statistical Yearbook (2006, 2018)

Year	Carbon Emissions from Tourism Traffic(10,000 Tons)			Total(10,000 Tons)	Per capita tourists (kg/person)
	Railway	Highway	Civil Aviation		
2005	2.89	161.24	248.11	412.24	32.05
2006	3.32	68.15	284.51	355.98	26.19
2007	3.38	126.86	312.60	442.85	30.09
2008	3.36	207.35	307.72	518.43	35.61
2009	3.49	230.37	339.93	573.79	34.42
2010	3.71	250.11	436.96	690.78	37.56
2011	4.05	261.31	483.28	748.63	34.98
2012	4.34	262.26	508.52	775.12	33.50
2013	4.40	117.10	538.87	660.37	26.22
2014	5.05	119.01	575.26	699.32	26.74
2015	5.56	111.97	635.63	753.17	27.61
2016	5.62	101.26	701.69	808.56	28.34
2017	5.73	85.53	780.42	871.68	29.30

the largest proportion of passenger volume. Meanwhile, existing studies have shown that air traffic is the main source of carbon emissions from tourism-related traffic and that its contribution to total domestic tourism-related carbon emissions is more than 55% (Chen et al.2018). For the situation that Beijing civil aviation passenger volume occupies an absolute dominant position, Beijing civil aviation traffic carbon emissions show an increasing trend year by year, and the growth rate is faster. Compared with 2016, the growth rate of civil aviation carbon emissions in 2017 is 11.22%. In addition, compared with the railway traffic mode, the growth rate of carbon emissions from railway traffic is slower. As can be seen from Table 3 tourism carbon emissions from railway has a growth rate of 1.96% in 2017 compared with 2016; the carbon emissions from highway began to slow down in 2011 and showed a downward trend after 2012. This may be related to the implementation of the travel license plate restriction policy in Beijing in April 2011. It indicated that the release of this policy will have a certain effect on the emission reduction of tourism traffic carbon in the future.

3.2 Decoupling analysis

The decoupling of Beijing economic growth from carbon emissions in Beijing's tourism traffic sector is displayed in Table 4. According to Table 4., the decoupling relationship between economic growth and carbon emissions from tourism traffic sectors in Beijing from 2005 to 2017 is mainly in a state of weak decoupling, indicating that the economic growth of Beijing and carbon emissions in tourism traffic sectors are in a weak coupling state, and the development of Beijing is developing in step with the change of carbon emissions. The decoupling state can be divided into two phases: expansive coupling (2005–2008) and weak decoupling (2008–2017). In the first stage, the decoupling relationship in 2005–2006 is mainly manifested as expansive negative decoupling, indicating that

Table 4 Decoupling of Beijing's economic growth from carbon emissions in Beijing's tourism traffic sector during 2005–2017

Year	ΔC	ΔG	DE	Decoupling state
2005-2006	0.26	0.17	1.53	expansive negative decoupling
2006-2007	0.16	0.21	0.76	expansive coupling
2007-2008	0.15	0.14	1.07	
2008-2009	0.04	0.09	0.44	weak decoupling
2009-2010	0.07	0.16	0.44	
2010-2011	0.01	0.15	0.07	
2011-2012	0.07	0.1	0.70	
2012-2013	-0.01	0.11	-0.09	strong decoupling
2013-2014	0.06	0.075	0.80	weak decoupling
2014-2015	0.02	0.08	0.25	
2015-2016	0.05	0.08	0.63	
2016-2017	0.07	0.1	0.70	

at this time, the growth rate of carbon emissions was faster than the economic growth rate, and the tourism traffic sectors in Beijing are insufficient in energy conservation and emission reduction, so the growth rate of carbon emissions is higher. From 2006 to 2008, the economic growth rate of Beijing was almost the same as carbon emission of the tourism traffic sectors; in the second stage, the economic growth rate of Beijing from 2008 to 2017 is slightly higher than the carbon emission rate of tourism traffic sectors, indicating that the carbon emission reduction policy has been implemented and made some progress during this period.

3.3 Study on the change mechanism of carbon emissions from tourism traffic

Due to the lack of data on energy consumption in Beijing's tourism traffic system and the fact that tourism traffic is a part of the whole traffic system, the decomposition of total carbon emissions in Beijing's traffic industry is also applicable to Beijing's tourism traffic. Therefore, this paper will decompose the influencing factors of carbon emissions in Beijing's tourism traffic. From the perspective of energy consumption, this paper calculates the carbon emissions of tourism traffic in Beijing. The selected energy carbon emission coefficients are as follows (Table 5):

According to the LMDI approach and the data collected for calculating carbon emissions (Table 6), the decomposition results of the factors of Beijing's tourism traffic carbon emissions are calculated by using Eqs. (4–12) (Table 7).

Based on the data in Table 7, we were able to analyze the impact of the above factors on the carbon emissions of tourism traffic (Fig 3).

Table 5 Carbon emission coefficient of various energy sources

Coal	Gasoline	Kerosene	Diesel oil	Fuel oil	Natural gas	Liquefied petroleum gas	Electric power
(kgCO ₂ /kg)							(tC/tstandard coal)
1.9003	2.9251	3.0179	3.0959	3.1705	2.1731	3.1013	2.2132

Table 6 Carbon emissions factor data of travel traffic in Beijing from 2005 to 2017

Year	CO ₂	P	R	GDP	T	E
Unit	(10,000 t)	(Hundreds of millions of people)	(100 million yuan)		(100 million kilometers)	(10,000 t)
2005	1013.13	12.86	1300.0.	7141.40	8380.78	563.39
2006	1272.57	13.59	1482.70	8312.60	8254.54	717.60
2007	1470.78	14.72	1753.60	10071.90	9603.46	840.79
2008	1686.46	14.56	1907.00	11392.00	10419.98	993.90
2009	1760.35	16.67	2144.50	12419.00	11464.76	1025.24
2010	1896.97	18.39	2425.10	14441.60	13995.40	1104.84
2011	1915.47	21.40	2864.30	16627.90	15286.50	1185.89
2012	2056.98	23.13	3301.30	18350.10	15957.88	1235.10
2013	2050.20	25.19	3666.30	20330.10	14987.72	1145.52
2014	2170.68	26.15	3997.00	21944.10	16027.25	1204.20
2015	2220.38	27.28	4320.00	23685.70	17476.78	1249.40
2016	2326.71	28.53	4683.00	25669.10	18893.13	1312.70
2017	2460.08	29.75	5122.40	28014.90	20558.45	1386.80

CO₂ represents carbon dioxide emissions; P represents tourists scale; R represents tourism income; GDP represents Gross Domestic Product; T represents passenger volume; E represents traffic energy consumption.

Table 7 The decomposition result of factors influencing carbon traffic in tourism traffic in Beijing from 2005 to 2017

Year	ΔCp	ΔCa	ΔCr	ΔCg	ΔCq	ΔCs	ΔCO_2
2005	0	0	0	0	0	0	0
2006	56.48	78.54	20.91	-171.51	264.00	-9.47	238.94
2007	149.44	182.98	49.46	-230.63	293.41	-16.41	428.24
2008	147.32	308.17	99.66	-296.26	415.92	-56.68	618.13
2009	314.85	293.08	64.10	-291.47	346.60	-45.21	681.96
2010	453.61	337.60	102.40	-242.90	203.91	-35.53	819.09
2011	669.14	368.85	72.55	-320.80	188.22	-46.07	931.89
2012	775.48	455.75	15.56	-395.96	186.18	-84.77	952.24
2013	918.49	498.51	12.81	-635.37	175.42	99.78	1069.63
2014	997.29	581.50	-0.83	-666.61	156.38	104.85	1172.57
2015	1076.08	642.87	-2.76	-664.21	88.05	108.98	1249.01
2016	1169.87	712.08	-3.22	-685.07	48.48	120.79	1362.91
2017	1271.67	808.34	-6.72	-712.16	5.23	139.42	1505.78

ΔCp , ΔCa , ΔCr , ΔCg , ΔCq , and ΔCs , respectively, indicate tourists scale, the level of per capita tourism consumption, the contribution of tourism industry to GDP, passenger traffic volume per unit GDP, energy consumption per unit passenger traffic volume and energy structure elements, ΔCO_2 represents the change of carbon emissions from base year to year t (10,000 tons)

The carbon emissions of Beijing’s tourism traffic show an overall increasing trend from 2006 to 2017. Among the decomposed factors, the tourists scale, energy consumption per unit passenger traffic volume and per capita tourism consumption level have consistently

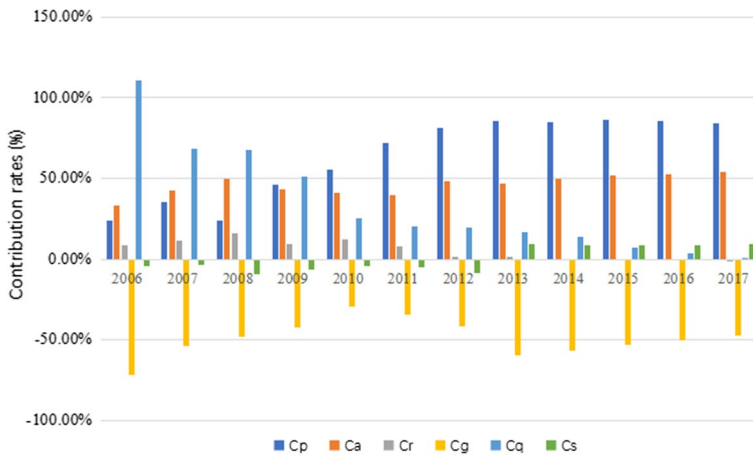


Fig. 3 Trends in the contribution of various factors to the carbon emission of tourism traffic

shown positive effects on the increase of carbon emissions, while the traffic volume per unit GDP has always shown negative effects, and the contribution of tourism industry to GDP and energy structure have shown positive and negative effects. As shown in Fig. 3, the contribution rate of each decomposition factor to the carbon emission of tourism traffic can be seen. On average, the tourists scale contributes the most to the carbon emission of tourism traffic in Beijing, and the average contribution rate of this factor reaches 63.71%. And the per capita tourism consumption level and energy consumption per unit passenger traffic volume, with an average contribution rate of 45.89 and 33.54%, respectively. In 2017, the absolute value of the influencing factors is as follows: tourists scale is 84.45%, per capita tourism consumption level is 53.68%, passenger traffic turnover effect per unit GDP is -47.30% , energy structure effect is 9.26%, tourism industry effect on gross product is -0.45% , and energy consumption effect per unit passenger traffic turnover is 0.35%.

The mechanism of carbon emissions change in tourism traffic is analyzed as follows:

- (1) The tourists scale is the dominant factor in the growth of Beijing's tourism traffic carbon emissions during the research period. From 2006 to 2017, the number of tourists in Beijing increased from 1.286 billion to 2.975 billion, and the contribution rate of tourists increased from 23.64 to 84.45%. The contribution rate of tourists scale is far greater than other factors, and its influence on carbon emissions of tourism traffic keeps rising steadily.
- (2) Per capita tourism consumption level and per unit passenger traffic volume have a positive effect on the growth of Beijing's tourism traffic carbon emissions. The carbon emissions of per capita tourism consumption increased from 564,800 tons in 2006 to 12,716,700 tons in 2017. It shows that high-quality consumption experience and increasingly convenient traffic make tourists' choices in travel more abundant. Correct guidance of tourists' consumption behavior is an important link to reduce carbon emissions and achieve green and healthy development of tourism industry. From 2006 to 2017, the contribution rate of energy consumption per unit traffic turnover decreased from 110.49 to 0.35%. It suggests that although energy consumption per unit traffic

volume always shows positive effects, with the development of science and technology, the use of new energy sources and the promotion of “one-stop” tourism traffic have gradually decreased the positive effect of this factor, which may become a breakthrough in reducing traffic carbon emissions.

- (3) The energy structure effect has a weak negative effect on the growth of Beijing’s tourism traffic carbon emissions in the early stage of the study, and then it turns into a positive effect. For traffic energy consumption, an energy system with a high proportion of fossil energy, such as coal, will produce more carbon emissions than an energy system with a low proportion of fossil energy. For Beijing, the energy consumption of kerosene occupies an absolute advantage, which makes the carbon emissions of traffic energy increase year by year. This is also the main reason that the effect of energy structure has changed from negative effect to positive effect since 2013. In terms of energy use structure, the fossil energy consumption structure of Beijing is constantly changing. The proportion of coal, gasoline and natural gas continues to decline, while the proportion of kerosene, diesel and liquefied petroleum gas increases, which causes the total CO₂ emission of Beijing to increase from −94,700 tons in 2006 to 1,394,200 tons in 2017.
- (4) Traffic volume per unit GDP has a significant negative effect, but the negative effects of the above factors are decreasing. It can be concluded that: Beijing’s per unit GDP traffic volume has an obvious effect on reducing the carbon emissions of tourism traffic, reflecting the gradual development and improvement of Beijing’s traffic system, the level of public service of tourism traffic and the traffic volume rate have been greatly improved, and the per unit GDP traffic volume has been greatly increased. However, the proportion of civil aviation in Beijing’s traffic mode is larger than that of other modes, and the carbon emission coefficient of civil aviation is the largest compared with other modes, which means that the carbon emission of civil aviation under the same unit GDP is also larger than that of other modes of traffic. This is also the reason why the negative effect of restraining the traffic volume factor of Beijing’s unit GDP is decreasing year by year.
- (5) The contribution of tourism industry to GDP shows positive effect in the early stage of the study and then turns to negative. The rapid development of tourism industry has achieved initial results in reducing carbon emissions in Beijing. Attaching importance to the economic development of tourism industry, changing the mode of economic growth, and developing green and efficient tourism industry have played an increasingly important role in restraining carbon emissions in Beijing’s tourism traffic.

4 Discussion and conclusion

This study calculated the carbon emissions of tourism traffic in Beijing, and employed LMDI approach and Kaya equation to analyze and calculate the factors affecting the carbon emissions of tourism traffic through the bottom-up method. According to the calculation results, in the process of economic development and tourism industry development in Beijing, the carbon emissions of tourism traffic increased from 4.1224 million tons in 2005 to 8.7168 million tons in 2017, with a growth rate of 111.45%. Through the calculation of contribution rate, tourists scale has become a major driver of the rapid increase of tourism traffic carbon emissions. Also, the increase of per capita consumption level has promoted the increase of tourism traffic carbon emissions. However, the contribution rate of tourism

industry to GDP has a significant inhibitory effect on tourism traffic carbon emissions. This phenomenon shows that increasing the transformation of tourism development and promoting the upgrading of tourism industry will reduce the carbon emissions of tourism traffic. That is to say, the restraint effect of economic scale factor is obvious and cannot be ignored. Although the energy intensity factor has led to the increase in carbon emissions from tourism traffic, its impact on carbon emissions from tourism traffic has gradually become smaller due to the transformation and development in recent years.

Furthermore, the energy consumption structure of the traffic sector is greatly influenced by the mode of traffic. In recent years, Beijing's energy consumption mainly consists of petroleum products such as gasoline, diesel oil and kerosene. However, in terms of the proportion of energy consumption, the proportion of electric power has slightly decreased, which indicates that Beijing is insufficient in the promotion and utilization of new energy such as electric power. The tourism traffic energy is still dominated by traditional energy sources such as coal and petroleum, so the evolution of energy structure has less impact on the carbon emissions of Beijing's tourism traffic. Therefore, it is necessary to increase the proportion of new green energy. Meanwhile, promoting the development of new technology emission reduction and strengthening scientific and technological investment and research in traffic industry is one of the measures to promote carbon emission reduction in tourism traffic in Beijing.

Furthermore, this study also uses Tapio model to explore the decoupling relationship between economic development and tourism carbon emissions in Beijing. The results show that Beijing's economic growth and carbon emissions of tourism traffic are in a weak coupling state, which indicates that Beijing's economic development and tourism traffic carbon emissions are synchronous.

5 Policy recommendations

According to the calculation and analysis of carbon emissions of tourism traffic in Beijing, the main policy suggestions for energy conservation and emission reduction of tourism traffic in Beijing in the future are put forward as follows:

- (1) First, LMDI decomposition shows that tourists scale has a significant positive effect on tourism traffic carbon emissions. Beijing, as the capital, has a rapid development of tourism industry. In the case of the sustained growth of energy consumption demand and the continuous growth of the number of tourists, tourists should be encouraged to choose low-carbon travel tools. In this way, we can reduce the carbon emissions of tourism transportation in the short term
- (2) Second, build and improve the green traffic system, and establish the concept of low-carbon tourism. Beijing has a large flow of people, accompanied by huge traffic pressure. Therefore, it is particularly important to speed up the construction of a developed high coverage, efficient and punctual public transport system, which can reduce the carbon emissions of tourism traffic.
- (3) Third, develop eco-tourism. Vigorously develop eco-tourism and increase the proportion of tourism industry in GDP. The research shows that the contribution of tourism industry to GDP has a restraining effect on the increase of tourism traffic carbon emissions after 2014. Therefore, we should strengthen the development of tourism,

- accelerate the promotion of high-level eco-tourism activities, reduce carbon emissions and realize the development of low-carbon tourism.
- (4) Fourth, promote new energy-saving technologies and improve energy efficiency. In the whole industry, promote the use of energy-saving, new products and technologies, develop new energy actively, and strengthen the research and development of efficient and energy-saving means of traffic. At the same time, the government should provide good information services for traffic sectors to do well in energy conservation and emission reduction.
 - (5) Fifth, accelerate the adjustment of energy structure and develop low-carbon energy and renewable energy. At present, the energy consumption structure of Beijing is mainly kerosene, and the carbon emissions coefficient of kerosene is high, which is very unfavorable for energy conservation and emission reduction. However, the proportion of relatively low-carbon natural gas is too low. Therefore, we should adjust industrial policies to promote the development of natural gas industry, develop various new and renewable energy in a planned way, and strive to maintain a sustained growth in the proportion of non-fossil energy.

6 Research and prospect

The current research object of this study is Beijing's tourism traffic carbon emissions and its impact mechanism. However, there are limitations in this study. First, this study targets only Beijing. Future studies are needed to explore other tourism traffic destinations with special unique features in order to examine the differences of the factors on the growths of carbon dioxide emissions in different types of tourism destinations. Second, the time span of 13 years is relatively short to enable the study of long-term effects.

This paper calculates Beijing's tourism traffic carbon emissions, and analyses its impact mechanism and correlation. Future research expansion mainly focuses on:

In terms of the selection of influencing mechanism factors, in-depth analysis of internal and external factors and mechanism analysis of influencing tourism traffic carbon emissions can select factors that can reflect carbon emissions more accurately according to the actual situation, which is one of the research directions in the future.

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