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Estimation and Factor Decomposition of Carbon Emissions in China′s Tourism Sector

Szacowanie poziomu emisji i czynników rozkładu dwutlenku węgla w chińskim sektorze turystycznym

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Abstract

Based on data from 2000-2015, this study estimated the carbon emissions of China's tourism-related traffic, accommodation, and tourism activities. To quantify the factors governing tourism carbon emissions, this study employed the logarithmic mean Divisia index (LMDI). Furthermore, simultaneous equations models were applied to determine the impact of tourism volume, economic growth, and technological progress on tourism-related carbon emissions. The results showed that carbon emissions are continuously increasing, with tourism-related traffic being the main contributor to total carbon emissions in the tourism sector and private cars being the major source of traffic-related carbon emissions. LMDI and simultaneous equations analysis revealed that tourism volume was the main driving force behind the increase in tourism-related carbon emissions, whereas energy intensity and structure effects were less significant factors influencing the growth rate of carbon emissions in China's tourism sector.

Key words: energy consumption, carbon emissions, tourism economy

Streszczenie

Na podstawie danych z lat 2000-2015 w tym artykule oszacowane emisje węglowe związane z turystyką: ruch drogowy, zakwaterowanie i aktywność turystyczną. Aby określić ilościowo czynniki odpowiedzialne za związane z turystyką emisje węglowe użyto logarytmiczny Divisia index (LMDI). Następnie zastosowano modele symultanicznych równań, aby określić wpływ poziomu ruchu turystycznego, wzrost ekonomiczny i postęp techniczny na związane z turystyką emisje węglowe. Otrzymane rezultaty pokazuję, że poziom emisji węglowych nieustannie się zwiększa, przy czym głównym czynnikiem jest turystyczny ruch samochodowy, w szczególności samochodów prywatnych. LMDI i symultaniczne równania potwierdziły, że poziom ruchu turystycznego był głównym motorem odpowiedzialnym za wzrost związanych z turystyką emisji węglowych, natomiast energochłonność i czynniki strukturalne odgrywają mniejszą rolę we wzroście emisji węgla z chińskiej turystyki.

Słowa kluczowe: konsumpcja energii, emisje węgla, ekonomia turystyczna

1. Introduction

Effective tourism strategies are important from the perspective of sustainable development. Indeed, tourism can create sustainable income-generating opportunities and provide employment to absorb large numbers of semi-skilled or unskilled workers (Yiu et al., 2013). However, the environmental dimension of tourism sector should also be taken into consideration.

In 2015, the Chinese tourism sector witnessed an increase in visitors 4.4% to 1.184 billion tourists, making 2015 the sixth consecutive year with an above-average growth rate in tourism (UNWTO, 2016a). Meanwhile, the global tourism sector provides 285 million employment opportunities, and its contribution to the global GDP is 9.8%. It is predicted that by 2026, the global tourism sector will provide 370 million employment opportunities, contributing 13.3% to global GDP, amounting to 10.98 trillion USD (WTTC, 2016).

However, the rapid development of tourism has also increased carbon emissions (Scott et al., 2016a). The global tourism sector consumed 16,700 PJ of energy resources and emitted 1.12 Gt of CO_2 (Gössling et al., 2015) in 2010, making tourism-related carbon emissions an important issue. In addition, further studies have shown that tourism-related CO_2 emissions accounted for 4.4% of global carbon emissions (Peeters and Dubois, 2010), and CO_2 emissions per tourist increased by 24% from 2006 to 2014 (WTTC, 2015). Moreover, the probability that the world population will increase to 9.6-12.3 billion people (Patrick et al., 2014) over the next 100 years is 80%, and tourism-related CO_2 emissions are expected to maintain an average annual growth rate of 3.2% (Yuan et al., 2014). A more serious issue is that of energy management cooperation and conflict leading to an increase in carbon emissions. Andrews-Speed et al. (2014) predicted that annual carbon emissions will reach 17 Gt in 2040, which exceeds the United Nations' target of about 10 Gt for 2050. Thus, global environmental problems caused by tourism will become more prominent.

Although Western countries have been the main tourist sources and destinations, the number of inbound and outbound tourists in newly industrializing countries such as China has been increasing steadily (National Bureau of Statistics of China, 2015). The latest data show that in the first half of 2016, global tourism increased by 9%, mainly in Oceania and Asia (UNWTO, 2016a and 2016b). In fact, in 2013, China was among the top 12 countries globally in terms of the number of inbound tourists. More pertinently, China's number of outbound tourists and tourism consumption is ranked first in the world (China Statistical Yearbook, 2015).

China's per capita disposable income has been increasing, increasing the potential demand of China's tourism sector. Moreover, implementation of the two-child liberalization policy may lead to a larger population, which will increase the tourism volume. In the foreseeable future, China will become the largest tourism resources market among developing countries (UNWTO, 2014). In 2015, according to the China National Tourism Administration's statistics, the Chinese tourism sector became the largest national industry, with a total annual income of 4.13 trillion yuan. Tourism's direct contribution to the national GDP is 3.32 trillion yuan (4.9%), and its total contribution is 7.34 trillion yuan (10.8%). The tourism sector employs 27.98 million people directly, and indirect employment through tourism benefits up to 52.13 million people, accounting for 10.2% of the total domestic employed population (China Tourism Statistics Bulletin, 2016). Since China's economy is ranked second globally and the country's tourism industry significantly contributes to the national GDP, the study of China's tourism sector is not only beneficial to the country itself, but also of great significance to the world.

Additionally, China is the world's largest consumer of energy. Early in 2012, China's total coal consumption was more than four times that of the United States. China's CO_2 emissions in 2014 were 3,766.52 Mt more than that of the United States, making China the largest producer of CO_2 emissions globally (China Statistical Yearbook, 2015). Despite the significance of China's tourism sector, exact data of its energy consumption and carbon emissions do not exist. Therefore, it is necessary to estimate and decompose the total carbon emissions of the Chinese tourism sector. This would not only be helpful to reduce emissions in China, but could also be a model for other developing countries that are striving to develop tourism, especially where tourism is a pillar industry and carbon emission reduction is difficult. Therefore, this paper aims to measure the total carbon emissions of China's tourism sector more accurately and to try to find a reasonable method of emission reduction.

More specifically, compared with available literature (Luo et al., 2018; Xu, Reed, 2017; Peng et al., 2017) this this study makes two contributions to the study of carbon emissions in Chinese tourism sector: Firstly, in terms of the lack of research on carbon emissions in the Chinese tourism sector, this paper, estimating the total carbon emissions in China's tourism sector from 2000 to 2015, may fill the academic gap and further provide practicable data for relevant analyses and research. Moreover, this study adopted a cautious approach in calculating the carbon emissions of tourism sub-sectors by not using a single dataset by a single scholar. Instead, it referred to coefficients in different publications, such as carbon emissions measurements for different star-rated hotels. The weighted methods therefore enabled this study to provide results closer to reality. Secondly, this study used the logarithmic mean Divisia index (LMDI) decomposition technique to analyze the different characteristics of carbon emissions in different periods so as to avoid focusing on the gap between the starting and end points (2000 and 2015) or ignoring the influence of fluctuating trends in the segment between the beginning and end of the study period to the whole.

2. Literature Review

The literature on the development of a low-carbon tourism economy is sparse and mainly focuses on the measurement of carbon emissions in tourism, the decomposition of emission factors, and the means of tourism emission reduction.

Generally, there are two approaches to measuring carbon emissions in the tourism sector, namely *top-down* and *bottom-up*. The former regards tourism sub-sectors as a single department in the national economic system. Specifically, there are many approaches such as combining the Tourism Satellite Account (TSA) with the National Accounting Matrix Environmental Accounts, or combining the TSA with the National Accounting System. Perch-Nielsen et al. (2010) measured the greenhouse gas emissions in the Swiss tourism sector by using two different *top-down* approaches. Another method of measuring carbon emissions is by using accounting approaches such as applying Environmentally Extended Input-Output and using the production accounting or consumption accounting principles. Moreover, on the basis of the energy consumption balance sheet, the *tourism consumption stripping coefficient* can be used to calculate regional tourism-related carbon emissions in a *top-down* framework (Wu et al., 2015). The advantage of the *top-down* approach is that it avoids the complicated process of data collection from tourism sub-sectors at the beginning of the study. Its shortcomings include its dependence on a relatively complete tourism statistics system and the national environmental economic accounting system, as well as its inaccurate calculation results. For example, Meng et al. (2016) measured the total tourism-related carbon emissions in China by combining the TSA with the input-output model of the manufacturing sector. This author showed that indirect carbon emissions were more than twice that of direct carbon emissions. Specific data of tourism sub-sectors, however, are not accurate. Therefore, this approach is applicable to countries or regions with a small territory and where the data can be refined and easily collected such as New Zealand (Becken et al., 2001).

In contrast, the *bottom-up* approach is more broadly applied. For example, Gössling (2002) divided globally tourism-related carbon emissions into three parts: transportation, accommodation, and activity. Most studies focusing on calculating tourism-related carbon emissions use this classification method, but different authors draw different conclusions in different regions. Gössling (2002) first pointed out that the contribution rates of transportation, accommodation, and activity were 94, 4, and 2%, respectively; Becken et al.'s (2003) figures were 73, 17, and 10%, respectively; Kuo and Chen's (2009) figures were 67, 16, and 17%, respectively; and Wu and Shi's (2011) figures were 68, 30, and 2%, respectively. These authors therefore agree that transportation is the main source of tourism-related carbon emissions. Subsequently, in-depth studies have been carried out on transportation in the tourism sector. For example, Becken et al. (2003) think that the private car is the main contributor to traffic-related carbon emissions in domestic tourism, whereas Sun (2014) thinks that the main source of outbound tourism-related carbon emissions is international aviation, accounting for a proportion of 47%. In fact, most 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%.

On the other hand, some studies have focused on individual tourism sub-sectors. Becken et al. (2001) takes New Zealand as an example to describe the proportion of carbon emissions caused by various modes of transport in detail. This author thinks that the price of transportation is usually not as important as other characteristic variables of tourism, such as purpose of visit and length of visit . Therefore, starting from the transport price level, it would be difficult to achieve the desired emission reduction effect, for example, raising fuel prices would not effectively reduce the number of private car trips. Pieri et al. (2016) also conducted a detailed study of tourism-related traffic. Taking the location of Attica Beach Hotel, Greece, as an example, the author assessed travel-related carbon footprints to measure the carbon emissions resulting from passengers traveling to and from the hotel.

The second research direction includes the decomposition of tourism-related carbon emissions constitution factors to determine the cause of carbon emissions increase. Literature shows that the tourism volume effect is the main reason for increased carbon emissions, and appropriate research methods include the LMDI decomposition technique. Robaina-Alves et al. (2016) used LMDI to analyze CO_2 emission changes in the Portuguese tourism sector from 2000 to 2008. In addition, economists have used econometrics to explore the relationship between tourism-related carbon emissions and other variables. Using EU panel data from 1988 to 2009 for unit root and integration tests, Lee and Brahmasrene (2013) examined the relationship between economic growth and foreign direct investment in terms of tourism, CO_2 emissions, and long-term equilibrium and provided the correlation coefficients between the variables. The most important of these is that an increase in tourism revenue leads to a small decline in CO_2 emissions. This also provides a reference for the reduction of tourism-related CO_2 emissions.

The last research direction includes measures to reduce tourism-related emissions. The sustainable development of tourism must rely on energy-saving and emission reductions to truly become a *low-carbon* and *green* industry. Literature describes energy-saving and emission reductions in tourism from different perspectives, including tourism destinations (Borović and Marković, 2015) and participants (Gössling and Buckley, 2016). Eco-labels proposed by Gössling and Buckley (2016) will play a greater role in tourism-related emission reductions in the future. Waligo et al.'s (2013) study included tourism stakeholders and encouraged visitors, tourism industry, local communities, and governments to participate in sustainable tourism development. However, this author did not indicate the specific form of participation of the various subjects or the contribution of each group to reduce tourism carbon emissions. Fang et al. (2014) further pointed out that although governments can control carbon emissions and energy intensity, these control measures can inhibit economic growth to a certain degree.

Some authors also consider the contribution of technology to sustainable tourism by tracking time-series data over many years (Peeters et al., 2016). Among them, Wu and Shi's (2011) summary is a comprehensive theoretical analysis. This author individually listed possible problems of and solutions to tourism resources in a low-carbon economy. In addition, some authors have recently thought that tourism can form part of the global de-carbonization economy, for example, Scott et al. (2016b) concludes that the reduction of carbon emissions is costlier than and most likely outweigh its benefits. Therefore, a strategic framework and carbon emissions reporting system is required. De-carbonization is undoubtedly the key to sustainable tourism, but it is difficult to achieve. From this perspective, the de-carbonization of tourism development faces many challenges.

There is a gap between China's research into domestic CO_2 emissions and that of foreign countries. In general, Chinese studies are varied and have certain deficiencies. Regarding study regions, Xu et al. (2011) proposed a differential dynamic system model with fuzzy coefficients, applied the model to Leshan City, Sichuan Province, and indicated the development trend of modern tourism in a low-carbon economy. However, Leshan is not a typical Western city, and therefore many policy recommendations cannot be extended to other areas. In the same year, Liu et al. (2011), taking Chengdu City, Sichuan Province, as an example, analyzed the energy demand and CO_2 emissions of the Western tourism industry. Although Chengdu can be considered a leading city in the Western economy, other provinces and cities cannot be compared with it. According to the latest China Bureau of Statistics data, for example, in 2016, Chengdu's GDP was 8.65 times that of Leshan, i.e., the gap is too large. Similarly, Sun (2016), who intended to reveal the dynamic relationship between tourism economic growth, technical efficiency, and carbon emissions, used a Leontief matrix and the National Economic Accounting System to analyze increases in Taiwanese carbon emissions in 2001 and 2011.

Furthermore, instead of empirical analysis of a single region, Wu et al.'s (2015) study compared the carbon emission targets of five Chinese provinces with different characteristics, namely Beijing, Zhejiang, Shandong, Hubei, and Hainan. Unfortunately, this author only carried out a comparative description of the data of these five provinces in three years (2009, 2010, and 2011), which did not adequately explain the trend of dynamic changes in carbon emissions. A similar problem appeared in Meng et al.'s (2016) study, where the author used a *top-down* measurement approach by combining the TSA with the input-output model in the manufacturing industry but calculated the total carbon emissions in China's tourism sector over only four years; this top-down calculation approach was inexact. Even though the analysis of the driving factors behind energy-related carbon emissions from a regional perspective is beneficial for China to meet its emission reduction goal, a comparative analysis of long-term dynamic trends is necessary.

In summary, China's research in this field has the following problems: First, the indicators used to measure tourism-related carbon emissions vary and emission intensity coefficients in the sub-sectors are not unified. Different calibers make a significant difference in analyzing the results of different studies. For example, the proportions of carbon emissions in the tourism accommodation sector were found to be 4% (Gössling, 2002), 17% (Becken et al., 2003), and 30% (Wu and Shi, 2011). The second problem is the lack of a comprehensive and long-term estimation of overall carbon emissions in the Chinese tourism sector and its influencing factors. For example, some of the studies mentioned above face the following problems: sample sizes were too small, the localities were not sufficiently comprehensive or representative or the time scales were too short. By analyzing the influencing factors of overall carbon emissions, some studies only focused on individual years, while other studies only analyzed the difference between the first year and the last year, ignoring the evolving trend of carbon emissions in the middle years (Wu et al., 2015). This paper solves both of the above two problems by estimating the carbon emissions of China's tourism sector from 2000 to 2015 and carrying out an LMDI decomposition analysis of carbon emission increments.

3. Empirical Methods and Data

3.1. Estimation Model for Carbon Emissions in Tourism

As China's TSA is not complete, it is difficult to measure total carbon emissions by a *top-down* method from a macro-perspective. Therefore, this study applied a *bottom-up* measurement method. The *bottom-up* method has been employed in previous studies focusing on carbon emissions in the Chinese tourism sector, including Wu and Shi (2011), Gössling (2002), and Becken et al. (2003), as mentioned above. This method enables the micro-decomposition of total carbon emissions and their subsequent summation as follows:

$$TE^n = \sum_{i=1}^{3} TE_i^n \qquad (1)$$

In this equation, TE^n represents total carbon emissions in the Chinese tourism sector in the nth year; and TE_i^n represents carbon emissions in the i-sub-sector of tourism in the nth year. This paper referred to the studies mentioned above and divided tourism-related carbon emissions into three categories: carbon emissions (1) from tourism-related traffic, (2) in tourism accommodation, and (3) in tourism activities. In this paper, *tourism-related traffic* means traffic with the purpose of traveling, including leisure, work, and service/shopping, amongst others. The traffic modes include passenger-carrying automotive, train, aviation, water and other transport. *Tourism accommodation* refers to star-graded hotels. *Tourism activities* include sightseeing, leisure travel, business travel, visiting friends and relations, and health recuperation holidays, amongst others.

3.1.1. Estimation of Carbon Emissions from Tourism-related Traffic

The estimated carbon emissions in tourism-related traffic were calculated by multiplying different means of transportation by their energy intensity rates consumption so as to obtain a weighted summation. However, different studies used different data. For example, Schafer and Victor (1999) considered the leisure trip distance of residents in developing countries to be 0.42 km per capita per day, so that carbon emissions in tourism-related traffic can be obtained by multiplying the traveling distance by the country's overall population and days per year. Wu and Shi (2011) applied this calculation to estimate carbon emissions from tourism-related traffic in China. When calculating traffic-related carbon emissions in a specific year, this method exposed no weaknesses, but it is considered inaccurate when calculating data by year over a long period.

In recent decades, the average rate of population increase in China has been approximately 5%, less than the increase in the number of tourists. Moreover, the number of tourism practitioners drastically grows (China Statistical Yearbook, 2015). Carbon emissions from tourism-related traffic should also include commuter traffic for tourism practitioners. Therefore, using this method to calculate traffic-related carbon emissions in the tourism sector would be inaccurate. Comparatively, visitor turnover can more accurately reflect the expansion of the scale of tourism. As a result, turnover volume of tourists was used as essential data rather than overall population. The specific estimation equation is as follows:

$$TE_1^n = \sum_{i=1}^{5} P^n \cdot p_i^n \cdot d_i^n \cdot uec_i^n \cdot cec_i \qquad (2)$$

In this equation, TE_1^n represents the total carbon emissions in tourism-related traffic; P^nrepresents the number of tourists in China in the nth year; p_i^n represents the proportion of tourists using the i-th transport means in total volume in the nth year[1]; d_i^n represents the average transport distance of the i-th transport mode in the nth year; $P^n \cdot p_i^n \cdot d_i^n$ represent tourist turnover volume of the i-th mode in the nth year; and uec_i^n and cec_i represent the energy consumption and CO_2 emission intensities (CO_2 emissions coefficient) of the i-th transport mode, respectively. It should be noted that cec_i is constant over the years. According to the IPCC (2006), CO_2 emission intensities are calculated as follows: $cec_j = N_j \times CC_j \times O_j \times B$, where j refers to energy types, N_j to conversion factor for changing fuel into energy, CC_j to carbon content of 1 trillion joules of energy, O_j to carbon oxidation factors, and B to molecular weight ratio of CO_2 and C. Therefore, cec_i is constant if the i-th transportation uses the same energy kind over the years. Data for P^n, p_i^n, and d_i^n were obtained from the *China Statistical Yearbook* and *China Tourism Statistical Yearbook*. Data for uec_i^n were obtained from *China Energy Statistical Yearbook* 2011 and calculation results based thereupon. Data for cec_i were obtained from IPCC (2006).

3.1.2. Estimation of Carbon Emissions in Tourism Accommodation

The estimation of carbon emissions in tourism accommodation is usually calculated by regional total numbers of beds multiplied by occupancy rates and subsequently by the carbon emissions coefficient (or energy consumption). However, Gössling (2002) mentioned that carbon emission intensity varies across the different grades of the star-graded hotels. For example, the minimum hotel carbon emissions coefficient can be 1.7 kg per bed per night and the maximum can be 145.1 kg per bed per night. If calculated by a unified coefficient (Wu and Shi, 2011; Tao and Huang, 2014), results can be inaccurate; for example, Wu and Shi (2011) defined this coefficient as 155 MJ in 2001-2008. This paper determined the

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[1] Since we could not directly find the proportion of tourist volume using the i-th transport means in total volume, we used the proportion of passengers using different modes of transport in the total passengers volume to instead.

energy intensity rates in accordance with the actual situation in different star-graded hotels.

Gössling (2002) showed that the minimum energy intensity per bed per night of tourism accommodation venues was 10.9–25 MJ, and the maximum was 256-916 MJ (916 MJ was measured only in large resort hotels where energy systems were immature. Generally, the average energy intensity (energy consumption per bed per night) of large resort hotels was around 500 MJ), and the average energy consumption was 130–180 MJ. Therefore, coefficients for this study verified those of Gössling (2002) and met the requirements of differentiation, which means that estimated results are more accurate. Specifically, the estimation model for carbon emissions in tourism accommodation was calculated as follows:

$$TE_2^n = \sum_{i=1}^{5} 365 \times B_i^n \times R_i^n \times uec_i^n \times z \qquad (3)$$

In this equation, TE_2^n refers to the total carbon emissions in China's tourism accommodation in the nth year; B_i^n represents the total number of beds in an i-star hotel in the nth year; R_i^n represents occupancy rates of the numbers of beds in an i-star hotel in the nth year; uec_i^n refers to the energy intensity (consumption per bed per night) in an i-star hotel; *z* refers to the conversion coefficient of energy to CO_2 emissions, being 158544 $kgCO_2$/TJ in China[2]. The data for B_i^n and R_i^n were obtained from *China Tourism Statistical Yearbook*.

3.1.3. Estimation of Carbon Emissions from Tourism Activities

There is less controversy in the estimation of carbon emissions from tourism activities, classified into sightseeing, leisure travel, and business travel, amongst others, according to different purposes. However, many researchers neglect the changes of energy consumption over time, but this paper intends to remedy this limitation by using the following calculation model:

$$TE_3^n = \sum_{i=1}^{6} V^n \times k_i^n \times uec_i^n \times z \qquad (4)$$

In this equation, TE_3^n represents the total carbon emissions in tourism activities in the n-th year; V^n represents tourism volume in the n-th year; k_i^n and uec_i^n represent the proportion of tourist flow carrying out the i-th activity in the total visitor volume in the n-th year and its corresponding energy intensity, respectively; Z refers to the conversion coefficient of energy to CO_2 emissions, being 158544 $kgCO_2$/TJ in China. The data for V^n and k_i^n were obtained from *China Tourism Statistical Yearbook*.

3.3. LMDI and Identity Equation

The LMDI model was presented by Kaya (1989) for the purpose of evaluating the influence of human activities on CO_2 emissions. This decomposition equation itself has no residual error, and it can therefore accurately reflect the explanatory power of each effect on the carbon emissions increment. For instance, Lina and Long (2016) applied LMDI to decompose driving factors behind carbon emissions in China's chemical industry, and Ang and Su (2016) applied LMDI to analyze total carbon intensity of global electricity. Through expansion, LMDI can also be used to decompose factors influencing tourism-related carbon emissions and can be calculated as follows:

$$TE = \sum_{i=1}^{3} \left(\frac{TE_i}{FE_i} \times \frac{FE_i}{FE} \times \frac{FE}{Y} \times \frac{Y}{P} \times \mathrm{P}\right) \qquad (6)$$

In this equation, *TE* is the total tourism-related carbon emissions; TE_i refers to CO_2 emissions of the i-th sub-sector in the tourism industry; FE_i represents energy consumption of the i-th sub-sector in the tourism industry; *FE* represents the total energy consumption in the tourism sector; *Y* is total revenue in the tourism sector; and *P* represents the volume of tourism flow (total number of tourists).

Then, we introduce the following short-hand notations:

$$f_i = \frac{TE_i}{FE_i}; s_i = \frac{FE_i}{FE}; e = \frac{FE}{Y}; c = \frac{Y}{P}; p = P \qquad (7)$$

In this equation, f_i, s_i, *e*, *c*, and *p* represent the carbon emissions coefficient effect, sector structural effect, energy intensity effect, tourism consumption level effect, and tourism volume effect, respectively. If the total tourism-related carbon emissions have TE^0 as base period and TE^T as period *T*, the increment of total tourism-related carbon emissions can be decomposed as follows:

$$\Delta TE = TE^T - TE^0 = \Delta TE_{f_i} + \Delta TE_{s_i} + \Delta TE_e + \Delta TE_c + \Delta TE_p \qquad (8)$$

From the LMDI, the equations for calculating the contribution of each decomposing factor are as follows:

$$\Delta TE_{f_i} = \sum_{i=1}^{3} \left(\frac{TE_i^T - TE_i^0}{\ln TE_i^T - \ln TE_i^0} \times \ln \frac{f_i^T}{f_i^0}\right) \qquad (9)$$

$$\Delta TE_{s_i} = \sum_{i=1}^{3} \left(\frac{TE_i^T - TE_i^0}{\ln TE_i^T - \ln TE_i^0} \times \ln \frac{s_i^T}{s_i^0}\right) \qquad (10)$$

$$\Delta TE_e = \sum_{i=1}^{3} \left(\frac{TE_i^T - TE_i^0}{\ln TE_i^T - \ln TE_i^0} \times \ln \frac{e^T}{e^0}\right) \qquad (11)$$

$$\Delta TE_c = \sum_{i=1}^{3} \left(\frac{TE_i^T - TE_i^0}{\ln TE_i^T - \ln TE_i^0} \times \ln \frac{c^T}{c^0}\right) \qquad (12)$$

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[2] According to Schafer and Victor (1999), the conversion coefficient of energy to carbon is defined as 43.2 gC/MJ in accommodation, and many researchers have used it in their studies, such as Gössling (2002), Wu and Shi (2011). On the basis of conversion factor of C to CO_2 being 3.67 in China, we calculated the conversion coefficient of energy to CO_2 emissions 158544 $kgCO_2$/TJ.

$$\Delta TE_p = \sum_{i=1}^{3} \left(\frac{TE_i^T - TE_i^0}{\ln TE_i^T - \ln TE_i^0} \times \ln \frac{p^T}{p^0} \right) \tag{13}$$

In these equations, the carbon emissions coefficient of each type of energy is taken as a fixed constant, so that ΔTE_{f_i} is 0.

3.4. Simultaneous Equations Model

Although the LMDI analysis captures the absolute amount fluctuations of carbon emissions, it may leave out many socio-economic variables. Therefore, we applied simultaneous equations for further study. A separate simultaneous equations model, shown below as equation system (14), had to be built to analyze the determinants.

$$\begin{gathered} \ln CO2_t = \alpha_1 \ln energy_t + \alpha_2 prop\_traffic_t + \alpha_3 \ln government_t + \varepsilon_t \\ \ln energy_t = \beta_1 \ln tourists_t + \beta_2 \ln tourincome_t + \beta_3 \ln tensity_t + \\ \beta_4 \ln selfdriving_t + \beta_5 \ln fivestar_t + \beta_6 \ln leisure_t + \mu_t \end{gathered} \tag{14}$$

In the first equation, the carbon emissions of tourism ln*CO*2 are affected by the total energy consumption ln*energy* and energy structure, and we used the proportion of energy consumption from tourism-related traffic *prop_traffic* as energy structure variable, since traffic is a major carbon source. In addition, China's carbon emissions cannot be solved by relying solely on the market. Currently, than the direct control and voluntary means, economic means guide government policy more effectively. The most typical economic means is the government's fiscal policy. Many studies have found that taxation or increased fiscal spending on carbon emissions is effective for reducing emissions (Hansen and Hendricks, 2006; Floros and Vlachou, 2005; Zhang, 2000). Therefore, this paper placed the government's energy conservation and environmental protection expenditure ln*government* into the explanatory variables to examine its impact on carbon emissions.

In the second equation, ln*energy* is an independent variable. Ehrlich and Holdren (1971) held that population, affluence, and technology all had significant influences on the environment. This model came to be expressed as follows: $I = P´ A´ T$. I, P, A, and T respectively refer to impact, population, affluence, and technology. Based on the IPAT model, we assigned the number of tourists ln*tourists*, tourism income ln*tourincome*, and energy intensity ln*intensity* as independent variables. Moreover, from the previous analysis, we understood that the three sub-sectors with their development and changes have a certain impact on energy consumption. Therefore, variables that represent sub-sectors' developments were also incorporated into the equation, defined as ln*selfdriving*, ln*fivestar*, and ln*leisure*, which respectively represent turnover volume of private cars, the number of occupancy beds in five-star hotels, and the number of tourists taking leisure travel.

Since energy consumption was the dependent variable in the second equation and the independent variable in the first equation, it was an endogenous variable of the simultaneous equations. The energy intensity was closely related to the energy consumption and hence it was an endogenous variable. The remaining variables were exogenous variables.

This simultaneous equation system was estimated by three-stage least squares, which considers correlations of random disturbance in terms of different equations compared to two-stage least squares.

3.5. Data Sources

Most of the data in this paper were obtained from the *China Tourism Statistical Yearbook*, *China Energy Statistical Yearbook*, *China Statistical Yearbook*, and *China Traffic Statistical Yearbook*. The energy intensity index, which cannot be determined directly, is critical in calculating carbon emissions. We measured the energy intensity by employing the existing research results and data from some official sources, such as *Development Statistics Bulletin of the Transport Industry*, *Civil Aviation Industry Development Statistics Bulletin*, and *Railway Statistics Bulletin*. The data for CO_2 emissions coefficients were obtained from IPCC (2006) and Becken et al. (2001). Data sources will not be mentioned separately below.

4. Empirical Results

From the above analysis, in 2000-2015, tourism-related carbon emissions fluctuated. Based on features of variation, carbon emissions were grouped into three stages: 2000-2007, 2007-2008, and 2008-2015, and LMDI factor decomposition of these three stages was applied. Using equations (6)-(13), sector structural, energy intensity, tourism consumption level, and tourism volume effects could be obtained (Table 1).

From Table 1, it can be seen that each effect in different time stages had different features. In the first stage, all the factors added carbon emissions. Unlike in the first stage, the factor effects in the other two stages and over the entire study period from 2000 to 2015 were negative or positive. The absolute ratio values of positive and negative effects were 0.62, 4.53, and 15.54, respectively, which demonstrates that in most stages the increasing effect of carbon emissions remained larger than the curbing effect, although the curbing effect was larger than the increasing effect in the second stage from 2007 to 2008. Further measures for emissions reduction are needed urgently, as carbon emissions will continue to increase.

We modeled the simultaneous equations of CO_2 emissions and energy consumption in the tourism industry as functions of some socio-economic variables. The analysis was based on limited data, namely 16 years from 2000 to 2015.

Table 2 reports the estimation results of equation (14), and we interpreted each column as a whole for

Table 1. Effects of Factors Influencing Tourism-related Carbon Emissions Change in China over the Study Period (2000-2015) (Mt)

Year	Sector Structural	Energy Intensity	Tourism Consumption Level	Tourism Volume	ΔCO_2
2000-2007	0.71	0.18	2.77	14.57	18.24
2007-2008	1.19	-0.59	0.00	-1.33	-0.73
2008-2015	-4.91	-7.77	20.88	36.53	44.73
2000-2015	3.44	-4.28	13.05	50.03	62.24

Table 2. Simultaneous Equations of CO_2 Emissions and Energy Consumption in Tourism Industry (20002015)

Independent Variables	Dependent Variables and indexes	Model 1	Model 2	Model 3	Model 4
ln*CO₂*	ln*energy*	1.0759*** (0.14)	1.0102*** (0.15)	1.080*** (0.14)	1.0725*** (0.14)
	prop_traffic	-3.0330*** (0.54)	-2.9819*** (0.54)	-2.9938*** (0.53)	-3.0314*** (0.53)
	ln*government*	0.1800** (0.09)	0.2180** (0.09)	0.1734** (0.09)	0.1820** (0.09)
	R^2	0.9891	0.9889	0.9891	0.9891
ln*energy*	ln*tourists*	0.3787* (0.22)	0.3457* (0.26)	0.3736* (0.19)	0.4395* （0.24）
	ln*tourincome*	0.7920*** (0.09)	0.7882*** (0.15)	1.0157*** (0.09)	0.7711*** （0.09）
	ln*intensity*	38.7803*** (2.08)	36.5926*** (3.55)	37.4809*** (2.14)	39.1078*** （2.49）
	ln*selfdriving*	-0.0315 (0.03)		-0.0124 (0.03)	-0.0383 （0.04）
	ln*fivestar*	-0.0385 (0.026)	-0.0328 (0.03)		-0.0450 （0.03）
	ln*leisure*	0.0031 (0.01)	0.0059 (0.02)	0.0152 (0.02)	
	prop_selfdriving		-0.1667 (0.10)		
	prop_fivestar			-0.3954 (0.03)	
	prop_leisure				0.0084 （0.07）
	R^2	0.9999	0.9999	0.9998	0.9999

each model. Model 1 is the basic model. The growth rate of energy consumption of the tourism industry was consistent with that of carbon emissions, and an increase of 1% in energy consumption can increase CO_2 emissions by 1%. In contrast, the change in energy structure was the most critical factor affecting carbon emissions. From 2000 to 2015, the average tourism-related traffic energy consumption per 1% increase reduced carbon emissions by 3%. In the previous analysis, we found that the carbon emission intensity for traffic was lower than that of accommodation and tourism activities, that is, for the same energy consumption, the traffic carbon emissions are less than the other. Therefore, if our energy structure were adjusted to target lower carbon emissions, carbon emissions and greenhouse effects could be reduced to a large extent. The government's energy-saving and environmental protection expenditures did not play a role in carbon suppression. In contrast, if they increased by 1%, carbon emissions will increase by 0.18%. There are two possible reasons: First, the effect of energy saving and environmental protection policy is lagging behind. Second, China's policy efficiency is not high, for example, business trips for policy implementation may add to tourism carbon emissions. As a result, carbon emissions increased with the augmentation of energy saving and environmental protection spending.

The second part of the simultaneous equation system reports the impact of various variables on energy consumption. If the number of tourists and the tourism revenue increased by 1%, the energy consumption of tourism will increase by nearly 0.38% and 0.79%, respectively. With the increasing number of tourists and the booming tourism economy, energy conservation still has a long way to go.

Energy intensity is the most important factor for energy consumption. We noted that the total energy consumption increasing by more than 38% was a direct result of energy intensity increasing by 1%. In other words, technological progress has a significant influence on energy consumption, and energy-saving and emission reduction ought to rely on scientific and technological progress in China.

However, the development of activities with high energy consumption in each sub-sector, including the turnover volume of private cars in traffic, the occupancy of five-star hotels in accommodation, and the number of leisure travellers in tourism activities, has no significant impact on energy use. In other words, changes in the above factors, which mean changes in the internal economic structure of the three sub-sectors, do not cause distinct change of energy use.

Models 2-4 provide further robustness checks by substituting ln*selfdriving*, ln*fivestar*, and ln*leisure* by *prop_selfdriving*, *prop_fivestar* and *prop_leisure*, respectively, which represent the proportion of turnover volume of private cars in total turnover volume, the proportion of occupancy beds of five-star hotels in all hotels, and the proportion of leisure travellers in all tourists. As we expected, the significance and signs of all the coefficients did not change if compared to model 1, certifying that this framework is robust enough.

5. Conclusions and Policy Implications

Based on the data of 2000-2015, this study estimated the carbon emissions of China's tourism-related traffic, accommodation, and tourism activities. In order to find the factors that affect China's tourism-related carbon emissions, this study further used LMDI and simultaneous equations to determine the impact of the number of tourists, economic growth, and technological progress on the total amount and growth rate of carbon emissions. The main conclusions are as follows:

First, the total carbon emissions of China's tourism increased from 2000 to 2015, and the highest proportion of it was due to tourism-related traffic, with an average of 62%. The proportion of accommodation and tourism activities showed declining and rising trends, and changed from 19% to 7% and 10% to 18% respectively. The three sub-sectors had their own features: the main contributors to tourism traffic carbon emissions were private cars, followed by aviation whose carbon emissions accounted for higher and higher in the total emissions; the proportions of carbon emissions from four- and five-star hotels are increasing in accomodation and accounted for over 70% of total carbon emissions in 2015; carbon emissions from leisure travel accounted for increasing proportions in tourism activities and became the largest source of carbon emissions in 2009.

Finally, the most significant impact on total carbon emissions in the Chinese tourism industry was the substantial expansion of tourist volume and the improvement of people's consumption level. However, with regards to the growth rate of carbon emissions, the energy structure and intensity, which represent technological progress are the major factors. Therefore, the key solutions to reducing carbon emissions from China's tourism industry are to adjust energy structures and reduce energy intensity, both of which need technical innovation as a support.

Based on these results, we make three key recommendations.

First, the Chinese government should attempt to reduce the consumption of fossil energy in tourism especially in tourism-related traffic. Since reducing emissions from aviation transportation is difficult (Peeters et al., 2016), the major focus should be on private cars. China needs to put more financial resources into solving the problem of public transportation and appealing to the public to make the best use of public transport instead of private cars; experience from developed countries can be used as a reference in this regard. For example, Paris, France, has an extensive public transportation system that enables the procurement of long-term rail passes; London, United Kingdom, has an intelligent transportation system and diversified tickets; and the price of bus tickets in Vancouver, Canada, is determined by travel distance and intervals. Additionally, multiple approaches must be taken to improve energy efficiency, including revising regulations related to energy savings and environmental protection, which can guide and restrain the behavior of governments, companies, and citizens. China has issued four relevant laws since 1996 but has thus far been unable to achieve a low-carbon trajectory of energy savings and efficiency increases. Chinese policymakers must therefore adjust and optimize the country's industrial structure and energy mix, actively developing a modern tourism industry to reduce the energy consumption that accompanies economic development.

Secondly, the government should vigorously support technological innovation to reduce the energy intensity of accommodation and tourism activities. By improving the technological innovation system, the Chinese government can encourage the research, development, and promotion of high-efficiency, low-emissions technologies, including the use of renewable energy in tourism. Specifically, economic entities related to tourism accommodation, such as hotels and restaurants, should be targeted with regards to carbon emission reductions. The energy consumption structures of four- and five-star hotels, whose carbon emissions coefficients are higher than the average value, should be improved. Regarding lower star-rated venues, whose carbon emissions coefficients are lower than the average value, small-scale restaurants should be encouraged to improve service level to attract more tourists, which can directly and effectively reduce carbon emissions in tourism accommodation. Moreover, the scale of China's star-rated hotels is too large, and it is therefore necessary to reduce the operation scale of these hotels so as to improve the occupancy rates and energy consumption efficiency there. In addition, the carbon emission intensity of leisure travel was the highest one among the tourism activities, which could be reduced, for example, by controlling high energy consumption in resorts, encouraging tourists to participate in diversified tourism activities, and dispersing the distribution of carbon emissions from each type of activity.

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