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Carbon Footprint Analysis of Tourism Life Cycle: The Case of Guilin from 2011 to 2022

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Abstract: Low-carbon tourism is an important way for the tourism industry to achieve the United Nations Sustainable Development Goals and the goals of carbon peaking and carbon neutrality. In order to promote the development of Guilin as a world-class tourism city and ensure the sustainable development of the tourism industry in Guilin, this paper combines the concept of carbon footprint and the theory of life cycle to build a tourists' carbon footprint life cycle analysis model of Guilin. Taking tourists in Guilin as an example, the composition and changes of tourists' carbon footprint are dynamically analyzed. The research shows that: (1) The overall tourism carbon footprint of Guilin showed an upward trend during 2011–2019. From 2020 to 2022, due to the impact of COVID-19, Guilin's tourism carbon footprint has decreased significantly. The per capita carbon footprint of tourism in Guilin showed a downward trend from 2011 to 2022; (2) The order of the size of Guilin's tourism carbon footprint is tourism transportation > tourism catering > tourism accommodation > tourism activities; (3) From 2011 to 2022, the carbon footprint of tourism transportation in Guilin showed an obvious narrowing state, while the carbon footprint of tourism accommodation, tourism activities, and tourism catering showed an obvious expanding trend. Based on the characteristics of the carbon footprint of Guilin's tourism and the current situation of the development of Guilin's tourism, this paper puts forward suggestions on reducing carbon emissions, forms a new tool for evaluating and constructing low-carbon tourism, and provides a scientific basis and practical reference significance for the sustainable development of low-carbon tourism in Guilin.

Keywords: carbon footprint; low-carbon tour; carbon peak; carbon neutrality; transportation footprint; catering footprint; accommodation footprint; tourist activities footprint; world-class tourist city; Guilin

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1. Introduction

Tourism is an important contributor to global energy consumption, and climate change caused by the relationship between tourism development and carbon emissions is one of the biggest environmental challenges facing mankind [1]. The development goals of "carbon peak" and "carbon neutrality" are the inevitable choices to achieve sustainable development, and tourism activities are one of the key factors causing global climate change [2]. Tourism is traditionally regarded as a smokeless industry, but while promoting social and economic development, its carbon emissions have also attracted much attention. The seventh item of the Sustainable Development Goals of the United Nations calls for ensuring access to affordable, reliable and sustainable modern energy for all and reducing the carbon intensity of energy. By constructing a research framework for the measurement of tourism's carbon footprint, the carbon footprint of tourists can be scientifically assessed and its determinants analyzed so as to link up the objectives of SDG7. At the same time,

it should strengthen the cross-research with SDGs such as economic growth (SDG8) and climate change (SDG13), comprehensively use the life cycle theory model to analyze the relationship between tourism economic growth, energy consumption and carbon emissions, and formulate policies for the sustainable development of tourism. China's CO_2 emissions will strive to peak before 2030 and achieve carbon neutrality before 2060 [3]. China is the most productive country in the world. In order to achieve the goal of carbon neutrality, carbon emissions must be reduced [4]. China should vigorously develop a low-carbon and circular economy to promote green and high-quality economic development. Accelerate green and low-carbon integration of innovative technologies and promote carbon neutrality [5]. The implementation path of carbon neutrality also requires more complex models. Relevant models and tools are used to evaluate the carbon emission reduction capacity of cooperation between various industries and tourism industries, and quantitative research is conducted on the carbon neutrality capacity and potential of the tourism industry [6].

The World Tourism Organization defines the sustainable development of tourism as meeting the needs of both current tourism and tourism destinations as well as future tourists and tourism destinations [7]. Low-carbon tourism is a tourism development mode featuring "low energy consumption, low pollution, and low emission" [8]. In other words, in the process of tourism activities, technology, carbon sink mechanism, and low-carbon consumption mode are adopted to reduce carbon emissions and achieve sustainable development of tourism, and improve economic, social, and environmental benefits [9]. Low-carbon tourism aims to use low-carbon tourism transportation, accommodation, and various tourism activities to control greenhouse gas emissions generated by people in the process of tourism [10]. Transportation and accommodation, as important energy consumption subjects, are the core content of tourism carbon emission management. Gross [11] and Gossling [12] have linked tourism transportation carbon emissions with global climate change and conducted quantitative research. Zhao Hu [13] calculated the carbon emissions of tourism transportation in Hubei Province and proposed to actively guide tourists to take public transportation, such as the subway, bus, shared bike, and shared electric vehicles. Guide tourists to change the traditional concept of tourism, encourage tourists to choose outings near the city and short trips, as far as possible, to reduce the use of high-energy transportation. Hou Fang [14] and Guo Xiangyang [15] studied the factors that influence the carbon footprint of tourism transportation. Gong Lianhu and Yu Qing [16] believe that tourism traffic research should start with the level of comprehensive traffic and strategy. Bao Jigang [17] and Shao Chunfu [18] proposed that distance has a great influence on people's choice of tourism transportation mode. Ming Qingzhong [19] analyzed the carbon emissions of tourist accommodation and proposed that tourist accommodation is the second largest carbon source after tourist transportation, and hotels have the responsibility and potential to reduce emissions. Filimonau [20] calculated national and regional hotel carbon emissions, Tao [21], Wu [22], and Dascalali [23] calculated regional and other levels of hotel energy consumption and carbon emissions. Zha Jianping [24] pointed out that as one of the secondary tourism sectors, the complete carbon emission intensity of the accommodation industry is contributed by the indirect carbon emission intensity, which means that the accommodation industry obtains more carbon inflows from other sectors through the use of intermediate products. Yao Zhiguo [25] used the method of market research to investigate the travel distance, stay time, and tourism activities of tourists in Hainan Province.

China has entrusted Guilin with the important mission of building a world-class tourist city, which is the road to high-quality development for Guilin in the new stage of development. Guilin City must firmly establish and practice the concept that lucid waters and lush mountains are gold and silver mountains and plan its development from the perspective of the harmonious coexistence between man and nature [26]. Guilin is a well-known tourist city and an important transportation hub city. Facing the comprehensive tourism reform of Guilin, it is necessary for Guilin to vigorously develop low-carbon

tourism, help rural revitalization and build a low-carbon tourism city. Based on the above background, this paper, on the basis of constructing a tourism carbon footprint calculation model and using the principle of the tourist life cycle, empirically analyzes the status quo of tourism carbon emissions in Guilin during 2011–2022 from four parts: tourism transportation, tourism accommodation, tourism activities and tourism catering, and verifies whether Guilin can achieve low-carbon tourism sustainable development. On this basis, it summarizes the specific path and prospect of low-carbon tourism implementation and promotes the low-carbon sustainable development of Guilin tourism.

2. Materials and Methods

2.1. Study Area

Guilin is a key tourist city and a famous historical and cultural city in China. See (Figure 1) for the general picture of Guilin. Guilin has a large number of tourism resources, a wide range of scenic spots, and a good geographical combination. The whole Guilin tourism area radiates around with Guilin City as the core, showing a circular distribution, covering an area of more than 20,000 km^2. According to the data released by the website of Guilin Culture, Radio, Film and Tourism Bureau, by 2022, there will be 55 hotels in the city, including 5 5-star hotels, 14 4-star hotels, 33 3-star hotels and 3 2-star hotels, with a total of more than 22,993 beds, 25 international travel agencies and 85 domestic travel agencies. In terms of comprehensive reception capacity, industrial scale, industrial service quality, infrastructure, supporting conditions, and industrial linkage function, it has reached a higher level and grade in China.

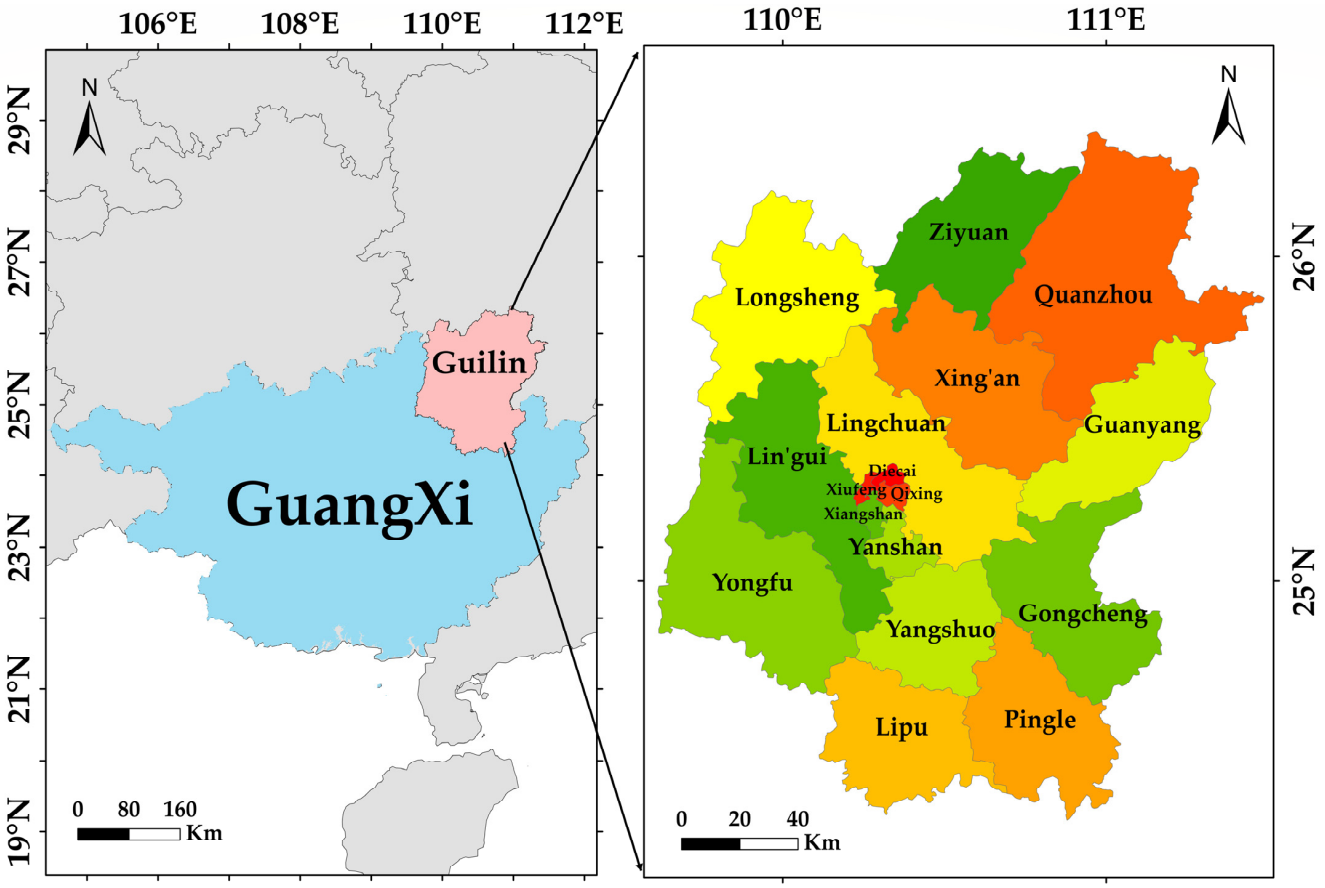

Figure 1. Geographical location of Guilin (study area). Date source: Portal Website of Guilin People's Government of Guangxi.

2.2. Data Sources

The time interval of this study is from 2011 to 2022, and the indicators involved include the total number of tourists to Guilin each year, total tourism income, tourist turnover of different modes of tourism transportation, the number of beds and room rental rate of star-rated hotels, the proportion of different types of tourism activities in the total number of tourists to Guilin, the average number of stay days of tourists to Guilin, etc. The above data comes from the "China Statistical Yearbook," "China Tourism Statistical Yearbook", "China Tourism Statistical Yearbook" (copy), "Tourism sampling survey data", "Guangxi Statistical Yearbook", and "Guilin Economic and Social Statistical Yearbook". The number and list of tourist attractions in Guilin, the proportion of tourism consumption of various departments in Guilin, and the per capita travel distance of different means of transportation come from the Internet and tourism department visits. The selection ratio of different types of transportation, carbon emissions per unit kilometer, carbon emissions per bed per night in hotels of different grades, and the average carbon emissions generated by different types of tourism activities all come from domestic and foreign scholars' research results and relevant empirical studies.

The data used for model testing are extracted from the per capita carbon footprint of tourism in Guilin from 2011 to 2022. The per capita carbon footprint of tourism is derived from the ratio of the total carbon footprint of tourism in Guilin in corresponding years to the number of tourists in each year, which is explained in detail below.

2.3. Methods

Through consulting existing studies, it can be found that in the process of tourism, the carbon footprint of tourists in a tourism life cycle includes transportation, accommodation, activities, and catering. Therefore, this paper mainly calculates the carbon footprint of tourism transportation, accommodation, activities, and catering and selects the life cycle method to evaluate and measure the carbon footprint of Guilin's tourism industry from the perspective of tourists from the bottom up. Based on the measurement methods of tourism carbon footprint by Xiao Jianhong [27], Zhou Nianxing [28], Wang Jiani [29], Xie Yuanfang [30], Zheng Qunming [31], Ma Jing [32], and Huang Shuo [33], this paper constructs the model of Guilin's tourism carbon footprint as follows.

2.3.1. Carbon Footprint Model of Tourism and Transportation

Tourism transportation is an important part of tourism and a prerequisite for tourism development. The carbon footprint value of tourism transportation accounts for a large proportion of the total carbon footprint value of tourism. In this paper, the model of Guilin's tourism carbon footprint is as follows:

$$TCF_t = \sum N \times \alpha_i \times D_i \times Q_i \times \beta_i \quad (1)$$

TCF_t represents the carbon footprint of tourism and transportation, i Denotes different types of transportation (rail, road, civil aviation, water transport), N represents the total number of tourists to Guilin every year, α_i represents the annual proportion of tourists taking Class i tourist transport; D_i represents the annual per capita driving distance taking Class i tourist transport; Q_i represents the carbon emission coefficient per kilometer per person taking class i tourist transport; β_i represents the equilibrium factor of type i tourist transport.

2.3.2. Carbon Footprint Model of Tourist Accommodation

Guilin is a famous tourist and leisure holiday destination in China. With the rapid development of tourist accommodation, it is very important to reduce the carbon footprint of tourist accommodation. Based on this, this paper constructs the carbon footprint model of Guilin tourist accommodation as follows:

$$TCF_h = \sum N \times \gamma_i \times D_i \quad (2)$$

TCF_h represents the carbon footprint of tourist accommodation, N represents the number of beds owned by Class i (5-star, 4-star, 3-star, and 2-star) accommodation types, γ_i represents the annual average room occupancy rate of Class i accommodation types, and D_i represents the carbon emission coefficient per bed per night of Class i accommodation types.

2.3.3. Carbon Footprint Model of Tourism Activities

Nowadays, the forms of tourism activities are more and more diversified, and tourists pay more attention to the experience of tourism. More and more tourists are willing to participate in sightseeing, leisure and entertainment, health and recuperation and other tourism activities. Different tourism and entertainment activities have different carbon footprint values. Accordingly, this paper defines the carbon footprint model of Guilin's tourism activities as follows:

$$TCF_a = \sum N \times \theta_i \times D_i \quad (3)$$

TCF_a represents the carbon footprint of tourism activities, N represents the total number of annual tourists to Guilin, θ_i represents the proportion of annual tourists participating in class i tourism activities (sightseeing, vacations, leisure and entertainment, business trips, visiting friends and relatives, and health and recuperation.), and D_i represents the amount of CO_2 emitted by each person of type I tourism activities.

2.3.4. Tourism and Catering Carbon Footprint Model

At present, people's consumption patterns and demands are constantly improving and changing, and the tourism and catering industry is also constantly upgrading. More and more restaurants provide high-quality food and services, which further promotes the development of the tourism and catering industry. The carbon footprint value of tourism and catering is also an important part of the carbon footprint value of tourism. Based on this, this paper constructs the carbon footprint model of tourism and catering of Guilin City as follows:

$$TCF_f = \sum N \times D \times F_i \times \delta_i \quad (4)$$

TCF_f represents the carbon footprint of tourism and catering; N represents the total number of tourists visiting Guilin each year; D represents the average number of days tourists stay; F_i represents the amount of food tourists consume per day; δ_i represents the carbon emission index of Class i food.

2.3.5. Total Tourism Carbon Footprint Model

According to the tourism life cycle evaluation theory, tourism transportation, tourism accommodation, tourism activities and tourism catering account for most of the tourism carbon footprint value, and tourism carbon footprint is equal to the sum of tourism transportation carbon footprint, tourism accommodation carbon footprint, tourism activity carbon footprint and tourism catering carbon footprint. Based on this, the total tourism carbon footprint model of Guilin is established as follows:

$$TCF_s = TCF_t + TCF_h + TCF_a + TCF_f \quad (5)$$

TCF_s represent the total carbon footprint of tourism, which is the sum of the carbon footprint of all links in tourism activities. TCF_t represents the carbon footprint of tourism transportation, TCF_h residence represents the carbon footprint of tourism accommodation, TCF_a live represents the carbon footprint of tourism activities, and TCF_f meal represents the carbon footprint of tourism and catering.

3. Results and Analysis

3.1. Carbon Footprint Analysis of Tourism Transportation

Tourism transportation accounts for the largest proportion of carbon emissions, accounting for 75% of the entire industry. In China, tourism transportation also accounts for

67.72% of the entire tourism industry's carbon emissions and is the main source of tourism carbon dioxide emissions. Citing Gossling [34], carbon dioxide emission coefficients and equilibrium factors of various vehicles are calculated (Table 1).

Table 1. Carbon dioxide emission coefficient and equilibrium factor of different tourism traffic types in Guilin.

Traffic Type	Railway	Highway	Water Transport	Civil Aviation	Others
Carbon dioxide emission Coefficient (kg/km)	0.025	0.047	0.07	0.14	0.018
Equivalence Factor	1.05	1.05	1.05	1.07	1.05

After various relevant parameters are determined, the carbon footprint of Guilin tourism traffic during 2011–2022 is calculated according to the traffic carbon footprint model, and the results are shown in (Figure 2) below. From 2011 to 2013, the carbon footprint of Guilin's tourism traffic showed a significant growth trend, and from 2014 to 2015, it showed a declining trend. From 2016 to 2019, the carbon footprint of Guilin's tourism traffic continued to increase and reached its peak in 2019, about 1.2 times that of 2011. By 2020, the carbon footprint of Guilin's tourism transportation will be reduced by about 50%. Due to the decrease in the number of tourists caused by the outbreak of COVID-19, carbon emission transportation will be sharply reduced. From 2021 to 2022, the carbon footprint of tourism transportation in Guilin gradually increased, but the total amount was significantly less than the carbon emission before 2019.

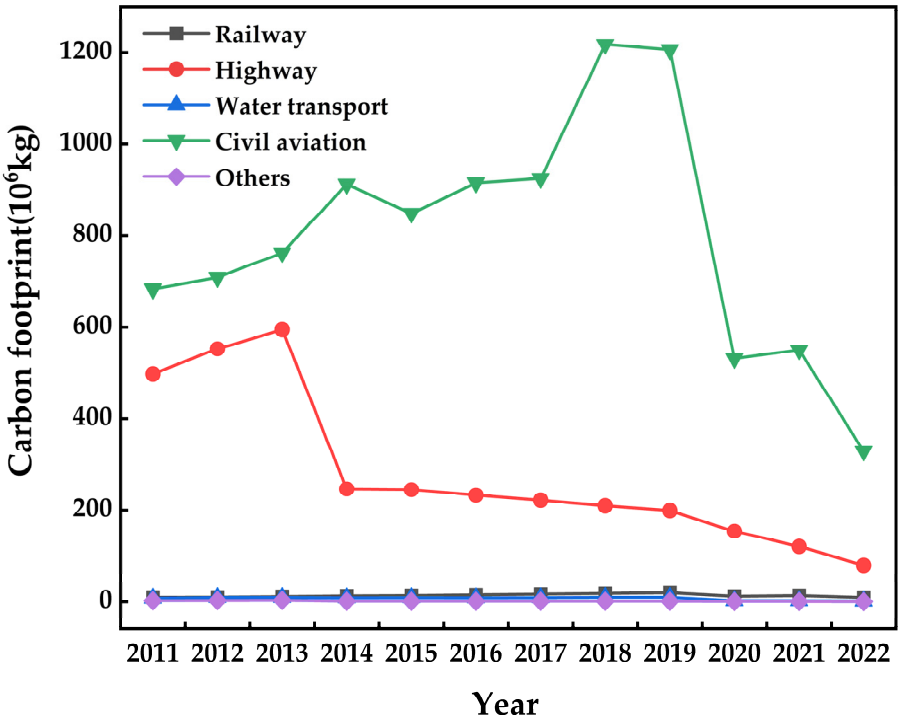

Figure 2. Tourism traffic carbon footprint of Guilin from 2011 to 2022. Data source: Guilin Economic and Social Statistical Yearbook (2011–2022).

From the perspective of the carbon footprint of tourism transportation, the passenger volume of aircraft accounts for about half of the number of people taking the railway, but its unit energy consumption is the largest and carbon emissions are the largest. Its carbon footprint increased from 683.60 $\times$ 10^6 kg in 2011 to 1206.14 $\times$ 10^6 kg in 2019, which is

about 63 times the carbon emissions of the railway. Roads followed, accounting for 47%. Railways have the smallest carbon footprint at around 11.7%.

3.2. Carbon Footprint Analysis of Tourist Accommodation

According to the current situation of the accommodation industry in Guilin, tourist accommodation is mainly divided into star hotels, social hotels, resorts, and family hotels. The analysis report of sampling survey data of domestic tourists in Guilin shows that most overnight tourists in Guilin choose star-rated hotels with higher service grades, to stay. Moreover, the statistical data in the China Tourism Statistical Yearbook are mainly the number of beds and rental rate of star-rated hotels, so this paper mainly calculates the carbon footprint of star-rated hotels. The carbon emission coefficients of different star-rated hotels based on Liang Hui's [35] research results are shown in (Table 2).

Table 2. Carbon dioxide emission index of star-rated hotels of different grades. (kg/bed · night).

Hotel Star Level	Five Star	Four Star	Three Star	Two Star
Carbon dioxide emission index	24.57	20.61	17.44	11.1

The carbon footprint of tourism accommodations in Guilin from 2011 to 2022 can be calculated according to the occupancy rate of each-star hotel. The results are shown in (Figure 3). From 2011 to 2022, the carbon footprint of tourism accommodation in Guilin accounted for a relatively stable proportion of the total tourism carbon footprint, with an average proportion of 4.42%. The carbon footprint of tourist accommodation has been decreasing since reaching its peak in 2017, mainly due to Guangxi's deployment of hotel star reviews across the province in 2017. Star judges at all levels carry out a comprehensive inspection of the service standards and quality of star hotels, supporting facilities and equipment, operation and management level, maintenance, cleanliness, hygiene, and production safety. The hotels that fail to meet the standards will be removed from the star-rated hotel team to ensure the quality of hotels in the province. The quality of hotels in Guilin will be improved so that the impact of the carbon footprint of the lodging industry on the environment will be reduced.

From the perspective of the composition of the carbon footprint of tourist accommodation, by 2017, the number of five-star and three-star hotel beds is large and increasing, and the carbon emissions generated by five-star hotels account for about 35.39% at most; in addition, the carbon footprint of three-star hotels accounts for about 32.90%, and the carbon footprint of two-star hotels accounts for the least, about 6.39%. Compared with 2022, the number of five-star hotel beds in Guilin decreased from 8865 to 7431 in 2017. However, the carbon footprint of five-star hotels showed a decreasing trend when the rental rate increased, indicating that the number of hotel beds has an impact on the carbon footprint of tourist accommodations. Although the number of beds in three-star and four-star hotels has increased significantly, the carbon footprint of three-star and four-star hotels has decreased due to the decrease in the room rental rate, indicating that the hotel rental rate is another important factor affecting the carbon footprint of tourist accommodation.

The higher the hotel grade, the greater the unit energy consumption and the more carbon emissions, so the hotel grade will affect the carbon footprint of tourism accommodation. The number of three-star hotels in Guilin is the largest, followed by four-star hotels, while the number of five-star hotel beds is small and decreasing, indicating that the construction of high-grade tourism star hotels in Guilin needs to be further improved. In recent years, Guilin has made great efforts to build a dominant position in the tourism industry. It has made the participation process of star-rated hotels more standardized and the evaluation criteria stricter, and downgraded or selected star-rated hotels with poor infrastructure and professional services. To sum up, the grade, the number of beds, and the rental rate of star-rated hotels are the main factors affecting the carbon footprint of tourist

accommodation. The higher the hotel level, the more beds, the higher the average annual rental rate, and the larger the carbon footprint of tourist accommodation.

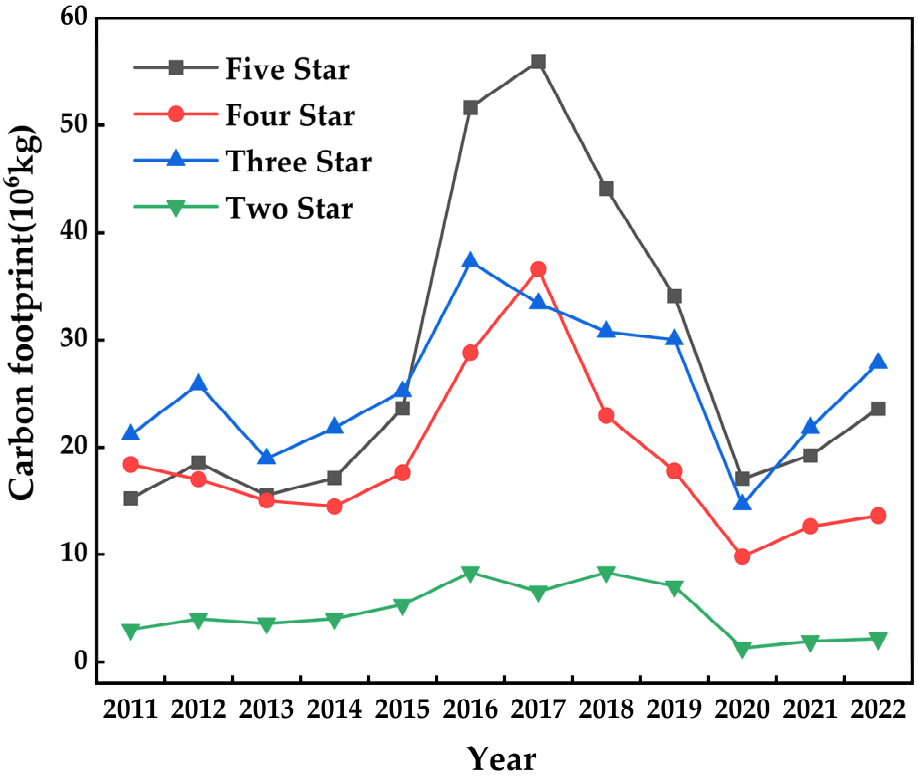

Figure 3. The carbon footprint of tourism and accommodation in Guilin from 2011 to 2022. Data sources: China Tourism Statistical Yearbook (Copy) (2011–2022), Guangxi Statistical Yearbook (2011–2022), Guilin Economic and Social Statistical Yearbook (2011–2022).

3.3. Carbon Footprint Analysis of Tourism Activities

According to the purpose of tourism, tourism activities can be divided into sightseeing, leisure holidays, business trips, visiting relatives and friends, cultural exchanges, health and recuperation, etc. With the advent of the mass tourism era, tourism activities are more personalized and diversified, and different forms of tourism activities have obvious differences in carbon dioxide emissions. Based on the research results (Table 3) of Shi Peihua [36], the CO_2 emission index of different types of tourism activities is determined by classifying tourism activities into five categories: sightseeing, leisure, business trips, visiting relatives and friends, and other categories.

Table 3. Carbon dioxide emission index of different tourism activities. (g/person).

Type of Tourism Activities	Sightseeing	Recreational	Business	Visit Friends	Recuperation	Others
Carbon dioxide emission index	417	1670	786	591	1670	172

The composition of various tourist activities in Guilin is based on the sub-composition proportion of the number of tourist activities of national residents, and the data is from the Tourism Sample Survey Data. Combined with the relevant parameters in Table 3, the number of tourists in Guilin and the proportion of tourists in various types of tourism activities during 2011–2022 are brought into the equation, and the calculation results are shown in (Figure 4). From 2011 to 2019, the carbon footprint of tourism activities in Guilin has been increasing, and from 2020 to 2022, the carbon footprint of tourism activities will

decrease as the number of tourists decreases due to the COVID-19 pandemic. With the development of the economy, people's tourism concept has gradually changed. More and more tourists choose low-carbon tourism that can be close to nature, and tourism activities are more and more focused on natural scenery sightseeing with low energy consumption. Compared with traditional forms of tourism, leisure holidays and health retreats pay more attention to the tourist experience, thus increasing many services and consuming more energy, which has a direct impact on the carbon footprint of tourism activities. The carbon footprint of leisure holidays reached the largest in 2019. As people's awareness of low-carbon travel increases and the proportion of business travel increases, so does the carbon footprint. The carbon footprint of leisure vacations accounts for 29.06% of the carbon footprint of tourism activities, indicating that the negative impact of leisure vacations on the environment is more critical.

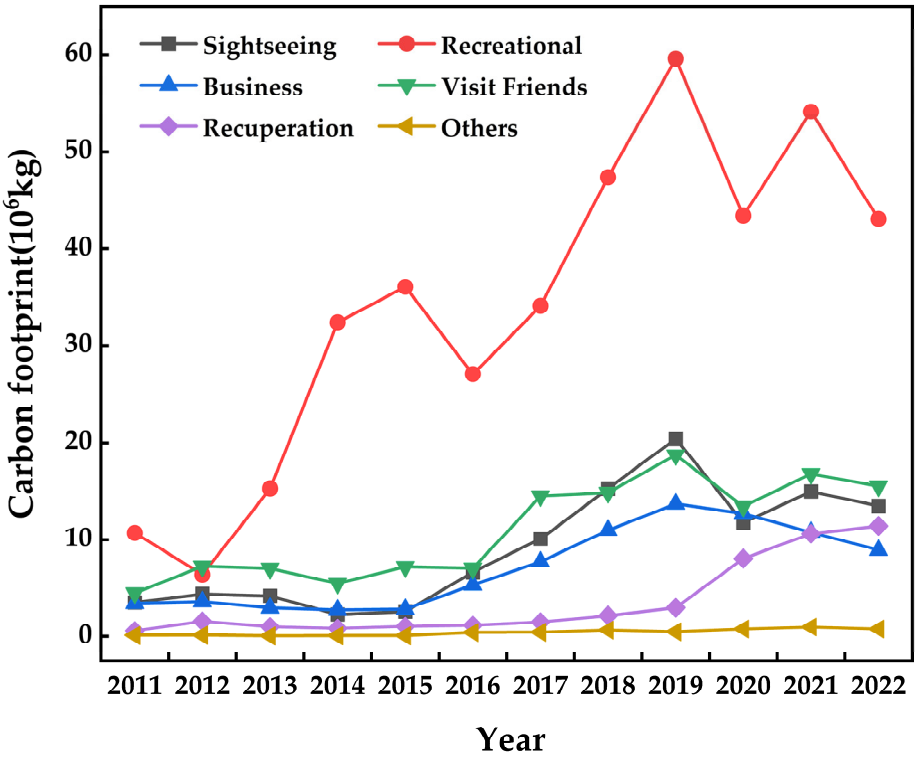

Figure 4. The carbon footprint of Guilin's tourism activities from 2011 to 2022. Data sources: Tourism Sampling Survey Data (2011–2022), China Tourism Statistical Yearbook (2011–2022), Guilin Economic and Social Statistical Yearbook (2011–2022).

Although the total carbon footprint of tourism activities increases year by year, its proportion in the total carbon footprint of tourism decreases year by year. Compared with other tourism sectors, although the carbon footprint of tourism activities is high, its impact on the environment tends to weaken. The photosynthesis of forests, grasslands, and aquatic plants in natural landscapes has the function of absorbing and storing carbon dioxide in the atmosphere to eliminate part of the carbon emissions caused by tourism activities. With the construction of the innovation demonstration zone of the National Sustainable Development Agenda and the building of a world-class tourism city in Guilin, the impact of tourism activities on the deteriorating environment has been alleviated to some extent.

3.4. Carbon Footprint Analysis of Tourism and Catering

According to the research results, the per capita food consumption of tourists in Guilin City was used to estimate the carbon footprint of tourism and catering. According to the research results of Zhang Ruiying [37], the tourist catering structure is shown in (Table 4).

Table 4. Tourism catering structure of Guilin.

Food	Per Capita Consumption per Day (kg)	Food Carbon Index
Grain	0.62	0.64
Vegetables	0.5	0.16
Edible vegetable oil	0.05	3.36
Pork	0.06	12.8
Beef	0.01	12.8
Mutton	0.01	12.8
Poultry	0.02	12.8
Egg	0.05	10.4
Fish	0.04	16
Melon and fruit	0.2	0.16

According to the calculation formula of catering carbon footprint, combined with the relevant parameters in Table 4 and the calculation model of catering carbon footprint, the calculation results are shown in (Figure 5). According to the European Commission [38], the human diet consumes 23% of the Earth's resources and accounts for 18% of global greenhouse gas emissions, so diet is also an important source of carbon emissions. As can be seen from Figure 5, the carbon footprint of tourism and catering in Guilin increased year by year, but the growth rate slowed down. The annual increase rate of the carbon footprint of catering was the highest from 2016 to 2019, which was due to the increase in the number of tourists leading to the increase in the carbon footprint of catering. The carbon footprint of the catering industry will decrease significantly in 2020–2022, which is due to the significant decrease in the number of tourists to Guilin due to the outbreak of COVID-19. The growth rate of the carbon footprint of tourism and catering was higher than that of the number of tourists. Although the average length of stay of tourists increased, the increase was small. Therefore, the increase in the carbon footprint of tourism and catering was mainly due to the increase in the consumption of energy-dense food. The main food consumed by tourists in Guilin includes cereals, fresh vegetables, edible vegetable oil, pork, beef, mutton, poultry, fresh eggs, fish, fresh melons, and fruits. Except for fish, the food energy density was between 1 MJ/kg–80 MJ/g. This shows that tourists consume more food with high carbon dioxide emissions, while the consumption of vegetables, fresh melons, and fruits with low carbon dioxide emissions is decreasing.

3.5. Comprehensive Analysis of Tourism Carbon Footprint

As can be seen from (Figure 6), the total carbon emission of tourism in Guilin is on the rise as a whole, increasing from 1443.63×10^6 kg in 2011 to 2546.58×10^6 kg in 2019. In 2019, it accounted for 14% of total carbon emissions. From the perspective of component proportions, tourism transportation is the main body of tourism carbon emissions, accounting for the largest proportion, accounting for about 70% annually, followed by tourism catering at about 22.5%, tourism accommodation at about 4.42%, tourism activities accounted for the smallest proportion, accounting for about 3.07% annually. From 2011 to 2019, the average annual growth rates of the carbon footprint of Guilin's tourism transportation, tourism accommodation, tourism activities and tourism catering were about 2.44%, 6.73%, 50.92% and 57.52%, respectively. From 2020 to 2022, the average annual growth rates of the carbon footprint of Guilin's tourism transportation, tourism accommodation, tourism activities and tourism catering are about −19.95%, 28.40%, 1.68% and −0.64%, respectively. It can be seen that due to the impact of COVID-19, the carbon footprint of transportation is greatly affected, with a negative annual growth rate, followed by tourism catering. The proportion of tourism transportation in the total carbon footprint during 2011–2022 (Table 5) indicates that tourism traffic is the main component of the total carbon footprint of Guilin City and the decisive factor of the tourism carbon footprint of Guilin City. Although the proportion of carbon emissions from tourism activities is the smallest, the annual average growth

rate is the highest. The changing trend of its composition is gradually increasing, and the carbon emissions generated in the future cannot be ignored. The tourist scale of the tourism industry in Guilin is expanding year by year, and the total carbon emission of the tourism industry is increasing day by day. However, (Figure 7) shows that the per capita carbon footprint of the tourism industry in Guilin is gradually decreasing, indicating that the low-carbon level of the tourism industry in Guilin has been continuously improved.

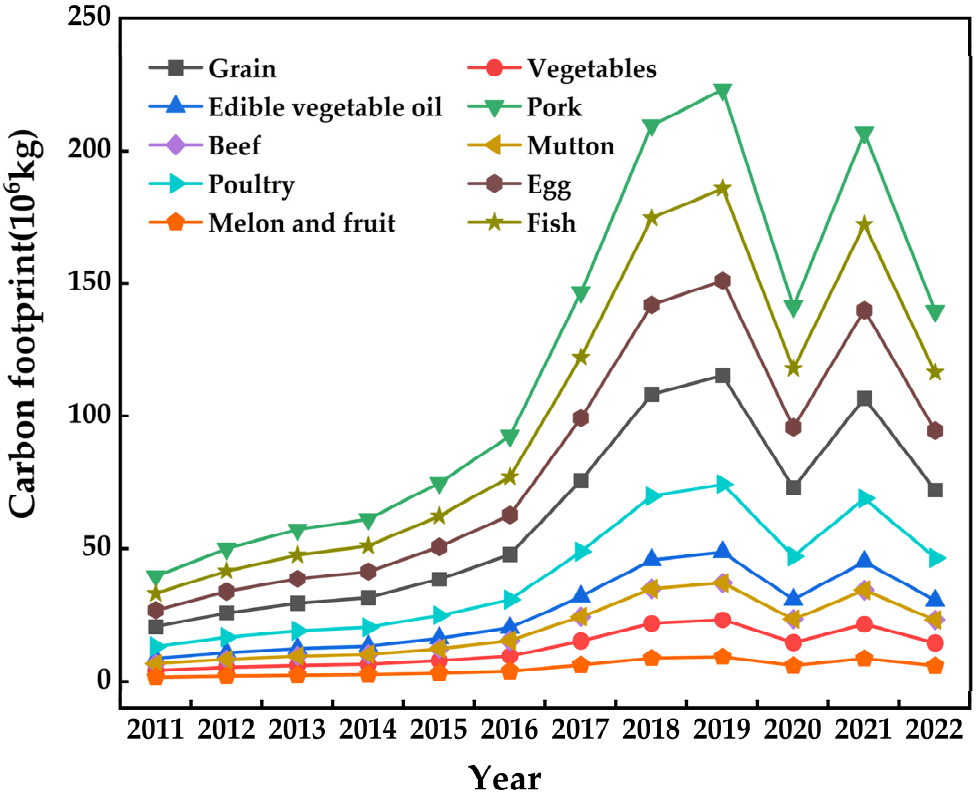

Figure 5. The carbon footprint of tourism and catering in Guilin from 2011 to 2022. Data source: Guilin Economic and Social Statistical Yearbook (2011–2022).

Table 5. The proportion of tourism transportation in total carbon footprint during 2011–2022.

Year	Proportion
2011	84.55%
2012	82.69%
2013	82.87%
2014	79.42%
2015	74.85%
2016	70.02%
2017	58.17%
2018	60.35%
2019	59.09%
2020	53.17%
2021	79.47%
2022	76.29%

Data sources: China Tourism Statistical Yearbook (Copy) (2011–2022), Guangxi Statistical Yearbook (2011–2022), Guilin Economic and Social Statistical Yearbook (2011–2022).

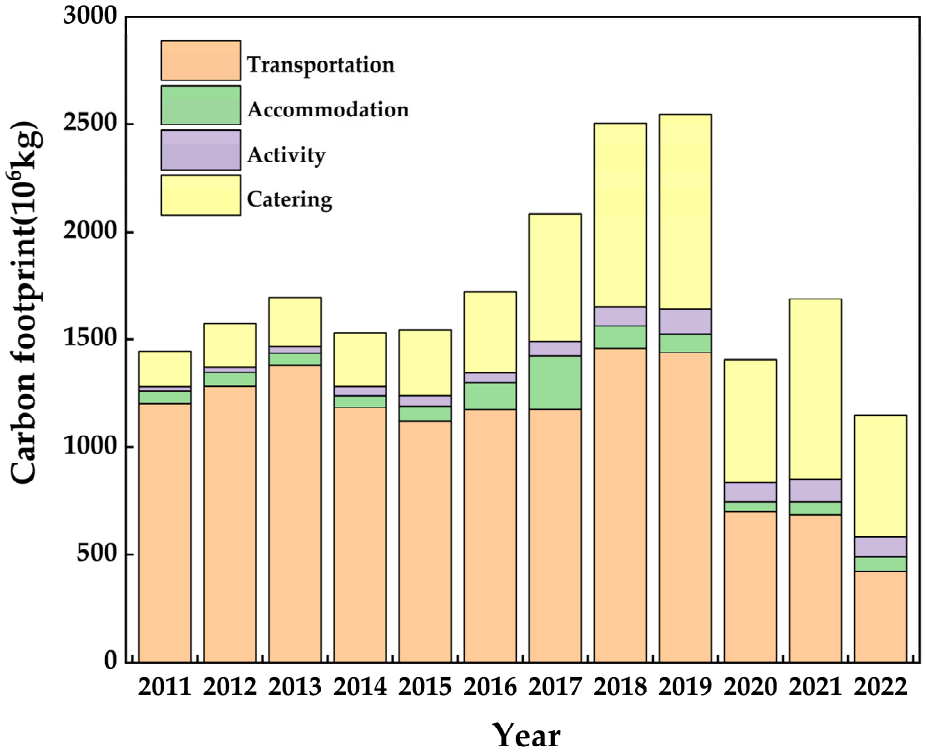

Figure 6. Composition of Guilin's tourism carbon footprint from 2011 to 2022. Data sources: China Tourism Statistical Yearbook (Copy) (2011–2022), Guangxi Statistical Yearbook (2011–2022), Guilin Economic and Social Statistical Yearbook (2011–2022).

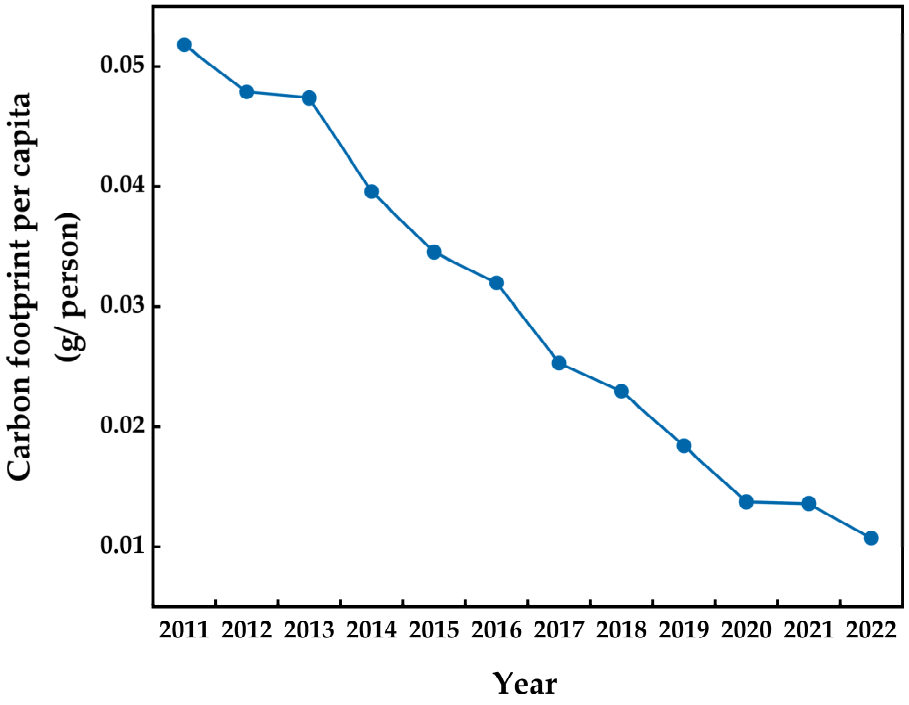

Figure 7. Per capita carbon footprint of Guilin tourism from 2011 to 2022. Data sources: China Tourism Statistical Yearbook (Copy) (2011–2022), Guangxi Statistical Yearbook (2011–2022), Guilin Economic and Social Statistical Yearbook (2011–2022).

3.6. Comprehensive Analysis of Sustainable Development of Low-Carbon Tourism in Guilin

The main influencing factor of Guilin's tourism carbon footprint is the number of tourists to Guilin. Linear fitting is conducted on the mathematical relationship between the two. The impact of COVID-19 in 2020–2022 led to the deviation of the data analysis between the number of tourists and the carbon footprint, so the linear fitting year is 2011–2019. The relationship between the tourism carbon footprint and the number of tourists in Guilin from 2011 to 2019 is shown in (Figure 8). The number of tourists in Guilin from 2011 to 2019 is taken as the *X*-axis, the corresponding carbon footprint value is taken as the *Y*-axis, and its nine coordinate scatter points are drawn for linear fitting. As can be seen from the figure, the nine scattered points can basically be connected in a straight line. The functional formula of tourist number X and tourism carbon footprint Y is y = 0.107x + 1183.2 because the R^2 value is 0.9465, indicating that the fitted functional formula is more than 94% to explain the corresponding data of 9 years, which is highly reliable. Under the condition that the carbon footprint of all tourism links is stable, Guilin City can realize the sustainable development of low-carbon tourism under the current growth rate of the number of tourists received.

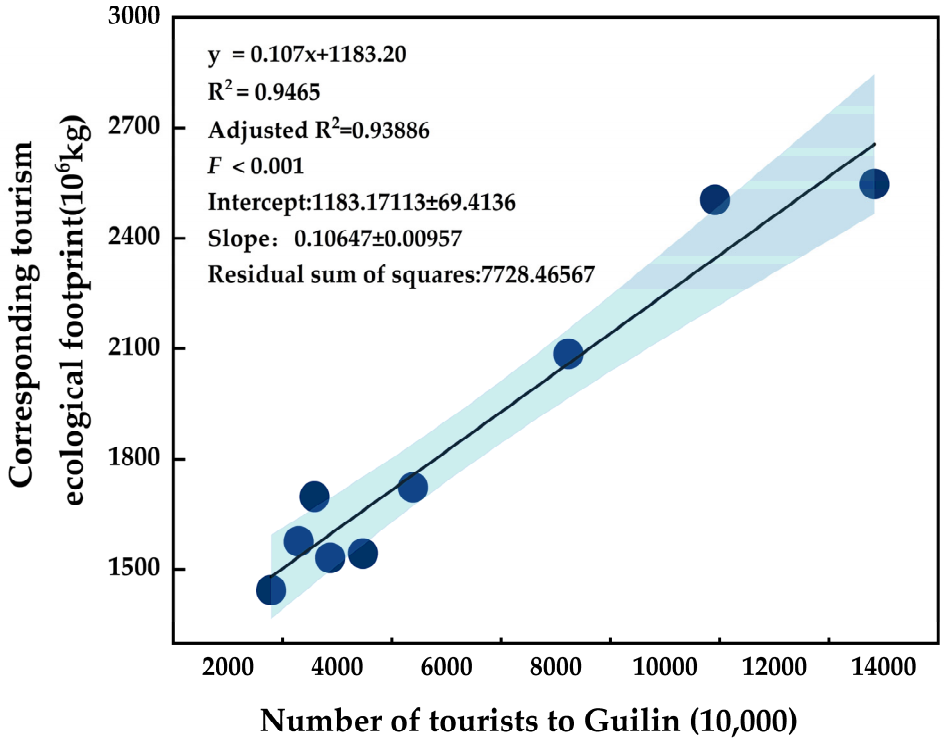

Figure 8. The relationship between the number of tourists and tourism carbon footprint in Guilin from 2011 to 2019. Data sources: China Tourism Statistical Yearbook (Copy) (2011–2022), Guangxi Statistical Yearbook (2011–2022), Guilin Economic and Social Statistical Yearbook (2011–2022).

4. Discussion

There are obvious differences in the carbon footprint of all sectors of tourism in Guilin, followed by tourism catering, tourism accommodation and tourism activities. From the perspective of transportation mode, aircraft has the greatest impact on the environment, and the carbon footprint of tourism transportation accounts for the highest proportion, which is consistent with Du Peng's [39] analysis and research results on the characteristics of the carbon footprint of tourism transportation. Railways are the means of transportation with the smallest carbon emission per unit, but with the increase in the number of tourists, its carbon footprint shows an increasing trend, indicating that the number of tourists received in Guilin has an impact on the carbon footprint of tourism transportation, which is similar to the analysis result of Yang Junhui [40] on the carbon emission of tourist transportation in

Guilin. With the development of the economy, people pay more attention to the comfort and convenience of travel. Coupled with the continuous construction and improvement of Guilin Liangjiang International Airport, the public transport complex, including buses, taxis, intercity railways, and long-distance passenger transport, is gradually improved. The airport constantly opens new tourist routes, and it is very convenient to book cheap airlines and discount air tickets online. Air travel has become the first choice for tourists traveling between medium and long distances. From the perspective of the carbon footprint of tourism activities, the total amount and average value are far smaller than the carbon footprint of tourism transportation, tourism accommodation and tourism meals, which is consistent with the conclusion of Yang Shasha's [41] research on the development trend of carbon emissions from tourism activities in Guilin. From the perspective of the research time span, the research time span of this paper is 10 years, which has a certain reference. The follow-up research can be carried out around the cross-space and cross-scale comparison so as to further systematically analyze the relationship between the tourism economy and the environment. From the perspective of carbon footprint model construction, the index classification of the constructed model is detailed and consistent with the actual situation of Guilin tourism.

5. Managerial Applications

As for Guilin's tourism industry management department, the model used in this study can be used as an important scientific basis for the formulation and implementation of the "Guilin Low-Carbon Tourism Standard" so as to establish a good management system and effectively promote the sustainable development of low-carbon tourism in Guilin. As for tourism enterprises in Guilin, the model used in this study can be used to explore the development, design and evaluation of low-carbon tourism products and tourist routes in Guilin, actively publicize the advantages of low-carbon tourism products, better promote and improve low-carbon tourism culture, promote low-carbon consumption, and realize the green, sustainable and efficient growth of Guilin's tourism economy. At the same time, enterprise management and low-carbon tourism can also be combined to achieve better management and development.

6. Conclusions

In this paper, the life cycle theory of tourist carbon footprint is used to build a tourism carbon footprint model, and the low-carbon tourism carbon footprint data of Guilin from 2011 to 2022 are quantitatively calculated and analyzed. The conclusions are as follows:

1. From 2011 to 2019, carbon emissions from Guilin's tourism industry kept increasing, with an average annual growth rate of about 4.81%. From 2020 to 2022, due to the impact of the novel coronavirus epidemic, the number of tourists in Guilin decreased, and the total amount of tourism carbon emissions decreased relatively, which is consistent with the truth. Tourism accommodation, tourism activities and tourism catering in Guilin have a great impact on the carbon emissions of greenhouse gases, and the carbon footprint is also seriously affected. From 2011 to 2022, the per capita tourism carbon footprint in Guilin gradually decreased, indicating that the low-carbon sustainable development level of the tourism industry in Guilin has been continuously improved. The proportion of carbon emissions from tourism activities and tourism catering in the total carbon emissions from tourism in Guilin has been increasing since 2011, and the growth rate of carbon emissions from tourism activities is slow but still on the rise. The emission reduction of the tourism industry in Guilin should focus on reducing the carbon emissions of tourism transportation and should not ignore the carbon emissions of tourism accommodation, tourism activities, and tourism catering. The results show that this model can further and gradually explore the problems existing in the sustainable development of low-carbon tourism in Guilin, provide important methods and scientific theoretical basis for tourists' low-carbon

tourism behavior, meet the requirements of tourists' travel, and be widely used in the assessment and management of low-carbon tourism environmental impact;

2. Through data analysis, it can be seen that the tourism industry management department of Guilin should vigorously develop public transportation, shared transportation and other environmentally friendly and low-carbon transportation modes in the scenic spot, build an ecological parking lot in the scenic spot, and encourage low-carbon travel of tourists on the premise of ensuring the convenience of tourists. Different accommodation types have a large difference in the proportion of tourism accommodation carbon footprint. The realization of low-carbon tourism accommodation in Guilin should focus on three-star hotels and above to implement low-carbon business strategies. Guilin is rich in agricultural resources, which can rely on the corresponding agricultural products industry, develop green catering brands such as agritainment, build an "ecological home" based on the development mode of integrating agriculture and tourism, and promote the development of low-carbon tourism with the development of the ecological industry;
3. The Guilin tourism industry is an important component of our country's tourism industry. To implement the low-carbon transformation of the tourism industry, it is necessary not only to give full play to the leading role of the government but also to be good at guiding tourists to low-carbon consumption and cultivating their low-carbon awareness. At the same time, it is necessary to give full play to the bonding role of travel companies, implement low-carbon travel strategies, build low-carbon brands of tourism cities, and make low-carbon travel concepts of cities deeply rooted in people's hearts. Thus, while promoting the low-carbon transformation of the tourism industry, it will promote the sustainable development of low-carbon tourism in Guilin and make Guilin a world-class tourism city.

7. Limitations

The region involved in this study is relatively simple and has limitations in terms of research scale. Subsequent studies can focus on cross-space and cross-scale comparison. In terms of calculation data, carbon emissions generated by indirect energy are not taken into account, so there is a certain deviation from the actual results. In future studies, data collection and collation should be more refined and comprehensive, and the accuracy of parameters should be increased to make it highly consistent with the actual situation of the research destination so as to enhance the practical guiding significance of the research.

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