Environmental Science and Pollution Research (2021) 28:66448–66463
https://doi.org/10.1007/s11356-021-14956-6

RESEARCH ARTICLE

# The empirical decomposition and peak path of China's tourism carbon emissions

Xiaojun Ma[1] · Miaomiao Han[1] · Jian Luo[2] · Yanqi Song[1] · Ruimin Chen[1] · Xueying Sun[1]

Received: 6 April 2021 / Accepted: 13 June 2021 / Published online: 31 July 2021

**Abstract**
Carbon emissions from tourism are an important indicator to measure the impact of tourism on environmental quality. As the world's largest industry, tourism has many related industries and is a strong driver of energy consumption. The emission reductions it can achieve will directly determine whether China's overall carbon emission reduction target can be met. This paper analyzes the drivers of the evolution of carbon emissions from the tourism industry in China over the period 2000–2017 as a research sample using the Generalized Dividing Index Method (GDIM), and on this basis, it uses scenario analysis and Monte Carlo simulation to predict the carbon peak in tourism for the first time. The research results show that the scale of industry and energy consumption are the key factors leading to increased tourism carbon emissions, and the carbon intensity of tourism industry, energy consumption carbon intensity, investment efficiency, and energy intensity are the main factors leading to reduced carbon emissions from tourism. The scale of investment and the carbon intensity of investment have a dual effect; the scenario analysis and Monte Carlo simulation used to predict peak carbon in China's tourism industry show that the peak carbon will occur approximately in 2030. The government needs to further guide and encourage the tourism industry to increase investment activities targeting energy conservation and emission reduction. Under the conditions of strictly implementing energy conservation and emission reduction measures and vigorous promotion of the transformation and upgrading of tourism development methods, the tourism industry will have considerable potential to reduce carbon emissions.

**Keywords** Tourism · Carbon peak · Generalized Dividing Index Method · Scenario analysis · Monte Carlo simulation

## Introduction

Responding to climate change has become a common global environmental challenge, and reducing carbon dioxide emissions and promoting a low-carbon economy have become the consensus among all countries. In recent decades, China's economy has continued to grow, and energy consumption, driven by rapid urbanization and industrialization, has grown rapidly for a long time. This has attracted considerable attention to China's carbon emissions from all over the world and required China to undertake a larger share of emission reduction tasks. Following China's first proposed binding energy-saving indicators in the "Eleventh Five-Year Plan," in 2009, it also proposed for the first time the target of controlling greenhouse gas emissions by reducing carbon emissions per unit of GDP by 40 to 45% in 2020 compared to 2005. China's "Twelfth Five-Year Plan" and "Thirteenth Five-Year Plan" successively proposed binding energy intensity and carbon emission intensity control targets. In addition, in September 2020, General Secretary Xi delivered an important speech at the general debate of the 75th United Nations General Assembly, clearly proposing that China will strive to reach peak carbon dioxide emissions before 2030. How to achieve this goal requires effort and attention from all parts of society.

With the rapid development of the tourism economy, the pressure of the tourism industry on the ecological environment has gradually become prominent, and the traditional concept of tourism as a "smoke-free industry" has gradually been subverted. The tourism industry accounts for 4 to 6% of total global anthropogenic carbon emissions. If effective mitigation

Responsible Editor: Philippe Garrigues

✉ Jian Luo
2963370029@qq.com

[1] School of Statistics, Dongbei University of Finance and Economics, Dalian 116025, China

[2] School of Statistics, Jiangxi University of Finance and Economics, Jiangxi 330013, China

measures are not taken, carbon emissions from the tourism industry may increase by 1.5 times over the next 30 years (Scott et al. 2007). In 2009, the World Tourism and Travel Council (WTTC) determined that by 2035, CO2 emissions from the tourism industry will be reduced by 50% from 2005 levels. According to 2020 *China Statistical Yearbook* data, the total number of tourists in 2019 reached 6.151 billion. The construction, operation, and maintenance of the associated large-scale tourism facilities consume energy and generate substantial carbon emissions. Carbon peaking is China's major decision-making and deployment to cope with global climate change, unswervingly follow the path of green and low-carbon development, and force high-quality development with target constraints. The tourism industry must shoulder this mission and responsibility and work together to find solutions. Put forward the goal and vision of peaking the carbon in the tourism industry, which will promote the high-quality development of China's tourism economy, the overall green and low-carbon transformation of the society, and the high-level protection of the ecological environment. It will play an important guiding role in accelerating the implementation of green and low-carbon transformation and long-term low-carbon development strategies, as well as advancing the process of global governance, which is of very important practical significance. Therefore, accurately identifying the influencing factors that affect the tourism industry's carbon emissions, scientifically predicting the carbon peaks of China's tourism industry under different policy orientations, and proposing specific carbon emission reduction measures are the relevant choices for the modern tourism industry to achieve sustainable development of the tourism economy. It is a necessary condition for China to successfully fulfill its commitment to a 2030 carbon peak.

The following structure of this paper consists of four parts. In the "Literature review," we review previous studies. In the section of "Model methods and data," we describe the measurement methods of tourism carbon emissions, GDIM decomposition model, scenario analysis and Monte Carlo prediction model, data sources, and indicator selection instructions. In the "Results and discussion" section, we use the above model and the method to carry on the demonstration analysis and carry on the discussion to the result. Finally, we conclude our findings and discuss policy implications.

## Literature review

Domestic and foreign scholars have proposed many methods for analyzing carbon emissions according to different purposes, objects, and scales, mainly including the factor decomposition method (Bargaoui et al. 2014; Quan et al. 2020; Liu et al. 2007; Shuai et al. 2017; Zhao and Liu 2020), input-output method (Guo et al. 2018; Moran and Gonzalez 2007), model analysis method (Liu and Xiao 2018), and life cycle method (Jin et al. 2014; Shan et al. 2020). Their scopes of application and advantages and disadvantages are shown in Table 1.

Existing research on tourism carbon emissions focuses on three aspects: the measurement of tourism carbon emissions, the relationship between the economic growth and carbon emissions in tourism, and the degree of influence of various driving factors on tourism carbon emissions. Regarding the

**Table 1** Classification of tourism carbon emission analysis methods

| Method | Category | Scope of application | Pros and cons |
|---|---|---|---|
| Factor decomposition | LMDI (Tang et al. 2017)<br>STIRPAT (Koak et al. 2020) | Decompose the change in the target variable into several influencing factors, and identify the degree of influence of each influencing factor | Convenient calculation, no residual items. Only a single absolute factor is discussed, and other absolute factors are not considered. Mostly limited to the "scale-technology-structure" influencing factor framework |
| Model analysis | Measurement model<br>Dynamic panel data model (Zha et al. 2019; Yu et al. 2021) | Use different parameters to analyze the emission reduction potential of countries and at other scales | It can effectively amplify the sample size and degree of freedom and reduce the multicollinearity among variables. The logic of the method is simple, and the requirements for data quality are high |
| Input-output method | (Surugiu et al. 2012; Munday et al. 2013) | Macro-scale research on cities, countries, etc. | Effectively express the direct and indirect impacts of the economy and tourism on the environment. Only uses industry data and cannot know the product situation |
| Life cycle method | (Hanandeh 2013) | Study the whole life process of the product, including the extraction, processing, manufacturing, and use of raw materials | A more comprehensive reflection of the environmental impact generated about by the accumulation effect. The requirements for data quality are high. If secondary data are used when the original data are not available, the results will be more inaccurate |

measurement of tourism carbon emissions, Gossling (2000) were the first to propose a method for systematically measuring tourism carbon emissions. Subsequently, Beckena et al. (2003) studied the energy consumption of tourism in New Zealand and found that the energy consumption of tourism transportation accounted for 65 to 73% of tourism's total energy consumption. Perch-Nielsen et al. (2010) constructed a framework for measuring the intensity of Swiss greenhouse gas emissions and compared Swiss greenhouse gas intensity with other European countries, providing an important reference for measuring the carbon emission level of a country or region's tourism development. Shi and Wu (2011) adopted the "bottom-up" method to systematically estimate the energy consumption and carbon dioxide emissions of China's tourism industry for the first time. Regarding the relationship between the growth of the tourism sector and carbon emissions, Zaman et al. (2016) and Len et al. (2014) identified and analyzed the relationship between economic growth and carbon emissions in the tourism sector in developed and developing countries. They found that economic growth increases carbon emissions. Moreover, the economic growth of tourism has a higher impact on carbon emissions in developed than that in developing countries. Sun (2016) used an extended input-output environment model to reveal the dynamic relationship between growth in the tourism sector, tourism carbon emissions, and technical efficiency. Regarding the factors affecting carbon emissions in the tourism industry, the logarithmic mean Divisia index (LMDI) decomposition method and the scalable random environmental impact assessment model (STIRPAT) are the most widely used. Robaina-Alves et al. (2016) and Liu et al. (2011) used LMDI to study the influencing factors of tourism carbon emissions in Portugal and Chengdu, respectively, and concluded that the number of tourists is the primary factor leading to an increase in carbon emissions and that energy intensity is the key factor in reducing carbon emissions. Koak et al. (2020) adopted the STIRPAT model to quantitatively analyze the different contributions of driving factors, such as tourism development, the urbanization rate, and energy intensity, to tourism carbon emissions. However, both the LMDI and STIRPAT decomposition methods are constrained by identity, which makes the decomposition results inaccurate. Vaninsky (2014) proposed a new decomposition method—GDIM—which overcomes the defects of the existing exponential decomposition methods mentioned above and can more comprehensively and accurately quantify the actual contributions of different factors to the evolution of carbon emissions. It has been widely used in the mining industry (Shao et al. 2016), industry (Quick 2014), transportation industry (Guo and Meng 2019), power industry (Zhu et al. 2018; Yan et al. 2019), etc.

In recent years, the prediction of carbon emission peaks has become a lively research topic in the academic circles. The scenario analysis method is a common auxiliary forecasting model. The greatest advantage of scenario analysis is that it can predict certain trends of future carbon emission changes and avoid overestimating or underestimating future changes and their impacts (Tao et al. 2019). The model can assist in predicting the optimal peak path by setting different scenarios and determining the optimal carbon emission reduction method. However, this method cannot be used alone and often appears in the form of "method + scenario analysis." The common methods mainly include IPAT model, STIRPAT model, system dynamics, and artificial neural network. For example, Yue et al. (2013) used the IPAT model combined with the scenario analysis method to set 54 plans to predict carbon emissions in Jiangsu Province to determine the best carbon emission reduction path. Fang et al. (2019) used the expanded STIRPAT model and scenario analysis to predict the carbon emission peak path of China's 30 provinces in 2030 and found that only 26 provinces may reach the peak carbon emission. Du et al. (2019) studied the carbon emissions of China's construction industry under different scenarios through system dynamics, and the results of the study showed that by 2025, carbon emissions will reach 992.11 million tons. Xu et al. (2019) used a dynamic artificial neural network to predict that China's carbon dioxide emissions will reach 10.08, 10.78, and 11.63 billion tons in 2029, 2031, or 2035 under low, medium, and high growth scenarios, respectively. As an uncertain analysis method, Monte Carlo simulation has been widely used in the analysis and research of uncertain events due to its comprehensive flexibility (Shao et al. 2017), but it has not been widely used by researchers on carbon emission reduction paths in China. If Monte Carlo simulation and scenario analysis can be organically combined, the optimal emission reduction path can be identified (Zhang et al. 2020).

Although the research on carbon emissions in the existing literature is increasingly diversified and the research methods are gradually improved, there are still some deficiencies: (1) There is a lack of factor decomposition methods. Most of the literature on the analysis of factors affecting tourism carbon emission focuses on the LMDI and STIRPAT methods, which decompose the change in target variables into several influencing factors and identify the influence degree of each influencing factor. The LMDI decomposition method makes all factors depend on each other to some extent. Although the STIRPAT decomposition method can better fit the relationship between resources, the environment, and social and economic indicators, it is mostly limited to the "scale, technology, and structure" influencing factor framework. (2) The selection of factors is one-sided. The influencing factors selected by the existing research on tourism carbon emissions are relatively fixed but not comprehensive, most of which are limited to the consumption level, the number of tourists, and industrial structure, while the influence of investment factors on tourism carbon emissions is ignored. (3) The forecast trend analysis is weak. Although research on carbon peaks has addressed the construction industry (Li et al. 2019), industry (Zhou et al. 2018), power industry (Gu et al. 2015; Tao et al. 2019), and other industries and sectors, the research on carbon peaks in tourism is relatively limited.

Given the current state of the literature, the main content and innovations of this article are as follows: (1) In terms of research methods, GDIM was used to analyze the driving factors of China's tourism carbon emissions from 2000 to 2017. The decomposition results of the GDIM model are not constrained by identities, and the dependence between variables is eliminated. Based on the investigation of the influence of absolute factors, the potential factors can be taken into account, so the accuracy of the factors affecting tourism carbon emissions can be improved. (2) In the selection of research factors, as investment factors have been neglected in the existing literature, this paper provides a new perspective for studying the factors affecting carbon emissions in the tourism industry. Therefore, in terms of variable selection, this article introduces three investment-related factors, namely, investment scale, investment efficiency, and investment intensity, to examine the impact of investment on the evolution of tourism carbon emissions. (3) In terms of trend analysis, the scenario analysis method and Monte Carlo simulation method are used to forecast the carbon emissions of China's tourism industry. Analyzing the future changes in tourism carbon emissions can serve as guidance for the government when formulating policies, help the tourism industry realize the transition to low-carbon development as soon as possible, and make adjustments as soon as possible to support the national carbon emission plan and reach the carbon peak earlier.

## Model methods and data

### Estimation method of China's tourism carbon emissions

From a global perspective, there is no systematic method for estimating energy consumption and carbon dioxide emissions in the tourism industry (Kuo et al. 2012). In existing studies, both "top-down" and "bottom-up" methods have been used (Becken and Hay 2007; Goessling et al. 2005). The so-called "top-down" method directly estimates the proportion of energy consumption and emissions of tourism within a complete system (such as a country or region). The "bottom-up" approach starts with data from visitors arriving at the destination and works its way up the hierarchy to calculate energy consumption and emissions. The "top-down" approach requires national or regional statistics on energy consumption and the monitoring of carbon dioxide emissions. In China's *Energy Statistical Yearbook*, the energy-consuming sectors mainly include industry, mining, construction, and transportation, and there is no statistical item for energy consumption in the tourism or service industries. In addition, China does not have a statistical monitoring system for greenhouse gas emissions. Therefore, it is difficult to use a "top-down" approach to estimate energy consumption and carbon dioxide emissions from the tourism industry. This research adopts the "bottom-up" approach to measure the carbon emissions of China's tourism industry from 2000 to 2017 and draws lessons from the research of Beckena et al. (2003) and Shi and Wu (2011) to determine the tourist traffic, tourist accommodations, and tourism activities to identify the carbon emissions of key areas of the tourism industry. The method used here to calculate carbon emissions and aggregate various sources in the tourism industry using the "bottom-up" approach is as follows:

$$C = \sum_{i=1}^{3} C_i \tag{1}$$

$C$ represents the total carbon emissions from the tourism industry, and $i$ represents three sectors: tourism transportation, tourism accommodation, and tourism activities.

$$C_1 = \sum_{i=1}^{4} Q_m \cdot P_m \cdot \alpha_m \tag{2}$$

$C_1$ represents the total carbon emissions of tourism transportation; $m$ represents the four transportation modes of road, aviation, railway, and water transportation; $Q_m$ is the passenger turnover of the $m$-type transportation mode; and $P_m$ is the proportion of tourists in the passenger turnover of the $m$-type of transportation. The $\rho$ values of road, air, rail, and water transportation are 13.8%, 64.7%, 31.6%, and 10.6%, respectively. $\alpha_m$ is the carbon emission factor of the $m$ type of transportation, and the emission factors of road, airplane, railway, and water transportation are 133, 137, 27, and 106, respectively (Shi and Wu 2011).

$$c_2 = \sum N \cdot R \cdot \beta \tag{3}$$

$c_2$ represents the total carbon emissions of travel accommodations. $N$ is the number of beds in a tourist hotel room. $R$ is the average room utilization rate of tourist hotels. $\beta$ is the carbon dioxide emission factor per bed per night. The value is 2.458 g $bed^{-1}$ night (Wei et al. 2012).

$$C_3 = \sum_{j=1}^{4} K_j \cdot \beta_j \tag{4}$$

$c_3$ is the total carbon emissions from tourism activities. $K_\mathrm{j}$ is the number of tourists in $j$ tourism activities and combines the number of inbound tourists, urban residents, and rural residents, and $\beta_\mathrm{j}$ is the carbon dioxide emission factor of j tourism activities. The carbon dioxide emission factors of sightseeing, business travel, leisure vacation, visiting relatives and friends, and other types of tourism activities are 417, 786, 1670, 591, and 172 g $person^{-1}$, respectively (Shi and Wu 2011).

## Decomposition method for tourism carbon emission factors

The GDIM mainly establishes a multidimensional factor decomposition model through the deformation of the Kaya identity to reveal the causes of carbon emission changes. Based on the basic principles of GDIM, the expressions for tourism carbon emissions and related influencing factors are as follows, the variables and specific meanings involved in model are shown in Table 2.

$$CO_2 = TVA \times \left(\frac{CO_2}{TVA}\right) = EC \times \left(\frac{CO_2}{EC}\right) = IS \times \left(\frac{CO_2}{IS}\right) \tag{5}$$

$$\frac{TVA}{IS} = \left(\frac{CO_2}{IS}\right) \div \left(\frac{CO_2}{TVA}\right) \tag{6}$$

$$\frac{EC}{TVA} = \left(\frac{CO_2}{TVA}\right) \div \left(\frac{CO_2}{EC}\right) \tag{7}$$

$$Z = X_1X_2 = X_3X_4 = X_5X_6 \tag{8}$$

$$X_7 = \left(\frac{X_1}{X_5}\right) \tag{9}$$

$$X_8 = \left(\frac{X_3}{X_1}\right) \tag{10}$$

To further use the GDIM method, Formulas (8). (9), and (10) are transformed into the following formulas:

$$Z = X_1X_2 \tag{11}$$

$$X_1X_2 - X_3X_4 = 0 \tag{12}$$

$$X_1X_2 - X_5X_6 = 0 \tag{13}$$

$$X_1 - X_5X_7 = 0 \tag{14}$$

$$X_3 - X_1X_8 = 0 \tag{15}$$

For factor $X$, use function $Z(X)$ to represent its contribution to changes in carbon emissions. Construct a Jacobian matrix $\Phi_X$ composed of various influencing factors from Formulas (12), (13), (14), and (15):

$$\Phi_X = \begin{pmatrix} X_2 & X_1 & -X_4 & -X_3 & 0 & 0 & 0 & 0 \\ X_2 & X_1 & 0 & 0 & -X_6 & -X_5 & 0 & 0 \\ 1 & 0 & 0 & 0 & -X_7 & 0 & -X_5 & 0 \\ -X_8 & 0 & 1 & 0 & 0 & 0 & 0 & -X_1 \end{pmatrix} \tag{16}$$

According to the GDIM method, the amount of change $\Delta Z$ in the tourism industry's carbon emissions can be decomposed into the sum of the contributions of various influencing factors, as shown in the following formula:

$$\Delta Z[X|\Phi] = \int_L \nabla Z^T \left(I - \Phi_X \Phi_X^{+}\right) dX \tag{17}$$

In Formula (17), $L$ represents the time span $\Delta Z = (X_2\ \ X_1\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0)$, $I$represents the identity matrix, and "+" represents the generalized inverse matrix. If the column vectors in the Jacobian matrix $\Phi_X$ are linearly independent, then $\Phi_X^{+} = \left(\Phi_X^T \Phi_X\right)^{-1} \Phi_X^T$. This article decomposes the changes in tourism carbon emissions into the sum of 8 factors: $\Delta Z_{X1}$, $\Delta Z_{X2}$, $\Delta Z_{X3}$, $\Delta Z_{X4}$, $\Delta Z_{X5}$, $\Delta Z_{X6}$, $\Delta Z_{X7}$, and $\Delta Z_{X8}$.

## Tourism peak carbon emissions forecast

### Scenario analysis of tourism carbon emission forecast

Based on the factor decomposition results, the main driving factors in the evolution of tourism carbon emissions are industry scale and tourism industry carbon intensity, while the energy consumption energy intensity and energy intensity have considerable potential to drive emission reduction, and future

**Table 2** Variables included in the model

| Symbols in the model | Definition | Meaning | Unit |
|---|---|---|---|
| $Z=CO_2$ | Carbon emissions | Total carbon emissions from tourism | 10,000 tons |
| $X_1=TVA$ | Industry scale | Total output value of tourism industry | 100 million yuan |
| $X_2=CO_2/TVA$ | Tourism industry carbon intensity | Carbon emissions per unit of tourism output value | Tons/10,000 yuan |
| $X_3=EC$ | Energy consumption scale | Total energy consumption of tourism | 10,000 tons of standard coal |
| $X_4=CO_2/EC$ | Energy consumption carbon intensity | Carbon emissions per unit of energy consumption | Tons/ton standard coal |
| $X_5=IS$ | Investment scale | Fixed asset investment in tourism | 100 million yuan |
| $X_6=CO_2/IS$ | Investment carbon intensity | Carbon emissions per unit of investment in fixed assets | Tons/10,000 yuan |
| $X_7=TVA/IS$ | Investment efficiency | Output value of unit investment in fixed assets | Yuan/yuan |
| $X_8=EC/TVA$ | Energy intensity | Energy consumption per unit output value | Tons of standard coal/10,000 yuan |

carbon emission reduction policies should be mainly formulated and implemented around these factors. Therefore, this paper constructs the following expressions containing relevant factors for scenario analysis:

$$Z = TVA \times \left(\frac{CO_2}{EC}\right) \times \left(\frac{EC}{TVA}\right) \tag{18}$$

If the rates of change of industry scale, energy intensity, and energy consumption carbon intensity are $\delta$, $\varepsilon$, and $\omega$, then

$$TVA_{t+1} = TVA_t(1+\delta) \tag{19}$$

$$\left(\frac{EC}{TVA}\right)_{t+1} = \left(\frac{EC}{TVA}\right)_t (1+\varepsilon) \tag{20}$$

$$\left(\frac{CO_2}{EC}\right)_{t+1} = \left(\frac{CO_2}{EC}\right)_t (1+\omega) \tag{21}$$

Therefore, the following relationship exists:

$$\begin{aligned} Z_{t+1} &= TVA_{t+1} \times \left(\frac{EC}{TVA}\right)_{t+1} \times \left(\frac{CO_2}{EC}\right)_{t+1} \\ &= TVA_t \times (1+\delta) \times \left(\frac{EC}{TVA}\right)_t \times (1+\varepsilon) \times \left(\frac{CO_2}{EC}\right)_t \times (1+\omega) \end{aligned} \tag{22}$$

The rate of change in tourism carbon emissions can be expressed as follows:

$$\mu = (1+\delta) \times (1+\varepsilon) \times (1+\omega) - 1 \tag{23}$$

To predict future trends in the evolution of tourism in carbon emissions, then put forward deserve further exploration of issues such as tourism carbon emissions. This article considers the past trends of various factors influencing the tourism industry, the potential for emission reduction, and the difficulty of implementing emission reduction policies. We set three scenarios for future development as a baseline scenario, a low-carbon scenario, and a high-carbon scenario.

(1) Baseline scenario. This scenario basically does not make adjustments to the tourism industry and is estimated in accordance with existing energy-saving potential. On the one hand, it maintains healthy economic growth, and on the other hand, it realizes a strong low-carbon travel policy. During the "Thirteenth Five-Year Plan" period, various localities continued to promote the construction of a green tourism product system. This article sets relevant parameters based on the "Thirteenth Five-Year" Tourism Development Plan and other policy documents (State Council 2016).

(2) Low-carbon scenario. This scenario emphasizes the coordinated development of the economy and environment, highlights the importance of low-carbon environmental protection, vigorously develops non-fossil energy industries, strengthens the transformation of the energy structure, promotes the industrialization of new technologies, strengthens the construction of tourism industry infrastructure, and gradually realizes smart green growth. Green tourism-related infrastructure and effective management of tourism activities are employed to reduce carbon dioxide emissions.

(3) High-carbon scenario. This scenario is set in the context of faster economic growth, greater energy intensity, and greater carbon intensity in energy consumption. No measures or energy-saving and emission reduction measures are taken to control the growth of tourism carbon emissions. In this case, the economy is an "extensive" economy that entails high energy consumption.

We make some adjustments according to Formula (18). The setting of each influencing factor is as follows:

(1) Industry scale. Collecting and sorting the annual numbers over the years considered, we find that the total output value of the tourism industry increased by 14.60% from 2015 to 2016 and the total output value of the tourism industry increased by 14.72% from 2016 to 2017. The "Thirteenth Five-Year" Tourism Development Plan is expected to have been completed in the tourism industry by 2020. The total output value is 7 trillion yuan, with an average annual growth rate of 11.18%. In addition, due to the present COVID-19 pandemic, the situation is difficult to estimate, and this study does not consider the impact of the pandemic at present. According to the "Thirteenth Five-Year" Tourism Development Plan, the benchmark case is that the annual growth rate of the total output value of the tourism industry is 11.2% from 2018 to 2020, 8.2% from 2021 to 2025, 5.3% from 2026 to 2030, and 2.6% from 2031 to 2040. The other two cases have a 1% change relative to the baseline case.

(2) Energy intensity. The energy intensity setting refers to the "Thirteenth Five-Year Plan for Energy Emission Reduction (Energy Bureau 2017)," which proposes that by 2020, the national energy consumption per 10,000 yuan of GDP will have been reduced by 15% compared with that in 2015, an average annual reduction of 2.8%. Lin and Liu (2010) predicted that my country's energy intensity will decline at an average annual rate of 3.1% from 2016 to 2020, and this result is similar to that in the tourism industry. Based on this, the benchmark scenario is that the energy intensity of the tourism industry will decrease by 2.8% annually from 2018 to 2020, by 2.4% annually from 2021 to 2025, by 2.1% annually from 2026 to 2030, and by 2.1% annually from 2031 to 2040. Energy intensity thus falls by an average of 1.9% annually. The other two cases exhibit a 0.5% difference from the baseline case.

(3) Energy consumption carbon intensity. The energy consumption carbon intensity is set according to the

"Energy Development Strategy Action Plan" (State Council 2014) and the "Energy Production and Consumption Revolution Strategy (National Development and Reform Commission and Energy Administration 2017)." In addition, Lin and Liu (2010) predicted that the average annual growth rate of China's energy consumption carbon intensity from 2016 to 2020 would be −0.6%. With the development of technology and the use of clean energy, the marginal cost of reducing energy consumption carbon intensity is increasing. The larger the value, the slower the rate of reduction in the carbon intensity index of energy consumption. The baseline scenario is that the carbon intensity of energy consumption will be reduced by 0.8 per year from 2018 to 2020, 0.6 per year from 2021 to 2025, 0.4 per year from 2026 to 2030, and 0.3 per year from 2031 to 2040. The other two scenarios have a 0.15% change relative to the baseline scenario.

### Monte Carlo simulation of CO2 emissions in the tourism industry

The scenario analysis assumes that the rate of change of each factor remains unchanged, but the actual situation is that these three variables all change dynamically. The Monte Carlo method overcomes the static limitations of scenario analysis and can dynamically predict changes in carbon dioxide emissions. The method of randomly taking values for each variable according to its own probability of occurrence and then combining these values with the random values of other variables is based on the Monte Carlo simulation method. For each stage of the tourism industry scale growth rate, energy intensity growth rate, and energy consumption carbon intensity growth rate, 5 discrete values and corresponding probabilities are set. The discrete values are based on the previous scenario analysis. The benchmark scenario value is assigned the highest probability, the other probability distributions are set symmetrically, and the probability of reaching the extreme minimum and maximum values is 5%. The probability distribution of each variable is shown in Table 3.

### Data source

The basic data used in this paper are from the *China Tourism Statistical Yearbook* and its analogues, *China Transport Yearbook*, *China Statistical Yearbook*, China Domestic Sampling Survey Data, Sampling Survey Data of Incoming Tourists, Analysis Report on Tourism Industry Development Trends and Investment Decision-making, and Annual Tourism Report from 2001 to 2018. Since the fixed asset investment in the statistical data is calculated at the current price in the current year, it is not comparable, so the data are transformed into constant prices based on the year 2000. The carbon emission factors of various modes of transportation, the proportion of tourists in passenger turnover, the carbon emission factors of each bed per night, and the carbon emission coefficients of tourism activities are derived from the existing research results both domestic and foreign.

### Indicator selection instructions

Through the GDIM decomposition method, eight representative factors are selected from the three aspects of industry scale, energy consumption scale, and investment scale to analyze the carbon emissions of the tourism industry. First, in terms of the investment scale, due to the lack of statistical research on tourism, there are still no specific investment statistics for tourism. Tourist hotels, travel agencies, and tourist attractions, as the three core sectors of tourism, are the core carriers of inbound regional tourism and the key areas of tourism investment. Among them, investment in fixed assets is the most basic, and the original value of fixed assets in the three core sectors (referring to the total amount of money spent by an enterprise on the construction, purchase, installation, reconstruction, expansion, and technical transformation of a fixed asset) is used to represent the investment scale (Zha et al. 2019). Second, in terms of the industry scale factor, the added value of tourism is the added value generated by the tourism industry and other industries of the economy in response to domestic tourism consumption. Some domestic documents, when discussing the development of tourism, equate three indicators, namely, total income from tourism, foreign exchange earned via tourism, and value added of tourism, to illustrate the remarkable achievements in tourism development. Tang et al. (2017) used total tourism revenue to represent the scale of the tourism industry. Finally, in terms of energy consumption scale factors, energy consumption in the tourism production process is also an important indicator for measuring the impact factors of tourism carbon emissions, but the *Energy Statistics Yearbook* does not provide detailed statistics on energy consumption in tourism or related service industries. This paper adopts the calculation method for energy statistics in tourism by Shi and Wu (2011).

## Results and discussion

### Decomposition results of tourism carbon emission factors

Based on the GDIM method, this paper uses R software to decompose the factors influencing China's tourism carbon emissions from 2000 to 2017 and obtain the industry scale ($X_1$), energy consumption scale ($X_3$), investment scale ($X_5$), tourism industry carbon intensity ($X_2$), energy consumption

**Table 3** The probability distribution of each variable

| Years | $X_4$ | | $X_8$ | | $X_1$ | |
|---|---|---|---|---|---|---|
| | Growth rate | Probability | Growth rate | Probability | Growth rate | Probability |
| 2018–2020 | −0.63% | 5% | −2.1% | 5% | 13% | 5% |
| | −0.65% | 20% | −2.3% | 20% | 12.2% | 25% |
| | −0.8% | 50% | −2.8% | 50% | 11.2% | 40% |
| | −0.95% | 20% | −3.3% | 20% | 10.2% | 25% |
| | −0.97% | 5% | −3.5% | 5% | 9.4% | 5% |
| 2021–2025 | −0.40% | 5% | −1.3% | 5% | 9.4% | 5% |
| | −0.45% | 20% | −1.9% | 20% | 9.2% | 25% |
| | −0.6% | 50% | −2.4% | 50% | 8.2% | 40% |
| | −0.75% | 20% | −2.9% | 20% | 7.2% | 25% |
| | −0.80% | 5% | −3.2% | 5% | 7.0% | 5% |
| 2026–2030 | −0.1% | 5% | −1.2% | 5% | 6.8% | 5% |
| | −0.25% | 20% | −1.6% | 20% | 6.3% | 25% |
| | −0.4% | 50% | −2.1% | 50% | 5.3% | 40% |
| | −0.55% | 20% | −2.6% | 20% | 4.3% | 25% |
| | −0.7% | 5% | −3.0% | 5% | 4.0% | 5% |
| 2031–2040 | −0.1% | 5% | −1.2% | 5% | 3.8% | 5% |
| | 0.15% | 20% | −1.4% | 20% | 3.6% | 25% |
| | −0.3% | 50% | −1.9% | 50% | 2.6% | 40% |
| | −0.45% | 20% | −2.4% | 20% | 1.6% | 25% |
| | −0.5% | 5% | −2.6% | 5% | 1.0% | 5% |

carbon intensity ($X_4$), investment carbon intensity ($X_6$), investment efficiency ($X_7$), and energy intensity ($X_8$). To facilitate the analysis, the research period is divided into 4 stages, 2000–2004, 2005–2009, 2010–2014, and 2015–2017, and the factor decomposition result is calculated according to the formula. The detailed classification and impact effects are shown in Table 4, and the contribution of carbon emissions is shown in Figure 1.

## Analysis of industrial factors

Figure 1 shows that the industrial scale and energy consumption scale of the tourism industry from 2000 to 2017 almost always played a role in promoting growth. Tang et al. (2017) reached a similar conclusion: the scale of the industry is the main contributor to the increase in carbon emissions from China's tourism industry. As shown in Fig. 1, the industry scale is the factor that contributes the most to the increase in carbon emissions. The effect of promoting growth first strengthened and then weakened, leading to 7.10 million tons, 12.694 million tons, 31.906 million tons, and 12.3809 million tons of carbon emissions. The reason is that with the rapid development of China's economy, the improvement of people's living standards, and the increase of leisure time, tourism has gradually become a necessity in life. On the other hand, with the continuous improvement of tourist facilities, the transportation industry has also developed rapidly. For example, the number of private cars has increased from 6,253,300 in 2000 to 225,079,900 in 2019, which has brought great convenience to people's travel. The combined effect of these two aspects has promoted the rapid increase in the added value of the tourism industry and has also brought about an increase in the tourism industry's carbon emissions At present, China's tourism industry is in a state of vigorous development, and resistance to emission reduction in the future will grow. Therefore, to account for the dual needs of economic development and carbon dioxide emission reduction, green

**Table 4** Classification of factors affecting carbon emissions of China's tourism industry from 2000 to 2017

| Category name | Factor name | Impact effect |
|---|---|---|
| Industrial factor | $X_1$ | + |
| | $X_2$ | − |
| | $X_7$ | − |
| Energy factors | $X_3$ | + |
| | $X_4$ | − |
| | $X_8$ | − |
| Investment factors | $X_5$ | ± |
| | $X_6$ | ± |

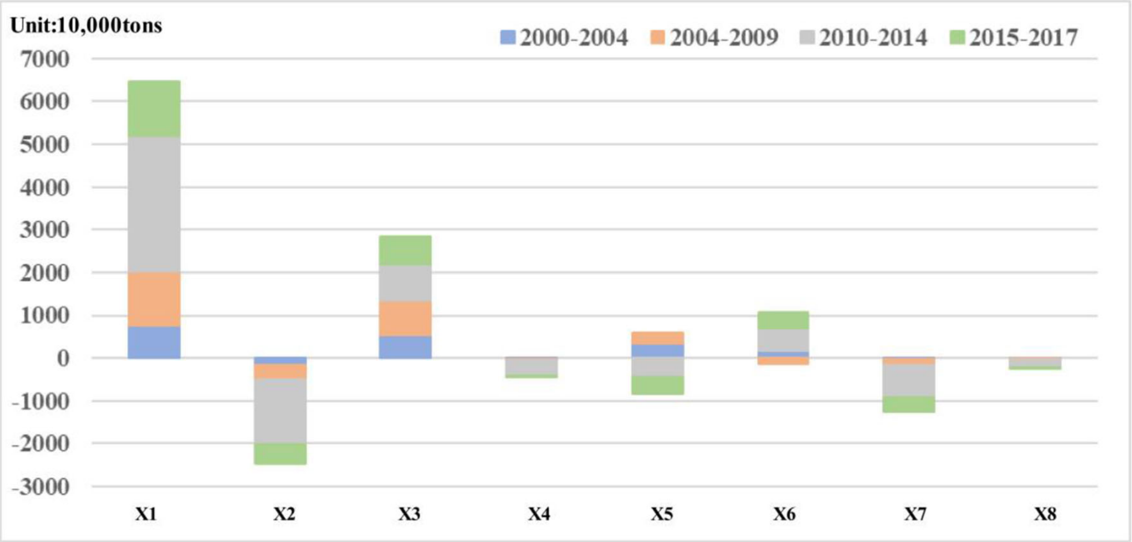


**Fig. 1** The decomposition results of the staged factors of tourism carbon emissions

tourism, technology tourism, and smart tourism should be vigorously implemented, and the tourism economy should be promoted to pursue the development track of innovation-driven and endogenous growth, which are inherent requirements for the low-carbon development of China's tourism industry.

Overall, the tourism industry carbon intensity is a key factor in reducing carbon emissions and can allow the tourism industry to begin to reduce emissions. Emissions intensity increased from 1.6564 million tons in 2000–2004 to 3.30 million tons in 2005–2009, then increased to 15.3362 million tons in 2010–2014, and finally decreased to 4.3204 million tons in 2015–2017. This shows that China's tourism industry has adjusted policies driving the development of the tourism industry in recent years, striving to achieve transformation and leapfrog development; efforts at reducing carbon emissions have been effective, and the tourism industry has been well developed. This conclusion is similar to that of Tomas Baležentis et al. (2012), who found that industrial carbon intensity is a key factor in reducing carbon emissions from rural tourism in the country. The emission-promoting effect of investment efficiency is second only to the tourism industry carbon intensity, which increased from 189,800 tons in 2000–2004 to 1,546,100 tons in 2005–2009, then increased to 7,525,600 tons in 2010–2014, and finally decreased to 3,444,900 tons in 2015–2017. This means that China has initiated effective sustainable tourism investment to reduce the negative impact of tourism on the environment and further promote the development of tourism. These investments could help the country use greener technologies, which could improve energy efficiency, increase renewable energy use, and effectively manage tourism activities.

### Analysis of energy factors

The growth-promoting effect of the energy consumption scale also showed a trend of first strengthening and then weakening. It reached its maximum value in 2010–2014, which was 8.46 million tons. The development of long-distance transportation has lengthened people's travel distances, leading to an increase in tourism energy consumption from 17,164,600 tons of standard coal in 2000 to 69,931,300 tons of standard coal in 2017. In addition, the improvement of living standards has increased people's shopping and entertainment activities during travel and tends to consume with high carbon emissions, which has led to an increase in carbon emissions from the tourism industry. Then decreased to 6.661 million tons in 2015-2017, mainly due to China's "Twelfth Five-Year Plan." The plan's outline advances the goals of controlling total energy consumption, promoting the efficient and clean conversion of energy, and deepening the reform of the energy system and mechanism. The tourism industry has also accordingly implemented controls on energy consumption intensity and total consumption.

The emissions-reducing effect of energy consumption carbon intensity was significantly enhanced from 2010 to 2014, and the reduction remained fairly similar in the other periods considered, remaining at 100,000 to 450,000 tons. This is a manifestation of the initial results of China's energy structure adjustment and optimization. Energy intensity showed a weak positive effect on carbon emissions, which changed from 71,200 tons in 2000–2004 to 169,200 tons in 2005–2009. The largest contribution was 1,871,900 tons in 2010–2014, but the value then decreased to 371,000 tons. Energy intensity reflects the overall energy efficiency of economic activities, and there is considerable room for improvement in energy efficiency in the future. Some domestic and foreign studies have also confirmed the importance of energy intensity for carbon emission reduction, such as Ma et al. (2018) and Li et al. (2019).

## Analysis of investment factors

The impact of the investment scale on carbon emissions has a dual effect. From 2000 to 2009, investment scale was positively associated with carbon emissions, and from 2010 to 2017, this association became negative. The reduction effect reached 4,474,200 tons in the intermediate time period. In the boosting effect, investment is used to expand tourist attractions and tourism services to attract more tourists. According to rebound effect theory (Berkhout et al. 2000), the energy efficiency improvement generated by technological progress will lead to additional energy use and carbon emissions. In the reduction effect, investment in green tourism-related infrastructure and effective tourism activity management can effectively reduce carbon dioxide emissions. Shao et al (2017) analyzed China's manufacturing industry and concluded that the scale of investment is the primary factor increasing carbon emissions. The reason for this difference may be that the manufacturing sector is a labor- and resource-intensive sector. Since the beginning of the twenty-first century, the rapid development of the manufacturing sector has been accompanied by an extensive development model. Productive investment includes investment in fixed assets and foreign investment, which are used to create social wealth and expand the scale of production, resulting in considerable energy consumption, pollution, and carbon dioxide emissions. The tourism industry is a medium-tech sector, and investment will lead to a decline in environmental quality and an increase in carbon dioxide emissions. It will also bring new management models and advanced technologies to curb the increase in carbon dioxide emissions by improving energy efficiency and other means. The changes in investment carbon intensity are also more complicated. Only in 2005–2009 were carbon emissions reduced by 1,341,800 tons, and the other time periods all saw increases.

Therefore, when formulating specific emission reduction policies in the future, it is necessary not only to strengthen the negative effect on carbon emissions but also to pay attention to increases in the promotion effect. To more clearly reflect the dynamic effects of various factors on the evolution of carbon emissions from 2000 to 2017, this paper sets 2000 as the base period and obtains the cumulative contribution rate of various factors to carbon emissions, as shown in the figure below.

As shown in Fig. 2, during the period 2001–2017, the industry scale was the primary factor in the increase in carbon emissions from the tourism industry. The carbon emissions increased from 1.246 million tons in 2001 to 13.08585 million tons in 2017. The average annual growth rate is 33.76%, and the contribution of industry scale to tourism carbon emissions has always been positive, with a contribution rate of 334.85% in 2017. The energy consumption scale is also an important factor that increases tourism carbon emissions. Its growth rate is relatively flat. Its average annual growth rate from 2001 to 2017 was 21.09%. By 2017, it had caused a total of 18.2606 million tons, with a contribution rate of 62.83%. The tourism industry

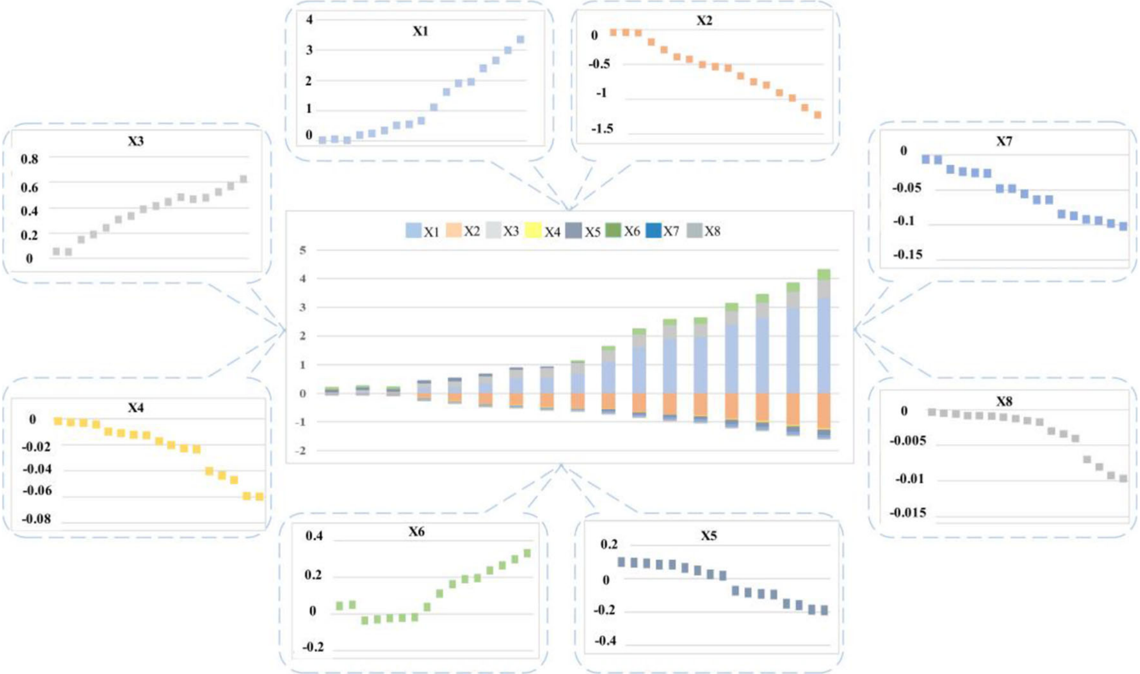


**Fig. 2** Cumulative contribution of factors influencing changes in tourism carbon emissions

carbon intensity is a key factor in promoting the reduction of carbon emissions, with an average annual growth rate of 14.36% and a contribution rate of 22.24% in 2017. The effect of the investment scale has fluctuated, the emissions-increasing effect of the investment scale increased at an average annual rate of 13.33% after 2010, and the cumulative contribution rate was 19.11% in 2017. Neither energy consumption carbon intensity nor energy intensity has a significant effect on reducing carbon emissions, and their contribution rates by 2017 were 4.64% and 0.97%, respectively. The above results show that the energy intensity and energy structure adjustments advocated by the tourism industry are far from the expected level of promoting carbon emission reduction, and there is still considerable room for improvement.

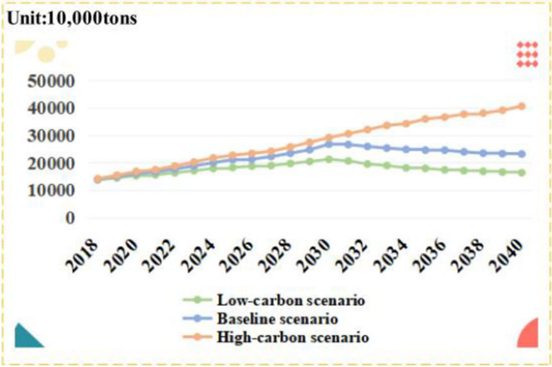
## The forecast of peak tourism carbon emissions

### Scenario analysis

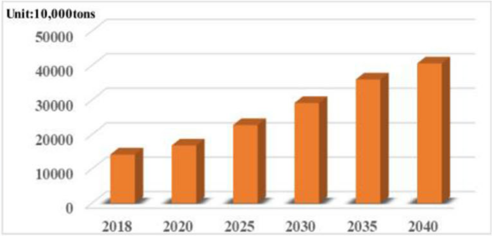
According to the three scenarios previously established, the predicted trend in China's tourism carbon emissions from 2018 to 2040 can be obtained as shown in Fig. 3.

In the baseline scenario, the peak of China's tourism carbon emissions will be in 2030, at 267,718,400 tons. The average annual growth rate of carbon dioxide emissions from China's tourism industry from 2031 to 2040 will be negative and will continue to grow from 2018 to 2030; then, the annual carbon dioxide emissions will decrease annually starting in 2031. This result shows that the government's active emission reduction measures to promote energy conservation and green development in tourism can effectively control the rapid growth of tourism carbon emissions. China's tourism industry may achieve the goal of reaching peak carbon in 2030.

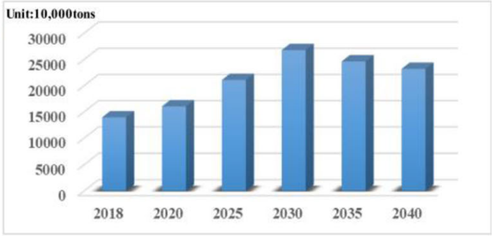
Under the low-carbon scenario, peak carbon in China's tourism industry is the same as in the baseline scenario. However, the peak is at 212.4011 million tons, which is 55.317 million fewer tons than the baseline scenario, which also shows the feasibility of the low-carbon scenario. From 2018 to 2030, the growth rate of carbon emissions in China's tourism industry will slow significantly, with an average annual growth rate of 3.6%, and the average annual rate of reduction in carbon emissions from 2031 to 2040 is 2.5%. The low-carbon scenario can promote green recycling and low-carbon development, improve energy efficiency in the tourism industry, and reduce energy consumption.



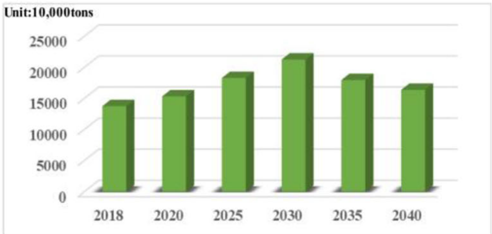
(a)China's tourism carbon emission peak forecast trend under three scenarios



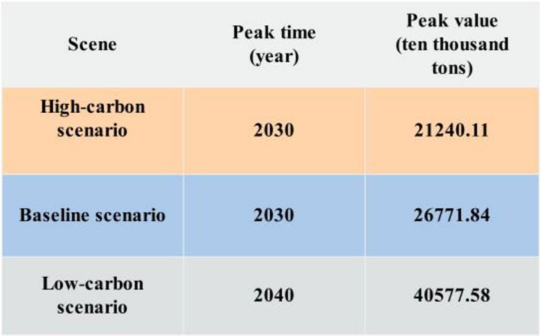
(b)China's tourism carbon emissions forecast under the high-carbon scenario



(c)China's tourism carbon emissions forecast under the baseline scenario



(d)China's tourism carbon emissions forecast under the low-carbon scenario



| Scene | Peak time (year) | Peak value (ten thousand tons) |
|---|---|---|
| High-carbon scenario | 2030 | 21240.11 |
| Baseline scenario | 2030 | 26771.84 |
| Low-carbon scenario | 2040 | 40577.58 |

(e)The specific value of China's tourism industry carbon peak

**Fig. 3** China's tourism industry's carbon emissions forecast in three scenarios from 2018 to 2040

Under the high-carbon scenario, it will be very challenging for China's tourism industry to achieve carbon emission targets. As shown in Fig. 3, as of 2040, China's tourism carbon emissions will not yet have peaked. Under the high-carbon scenario, the expected carbon emissions of the tourism industry in the future will be at least 2 to 3 times those of the present, and China will not be able to achieve the goal of reaching peak carbon emissions in 2030. This result means that if the rapid economic growth rate and greater energy carbon intensity are maintained without the implementation of emission reduction policies, the carbon emissions generated by China's tourism industry will continue to increase each year.

### Monte Carlo dynamic simulation analysis

According to the data in Table 3, Monte Carlo simulation was performed using MATLAB software, and 500,000 simulations were performed to generate random data, thereby obtaining tourism carbon emissions from 2025 to 2035, as shown in Fig. 4.

The results obtained show the highest probability of peak carbon emissions in the tourism industry in 2030. The average carbon peak occurs in 2029, and the average value of the carbon peak is 246,444,600 tons. The scenario analysis and Monte Carlo dynamic simulation analysis results show that under the conditions of medium-speed economic development and medium-speed technological progress, tourism carbon emissions will peak at essentially the same time as those of the country as a whole. In addition, the carbon intensity value of China's tourism industry in 2035 obtained by Monte Carlo simulation is very close to the national goal of achieving a 50% reduction in tourism industry carbon dioxide emissions by 2035 from 2005 levels, but the decline is not ideal. This shows that according to the current development path, energy saving, consumption reduction, and energy utilization technology, China still has work to do to meet the 2009 WTTC emission reduction target. In the future, China also needs to increase emission reduction efforts and strive to achieve the promised emission reduction targets.

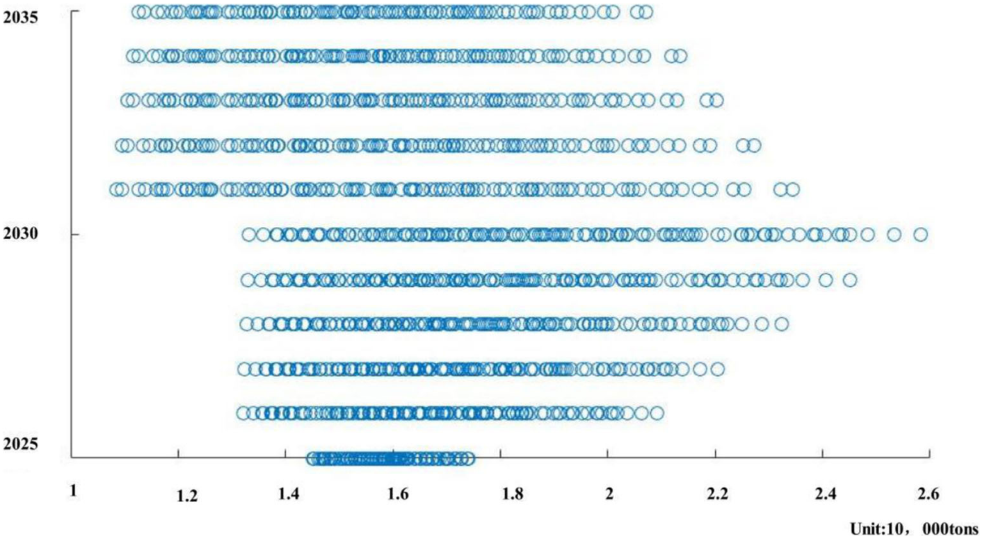
## Conclusions and policy implications

### Conclusions

This article uses a GDIM model to decompose carbon emissions factors in China's tourism sector for the period 2000–2017. On this basis, the average annual change rate of the main influencing factors is set in combination with the relevant policy objectives formulated by the government. We use scenario analysis and Monte Carlo simulation to obtain static and dynamic predictions for peak carbon emissions in China's tourism sector. The main research conclusions are as follows:

(1) From the decomposition results of the GDIM, among the various emissions-promoting effects, the emissions-promoting effect of industry scale is the strongest, followed by the energy consumption scale. The investment scale first promotes the growth of carbon emissions and then restrains it. Tourism industry carbon intensity is the primary factor in reducing tourism carbon emissions, followed by investment efficiency. However, both energy consumption carbon intensity and energy intensity have no significant effect on carbon emissions. Therefore, they have considerable potential to reduce carbon emissions in the future. The impact of investment carbon intensity on carbon emissions can both promote and inhibit carbon emissions.

**Fig. 4** Scatter plot of peak carbon in China's tourism industry under unified consideration



(2) The results of the scenario analysis for forecasting tourism carbon emissions reveal that there are obvious differences in the potential evolution of carbon emissions under different scenarios. Under the baseline and low-carbon scenarios, tourism carbon emissions will continue to grow before 2030, and the average annual growth rate of carbon emissions from 2018 to 2030 will be 0.9% ~ 3.6% and 0.6% ~ 2.0%, respectively. However, the carbon peak corresponding to the high-carbon scenario will not appear until 2040.
(3) The results of the Monte Carlo dynamic simulation analysis show that carbon use in the tourism industry will peak 2030, which is basically the same as the time as the national carbon peak. The year of peak carbon is basically the same as the results obtained in the scenario analysis, but the value corresponding to the carbon peak differs from the results obtained from the scenario analysis.

This study has measured the carbon emissions of China's tourism industry and analyzed its driving factors and carbon peaks, but there are still shortcomings: Due to the difficulty of variable measurement, only the three key areas of tourism activities, tourism accommodation, and tourism transportation are estimated, and the carbon emissions of other tourism-related sectors are not estimated, so there is a deviation from the actual value to some extent. We will make efforts in the future to improve the accuracy of the measurement and provide a more scientific decision-making basis for the sustainable development of the tourism industry. In addition, future research expansion should mainly focus on the following: Are there differences in the influencing factors and carbon peak time in the provincial tourism industry? What impact do they have on the carbon emission intensity of domestic tourism and inbound tourism? Will they have a spillover effect on the carbon emissions of tourism in neighboring provinces and cities through the spatial transmission mechanism? These issues need to be further studied.

## Policy implications

To achieve the emission reduction target of China's tourism industry and further implement the green and low-carbon development strategy, the following suggestions are proposed based on the research conclusions of this article:

(1) Industry scale has a significant positive effect on the changes in China's tourism carbon emissions, which shows that the rapid development of the tourism economy will inevitably bring about a rapid increase in carbon emissions. Only by changing tourism development and gradually decoupling economic growth from carbon emissions in the tourism sector can the sustainable development of tourism be realized. In terms of transportation, the use of energy-saving and new energy vehicles should be advocated outside the scenic area to reduce carbon emissions from aviation and automobiles. In the scenic area, transportation methods such as walking and sharing bicycles are encouraged to replace motor vehicles. In terms of accommodation and catering, choose green and pollution-free food catering, avoid using plastic tableware, and choose low-carbon and environmentally friendly hotels. In terms of entertainment and shopping, tourists should be guided to participate in low-carbon and environmentally friendly amusement projects and buy green and low-carbon tourist souvenirs. During holidays, it is not only necessary to reasonably control the number of tourists, but also to tap the low-carbon potential of rural tourism and leisure tourism resources and apply low-carbon environmental protection technology to the construction of scenic spots. Use the low-carbon concept to create a green and pollution-free tourism model and low-carbon tourism products, and build a low-carbon tourism product system. Relevant departments should limit the number of businesses in the scenic area and the types of products they sell, so as to reduce the high-carbon consumption of tourists.
(2) The scale effect of investment has a weak impact on the changes in carbon emissions in the Chinese tourism industry. It basically had a positive effect before 2010, which is far from China's goal of promoting energy conservation and emission reduction. However, since 2010, the scale of investment has shown a negative effect that has been increasing each year. This shows that China's investment in resource conservation, recycling, and efficient utilization has achieved certain results since 2010, but the impact is still relatively weak. On the one hand, the government should strengthen the macro-control of fixed asset investment, improve the structure of fixed asset investment, and reduce the proportion of investment in high-energy-consumption and high-pollution industries. On the other hand, investment is mostly used in green tourism-related infrastructure and effective management of tourism activities to encourage and support the development of green industries to improve the overall efficiency of green investment in the tourism industry, for example, formulating low-carbon tourism incentives and punishment policies. In terms of incentives, companies that vigorously promote low-carbon tourism awareness, adopt low-carbon technologies, and use new energy can be encouraged through preferential taxation, financial subsidies, and lower loan rates to promote the development of low-carbon tourism. For tourism companies that do not adopt low-carbon development methods, relevant fees can be levied to prompt them to change their development models. For example, in the process of developing scenic spots, companies that cause

certain pollution to the environment due to some unreasonable behaviors, especially those behaviors that exceed carbon emissions, should be severely punished.

(3) The research results of this paper show that the development of a high-carbon model entails a considerable risk of emission increase. In the future, we need to fully innovate low-carbon and energy-saving technologies. In the future, it is necessary to fully innovate low-carbon energy-saving technologies, practice low-carbon environmental protection development concepts, increase low-carbon tourism promotion efforts, and strengthen low-carbon tourism talent training strategies. The carbon emissions of tourism transportation accounted for 78.85% of the total carbon emissions of the tourism industry. In response to this phenomenon, the energy utilization efficiency of oil products can be improved, and the proportion of natural gas, electric energy, and methanol used in automobile energy can be increased. From the perspective of tourism production, scenic spots need to build low-carbon tourism projects; advocate the use of new energy sources such as wind, water, solar, and combustible ice; and extensively use energy-saving and emission-reduction technologies. The government and relevant departments must strengthen publicity in a targeted manner, such as using television, radio, WeChat, Weibo, news client, and other informatization methods to vigorously promote the importance and positive impact of low-carbon tourism. At the same time, a “National Low-Carbon Tourism Promotion Day” can be established to carry out a variety of public education and publicity activities. Implement the strategy of “strengthening tourism by talents and rejuvenating tourism through science and education,” and train management personnel, professional technical personnel, tour guides, and other personnel in the tourism industry from time to time. Particular attention is paid to raising awareness of low-carbon environmental protection and innovation capabilities of low-carbon technologies.

**Availability of data and materials** The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Author contribution** All authors contributed to the study conception and design. Conceptualization: Xiaojun Ma. Formal analysis: Jian Luo. Writing—original draft: Miaomiao Han and Jian Luo. Writing—review and editing: Yanqi Song. Supervision: Xiaojun Ma. Software: Ruimin Chen. Investigation: Xueying Sun.

**Funding** This work was supported by the National Social Science Fund of China (grant numbers 19ZDA120).

## Declarations

**Ethics approval and consent to participate** Not applicable.

**Consent for publication** Not applicable.

**Competing interests** The authors declare no competing interests.

## References

Baležentis T, Kriščiukaitienė I, Baležentis A, Garland R (2012) Rural tourism development in Lithuania (2003–2010) — a quantitative analysis. Tour Manag Perspect 2-3:1–6. https://doi.org/10.1016/j.tmp.2012.01.001

Bargaoui SA, Liouane N, Nouri FZ (2014) Environmental impact determinants: an empirical analysis based on the STIRPAT model. Procedia Soc Behav Sci 109:449–458. https://doi.org/10.1016/j.sbspro.2013.12.489

Becken S, Hay EJ (2007) Tourism and climate change: risks and opportunities. https://xueshu.baidu.com/usercenter/paper/show?paperid=5812efa0e487da0dc9f54939e9b37697&site=xueshu_se. Accessed 12 Aug 2019

Beckena S, Simmonsb DG, Framptonc C (2003) Energy use associated with different travel choices. Tour Manag 24(3):267–277. https://doi.org/10.1016/S0261-5177(02)00066-3

Berkhout P, Muskens JC, Velthuijsen JW (2000) Defining the rebound effect. Energy Policy 28(6/7):425–432. https://doi.org/10.1016/S0301-4215(00)00022-7

Du Q, Shao L, Zhou J et al (2019) Dynamics and scenarios of carbon emissions in China’s construction industry. Sustain Cities Soc 48. https://doi.org/10.1016/j.scs.2019.101556

Energy Bureau (2017) Energy Emission Reduction “13th Five-Year Plan”. http://www.gov.cn/zhengce/content/2017-01/05/content_5156789.htm. Accessed 20 June 2018

Fang K, Tang YQ, Zhang QF, Song J, Wen Q, Sun H, Ji C, Xu A (2019) Will china peak its energy-related carbon emissions by 2030? Lessons from 30 Chinese provinces. Appl Energy 255:113852. https://doi.org/10.1016/j.apenergy.2019.113852

Goessling S, Peeters P, Ceron JP et al (2005) The eco-efficiency of tourism. Ecol Econ 54(4):417–434. https://doi.org/10.1016/j.ecolecon.2004.10.006

Gossling S (2000) Sustainable tourism development in developing countries: some aspects of energy use. J Sustain Tour 8(5):410–425. https://doi.org/10.1080/09669580008667376

Gu BH, Tan XC, Zeng Y, Mu Z (2015) Co2 emission reduction potential in china's electricity sector: scenario analysis based on LMDI decomposition. Energy Procedia 75:2436–2447. https://doi.org/10.1016/j.egypro.2015.07.210

Guo MY, Meng J (2019) Exploring the driving factors of carbon dioxide emission from transport sector in Beijing-Tianjin-Hebei region. J Clean Prod 226(20):692–705. https://doi.org/10.1016/j.jclepro.2019.04.095

Guo J, Zhang YJ, Zhang KB (2018) The key sectors for energy conservation and carbon emissions reduction in China: evidence from the input-output method. J Clean Prod 179(1):180–190. https://doi.org/10.1016/j.jclepro.2018.01.080

Hanandeh AE (2013) Quantifying the carbon footprint of religious tourism: the case of Hajj. J Clean Prod 52(1):53–60. https://doi.org/10.1016/j.jclepro.2013.03.009

Jin Y, Alexander O, Yan JY et al (2014) A hybrid life-cycle assessment of co2 emissions of a pv water pumping system in China - ScienceDirect. Energy Procedia 61:2871–2875. https://doi.org/10.1016/j.egypro.2014.12.326

Koak E, Ulucak R, Ulucak ZE (2020) The impact of tourism developments on co2 emissions: an advanced panel data estimation. Tour Manag Perspect 33:100611. https://doi.org/10.1016/j.tmp.2019.100611

Kuo N, Lin C, Chen P et al (2012) An inventory of the energy use and carbon dioxide emissions from island tourism based on a life cycle assessment approach. Environ Prog Sustain Energy 31:459–465. https://doi.org/10.1002/ep.10585

Len CJ, Arana JE, Alemn AH (2014) CO2 emissions and tourism in developed and less developed countries. Appl Econ Lett 21:1169–1173. https://doi.org/10.1080/13504851.2014.916376

Li B, Han SW, Wang Y, Wang Y, Li J, Wang Y (2019) Feasibility assessment of the carbon emissions peak in China's construction industry: factor decomposition and peak forecast. Sci Total Environ 706(1):135716.1–135716.13. https://doi.org/10.1016/j.scitotenv.2019.135716

Lin BQ, Liu XY (2010) Carbon emissions in China's urbanization stage: influencing factors and emission reduction strategies. Econ Res 45(08):66–78

Liu DN, Xiao BW (2018) Can China achieve its carbon emission peaking? A scenario analysis based on STIRPAT and system dynamics model. Ecol Indic 93(OCT.):647–657. https://doi.org/10.1016/j.ecolind.2018.05.049

Liu LC, Fan Y, Wu G, Wei YM (2007) Using LMDI method to analyze the change of Chinas industrial co2 emissions from final fuel use: an empirical analysis. Energy Policy 35:5892–5900. https://doi.org/10.1016/j.enpol.2007.07.010

Liu J, Feng TT, Yang X (2011) The energy requirements and carbon dioxide emissions of tourism industry of western China: a case of Chengdu city. Renew Sust Energ Rev 15(6):2887–2894. https://doi.org/10.1016/j.rser.2011.02.029

Ma XJ, Wang CX, Dong BY, Gu G, Chen R, Li Y, Zou H, Zhang W, Li Q (2018) Carbon emissions from energy consumption in china: its measurement and driving factors. Sci Total Environ 648:1411–1420. https://doi.org/10.1016/j.scitotenv.2018.08.183

Moran M, Gonzalez P (2007) A combined input-output and sensitivity analysis approach to analyse sector linkages and co2 emissions. Energy Econ 29(3):578–597. https://doi.org/10.1016/j.eneco.2006.02.004

Munday M, Turner K, Jones C (2013) Accounting for the carbon associated with regional tourism consumption. Tour Manag 36(3):35–44. https://doi.org/10.1016/j.tourman.2012.11.005

National Development and Reform Commission and Energy Administration (2017) Energy production and consumption revolution strategy. https://news.bjx.com.cn/html/20170425/822221. Accessed 15 Oct 2017

Perch-Nielsen S, Sesartic A, Stucki M (2010) The greenhouse gas intensity of the tourism sector: the case of Switzerland. Environ Sci Pol 13(2):131–140. https://doi.org/10.1016/j.envsci.2009.12.002

Quan CG, Cheng XJ, Yu SS, Ye X (2020) Analysis on the influencing factors of carbon emission in China's logistics industry based on LMDI method - ScienceDirect. Sci Total Environ 734:138473. https://doi.org/10.1016/j.scitotenv.2020.138473

Quick JC (2014) Carbon dioxide emission tallies for 210 U.S. coal-fired power plants: a comparison of two accounting methods. J Air Waste Manage Assoc 64(11):73–79. https://doi.org/10.1080/10962247.2013.833146

Robaina-Alves M, Moutinho V, Costa R (2016) Change in energy-related co2 (carbon dioxide) emissions in Portuguese tourism: a decomposition analysis from 2000 to 2008. J Clean Prod 111(JAN.16PT.B):520–528. https://doi.org/10.1016/j.jclepro.2015.03.023

Scott D, Amelung B, Becken S et al (2007) Climate change and tourism: responding to global challenges. Clim ChangeTourism Respond Global Challenges *12*(4):168–181. https://doi.org/10.1177/10634266040120030401

Shan W, Jin XB, Yang XH, Gu Z, Han B, Li H, Zhou Y (2020) A framework for assessing carbon effect of land consolidation with life cycle assessment: a case study in China. J Environ Manag 266:110557. https://doi.org/10.1016/j.jenvman.2020.110557

Shao S, Liu JH, Geng Y, Miao Z, Yang Y (2016) Uncovering driving factors of carbon emissions from China's mining sector. Appl Energy 166(mar.15):220–238

Shao S, Zhang X, Zhao XR (2017) The empirical decomposition and peak path of China's manufacturing carbon emissions—decomposition and dynamic scenario analysis of generalized Di index. China's Indu Econ 000(003):44–63 http://d.wanfangdata.com.cn/periodical/ChlQZXJpb2RpY2FsQ0hJTmV3UzIwMjEwMzAyEg96Z2d5amoyMDE3MDMwMDMaCHhxeGlzZXJr

Shi PH, Wu P (2011) Preliminary estimation of energy consumption and CO_2 emissions in China's tourism industry. Acta Geograph Sin 66(02):235–243 http://d.wanfangdata.com.cn/periodical/ChlQZXJpb2RpY2FsQ0hJTmV3UzIwMjEwMzAyEg1kbHhiMjAxMTAyMDA5Gghnam5kdmtnZA%3D%3D

Shuai CY, Shen LY, Jiao LD, Wu Y, Tan Y (2017) Identifying key impact factors on carbon emission: evidences from panel and time-series data of 125 countries from 1990 to 2011. Appl Energy 187:310–325. https://doi.org/10.1016/j.apenergy.2016.11.029

State Council (2014) The General Office of the State Council issued the "Energy Development Strategic Action Plan (2014-2020)". http://www.gov.cn/zhengce/content/2014-11/19/content_9222.htm. Accessed 25 June 2016

State Council (2016) "Thirteenth Five-Year" Tourism Development Plan. http://travel.people.com.cn/n1/2016/1226/c41570-28977992.html. Accessed 18 Sept 2016

Sun Y-Y (2016) Decomposition of tourism greenhouse gas emissions: revealing the dynamics between tourism economic growth, technological efficiency, and carbon emissions. Tour Manag 55(Aug.):326–336. https://doi.org/10.1016/j.tourman.2016.02.014

Surugiu C, Surugiu MR, Breda Z, Dinca AI (2012) An input-output approach of co2 emissions in tourism sector in post-communist Romania. Proc Econ Finance 3(Complete):987–992. https://doi.org/10.1016/S2212-5671(12)00262-6

Tang CC, Zhong LS, Ng P (2017) Factors that influence the tourism industry's carbon emissions: a tourism area life cycle model perspective. Energy Policy 109:704–718. https://doi.org/10.1016/j.enpol.2017.07.050

Tao Y, Li F, Wen ZG et al (2019) A hybrid scenario analysis for the selection of future greenhouse gas emissions reduction technologies in China's oil and gas industry. J Clean Prod 223:14–24. https://doi.org/10.1016/j.jclepro.2019.03.144

Vaninsky A (2014) Factorial decomposition of co2 emissions: a generalized Divisia index approach. Energy Econ 45(sep.):389–400. https://doi.org/10.1016/j.eneco.2014.07.008

Wei YX, Sun GN, Ma LJ et al (2012) Preliminary estimation of China's tourism transportation carbon emissions and regional differences. J Shaanxi Normal Univ (Natural Science Edition) 40(02):76–84. https://doi.org/10.3969/j.issn.1672-4291.2012.02.017

Xu GY, Schwarz P, Yang HL (2019) Determining China's co2 emissions peak with a dynamic nonlinear artificial neural network approach and scenario analysis. Energy Policy 128(MAY):752–762. https://doi.org/10.1016/j.enpol.2019.01.058

Yan QY, Wang YX, Baležentisc T et al (2019) Analysis of China's regional thermal electricity generation and co2 emissions: decomposition based on the generalized Divisia index - ScienceDirect. Sci Total Environ 682:737–755. https://doi.org/10.1016/j.scitotenv.2019.05.143

Yu T, Cox A, Chatziantoniou I (2021) Environmental degradation, economic growth and tourism development in Chinese regions. Environ Sci Pollut Res 28(3):33781–33793. https://doi.org/10.1007/s11356-021-12567-9

Yue T, Long R, Hong C et al (2013) The optimal co2 emissions reduction path in Jiangsu province: an expanded IPAT approach. Appl Energy 112(4):1510–1517. https://doi.org/10.1016/j.apenergy.2013.02.046

Zaman K, Shahbaz M, Loganathan N, Raza SA (2016) Tourism development, energy consumption and environmental Kuznets curve:

trivariate analysis in the panel of developed and developing countries. Tour Manag 54(Jun.):275–283. https://doi.org/10.1016/j.tourman.2015.12.001

Zha JP, He LM, Liu Y, Shao Y (2019) Evaluation on development efficiency of low-carbon tourism economy: a case study of Hubei province, China. Socio Econ Plan Sci 66(JUN.):47–57. https://doi.org/10.1016/j.seps.2018.07.003

Zhang X, Geng Y, Shao S, Dong H, Wu R, Yao T, Song J (2020) How to achieve China's co2 emission reduction targets by provincial efforts? – an analysis based on generalized Divisia index and dynamic scenario simulation. Renew Sust Energ Rev 127:109892. https://doi.org/10.1016/j.rser.2020.109892

Zhao GM, Liu CJ (2020) Carbon emission intensity embodied in trade and its driving factors from the perspective of global value chain. Environ Sci Pollut Res 27(2):1–14. https://doi.org/10.1007/s11356-020-09130-3

Zhou S, Wang Y, Yuan ZY, Ou X (2018) Peak energy consumption and CO2 emissions in China's industrial sector. Energy Strategy Rev 20: 113–123. https://doi.org/10.1016/j.esr.2018.02.001

Zhu L, He LC, Shang PP, Zhang Y, Ma X (2018) Influencing factors and scenario forecasts of carbon emissions of the Chinese power industry: based on a generalized Divisia index model and Monte Carlo simulation. Energies 11(9):2398.https://doi.org/10.3390/en11092398