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Scenario-based planning for a dynamic tourism system with carbon footprint analysis: A case study of Xingwen Global Geopark, China

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ABSTRACT

Since the concept of low-carbon has been incorporated in all aspects, low-carbon tourism, as one of the vital branches of low-carbon economy, has grasped much attention from researchers. Under the current trends, the actual emissions of greenhouse gas will be doubled the planned target in the future, which are obviously overlooked by the tourism industry. In terms of carbon footprint measurement, this paper proposes a multi-dimensional model with four low-carbon sub-systems including economy, environment, control and management and selects Xingwen Global Geopark as the sample in the scenario-based planning. Inspired by the idea of responsible tourism, this paper applies dynamic model in measuring carbon footprint, so as to provide future policy implications for geoparks. Through the scenario-based prediction of carbon footprint in Xingwen Global Geopark, we found it has experienced a constant promotion in low-carbon development with increasing carbon footprint but decreasing carbon intensity; the booming of tourists may bring worsen carbon footprint, slow-paced increase of tourists but poorer low-carbonization will possibly result in high carbon intensity; the current path is not the best and not conducive for middle and later period before 2030; the results of scenario analysis indicate that the win-win development can only be achieved through the low-carbon construction of scenic spots.

1. Introduction

On the commitment of 195 countries, the Paris Climate Agreement aims at significantly reducing greenhouse gas emissions to prevent severe climate changes. The tourism industry is aimed to reducing greenhouse gas emissions (target reduction of 70% by 2050). However, on the basis of current trends, greenhouse gas emissions in the same period will be twice the planned target in the future (Gössling and Scott, 2018). Greenhouse gas reduction requires the joint efforts of all countries, especially in the tourism industry, to balance the greenhouse gas emissions and economic growth (Paramati et al., 2017), so as to achieve sustainable tourism development.

Low-carbon tourism is inevitable in terms of sustainable tourism development. The level of low-carbon tourism can be measured by carbon emissions in various links (Xiao, 2015; He et al., 2017; Lenzen et al., 2018). Carbon footprint measurement is becoming an important tool for greenhouse gas management (Pandey et al., 2011). This measurement is based on a bottom-up analysis of terminal user behaviors and energy use, and a top-down analysis using environmental accounting and the Tourism Satellite Account (Smith, 1994; Becken and Patterson, 2006; Sun, 2014). Carbon footprint measurement mainly includes the input–output analysis (IOA) and the life cycle assessment (LCA) model. As a top-down analysis method, IOA is mostly applied to measure carbon footprint at the macro level and to reflect the initial, intermediate, and total inputs and the intermediate production of each department (Zhang et al., 2018), especially at national and provincial levels (Lundie et al., 2007; Cansino and Roman, 2016).

Comparatively, LCA is a bottom-up process-based approach that considers greenhouse gas emissions from “cradle” to “grave”, such as raw material extraction, production and processing, storage and transportation, use, and waste disposal (Schmidt, 2009). From the material extraction and manufacturing, transportation,

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construction, and operation phases of building materials to calculate the carbon footprint (Nadoushani and Akbarnezhad, 2015). The carbon footprint produced by solid waste, including collection, transportation, and treatment processes, and indirect carbon footprint is related to grid power supply and fuel production and distribution (Pérez et al., 2018; Wang et al., 2019). As for the tourism industry, tourist-related travel activities, i.e. food and accommodation traveling, shopping, and extra entertainment, are applied in the tourism life cycle for carbon footprint measurement (Kuo et al., 2012; Zhang et al., 2015; Rico et al., 2019). Actually, through the carbon footprint measurement, tourism activity which produces the highest carbon footprint will be identified. Besides, future scenarios are helpful for the destinations to develop strategic plans, set practical goals, and conduct actions for minimizing greenhouse gas emissions (Whittlesea and Owen, 2012). In addition, the carbon intensity measured by carbon footprint and economic benefits can reflect the balance between low-carbon tourism and economic tourism and is measured in company with carbon footprint, so as to provide objective research results.

In the dynamic study of tourism carbon footprint and carbon intensity, the system dynamics model can be applied in scenic systems. In recent years, combined with the system dynamics model, scenario planning in tourism management has attracted extensive academic attention (Carboni et al., 2018; Pizzitutti et al., 2017; Thanh and Carl, 2018). Although forecasting models, such as the time series model (Baggio and Sainaghi, 2016) and the neural network model (Silva et al., 2018), are accurate and widely applied, and they are extremely dependent on historical data, resulting in poor performance when data or conditions are limited (Thanh and Carl, 2018). Considering this imperfection, scenario planning is an alternative, which can help organizations prepare for possible events and increase system flexibility and innovativeness properly (Hiltunen, 2009). For example, different policymaking on future carbon tax could result in different tourism-related carbon emissions and economic welfare (Zhang and Zhang, 2018). Besides, the tourism manager's decisions have impacts on the low-carbon tourism system's performance (Zhang and Zhang, 2019).

As time goes by, responsible tourism has been redefined as integrated sustainability, which emphasizes the relationship among economic, environmental, and social responsibility (Goodwin, 2016), and also provides a new perspective for future study of low-carbon tourism. In Goodwin's opinions, attentions from public environmental responsibility should be paid to resource consumption, as well as the "green agenda" and other issues, e.g. noise, light, and solid-liquid waste pollution. Responsible tourism practitioners also concern about issues related to balancing economic benefits, managing the tourism destinations and addressing the protection of local areas. Besides, behavioral responsibilities have been emphasized in responsible tourism, such as those in economic, social, cultural, and environmental contexts. Especially, ethical behavior in environmental protection is a key component of responsible tourism (Gong et al., 2019). Since complex scenarios, e.g. responsible tourism, and interactive relationships among multiple elements in a system cannot be effectively represented by simply fitting the data, the system dynamics model is used in complex scenario planning, which dynamically reflects the micro-macro granularities, multiple time spans, multiple internal elements, total carbon footprint of scenic change process, and the variations in the system settings.

As a reflection of low-carbon development in scenic spots, low-carbon tourism systems have been extensively studied. Xu et al. (2011) explored the low-carbon tourism in Leshan city, China, based on the macro perspective of supply (tourist reception facilities) and demand (the number of tourists), and the energy subsystem was integrated into the supply and demand system, however ignoring the micro perspective such as tourists' activities. Luo et al., (2014) constructed a low-carbon tourism system that includes five economic and environmental subsystems from a scenic perspective and studied the decarbonated development of tourist attractions, however lacking incorporate analysis of carbon footprint and scenario planning. The studies of He et al. (2017) and Zhang and Zhang (2019) both simulated the low-carbon ecotourism in an urban context. The former focused more on traditional environmental elements, such as solid waste, waste water, and ecology (water supplies and green areas), while the latter established a low-carbon tourism system which not only includes environmental and economic elements, but also incorporates carbon emissions. However, the latter research also ignored some details, including carbon emissions from tourist activities and tourism destination management. Generally speaking, the previous studies rarely considered the tourist activities and scenic spot management, and the micro perspective including the carbon footprint of each key element in the system research was absent.

In this study, a carbon footprint measurement model is constructed and dynamic carbon footprint is calculated based on the established low-carbon tourism system, so as to modify the existing static measurements of carbon footprint. Responsible tourism is incorporated in the system dynamics model, followed by the scenario planning analysis to explore the scenic spot, low-carbon tourism development plan, vertical and horizontal comparison of its system, disclosure of carbon emissions and the environmental dimension, such as carbon footprint and carbon intensity. In the empirical study, Xingwen Global Geopark is selected as the object. Low-carbon control and construction are promoted by presenting low-carbon development, thereby forming certain policy recommendations to provide reference for other geoparks worldwide or similar types of low-carbon development research.

2. Proposing dynamic systems

2.1. System description

The United Nations Commission on Sustainable Development (UNCSD) proposed a driving—state—response (DSR) analysis framework. This framework has been cited in low-carbon tourism systems, in terms of high output, low pollution, and environmental friendliness. With the internal driving force and appeal of the development model, the current state of the resource environment and emission reduction technology of scenic spots is comprehensively measured to create a low-carbon development policy (Li and Yin, 2012). The system dynamics model can reflect the causal relationship and dynamic changes among various elements in a complex and dynamic low-carbon tourism system and provide a scientific practice for operational guidance of low-carbon tourism systems (Xiao, 2015). At the same time, these feedback loops have various factors that affect the current situation in a planned scenario for the future. In different stages, continuous feedbacks based on the future planning of scenic spot systems are necessary, in support of future development. To figure out this complex relationship, we choose the DPSIRM framework which discerns the causal relationships between elements, improves definitional clarity of elements and specially proposes the policy implications (Zhang et al., 2016). Therefore, DSR model applied in tourism has been developed into the DPSIRM framework in this study (Fig. 1), so as to solve the problems possibly occur in a detailed analysis.

The DPSIRM model is used to construct a low-carbon tourism system. The description of model is shown in Table 1.

The DPSIRM model of low-carbon tourism in scenic spots can reflect the driver, pressure, state, response and management of the system. However, further studies are needed to specify the inner

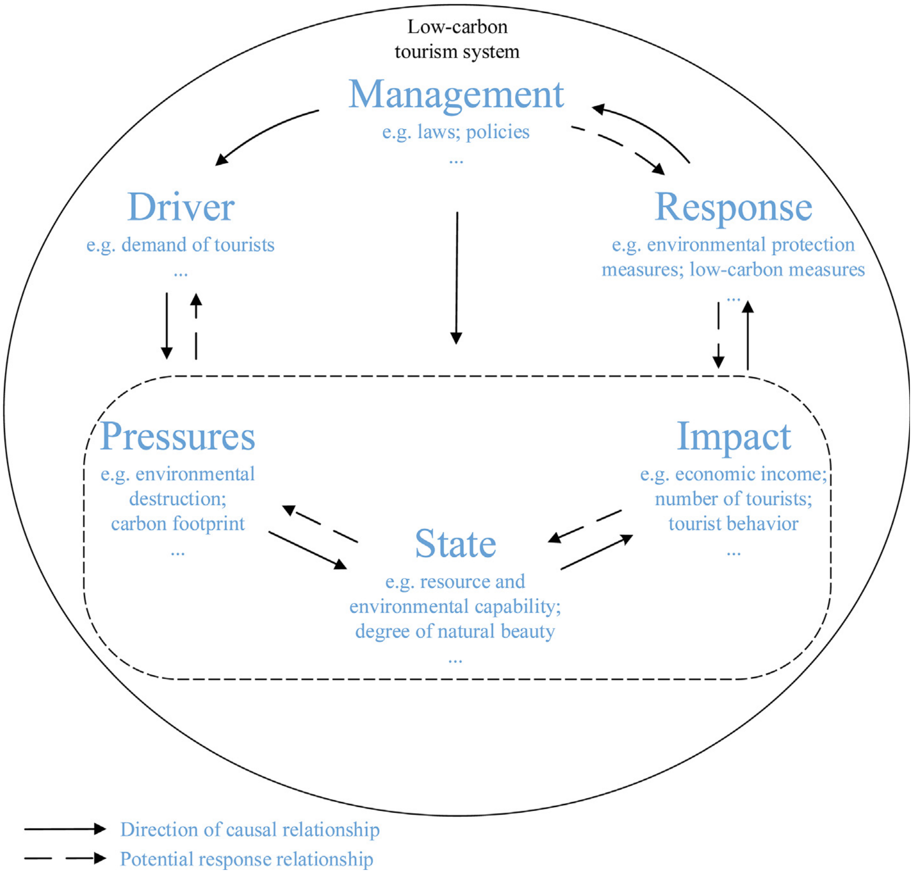

Fig. 1. DPSIRM model framework.

Table 1
Description of model.

Item	Description	Role presentation and internal relationship
D(Driving)	The tourists' demands, such as catering, shopping and tourism entertainment, will promote the development of tourism.	It will bring benefits and pressures to scenic spots simultaneously.
P(Pressure)	Environmental problems and tourism management problems, carbon footprint generated by tourists' demand, etc. can possibly cause exert pressure on scenic spots.	It will transform into a certain equilibrium state, e.g. "S", an existing state caused by pressure in scenic spots.
S(State)	Environmental carrying capacity, tourism resource capacity, the degree of natural beauty, etc. can reflect the state of scenic spots.	Tourism income, number of tourists, and environmental performance of scenic spots will be affected by "S". If new policies are developed, the existing state will be transformed into a new development state accordingly.
I(Impact)	"I" stands for the effects of "S" on economic income, resource and environmental performance, etc.	In order to alleviate the influence of "S", a series of measures will be taken by the scenic spots.
R(Response)	"R" is dynamic cater to the scenic spots' "impact", which contains diversified measures or scenario planning.	If the measures are suitable confront of the negative problems or scenic spots' "impact", the measures will be policies or laws after consideration and optimization.
M(Management)	Laws or policies related to the management and operation of scenic spots can be carried out.	Appropriate laws or policies will bring benefits to the scenic spots, e.g. constraining the potential threats, enlarging the beneficial sectors, etc.

connections of the internal system mechanism. In the macro respective, Luo et al. (2014) explored a low-carbon system which contains five subsystems, i.e. economic operation subsystem, social development subsystem, environmental representation subsystem, decarbonated control subsystem and constructive guarantee subsystem. In the micro respective, the system is based on the connotation of low-carbon tourism system, that is, from three aspects of resource development and utilization of scenic spots, low-carbon tourism activity, and low-carbon consciousness and awareness (Shi, 2014). For example, the configuration and experience of tourism toilets have effects on tourist satisfaction (Sun et al., 2016). It has been found that influencing factors of tourist satisfaction include transportation, service, and environment, through questionnaire survey (Liu et al., 2018). In addition, other factors, such as the planning of scenic spot goods and order of scenic spots that is influenced by tourist route designing, have effects on tourist satisfaction and thereby affecting the tourists' experience. During the journey, increasing tourists and corresponding consumption, and the scenic spot operations can produce carbon footprint, which could affect the economic and environmental performance of scenic spots. Meanwhile, influencing factors on which responsible tourism emphasizes include behavioral responsibility, resource limitation, environmental protection, and social responsibility, in promoting the sustainable tourism development (Goodwin, 2016) and reducing the production of carbon footprint. As shown in Fig. 2, the constructed low-carbon tourism system of scenic spots can be divided into four low-carbon subsystems, namely, low-carbon economy (LC-E^1), low-carbon environment (LC-E^2), low-carbon control (LC-C), and low-carbon management (LC-M).

Since tourism economy is the core business of scenic spots, LC-E^1 reflects the tourism economic development which consists of the number of tourists, tourism income, and tourism investment. The level of tourist consumption and number of tourists are the main factors that determine tourism revenue. Great number of tourists and high per capita tourism consumption results in high tourism revenue accordingly, which will contribute to more investment in tourism. Besides, the development trend of LC-E^1 is determined by the other three subsystems, i.e. LC-E^2, LC-C, and LC-M, which can influence the scenic attraction. Similarly, the growth of tourists has an impact on the three other subsystems and can produce additional carbon footprint and tourism revenue comparatively, leading to increasing carbon intensity eventually.

LC-E^2 consists of variables related to green coverage, solid waste, and waste water, indicating the environmental performance of the scenic spot. Generally, environmental protection investment of scenic spots and increasing eco-environmental awareness of tourists can reduce solid waste and waste water discharged in scenic spots, thereby reducing overall carbon footprint. Reasonable route planning and increase in eco-environmental awareness of tourists can also devote to the environmental performance of scenic spots. As reflected in the system, the pollution index reflects the negative environmental performance of scenic spots and can be analyzed through solid waste and waste water produced in tourists' activities. Similarly, natural beauty-loss index reflects the conflicts between human activities and natural beauty, and contains variables related to new buildings construction. In terms of carbon footprint, the green coverage will benefit the carbon sink, which means that vegetation destruction will result in the decrease of carbon sink. Besides, the solid waste and waste water can also produce carbon footprint.

LC-C primarily consists of tourists' activities, including catering, shopping and tourism entertainment, reflecting the need for green catering, low-carbon tourism commodity diversity, ecological toilet and environmental-friendly vehicle transportation configuration respectively. In term of the tourists' needs, it's preferred in LC-C to fully reduce the tourism consumption, enhance resource recyclability, and improve the tourists' experience. Reflected in this system, the transport, ecological toilet, green catering index, etc. will influence the comfort index, and buildings' construction will affect the natural beauty-loss index. Similarly, carbon footprint of LC-C is determined by the type of consumed energy, tourist-related consumption, commodity raw materials, the construction materials, etc.

Reflected in LC-M, service quality index and low-carbon management awareness can have an impact on the management of scenic spots, e.g. service quality index which reflects the quality of service in scenic spots, which is closely associated with tourists' satisfaction; low-carbon management awareness represents managers' low-carbon awareness and the staff's low-carbon service awareness, which can exert impacts on institutional improvement and tourists' environmental consciousness. At the same time, increasing awareness of LC-M can reduce the carbon emissions of scenic spots effectively, i.e. carbon footprints related to catering and shopping. As reflected in system, the service quality index will affect the comfort index; low-carbon management awareness will influence the carbon footprint of the low-carbon system.

2.2. Model variables

Table 2 shows the main variables applied in the low-carbon tourism system, including stock variables and auxiliary variables. Stock variables, e.g. the number of tourists, can be influenced by other auxiliary variables. Meanwhile, carbon footprint is associated with the number of tourists, as well as the related tourism revenue

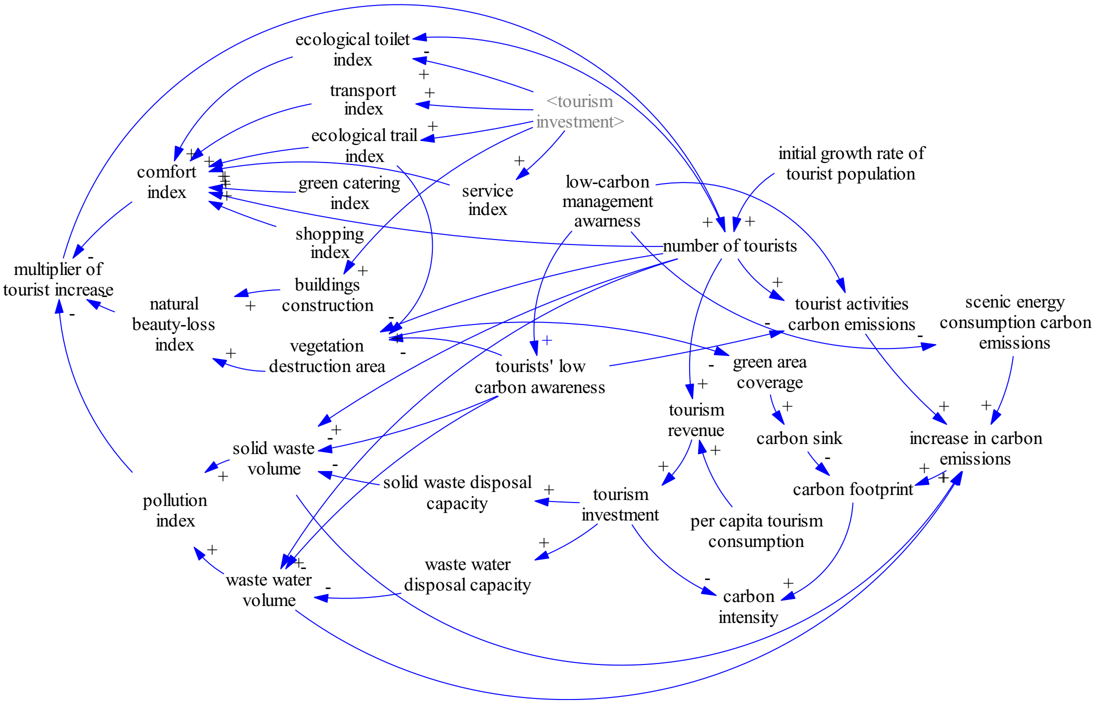

Fig. 2. Low-carbon tourism system for scenic spots.

Table 2
Variables in low-carbon tourism system.

Notation	Variable	Unit
NT	Number of tourists	10^4 persons
TR	Tourism revenue	10^4 yuan
K	The carrying capacity of scenic spots	10^4 persons
C_p	Per capita tourism consumption	yuan
t	Unit of time	year
n_1	Number of service personnel	A
n_2	Number of sightseeing vehicles	A
n_3	Number of ecological toilets	A
n_4	Ecological trails	A
r_1	Service staffing configuration	–
r_2	Vehicle configuration	–
r_3	Ecological toilet configuration	–
r_4	Ecological trail configuration	–
r_5	Shopping diversity	–
r_6	Solid waste treatment ratio	–
r_7	Waste water treatment ratio	–
d_1	Service staff with low-carbon service level	–
d_2	Vehicle with low-carbon level	–
d_3	Ecological toilet level	–
d_4	Ecological trails with low-carbon level	–
d_5	Shopping with low-carbon level	–
V_d	Vegetation damage area	m^2
P_s	Price of low-carbon substitute product	yuan
A_m	Low-carbon awareness of management	–
R_2	Consumption ratio of energy consumption of sightseeing vehicles	–
R_5	Selling ratio of high-carbon emission commodity growth	–
EI	Environmental protection investment	10^4 yuan
SW_p	Amount of solid waste generated by tourists	10^4 kg
SW_t	Amount of solid waste handled	10^4 kg
WW_p	Amount of waste water generated by tourists	10^4 kg
WW_t	Amount of treated waste water	10^4 kg
CF	Carbon footprint	10^4 kg
CI	Carbon intensity	kg/10^4 yuan

Note: the “-” represents “no dimension” among the units.

and other auxiliary variables.

2.3. Mathematical formulation

This section presents the selected formulations related to critical model assumptions, including the number of tourists, tourism revenue, carbon footprint, and carbon intensity. Carbon footprint of each key element can be assessed through the formulas shown as follows. Other equations with their initial values are presented in Appendix A (Table A). Relevant influencing factors or multipliers of the model, which are constructed and associated with the system thinking theory (Mai and Smith, 2015; Thanh and Carl, 2018), are presented in Appendix B (Figs. B1-B3) and tourism destination life cycle (BUTLER, 1980).

The equation for the number of tourists is specified as follows:

$$NT(t_i) = NT(t_{i-1})\cdot dNT(t_i)/dt + NT(t_{i-1})$$

$$= NT(t_0)\int_{t_0}^{t_i}(1 + dNT(t_i)/dt) \tag{1}$$

Where *NT* represents the number of tourists; t_i, t_{i-1}, and t_0 represent year *i*, year $i-1$, and the initial year, respectively; and *dNT*/ *dt* is the increasing rate of *NT* and is under the influence of *Multiplier*, as shown in Equation (2).

$$dNT(t_i)/dt = Multiplier(t_i)\cdot dNT(t_{i-1})/dt$$

$$= \prod_{1}^{i} Multiplier(i)\cdot dNT(t_0)/dt \tag{2}$$

Where *Multiplier* represents the factor that influences the growth rate of tourists, and is determined by the natural beauty-loss index, comfort index, and pollution index, which are from the other subsystems, i.e. LC-C, LC-M, and LC-E.

Using Equations (1) and (2), *NT* can be evaluated as follows:

$$NT(t_i) = NT(t_0)\int_{t_0}^{t_i}\left(1 + \prod_{1}^{i} Multiplier(i)\cdot dNT(t_0)/dt\right) \tag{3}$$

According the tourism destination cycle model, the current growth of tourists is affected by the current number of tourists, thus we applied the model proposed by (Zhang and Zhang, 2017).

$$dNT(t_i)\,/\,dt = r\cdot N\cdot(1 - NT(t_i)\,/\,K) \tag{4}$$

Where *K* represents the carrying capacity of scenic spots, *r* represents the growth of tourists.

Tourism revenue can be calculated as follows:

$$TR = NT\cdot C_p \tag{5}$$

Where *TR* represents the tourism income, and C_p represents the variation in per capita tourism consumption as time changes.

Carbon intensity can be expressed as

$$CI = CF/TR \tag{6}$$

Where CI denotes carbon intensity, CF represents carbon footprint, and TR is tourism income.

Tourists' economic activity can generate a considerable amount of human solid wastes. In developing countries, it's estimated that each visitor produces roughly 0.3–1.44 kg of solid waste per day during the journey (Troschinetz and Mihelcic, 2009). In 2012, Hall and Page mentioned that per tourist can produce up to 16.5 kg of solid wastes per week at a certain destination (Hall and Page, 2012). Therefore, the following equation is proposed:

$$SW_p = RANDOMUNIFOM(\min, \max, a) \tag{7}$$

In Equation (7), solid waste represents an average distribution of solid waste generated by each visitor per day from minimum to maximum, and a is an initial seed.

Low-carbon tourism incorporates the carbon footprint measurement model based on life cycle theory. In this study, the origins of carbon footprint are shown as follows: a) carbon footprint of tourists in scenic spots, such as dining, traveling, shopping, and other entertainment (Whittlesea and Owen, 2012). According to previous studies, carbon footprint produced by local residents are outside scenic spots and are thus excluded in this study; and b) carbon footprint produced by the scenic spots in the low-carbon tourism services, including ecological toilets, ecological trails, building materials, solid waste treatment, etc.

(1) Carbon footprint in tourism catering

As for a complete life cycle, carbon footprints related to food mainly include those produced in cultivation, transportation, storing, manufacture process, retail and cooking (Xu et al., 2018). If carbon footprint produced by food is mainly derived from local food, the energy consumption of food transportation process can be negligible (Zhen, 2013). And in the present study, we referred to (Zhang et al., 2015) and chose the intensity of food-related energy in calculation, as shown in Equation (8).

$$C_{food} = NT \cdot D \cdot \sum_{i=1}^{m} P_i \cdot ED_i \cdot \mu \tag{8}$$

Where NT is the number of tourists; D is the average traveling days of tourists; P_i is per tourist consumption of food i per day; ED_i is energy intensity of food i; μ is the carbon emission conversion factor.

(2) Carbon footprint in tourism sightseeing

Carbon footprint is mainly generated by the consumed energy in sightseeing, i.e. by vehicles, including those run by fuel and electricity. The calculation formula of tourism tour carbon footprint is as follows:

$$C_{sightseeing} = \sum_{j=1}^{n} L_j \cdot \beta_j \tag{9}$$

Where $C_{sightseeing}$ is the tour carbon footprint, L_j is energy j consumption in energy. β_j is the carbon emission coefficient of energy j.

(3) Carbon footprint in tourism shopping

Carbon footprint in shopping mainly refers to the energy consumption during the production of tourism products. The calculation formula of tourism shopping carbon footprint is

$$C_{shopping} = \sum_{i=1}^{m} \sum_{j=1}^{n} G_i \cdot H_j \cdot \beta_j \tag{10}$$

Where $C_{shopping}$ represents the carbon footprint of tourism shopping, G_i is the consumption of tourism commodity i, H_j is energy j consumption in the production of tourism commodity i per kilogram (Zhen, 2013).

(4) Carbon sink capacity reduced by the destruction of vegetation

Excessive tourists' activities can bring damage to vegetation in scenic spots or inhibit the development space for vegetation, thus reducing the carbon sink capacity of scenic spots. Formula for related carbon sink capacity is shown as follows:

$$NPP_{destroy} = \sum_{j=1}^{n} \frac{A_j^2 \cdot \alpha_j}{A} \tag{11}$$

Where $NPP_{destroy}$ is the total carbon sink capacity of the vegetation damaged by tourists; j is the land use type; α_j is the carbon emission coefficient of land j (Wang et al., 2016); A_j is the area of land j, and A is the total area of the scenic spot.

(5) Carbon footprint of ecological toilets

Existing research rarely focuses on the ecological carbon footprint of ecological toilets. Relevant national standard documents of China proposed measures taken in low-carbon management, e.g. reducing carbon emissions from the aspects of building materials, energy and water saving, and management low-carbonization awareness, etc. In the present study, the carbon footprint of ecological toilets is related to the energy and water saving of ecological toilets, i.e. the carbon footprint consumption of electric energy and sanitation sewage treatment. The carbon footprint from electric energy consumption is shown in Equation (12), whereas the carbon footprint of sanitation sewage treatment is shown in Equation (13).

$$C_e = Q \cdot \beta \tag{12}$$

Where C_e is carbon footprint of electricity in ecological toilets, Q represents electrical energy consumption, and β is the carbon emission coefficient corresponding to electrical energy.

$$C_s = NT \cdot D \cdot T_s \cdot \sum_{j=1}^{n} E_j \cdot \beta_j \tag{13}$$

Where C_s is the carbon footprint of the sanitary wastewater; T_s is the daily sanitary wastewater produced by tourists; E_j represents energy j consumption of sanitary wastewater treatment, including the electrical, diesel, chemical, material energy consumption and energy utilized from biogas (Singh et al., 2016).

$$C_{eco-toilet} = C_e + C_s\ . \tag{14}$$

Where $C_{eco-toilet}$ is the carbon footprint produced by ecological toilets.

(6) Carbon footprint of ecological trails

Carbon footprint of ecological trails construction is based on the calculation of building materials, the formula is shown as follows:

$$C_{eco-trail} = C_m + C_t + C_o \tag{15}$$

Where $C_{eco-trail}$ is the carbon footprint of the unit material, which includes the carbon emissions of the production of raw materials (C_m), transportation (C_t), and energy consumed in operation (C_o) (Chen, 2015).

(7) Carbon footprint of solid waste

The carbon footprint of tourism solid waste is divided into two parts, namely, the amount of CH_4 released from solid waste landfill and that of carbon emissions from solid waste treatment (Zhen, 2013). The calculation of former is based on IPCC (2014), shown as follows:

$$C_{CH_4} = s{\cdot}\eta{\cdot}DOC{\cdot}\omega{\cdot}(16/12) \times 0.5 \times (1/1000) \tag{16}$$

Where C_{CH_4} is the methane emission from landfills, produced from per kilogram of tourism waste; s is the amount of tourism waste in the landfill site in units of kg; η denotes tourism landfill rate (mass fraction) in percentage, the value of which can refer to the urban landfill rate; DOC is the amount of degradable organic carbon in the solid waste, and ω represents the decomposition rate of degradable organic carbon, the value is 77% referring to IPCC. The formula for calculating the carbon emissions of solid waste treatment energy consumption is

$$C_{co_2} = s{\cdot}\eta{\cdot}\sum_{j=1}^{n} E_j{\cdot}\beta_j \tag{17}$$

Where E_j is energy j consumption of solid waste treatment per kilogram.

The carbon footprint of tourism solid waste is calculated as follows:

$$C_{solidwaste} = C_{co_2} + C_{CH_4}{\cdot}GWP_{CH_4} \tag{18}$$

Where GWP_{CH_4} is the global warming energy of CH_4 relative to CO_2.

3. Low-carbon tourism experiments

3.1. Study area and data sources

3.1.1. Study area

Xingwen Global Geopark (105°0′E to 105°09′E, 28°08′N to 28°20′N), a world geopark and a national scenic spot, is located in Xingwen County, Yibin City, Sichuan Province. The geopark is located in the southern margin of the Sichuan Basin and is connected to the Sichuan-Yunnan Mountains, 429–1795 m above sea level. Xingwen Global Geopark combines the world's "three-musts" karst in one: surface stone forest landscape, underground cave, and world-class funnel. The famous landscapes in the park include Tianquan Cave, Shilin Xianzi, Big Funnel, Husband and Fever, Deaf Hanging, and Tianshi Cave. At present, Xingwen Global Geopark is constructed following the existing "5A" tourist scenic spot evaluation standards, with a 4A level and possible upgrades. The upgrade to 5A-level scenic spot needs to consider environmental protection and low-carbon construction. Low-carbon construction is the future trend and promotes the concentrated performance of responsible tourism. Therefore, through the construction of low-carbon tourism system in scenic spots, the changes in carbon footprint are analyzed. In this context, scenario planning presents extremely important guidance for low-carbon development planning and research of Xingwen Global Geopark.

3.1.2. Data sources

The statistical data used in this study is mainly collected from the China Statistical Yearbook, Yibin City Statistical Yearbook, Xingwen County Tourism Development Overall Plan (2015–2030), Xingwen County Tourism Economic Data (2010–2017), National Rectification and Promotion Plan for Establishing a 5A Tourist Attraction in Xingwen Scenic Spot, as well as interview records and research reports on tourism department data and tourist attractions. The carbon emission factors for different energy sources are referred to IPCC. Different levels of ecological toilets have different water consumption requirements. 1A–3A are subject to water consumption of Grade 1, Grade 2 and Grade 3 as specified in the documents of GB[1] 25502–2010, GB 28379–2012, and GB 25501–2010 in China. In addition, field research in the scenic spot provides the main food types, main types of shopping specialties, main types and quantities of generated solid waste, energy consumption in infrastructure. Some carbon emission coefficients are referred to existing studies, e.g. the footprint generated by different food types quotes from (Zhang et al., 2015), carbon footprint generated by different shopping products from (Williams et al., 2006; Fusi et al., 2014), carbon footprint generated by solid waste landfill from (Pérez et al., 2018).

3.2. Simulation model of Xingwen Global Geopark

Simulink can be applied to linear or nonlinear, continuous or discrete, or a mix of the systems and it's widely used in dynamical prediction of systems. Given the complexity of the simulation model and the analysis in Matlab 2017b, four subsystems are initially constructed, namely, LC-E^1, LC-E^2, LC-C, and LC-M. These subsystems are then reconstructed into a whole system, as shown in Fig. 3.

The mathematical models used in this simulation are simultaneous equations. The main modules include In, Out, Product, Integrator, Gain, Math function, and Scope. All parameters are inputted in the working space, which is simultaneously activated

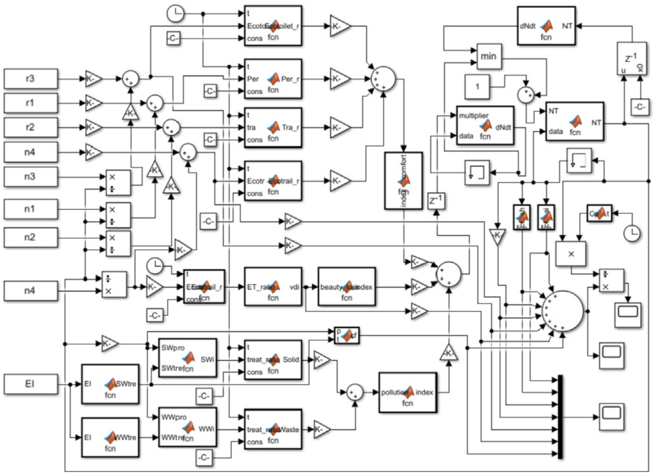

Fig. 3. Simulation of low-carbon tourism in Xingwen Global Geopark.

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[1] The abbreviation of "GB" refers to the compulsory standards that the manufacturing products should meet in China, including products related to public health, property, national safety, etc.

and used when operating the simulation model.

3.3. Model testing and validation

The test of the system dynamics model usually includes structural inspection and behavioral outcome testing. The former discriminates whether the simulation model is a description of the actual system, whereas the latter verifies whether the test model can produce acceptable output behavior results (Barlas, 1989).

Structural inspection is reflected in the analysis of causality diagram that each subsystem and index are reasonably fitted to the main characteristics of the actual system. Meanwhile, feedback loops and limit condition tests are necessary in checking whether all feedback loops in the system causality diagram produce the expected behavioral results. For example, positive feedback increases the corresponding indicators over time, whereas negative feedback is reversely reducing (Thanh and Carl, 2018).

In terms of behavioral outcome testing, this study uses the discrepancy coefficient, which is an assessment of the summarized difference between the simulation results and the known historical data. Range of the value is $[0,1]$, where 0 implies that the prediction result is perfect without any error, and 1 indicates the worst results. A discrepancy coefficient value between 0.4 and 0.7 denotes a good to general condition (Barlas, 1989). The calculation formula is shown in Equation (19).

$$U = \frac{\sqrt{\sum (S_i - \overline{S} - A_i + \overline{A})^2}}{\sqrt{\sum (A_i - \overline{A})^2} + \sqrt{\sum (S_i - \overline{S})^2}} \tag{19}$$

Where U is the discrepancy coefficient; S_i is the simulated value of i; A_i is the actual value of i; $\overline{S}$ is the mean value of the simulated value; $\overline{A}$ is the mean value of the actual value.

In terms of structural inspection, the model is based on the analysis of the actual system structure and internal elements, consisting integrated multiple domains. Viewed from the model, the structure reasonably reflects the main characteristics of the actual system. For Xingwen Global Geopark, the influence of positive and negative feedbacks on the index are reasonable through the feedback loop test. In addition, the model parameters have a clear definition and practical significance, derived from the statistics of several departments and field research institutes. Therefore, the model structure is consistent with the actual system.

As for the behavioral test, the low-carbon tourism system of Xingwen Global Geopark is simulated based on existing data from 2010 to 2017, and the results are analyzed later. Critical factors in the system, e.g. number of tourists, tourism revenue, carbon footprint, and carbon intensity, are selected. As shown in Figs. 4–7, the discrepancy coefficient of the behavioral results is 0.10, 0.12, 0.06, and 0.43, respectively. The results indicate that the model is well fitted and the simulation model is effective.

Extreme condition test results are shown in Fig. 8, the pattern of modelled behavior changed within a certain range, with tourists, tourism revenue, carbon footprint at the same time, when the development of scenic spots reach the limit state, that is the parameter is set to the limit value, the Xingwen Global Geopark maximum carrying capacity is 4.2 million.

3.4. Policy design and evaluation

The tourism development evaluated using the simulation model is summarized in Table 3. Scenario 1 represents the scenic spot follows a similar to linear development mode, e.g. considering the historical conditions and the most of data follows a liner trend after 2017 year. Scenario 2 selects the average of historical configuration state and assumes that the scenic spot will keep on the original development mode, it can represent the current development state of the scenic spot. Scenario 3, Scenario 4, Scenario 5 represents the low-carbon oriented scenario, economic oriented scenario, low-carbon and economic oriented scenario respectively. Under the low-carbon oriented scenario, the system focuses on the low-carbon construction of scenic spots, thus, the parameters that are conducive to the low-carbon tourism are appropriately upgraded and some parameters focusing solely on the economic benefits will be reduced. Under the economic oriented scenario, the parameters that are conducive to the economic growth of scenic spots are appropriately upgraded while weakening the low-carbon construction parameters. Low-carbon and economic oriented scenario aims at promoting the economic growth and low-carbon construction simultaneously. The scheme for setting the parameter values is shown in Table 3.

The variations of carbon footprint produced by various sources in Scenario 2, are provided in Fig. 9. As shown in Fig. 9, the carbon footprints of food, shopping, and solid waste treatment are relatively larger than the others, followed by those generated from sightseeing vehicles. Among the parameters, food produces the largest carbon footprint. In-depth analysis reveals several high-carbon foods in the catering consumption. At the same time, the measurement of food carbon footprint is based on the number of tourists. When green catering is fully promoted and the sense of tourists' responsibility is raised, the carbon footprint produced by tourists will decline and stay in stability. Carbon footprint produced by solid waste is the second largest. The main reason is that the scenic spot and the waste sorting treatment is not holistic, which ignores the preprocessing of wastes, instead, sends them directly to the refuse landfill. Meanwhile, the methane recovery of refuse landfill is lacked, thus leading to high carbon footprint of waste treatment. In terms of shopping, the food specialties in the scenic spot are mostly equipped with high carbon footprint, including meat products, i.e. silky chicken and duck plates. Inversely, low-carbon handicrafts, e.g. bamboo carvings and embroidery, can produce relatively less carbon footprint. However, in the current proportion of consumption, high-carbon footprint goods are the main choices of tourists. Thus, the reduced prices of those substitutes, i.e. low-carbon handicrafts, can bring significant benefits to the improvement of tourists' low-carbon consciousness, as well as the low-carbon construction of scenic spots. Fig. 9 shows that the carbon sink capacity of the vegetation area damaged by tourists is extremely small compared with the carbon footprint generated from other elements. Carbon footprint generated by ecological trails construction is greater than that of the damaged vegetation area capacity; Since the carbon footprint generated by ecological trails construction is one-off, whereas the carbon sink capacity of the damaged vegetation is continuous. Therefore, the threats of damaged vegetation area capacity are greater. From the future perspective, the scenic spot should focus on vegetation protection and select low-carbon materials for construction.

As shown in Fig. 10(a)–(c), if the scenic spot follows a similar to linear development mode, as designed in Scenario 1, the conditions will be the worst. Scenario 1 is equipped with least tourists and highest carbon intensity compared with the others, which is the most disliked development mode, indicating that the history-based linear development mode cannot meet the basic demand. In Scenario 2, the number of tourists will reach to 1.57 million persons, which is basically conformed to the *Xingwen county tourism development overall planning 2015–2030*. Even though the main ambition of scenic spots is economy-oriented with increasing carbon footprint but decreasing carbon intensity, this scenario is not the best for that it has neglected the positive effects of low-carbon

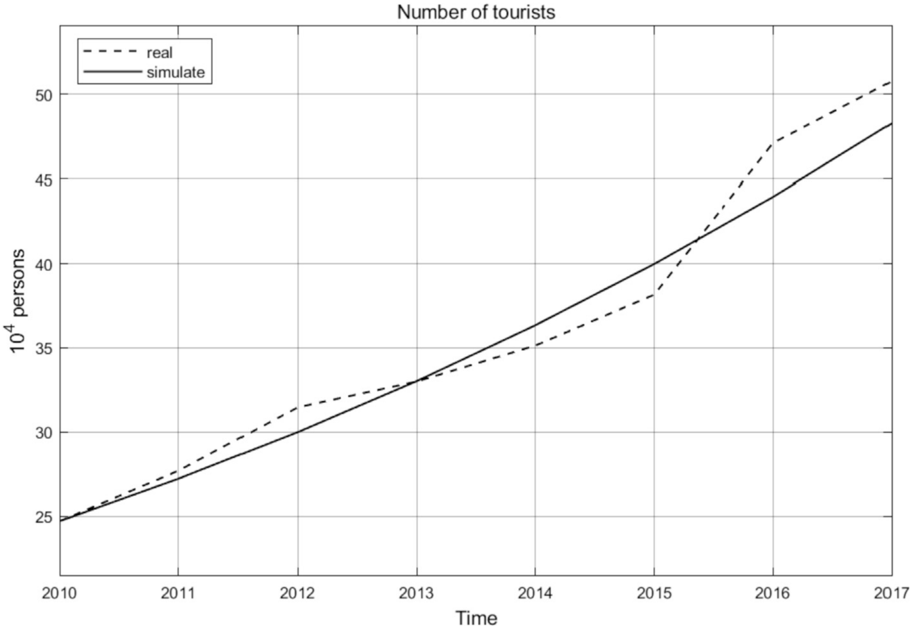


Fig. 4. Comparison in the number of tourists.

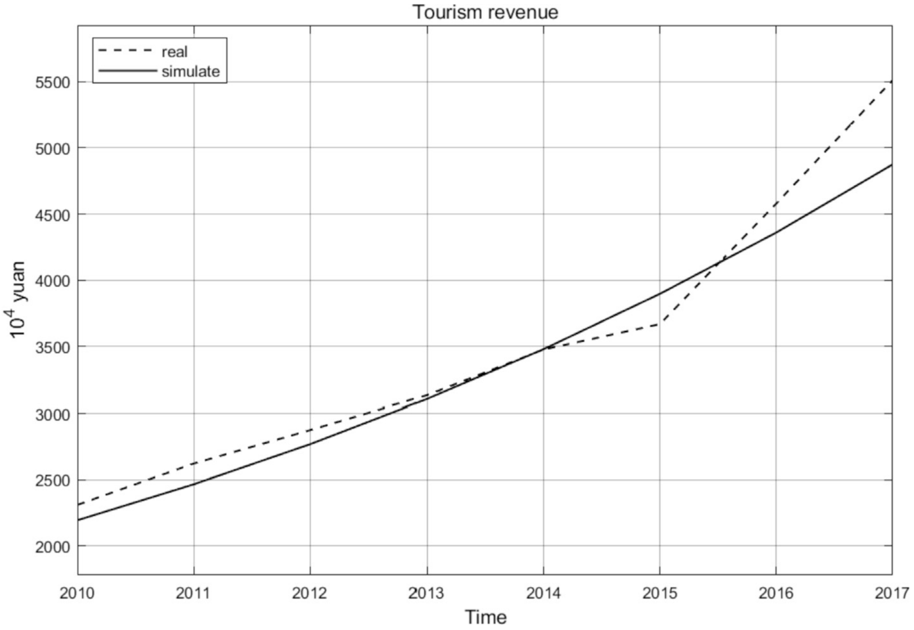


Fig. 5. Comparison in the tourism revenue.

construction. Considering the implementation of low-carbon policies, construction of low-carbon infrastructures, i.e. ecological toilets, ecological sightseeing vehicles, etc., the win-win game can be reached in the improvement of tourists' experience and reducing the carbon emissions, which is emphasized in Scenario 3. Since the construction of low-carbon tourism can benefit the attraction of scenic spots, Scenario 3 is scheduled to be neck to neck with Scenario 2 in economic performance, i.e. number of tourists, with much lower carbon footprint and intensity. However, it has hindered the normal operations of the scenic spot and has attracted relatively less tourists than Scenario 4 and Scenario 5. As for Scenario 4, which is the most common misconception of managers, economic benefits are greatly emphasized and reflected in the exploitation of land, high configuration rate of tourism-related infrastructures and recruitment of service staffs, and results in damages to the environment and carbon emissions. Obviously, Scenario 4 has the highest carbon footprint and intensity, in comparison with the others. In order to find a balance between economic and environmental benefits, Scenario 5 is adjusted via the comparison of Scenario 3 and Scenario 4, subjectively. As a reference of purely economic or environmental scheme, Scenario 5 performs better in overall improvement of the number of tourists, carbon footprint and carbon intensity, indicating a need for the scenic spot to transfer economic oriented scenario to low-carbon and economic oriented scenario, e.g. low-carbon construction. For Xingwen Global Geopark, it's time to move the emphasis on

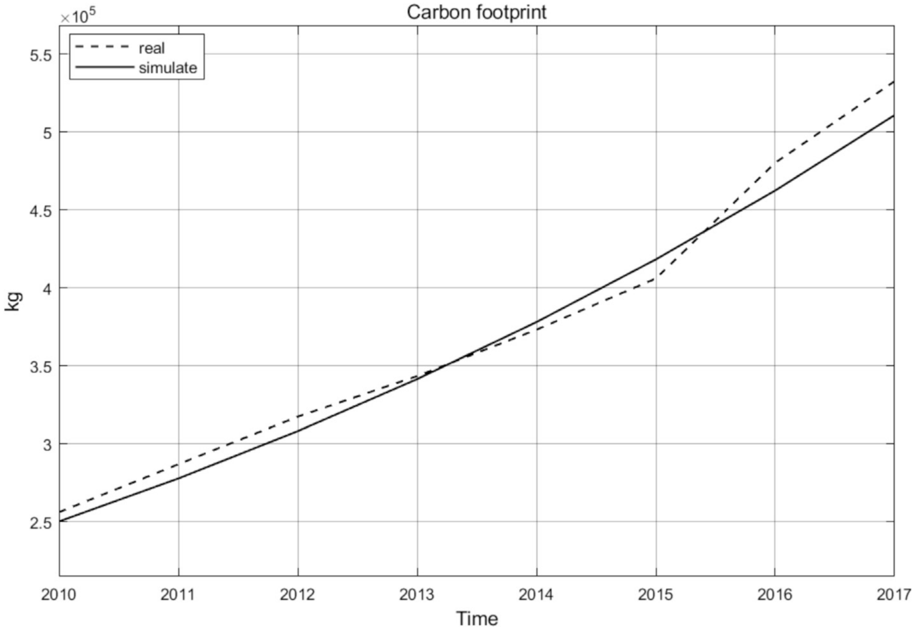


Fig. 6. Comparison in the carbon footprint.

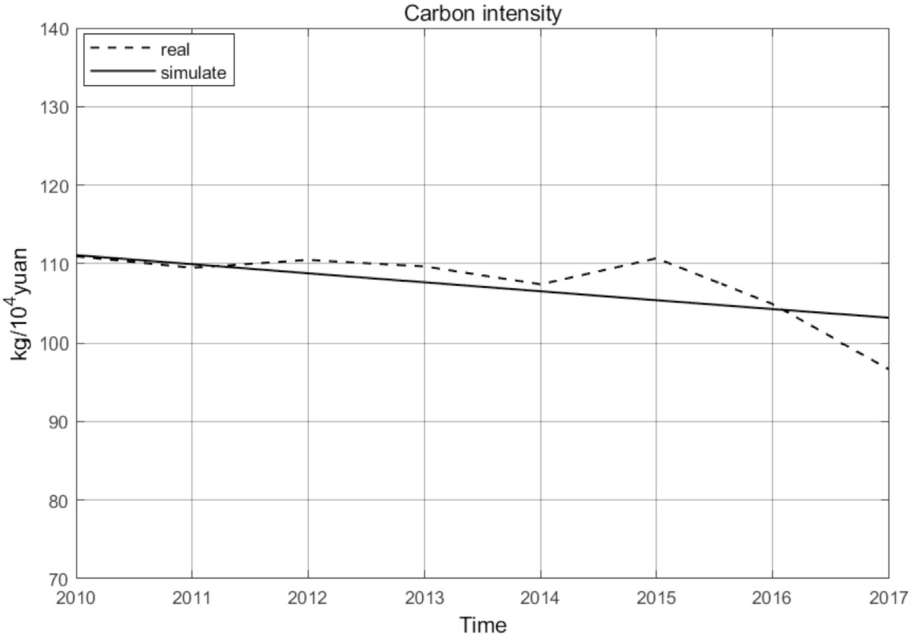


Fig. 7. Comparison in the carbon intensity.

economic growth to low-carbon construction, for future benefits.

Fig. 11 represents the development of various key elements in different scenarios, including the carbon footprints of: (a) food; (b) sightseeing; (c) shopping; (d) ecological trail; (e) ecological toilet; (f) $NPP_{destroy}$; and (g) solid waste.

In Fig. 11(a), it's shown that the carbon footprint produced from food can be reduced greatly via the lowered price of low-carbon commodities and raised low-carbon consciousness of tourists, considering the carbon footprint produced in the production and transportation of food as well. As shown in Fig. 11(b), the carbon footprint produced in sightseeing stays the lowest in Scenario 3, followed by Scenario 5, indicating a need for green energy in consumed fuel. Besides, as the configuration rate of sightseeing vehicles decreases, more tourists will choose to walk, reducing the carbon footprint produced by non-green energy. In Fig. 11(c), commodities with high carbon footprint are reduced via the lowered price of low-carbon commodities and raised low-carbon consciousness of tourists, and the development trend is similar to food. In Fig. 11(d), the construction of eco-trails is emphasized on the leverage of low-carbon materials and less exploitation of the land, which is proved to be environmental-benefited from the performance of low-carbon oriented scenario. Fig. 11(e) shows that the carbon footprint of ecological toilet is tourist-oriented, which means that under the same scale of tourists, higher standard eco-

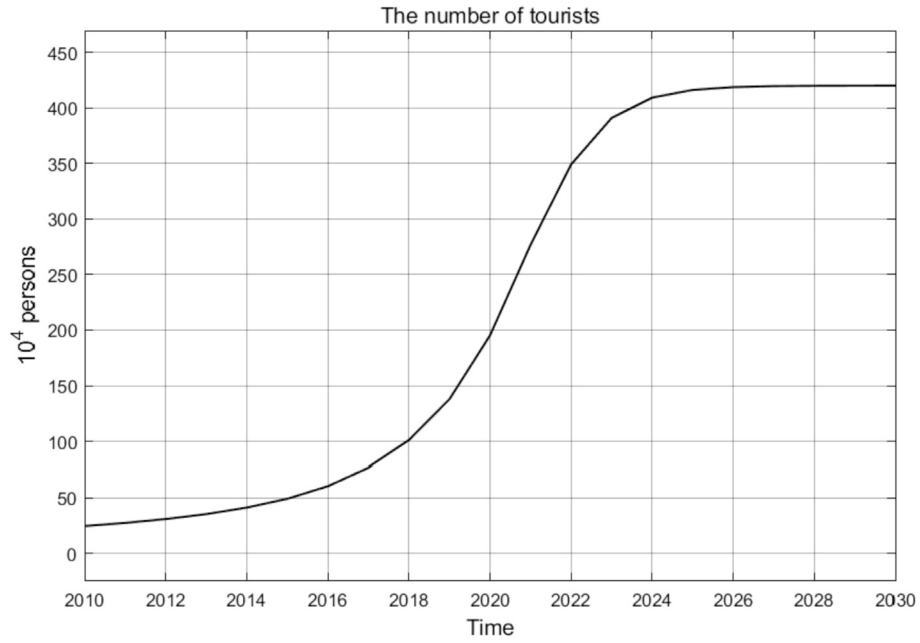


Fig. 8. Extreme condition test results for the number of tourists.

Table 3
Scenarios applied in Xingwen Global Geopark.

Policy parameters		Scenario 1	Scenario 2	Scenario 3 (low-carbon)	Scenario 4 (economic)	Scenario 5 (economic and low-carbon)
Service personnel	r_1	Linear increasing	0.72	−0.025	+0.05	+0.025
	d_1	0.8	0.8	+0.05	−0	+0.025
Transportation	r_2	Linear increasing	0.77	−0.025	+0.05	+0.025
	d_2	0.3	0.3	+0.05	−0	+0.025
Ecological toilet	r_3	1 build and 1rebulid/4 years	0.79	−0	+0.05	+0.025
	d_3	0.67	0.67	+0.05	−0	+0.025
Ecological trail	r_4	40m^2/5 years	0.8	−0	+0.05	+0.025
	d_4	0.8	0.8	+0.05	−0	+0.025
Shopping	r_5	0.6	0.6	+0	+0.2	+0.1
	d_5	0.8	0.8	+0.05	−0	+0.025
Environmental protection investment		Linear increasing	–	–	–	–
Solid waste treatment ratio		–	0.94	+0.05	+0	+0.025
Waste water treatment ratio		–	0.78	+0.05	+0	+0.025
A_m		1.5	1.5	3	2	1
P_s		3	3	1	3	5

toilets can benefit the environment by efficiently treating the wastes and producing less footprint. Therefore, eco-toilets are inevitable in the low-carbon construction. In Fig. 11(f), it's indicated that the construction of eco-trails can reduce the possibility for tourists to destroy the vegetation, thus reducing the carbon footprint. The idea of low-carbon construction has been supported again. Fig. 11(g) shows that the preprocessing of solid waste, e.g. classification, can bring benefits to the low-carbon construction of scenic spots. As the number of tourists increase, more solid waste will be produced and appropriate treatment of solid waste could reduce the carbon footprint generated to the environment.

4. Discussion

The present work constructs a low-carbon tourism system with four subsystems and integrates the carbon footprint calculation model to study the low-carbon tourism system, which is applied in Xingwen Global Geopark. Our results indicate that the current development mode (Scenario 2) appears that Xingwen Global Geopark is experiencing a constant promotion in low-carbon development with increasing carbon footprint but decreasing carbon intensity, but it is not best scenario, it will contribute a moderate number of tourists and the relatively high carbon footprint compared to the Xingwen Global geopark overall development plan, and if the scenic spot only advocate the economic development reckon without low-carbonization, will cause the highest carbon footprint in the future.

If the Xingwen Global Geopark corresponds with the current development mode (Scenario 2), the number of tourists is expected to increase year by year, reaching 1.57 million in 2030, which is in accord with the target of Xingwen Global Geopark. Under the consideration of low-carbon tourism, carbon footprint is likewise expected to increase year by year with the growth of tourism economy while the carbon intensity decreasing under the low-

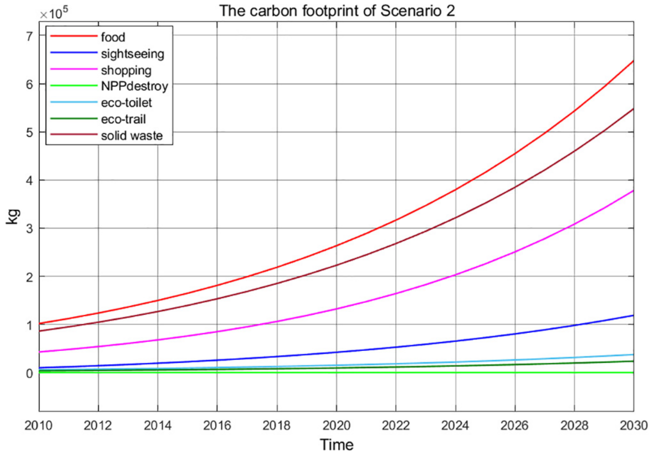
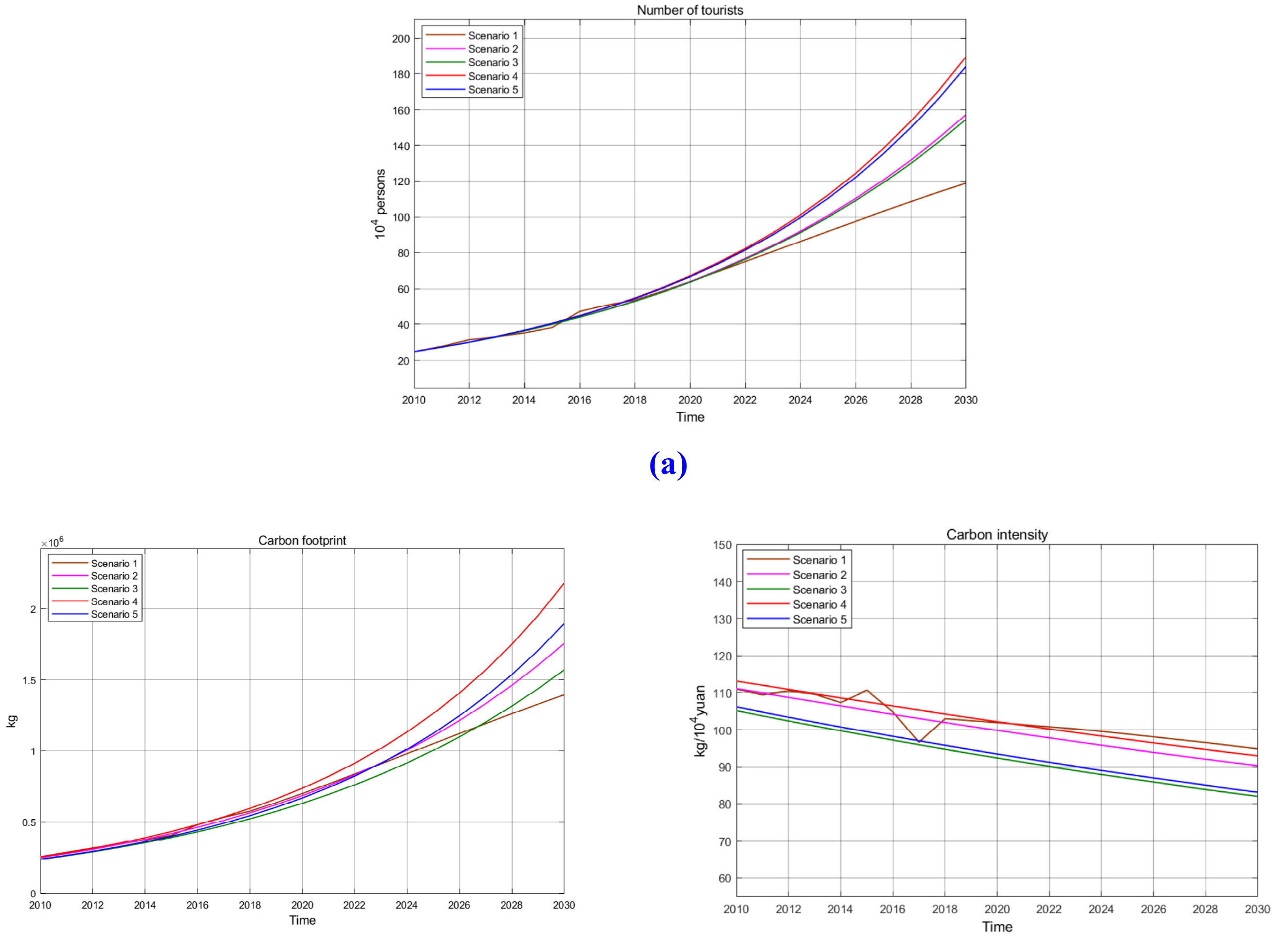


Fig. 9. Carbon footprint of Scenario 2 for Xingwen Global Geopark.

carbon schedule of scenic spots. At the same time, the carbon intensity will decrease from 111.0 to 90.3 kg/10^4 yuan, and the current carbon footprint of the scenic spot is mainly derived from tourism food, solid waste and shopping. Among the carbon footprint of tourists' activities, food has the largest carbon footprint, which is consistent with that of the national geological park tourism activities studied by (Tang, 2016). One additional thing to note that the just similar to linear data development mode (Scenario 1) is not likely to be a sustainable future for tourism development, it will contribute the lowest number of tourists and highest carbon intensity. In the economic oriented scenario (Scenario 4), the number of tourists will reach to 1.89 million, which indicates the best economic performance however the highest carbon footprint and intensity uncover the obvious weakness of this scheme. Carbon footprints of various key elements in different scenarios indicate that solid waste, food and shopping carbon footprints have a prominent performance, when considering responsible tourism, conform to Scenario 3 or Scenario 5, if responsible behavior of tourists is strongly practiced, and low-carbon management awareness of the scenic spot is improved, low carbon footprint will be generated despite a large number of tourists in the scenic spot. In terms of garbage sorting, the effects of responsible tourism can be reflected in improved garbage recovery rate and decreased carbon footprint. The reduction of carbon footprint of food and shopping can be achieved through adjusted prices and raised low-carbon consciousness; eco-toilets and eco-trails have considerably



(a)

(b)

(c)

Fig. 10. Main simulated objectives of five scenarios.

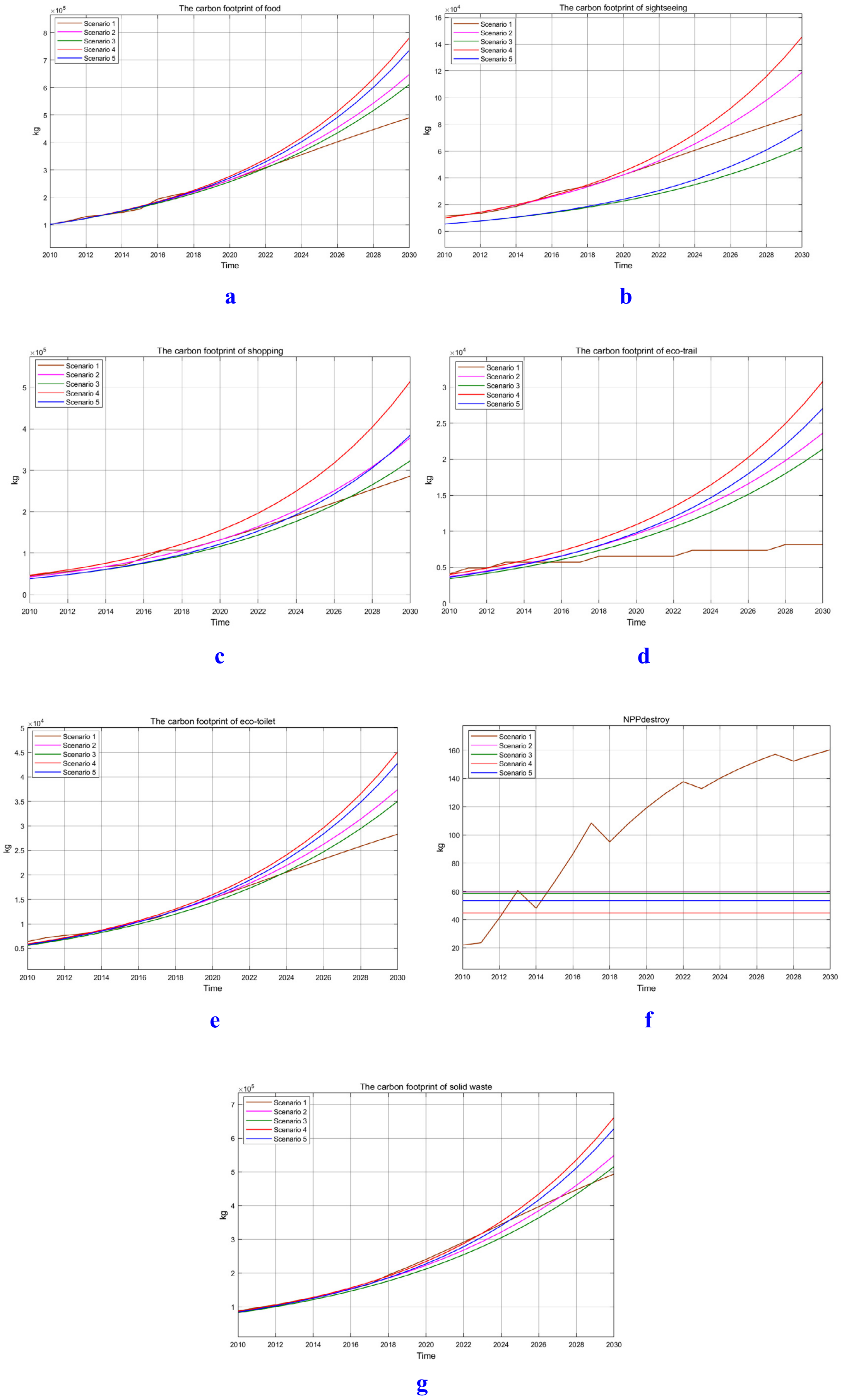


Fig. 11. Development of various key elements in different scenarios.

low-carbon footprints, and the results of eco-toilets have supported by the idea of low water discharge and energy consumption, while low-carbon footprint of eco-trails is supported by the low-carbon construction.

The above results show that under the future policy design, the practices and awareness of tourists, especially scenic spots can affect low-carbon tourism, with scenic spots as the leading undertaker in promoting low-carbon construction. For tourists, responsible tourism should be practiced, that is to enhance their awareness of low-carbon tourism and perform as a practitioner in tourism activities, e.g. catering and shopping. For the tourism commodities, the prices of high-carbon footprint goods can be increased, and more diversified low-carbon goods with lower prices could be introduced to provide more choices for the tourists. For the scenic spots, responsible tourism can be planted in the daily operations and long-term management, e.g. increasing the environmental protection investment, the area of the eco-trails, promoting the grade and application of eco-toilets, etc. Environmental protection investment should be initially increased and ensure that the treatment ratio of solid waste is as high as possible, and the solid waste should be transported to the landfill that possess biogas capture. Although the expansion of original trails itself can cause carbon footprint to some extent, the carbon footprint generated by widening the trails is one-off and carbon sink capacity of the damaged vegetation is long-term, thus widening the ecological trails appropriately with low-carbon materials, and optimizing the travel routes become a better choice. During the building or rebuilding process of toilets, high-grade and eco-friendly toilets, such as those at 3A and 2A grades, should be built to fit in the growth of touristsunder the low-carbon scheme. Besides, green energy could be used in substitute of traditional non-green energy to retain low carbon footprints while meeting the higher allocation rate of sightseeing vehicles.

According to the evidences mentioned above, further implications for the scenic spots and policy makers include: (1) Low-carbon investment in environmental protection must be increased. (2) Infrastructure construction, especially tourism ecological toilets, ecological trails and transportation infrastructures, should be upgraded and paid attention to the type of materials and energy. (3) Responsible tourism needs to be promoted among various tourism stakeholders, such as tourists and tourism practitioners to encourage behavior and environmental responsibility.

5. Conclusion

This study provides a framework for the study of low-carbon tourism systems inspired by the idea of responsible tourism, with carbon footprint incorporated. Then, Xingwen Global Geopark is selected as the case of low-carbon tourism system and the predicted future scenarios are designed, i.e. base current development state scenario, low-carbon oriented scenario, economic oriented scenario, low-carbon and economic oriented scenario, under which the path and developing conditions of the case scenic spot are analyzed, as well as the dynamic carbon footprint of key elements. Results show that the existing development mode can be improved through low-carbon construction. Although the tourism income is the highest under the economic oriented scenario, it will produce the largest carbon footprint. A win-win situation can be achieved through low-carbon construction. Besides, the carbon footprint produced by some key elements, i.e. food, solid waste, tourism shopping and sightseeing, prevails and needs more attention from the managers. This study provides a dynamic measurement of carbon footprint and focuses on the variation of carbon footprint under responsible tourism. Given its adaptation, the results and policy implications can also be applied to other world geoparks or similar type of scenic spots. However, this study also has limitations:

(1) As a synthesis of multi-discipline works, a realistic and reliable low-carbon tourism system consists of knowledge from two or more fields, e.g. environmental engineering, marketing, operations research, scheduling, etc. What we have completed is limited and it's highly recommended to establish a multi-discipline expert network in further study and provide a more rounded research into low-carbon tourism, as well as the operations and management of low-carbon scenic spots.
(2) In this study, responsible tourism is incorporated in a broad context, rather than explicit measurement, which leaves gaps in future work. Scholars interested in this topic may choose more specific aspects of responsible tourism to conduct a detailed study, rather than staying on the surface, and further research the relationship between carbon footprint and responsible tourism. Besides, this work could be examined in a broader group of samples, so as to fill the gap between the micro- and macro-study of dynamical carbon footprint applied in tourism management.

Author contributions

Z. W. designed the scenarios for case study; Y. L. and Y. M. designed and conducted the case study; Y. L. and Y. M. wrote and revised the paper; Y. M. and Z. S. collected and standardized the original data; Y. L., Y. M. and Y. Q. analyzed the results and organized the numerical and graphical report; Y. L. and Z. S. reorganized the paper and prepared the necessary materials for revision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A
Overview of equations

Variable Name	Equation	Description or reference
r_1	n_1/NT	
r_2	n_2/NT	
r_3	n_3/NT	
r_4	n_4/NT	
r_6	SW_t/SW_p	
r_7	WW_t/WW_p	
V_d	$246.31-248.21\ r_4$	Regressive calculation
pollution index	$0.4*(1-r_6)+0.6*(1-r_7)$	Mai & Smith (2018)
natural beauty-loss index	$V_d/750$	
comfort index	$(0.4r_1+0.6d_1+0.8r_2+0.2d_2+0.5r_3+0.5d_3+0.7r_4+0.3d_4)/4$	Calculated from data of questionnaire analysis
multiplier	DELAY (effect of pollution index on tourist growth, 1)+DELAY (effect of natural beauty-loss index on tourist growth, 1) +DELAY (effect of comfort index on tourist growth, 1)	Mai & Smith (2018)
tourist growth	MIN(multiplier,0.004422*NT (1-NT/420)	Calculated by tourism life cycle model and proposed
R_2	$1 + r_2-r_2\ (t_0)$	Proposed
R_5	$((100-A_m + P_s)-100)/100$	Walter (1998); Liu (2015)
C_p	$C_p = 91.235 + 1.621t$	Regressive calculation
CI	CF/TR	

Appendix B. Index used for dimensionless multipliers

Fig. B1. Effect of natural beauty_loss index.

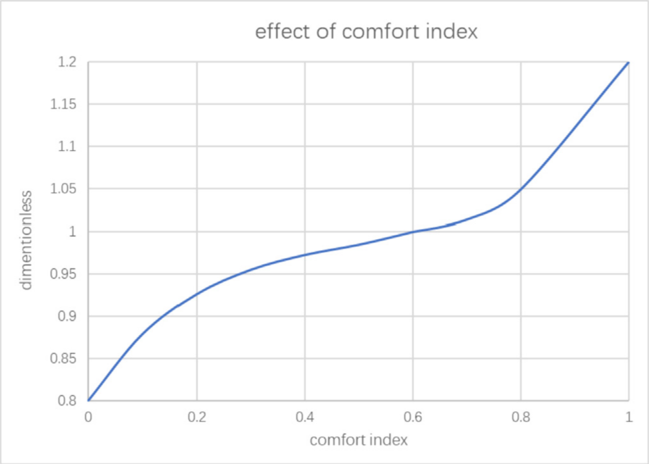

Fig. B2. Effect of comfort index.

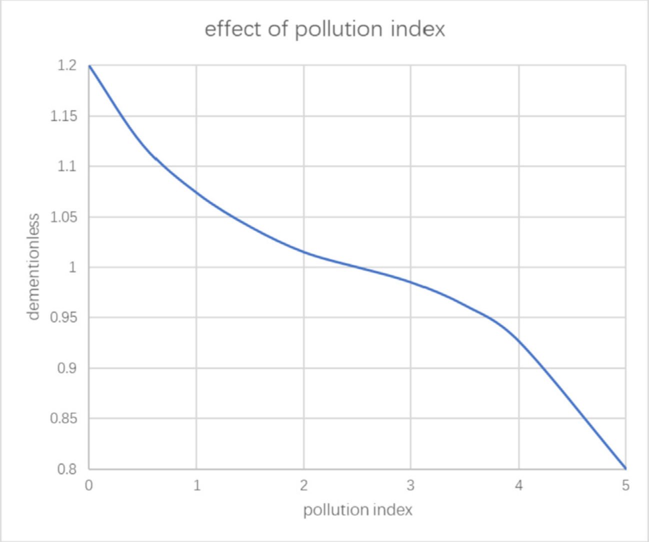

Fig. B3. Effect of pollution index.

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