Journal of Destination Marketing & Management 15 (2020) 100383

Contents lists available at ScienceDirect

Journal of Destination Marketing & Management

journal homepage: www.elsevier.com/locate/jdmm

Research paper

Dynamic assessment of tourism carrying capacity and its impacts on tourism economic growth in urban tourism destinations in China

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ARTICLE INFO

Keywords:
Tourism Carrying Capacity
Tourism economic growth
Environmental and tourists management
Urban tourism destinations
System dynamic model

ABSTRACT

For urban areas, Tourism Carrying Capacity (TCC) can be defined as the abilities of a destination to absorb and manage increasing tourism activities without a degradation in the tourism sector of the urban economy. To optimize the concept and assessment of TCC, this paper develops a dynamic carrying capacity model including three subsystems and 47 variables by System Dynamic (SD) method from a macroscopic perspective. Taking the top nine urban tourism destinations in China as the objects of the study, we compare how government investments in tourism resource, environmental protection, economy and infrastructure impact tourism growth through four scenarios. The results indicate that environment scenario simulation contributes to both TCC and tourism economic growth; the economic scenario simulation can increase the overall TCC, but harms to tourism economic growth compared with other scenarios; the resource scenario simulation has no significant change in TCC compared with the current scenario. The results suggest that to promote sustainable tourism development, TCC management should focus on environmental and tourists management policies, such as external environment improvement, behaviour rules and ecological concept establishment in personal daily life.

1. Introduction

In the past two decades, the tourism industry has been increasingly developing due to abundant recreational resources and convenient accessibility, which boosts local economies significantly. Specifically, the development of the tourism industry has some benefits to society, such as increasing employment, optimizing transportation, enhancing resident income and protecting cultural heritage (Shahzad, Shahbaz, Ferrer, & Kumar, 2017).

However, the over-development of tourism has caused negative impacts on the local environment, resources, social culture and regional resilience (Graymore, Sipe, & Rickson, 2010; Guan, Gao, Su, Li, & Hokao, 2011; Saveriades, 2000). Some social issues, such as overcrowding, environmental degradation, traffic congestion, the decline of quality of life, and cultural destruction, have attracted more and more attention. These issues can be defined as 'over-tourism', which means that the level of tourism development exceeds the maximum limit. According to Seraphin, Sheeran, and Pilato (2018), Venice suffers from over-tourism. The authors go on to argue that an ambidextrous management approach (including exploitation and exploration) should be adopted to support the sustainable development of Venice. In many cities, such as Florence, tourism development contributes to economic growth but also leads to massive problems. In particular, overcrowding is considered to be a crucial problem in those tourist cities (Popp, 2012). To cope with these problems, many scholars present proposals to adjust the tourism carrying capacity (TCC) of tourism destinations to achieve sustainable development and avoid over-tourism problems (Lobo, 2015). The mechanisms involved include controlling demand, managing tourist flows (Riganti & Nijkamp, 2008), mingling with locals, regulating temporal and spatial displacement, and so on.

Most previous scholars apply the TCC approach by calculating the maximum number of visitors (i.e. the number that a tourism destination can support based on its biophysical, ecological, economic and social conditions), but they ignore the impacts of some wider factors, such as regional resilience, air quality, and local environmental conditions. Moreover, such approaches only consider TCC in the context of a certain time and certain places (such as coastal areas, natural resorts or communities), while there is always a delay for implementing policies about TCC in practice. As such, the need for a dynamic TCC analysis is urgent. How do external factors impact on TCC currently and in the future? Can approaches other than that of calculating the maximum number of visitors can be used to optimize TCC in urban areas from a

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https://doi.org/10.1016/j.jdmm.2019.100383
Received 20 January 2019; Received in revised form 30 August 2019; Accepted 22 September 2019
Available online 12 December 2019
2212-571X/

Table 1
Definition of TCC.

Dimension	Characteristics	Authors
Ecological carrying capacity	Visitor limits in maintaining ecological function.	Martin and Uysal (1990); Hawkins and Roberts (1997); Mexa and Coccossis (2004).
Economic carrying capacity	Tourist limits without economic press.	Sowman (1987); Swarbrooke (1999).
Social carrying capacity	Maximum or adaptive limits of tourists or growth limits without an unacceptable decline in experience and society.	Mathieson and Wall (1982); Saveriades (2000); Chen and Teng (2016).
Comprehensive carrying capacity	Maximum or optimum limits of tourists or growth without an unacceptable destruction of the physical, biological, economic, sociocultural, and psychological conditions.	Zacarias et al. (2011); Cupul-Magaña and Rodríguez-Troncoso (2017).

dynamic perspective? Does TCC management have any influence on tourism economic growth? To address these questions, this paper investigates the impacts of TCC by considering aspects of economy, ecology and resource on the urban tourism economy, from a dynamic perspective, to provide more reasonable insights for tourism development policies.

The major purpose of this study is to quantitatively investigate the relationship between tourism economic growth and carrying capacity under a multivariate framework. The study develops three subsystems and 47 variables using the System Dynamic (SD) method, and the research object contains nine urban tourism destinations in China. In particular, it considers the impacts on TCC of tourism supporting resources, environmental protection, economy and infrastructure, and compares tourism growth under four scenarios (i.e. current, economy, environment, resource scenarios), which can be used by the government to make policies.

The rest of the paper is arranged as follows. Section 2 reviews the related literature. Section 3 describes the methods and models of the paper. The results are presented in the Section 4. In Section 5, the results are presented. Section 6 concludes the main insights of the study and sets out some future research directions. The main equations used in the study are presented in the appendix.

2. Literature review

2.1. Definition

The concept of carrying capacity was first proposed in recreation in the early 1960s (Mexa & Coccossis, 2004). Scholars explain TCC mainly from ecological, economic, and social perspectives, and the definition of TCC is explained in Table 1. The ecological definitions of TCC focus on the balance between tourists and physical environment tolerance. TCC is described as the number of tourists that a standard area of land can sustain without affecting local ecological function (Hawkins & Roberts, 1997; Martin & Uysal, 1990), causing any harm to its natural establishment (Mexa & Coccossis, 2004), or causing available facilities and infrastructure to become overcrowded (Roe, Leader-Williams & Dalal- Clayton, 1997). As for economic definition, TCC is considered as the number of tourists a destination can tolerate and absorb without economic stress or negative impacts on the economy (Swarbrooke, 1999).

To investigate TCC from the perspective of social definition, some scholars take the quality of tourists' experiences, residents' impact perceptions, tolerance or satisfaction and other social factors into account (Muler Gonzalez, Coromina, & Gali, 2018). TCC is defined as the maximum number of tourists (Mathieson & Wall, 1982), or the maximum level of use (in terms of numbers and activities) that can be absorbed without an unacceptable decline in the quality of tourists' experience and negative impact on the society of a destination (Saveriades, 2000). Chen and Teng (2016) establish a TCC system by examining how tourists perceive overcrowding, and the results show that beach cleanliness, safety, sediment and habitat management, information provision, and overcrowding are the main factors that tourists mainly concern about.

Researchers furthermore demonstrate that not only ecological factors but also social factors influence the number of tourists that a destination can support. The World Tourism Organization (UNWTO) indicates that TCC is "the maximum number of tourists in a destination, without causing destruction of the physical, economic, sociocultural environment and an unacceptable decrease in the quality of tourists' satisfaction". This definition states that carrying capacity relates to physical, perceptual, economic, social, and ecological components. Zacarias, Williams, and Newton (2011) identify TCC as the optimum number of visitors that can be sustained in a destination based on the physical, biological and management conditions. Cupul-Magaña and Rodríguez-Troncoso (2017) focus on an 'acceptable' or minimum impact on a destination considering the environmental characteristics, human activities and management factors. Moreover, visitor's satisfaction, experience, behavioral intention, threshold attendance, future attendance, resident experience (Canestrelli & Costa, 1991), and social environmental factors are proved to be determinants of theme park TCC (Zhang, Li, Su, & Hu, 2017).

2.2. System evaluating and thresholds setting

TCC is considered as a useful approach to manage tourism growth. Scholars are thus paying more attention to establishing TCC indicators and evaluate the maximum or adaptive limits of tourism development. Based on the definition of carrying capacity, three assessment approaches are mainly proposed in previous studies.

(1) Physical limits. Aiming to protect resources, the maximum limits of TCC can be measured by the maximum criterion of physical-ecological components, such as water, electricity, transportation, land, air, noise, community facilities, and the intensity of their impacts on both natural and cultural resources.
(2) Tourist limits. Utilized as a management tool of tourism destination, controlling the number of tourists has been found to be useful to avoid over-crowding problems in some protected natural areas. But critics argue that tourist management should not just emphasize on the number of people but on visitors' experience and behavior. Based on these ideas, the Limits of Acceptable Change Model (LAC) (Stankey, Cole, Lucas, Petersen, & Frissell, 1985), Visitor Impact Management (VIM) (Graefe, Kuss, & Vaske, 1990), and Visitor Experience and Resource Protection (VERP) were established to decide adopted tourists considering both the tourists' experience and resource conditions. Santana-Jiménez and Hernández (2011) use population density to measure the maximum capacity of a tourism destination based on the influence of tourist's perception of overcrowding. Ivanova (2015) constructs a LAC model to assess TCC in terms of "tourist presence" associated with four factors including length of stay, characteristics of the tourists/residents, geographic concentration of tourists, and degree of seasonality.
(3) Community-based limits. Carrying capacity relates to not only the relationship between tourists, but also the relationship between communities and tourists. Thus, the community-based approach was established to determine the sustainable limits in order to satisfy both tourists and residents. Jurado et al. (2012) consider the

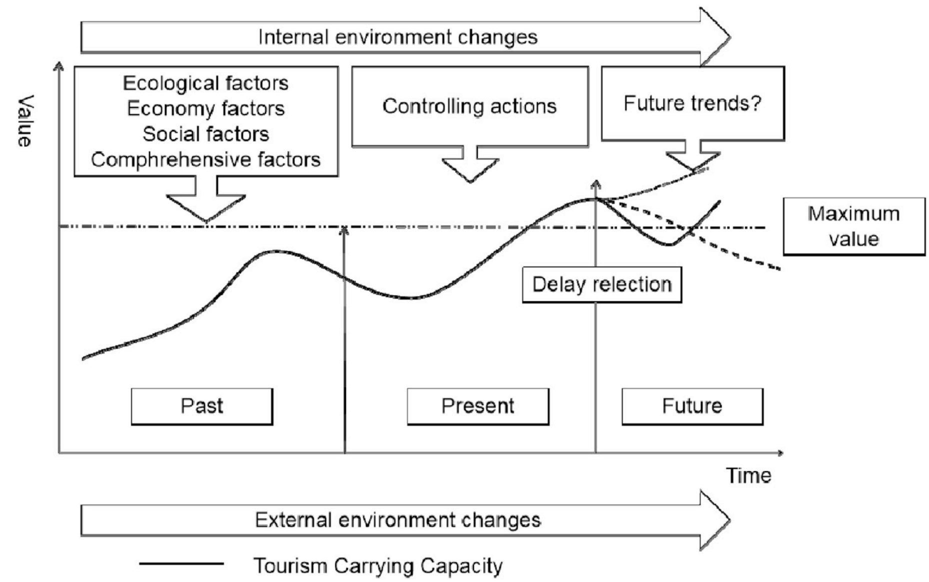

Fig. 1. TCC literature limitations.

growth limits as a strategy for sustainability, and establish a methodology using two synthetic indicators (weak and strong sustainability). Cisneros, Sarmiento, Delrieux, Piccolo, and Perillo (2016) estimate the carrying capacity for a beach by considering its environmental, urban, weather, and other factors, and then define three levels (physical carrying capacity, real carrying capacity and effective or permissible carrying capacity). With the aim of achieving long-run sustainable development, Marsiglio (2017) tries to find the balance between economic benefits and environmental costs, and then determine the optimal number of tourists considering the economic and environmental factors. Zhang, Li, and Su (2017) examine the impacts of attraction and spatial layout attributes on tourists' movement in a theme park, in order to optimize the theme park carrying capacity management.

2.3. Limitations of previous literature

Through an extensive literature review, limitations of the previous studies can be found in Fig. 1.

(1) System framework. There is a consensus among scholars that TCC is the maximum quantity of tourism activity (including the level of tourism development or tourist numbers) that a destination can absorb without any degradation (Cupul-Magaña & Rodríguez-Troncoso, 2017). Present research can be classified in four aspects: ecological TCC, social carrying capacity, economic carrying capacity and comprehensive carrying capacity. More and more internal and external factors have been considered as factors of sustainable tourism development. What, however, about the relationship between the internal factors and external factors? How do all the factors influence carrying capacity and the tourism growth? This paper will establish a system to describe the interactions between indicators that improves the effectiveness of the model. Moreover, numerous studies focus on tourists carrying capacity, or emphasize on recreation carrying capacity in coastal areas, natural resorts or communities. What about TCC in urban areas? The primary purpose of this study is therefore to construct a comprehensive TCC system framework from urban perspective.

(2) Threshold setting. Traditional TCC assessment studies evaluate the maximum level physically (Zacarias et al., 2011), or examine the most adaptive level of tourism growth or tourists' perceptions. Both these methods are applied on the basis of historical data or current statistics in a static approach. When the limit value has been determined, it is adopted as a static value whether or not the factors determining it are likely to be change. Moreover, the management policy seems to have a delay reaction, e.g. if a tourism resort comes across overcrowding problems, the controlling policy of reducing the number of tourists will be carried out, which usually turns out to be too late to recover from the new situation or deal with it before it appears (Santana-Jiménez & Hernández, 2011). According to Butler's Life Cycle of Tourism (TALC) model (Butler, 2006), the development of a tourism destination is dynamic, its level continually changing in the light of the new situations. The previous limits of growth should thus be extended to a higher level through changing environment, such as constructing new tourist products or transforming the supply-side environment. This paper identifies that TCC can be enhanced by improving internal and external factors, and the limits of growth will keep changing all the time. It will focus on the capacity for carrying tourism activities in urban tourism destinations without setting limits of tourism growth.

(3) Dynamic trends. Fig. 1 shows that current studies consider TCC as a sufficient approach to manage tourism development. But what about the future dynamic trends? Scholars have indicated that TCC should emphasize the dynamics of tourist demand, the environment and the time interval. Lobo (2015) establishes a dynamic method to examine thresholds to tourist carrying capacity considering environmental factors, air temperature, and the dynamics of the tourism. TCC is not just a limit of tourists, but a dynamic management tool that can be used to improve tourist visitation, or a positive and dynamic prism for the implementation of sustainable management.

When the TCC index of a destination rises up to the maximum value, some actions or strategies will be taken to control the conditions of tourism growth. After the action is carried out, it always takes a long time to recover or absorb, which can be called the 'delay reflection'. Meanwhile, with the rapid change of the internal and external environment factors, what is the future trend of TCC? TCC seems to be unpredictable, thus governments and managers need to pay more attention to it. Based on this, this paper utilizes system dynamic method to assess the TCC from present time to the future. The TCC system will become more quantitative and dynamic through simulating and comparing different policies.

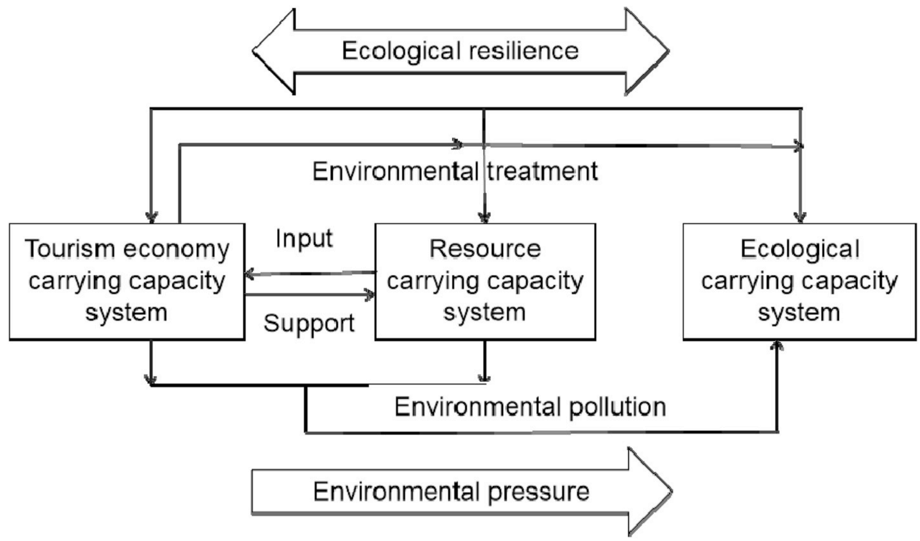

Fig. 2. Framework of TCC system.

3. Methods

Four different scenarios were designed to simulate the conditions of comprehensive TCC over the years 2010–2030 using SD model software 'VENSIM 9.0'. To build a dynamic TCC framework, the following four steps are constructed: (1) Identify research objective, establish the TCC system, and analyze the interactions between indicators; (2) Construct variables, feedback loops, stock-flow diagram, and equations for TCC system; (3) Simulate TCC under four scenarios (current, resource, environment, and economy scenarios), aiming to compare the effects of policy inclinations on TCC; and (4) Investigate dynamic and spatial changes from 2010 to 2030.

3.1. TCC system establishment

The paper sets out a comprehensive TCC concept in the context of urban areas. More specifically, it expands the definition of TCC from tourist limits to a comprehensive and dynamic concept. TCC is defined as the abilities of a destination to absorb increasing tourism activities without degradation in overall development recently and in the future considering tourism resource, economy and ecosystem.

The ecological system is characterized by resilience. Tourism environmental treatment is a carrier of TCC. Tourism activities and related economic development in tourism destinations are considered as the TCC-carrying objects. With the development of the tourism industry, resource exploitation and environmental pollution have become increasingly serious. Thus it is necessary to explore how to promote tourism sustainable development by adjusting TCC.

TCC is divided into three subsystems: tourism economy carrying capacity system (TECC), ecological carrying capacity system (ECC), and resource carrying capacity system (RCC). Each subsystem contains both pressure and support sectors. Fig. 2 represents that subsystem RCC produces tourism products such as tourism scenic spots, water and land, which determine the attraction level. These provide natural capital input in subsystem TECC. Support of subsystem TECC is combined with the infrastructure, transportation, labor force, and capital. But undesirable output of tourism activities, economic growth, and resource exploitation is represented by pollution, and it will produce pressure on the whole environment, part of which can be absorbed by resilience, or cleaned through protective treatment. Tourism growth will promote an increase in the fiscal expenditure of environmental protection. Subsystem ECC provides support by resilience and protective treatment. Only if the capability of self-repairing is greater than pollution producing will the TCC could be sustainable, otherwise the system would create a vicious circle of environmental degradation. Based on these explanations, the following examinations of each subsystem are formulated.

3.1.1. Tourism economy carrying capacity system (TECC)

Tourism economy carrying capacity would be influenced by six indicators, including per capita tourism income, tourism labor, tourism capital, transportation, infrastructure, and per capita gross domestic product (GDP). Thus, the tourism economy carrying capacity index can be examined by the weighted sum of the six indicators. These indicators are described in Table 2. According to economic theory, labor, capital, and resource are significant factors of economic growth (Du, Lew, & Ng, 2016; Liu, Nijkamp, & Lin, 2017). Therefore, interactions among these indicators in the TECC system should be analyzed. The tourism economy growth function is established here to examine the relationships among tourism economic growth and tourism labor, tourism capital, tourism resource and other control factors. The function is as follows:

$$Te_{it} = \beta_0 + \beta_1 Tl_{it} + \beta_2 Tc_{it} + \beta_3 Tr_{it} + \beta_4 X_{it} + \varepsilon_u \quad (1)$$

where, i and t denote city and time subscripts; Te_{it} represents a measure of total tourism income; Tl_{it} represents tourism labor force; Tc_{it} means tourism economy capital input, calculated by proportion of fiscal investment of tourism company; Tr_{it} is tourism resource abundance, calculated by the number of AAAA-level and AAAAA-level tourism scenic spots; X_{it} is a vector of control variables, including GDP, infrastructure and transportation; ε_{it} is an error term.

3.1.2. Ecological carrying capacity system (ECC)

Ecological carrying capacity system refers to ecological resilience, environmental pollution and environmental treatment. The ecological carrying capacity system can be sustainable when the self-repairing capacity exceeds the pollutant level, and minimizes the negative impacts on society and the environment. Ecological resilience is a useful index of environmental sustainability, which refers to the capacity of a system to deal with unexpected change, absorb unusual disturbances or adapt to external shocks while maintaining the same identity (Carpenter, Walker, Anderies, & Abel, 2001; Sheppard & Williams, 2016). It is difficult to measure ecological resilience, but we can find signals and establish indicators for it, such as green area, green area coverage rate, and air quality. All of these indexes reflect a self-repairing capacity, which will strengthen when the environmental treatment level increases, while it will decrease if the pollutant level increases. As shown in Table 2, the environmental treatment can be

Table 2
Weight and description of assessment indicators.

Subsystem	Indicators	Descriptions	Weight
Tourism economy carrying capacity system (A1)	Per capita tourism income (B1)	Total tourism income/Total tourists (yuan)	0.0530
	Tourism labor force (B2)	Number of tourism employment (unit)	0.0477
	Tourism capital (B3)	Accumulation of fixed assets investment (100 million yuan)	0.0476
	Tourism infrastructure (B4)	Number of tourism facilities (unit)	0.0483
	Transportation (B5)	Graded highway length (km)	0.0463
	Per capita GDP (B6)	GDP/population (yuan)	0.0408
Resource carrying capacity system (A2)	Tourism resource (B7)	Number of AAAA-level & AAAAA-level tourism scenic spots (unit)	0.0479
	Water supply (B8)	Per capita water supply (m^3)	0.0481
	Land supply (B9)	Constructive land (m^2)	0.0448
Ecological carrying capacity system (A3)	Ecological resilience (B10)	Green area (m^2)	0.0865
		Green area coverage rate (%)	0.0401
		Good ambient air quality rate (%)	0.0746
	Environmental pollution (B11)	Industrial waste solid emissions (10,000 ton)	0.0515
		Industrial waste water emissions (10,000 ton)	0.0490
		Industrial waste gas emissions (100 million cu.m)	0.0518
	Environmental treatment (B12)	Environmental protective investment (100 million yuan)	0.0709
		Sewage treatment rate (%)	0.0417
		Industrial waste solid utilized rate (%)	0.0565
		Residential garbage treatment rate (%)	0.0529

represented by indexes including protective investment, sewage treatment rate, and residential garbage treatment rate, and the pollutant level is calculated by an output rate of industrial waste and residential garbage.

3.1.3. Resource carrying capacity system (RCC)

Not only tourism resources but also land and water resource play a vital role in tourism development. Through rational exploitation, subsystem RCC will contribute to tourism economic growth, while excessive consumption will bring damage to ecological system.

$$RCC_{it} = \sum_{t=1}^{n} (W_1 Tr_{it} + W_2 L_{it} + W_3 Ws_{it}) \tag{2}$$

where, RCC_{it} denotes the resource carrying capacity; Tr_{it} represents tourism resource amount, which is also calculated by the number of AAAA-level and AAAAA-level tourism scenic spots; L_{it} donates regional land supply; Ws_{it} is regional water supply; W_1, W_2, W_3 is the weight of each indicator.

3.1.4. Tourism carrying capacity system (TCC)

TCC can be calculated by the multi-objective linear summation method (Shao & Ehrgott, 2016).

$$TCC_i = \sqrt{S_{i1}^2 + S_{i2}^2 + S_{i3}^2} \tag{3}$$

$$S_{is} = \sum_{j}^{J} x_{ij} w_j (i = 1,2,3, ...9; j = 1,2,3, ...J; s = 1,2,3) \tag{4}$$

where, S_{is} represents the carrying capacity of subsystem s in the city i; TCC_i is the final value of TCC for the city i; W_j donates the weight of indicator j; X_{ij} is the value of indicator j for the city i.

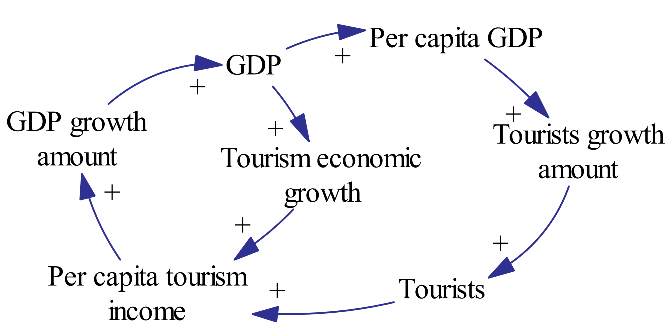

Fig. 3. Feedback loops in the system.

3.2. Establishment of SD model

A system dynamic (SD) model can be defined as the investigation of the information-feedback characteristics of managed systems and the use of models for the design of improved organizational form and guiding policy. It can be used to analyze the relationship among complicated indicators in a dynamic way.

Based on the former TCC system, a SD model was developed including three subsystems and 47 variables to examine the critical causal loops that affect the TCC. Two feedback loops are found in this system (shown in Fig. 3), which indicate that tourism economic growth is influenced by GDP, and tourists. GDP is affected by tourism economic growth, population, and tourists.

SD equations were then established based on feedback loops and equations (1)–(4) through Vensim software for the nine tourist cities respectively (shown in Appendix A). Based on the analysis of TCC and the relationship between indicators, a stock-flow diagram of the TCC system was designed (See Fig. 4) (Guan et al., 2011). After that, the data were dealt with and the stability of the model tested. Six variables, tourism resource, tourists, tourism economic growth, ecological resilience, environmental pollution, environmental treatment are chosen as drivers. The value of these variables is changed to simulate relevant policy scenarios to explore present and future development tendency from 2010 to 2030.

3.3. Assessment weight

The first step is to make the data dimensionless. The indicators are grouped into two types, i.e. 'benefit indicators' and 'cost indicators'. The former refers to the ones that result in improving tourism economic growth with their values increasing. 'Cost indicators' is on behalf of deteriorating tourism economic growth with their values increasing, including industrial waste emission and residential garbage produce. The Entropy Value Analysis method is then utilized to calculate the relative weights of each individual indicator (Ma et al., 2017). Following are the functions, and results are shown in Table 2.

$$\text{For the group of 'benefit indicators'}: X_{ij} = \frac{x_{ij} - x_{j\,\min}}{x_{j\,\max} - x_{j\,\min}} \tag{5}$$

$$\text{For the group of 'cost indicators'}: X_{ij} = \frac{x_{j\,\max} - x_{ij}}{x_{j\,\max} - x_{j\,\min}} \tag{6}$$

$$\overline{X_j} = n^{-1} \sum_{t=1}^{n} X_{ij} \tag{7}$$

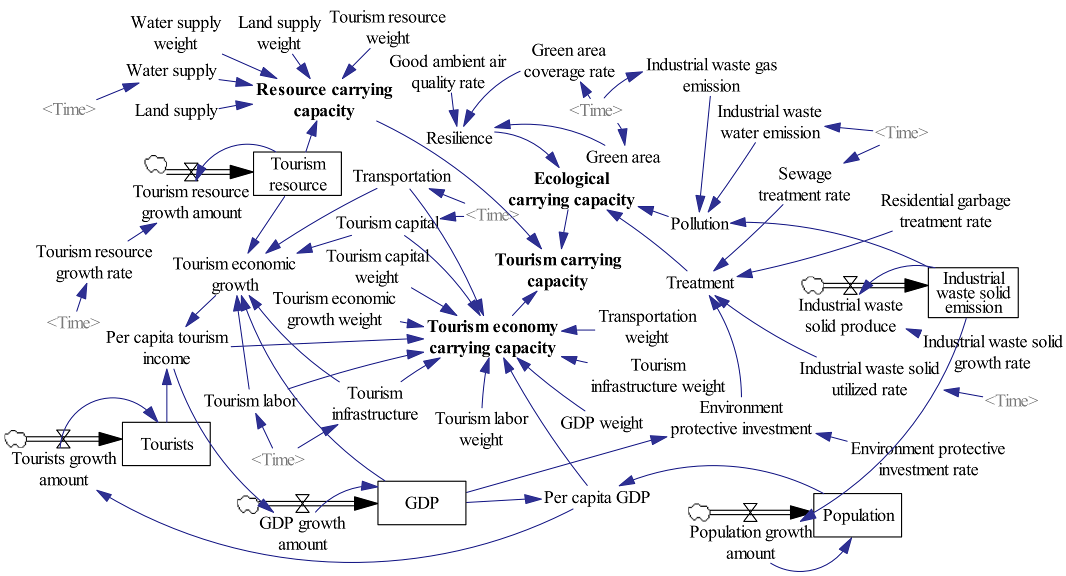

Fig. 4. Stock-flow diagram of TCC system.

$$S(X_j) = \sqrt{\sum_{j=1}^{m} [X_{ij} - \overline{X_j}]^2} \quad (\text{i}= 1,2, \ldots,\text{n}; \text{j}= 1,2, \ldots,\text{m}) \tag{8}$$

$$W_j = S(X_j)/\sum_{j=1}^{m} S(X_j) \tag{9}$$

where X_{ij} is the normalized value of indicator j for city i, $x_{j\,\min}$ and $x_{j\,\max}$ are the minimum and maximum values of indicator j, $S(X_j)$ represents the standardized value of indicator j, W_j is the weight of indicator j.

3.4. Study area and data collection

This study analyzes the TCC conditions of top nine urban tourist cities in China, comprising Beijing, Tianjin, Shanghai, Suzhou, Hangzhou, Wuhan, Chongqing, Chengdu, and Xian. As popular urban tourism destinations in China, these nine cities attract the greatest total number of tourists (including domestic and international tourists). A series of environmental, social, and over-tourism problems become constraints of sustainable development of tourism in these cities. Therefore, it is important to examine the level of TCC, and simulate the trends of TCC in the nine cities under different management strategies in a scientific way. The results can contribute to tourism decision-making on the part of the stakeholders and promote more sustainable approaches of TCC management.

In this paper, most of the indicators are directly collected from China Tourism Statistical Yearbook, China City Statistical Yearbook, China Statistical Yearbook and China Environment Statistical Yearbook from the years 2010–2016. Tourism economic growth is represented by total tourism income including domestic and international tourism income. Tourism labor force is the number of tourism employment. Tourism capital is calculated by accumulating fixed assets investment of tourism companies. Tourism infrastructure is the total quantity of travel agencies, hotels, and tourist attractions. Graded highway length is utilized to represent transportation. Tourism resource can be evaluated by many ways. Star-rating of scenic spots represents the reputation and attractiveness level of attractions in China (Yang & Fik, 2014):

Table 3
Initial value of main indicators.

Indicators	Beijing	Tianjin	Shanghai	Hangzhou	Suzhou	Wuhan	Chengdu	Chongqing	Xian
Tourists (10,000 person)	18,390	9373	22,197	6581	9409	8942	6819	16,174	5285
Tourism resource (unit)	70	12	22	25	27	12	17	44	15
Tourism resource growth rate (%)	0.027	0.239	0.197	0.099	0.076	0.084	0.175	0.113	0.141
Tourism labor (10,000 person)	14.73	2.23	13.08	3.77	3.17	2.21	5.47	4.22	2.74
Tourism capital (100 million yuan)	6,531,913	430,268	6,211,292	1,153,959	1,056,891	886,691	867,569	792,436	736,206
Tourism infrastructure (unit)	1549	409	1567	684	544.5	344	364	625	416
Transportation (km)	20,920	14,832	11,974	15,266	12,754	12,199	17,923	77,175	12,378
Population (10,000 person)	1962	1299	2303	689	638	1002	1149	2884	783
GDP (100 million yuan)	14,114	9225	17,166	5949	9229	5516	5551	7926	3243
Water supply (m^3)	120.80	70.81	163.10	2762.94	0.00	271.86	855.91	1616.80	307.90
Land supply (km^2)	16,411	11,917	6341	16,596	8657	8569	14,335	82,402	10,097
Green area (hectare)	62,672	19,221	120,148	16,394	13,987	15,447	16,734	37,695	10,959
Green area coverage rate (%)	37.00	32.10	38.20	39.95	42.70	37.17	39.43	40.57	40.43
Good ambient air quality rate (%)	50.96	59.18	69.04	66.30	65.75	51.78	57.80	80.80	68.49
Industrial waste solid emissions (10,000 ton)	1125.59	1546.00	2448.36	649.23	2300.00	1381.21	283.00	2869.00	267.29
Industrial waste solid growth rate (%)	−0.103	−0.041	−0.067	−0.148	0.021	−0.010	0.013	−0.028	−0.050
Industrial waste water emissions (10,000 ton)	8198	19,680	36,700	80,468	65,055	22,465	12,259	45,180	12,330
Industrial waste gas emissions (100 million cu.m)	4900	7686	12,969	4071	8271	4721	2225	10,943	792
Environmental protective investment rate (%)	0.018	0.012	0.03	0.02	0.017	0.018	0.019	0.028	0.02
Sewage treatment rate (%)	80.98	77.80	83.30	95.40	70.70	92.02	87.31	90.79	74.23
Industrial waste solid utilized rate (%)	66.00	98.00	95.00	94.13	98.73	95.96	98.76	80.40	98.05
Residential garbage treatment rate (%)	96.95	100.00	81.86	100.00	100.00	85.01	100.00	98.82	97.48

Table 4
Verification results in 2015 with the established SD model.

Cities	Index	Tourism resource (unit)	GDP (100 million yuan)	Water supply (cu.m)
Chengdu	Simulated data	38	11,451	540
	Real data	38	10,801	540.04
	Related error (%)	−0.06	−6.02	0.01
Xian	Simulated data	29	6127	275.61
	Real data	29	5801	275.61
	Related error (%)	0	−6	0
Tianjin	Simulated data	35	17,108	124.84
	Real data	35	16,538	124.84
	Related error (%)	0	−3	0
Shanghai	Simulated data	54	26,050	264.8
	Real data	54	25,124	264.8
	Related error (%)	0	−4	0
Beijing	Simulated data	79	23,497	123.8
	Real data	80	23,015	123.8
	Related error (%)	1	−2	0
Wuhan	Simulated data	18	11,766	940
	Real data	18	10,906	940.73
	Related error (%)	0	8	0
Suzhou	Simulated data	39	14,613	1011.4
	Real data	39	14,504	1011.38
	Related error (%)	0	−1	0
Hangzhou	Simulated data	40	10,333	3303.99
	Real data	40	10,050	3303.99
	Related error (%)	0	−3	0
Chongqing	Simulated data	75	16,309	1518.7
	Real data	75	15,717	1518.7
	Related error (%)	0.01	−3.77	0

specifically, AAAAA-level represents the highest level while A-level represents the lowest level. Thus, we use the summation of AAAA-level and AAAAA-level tourism scenic spots to represent the high-level tourism resource quantity. Water supply and land supply can be described by per capita water supply and constructive land, respectively. We use the indexes of green area, green area coverage rate, and good ambient air quality rate to represent ecological resilience. Environmental pollution is the weighted summation of industrial waste solid emissions, industrial waste-water emissions, industrial waste gas emissions. Environmental treatment consists of environmental protection investment, sewage treatment rate, industrial waste solid utilized rate, and residential garbage treatment rate. Table 3 presents the initial value of main indicators of the nine cities in year 2010.

4. Results

4.1. Validation of the SD model

Before simulating the TTC system, it is necessary to test the stability and feasibility of the model. Three variables including GDP, tourism resource, and water supply were selected to validate the model. The actual data in 2015 were compared with the simulated value in the same year. The results show that the related errors are typically within [-8%,8%], which confirms the validity and feasibility of the developed SD model in predicting dynamic change of TCC system (see Table 4).

4.2. Setting of different scenarios

The SD model can be used to simulate the results of different policies and predict future trends by adjusting variables and parameters. To do this, six indicators (tourism resource, tourists, tourism economic growth, ecological resilience, environmental pollution, environmental treatment) were used as the representative indicators, and four scenarios were established to simulate policy variations. In order to set up the four scenarios, the researchers introduced an increase in the maximum value among the current data of the positive simulated indicators by 10%, while the minimum value of the negative indicators was reduced by 10%.

Table 5 presents parameters in each scenario. Scenario 1: simulate the current situation with current value in all variables. Scenario 2: set tourism resource growth rate to 0.263. Scenario 3: control environment by reducing industrial waste solid growth rate to −0.162, increasing environmental protective investment rate to 0.031, and setting green area growth rate to 0.165. Scenario 4: control economic growth by increasing transportation growth rate, tourism infrastructure growth rate and tourism labor growth rate to 0.087, 0.054, and 0.041, respectively.

4.3. Simulation results

4.3.1. Trends of three subsystem

Tendencies of resource, ecological, tourism economy subsystems and TCC following the four scenarios were thus simulated. Figs. 5–7 present the output changes of TCC, ecological carrying capacity, resource carrying capacity, and tourism economy carrying capacity respectively for the four scenarios in 2030. Compared with the current scenario, the results indicate that the index of TCC will increase in the economy scenario and environment scenario. It is useful for the cities to improve TCC based on the economic policy and environmental policy. The index of TCC for Beijing, Hangzhou, Tianjin, Chengdu, Chongqing were ranked as the top five. The relative growth rate of TCC in Beijing, Hangzhou, Tianjin, Wuhan, Xian, Chengdu was higher in economy scenario than in environment scenario, while that of Shanghai, Suzhou, and Chongqing was higher in environment scenario than in economy scenario.

The ecological carrying capacity value was higher in environment

Table 5
Parameter setting of different scenario simulation.

Parameter	Maximum data	Scenarios		
		Resource scenario	Environment scenario	Economy scenario
Transportation growth rate	0.079	real data	real data	0.087
Tourism infrastructure growth rate	0.049	real data	real data	0.054
Tourism labor growth rate	0.038	real data	real data	0.041
Tourism resource growth rate	0.239	0.263	real data	real data
Green area growth rate	0.150	real data	0.165	real data
Environmental protective investment rate	0.028	real data	0.031	real data
Industrial waste solid growth rate	−0.148	real data	−0.162	real data

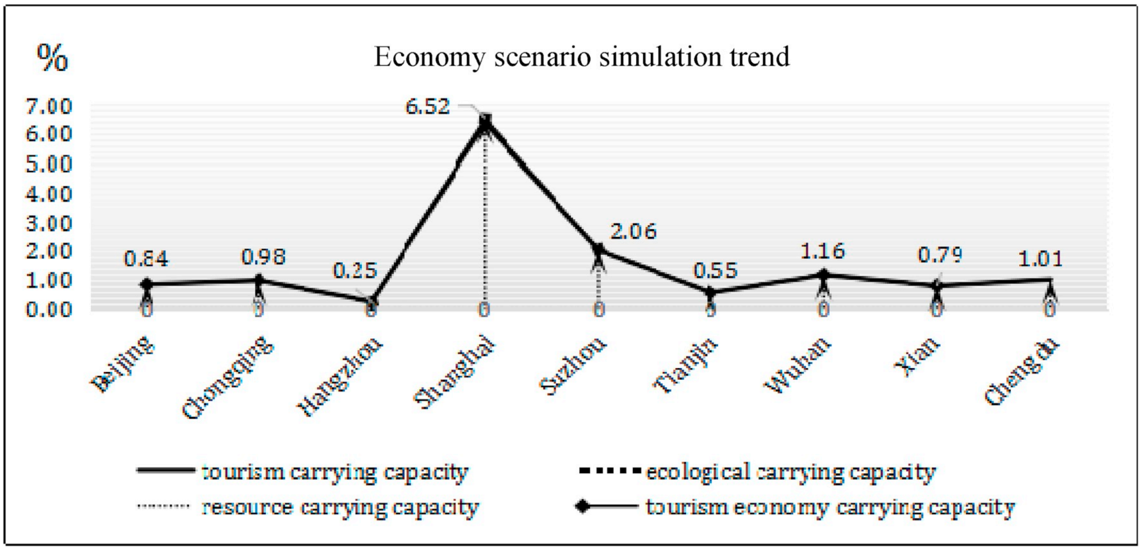

Fig. 5. Relative growth rate in the economy scenario compared with current scenario in 2030.

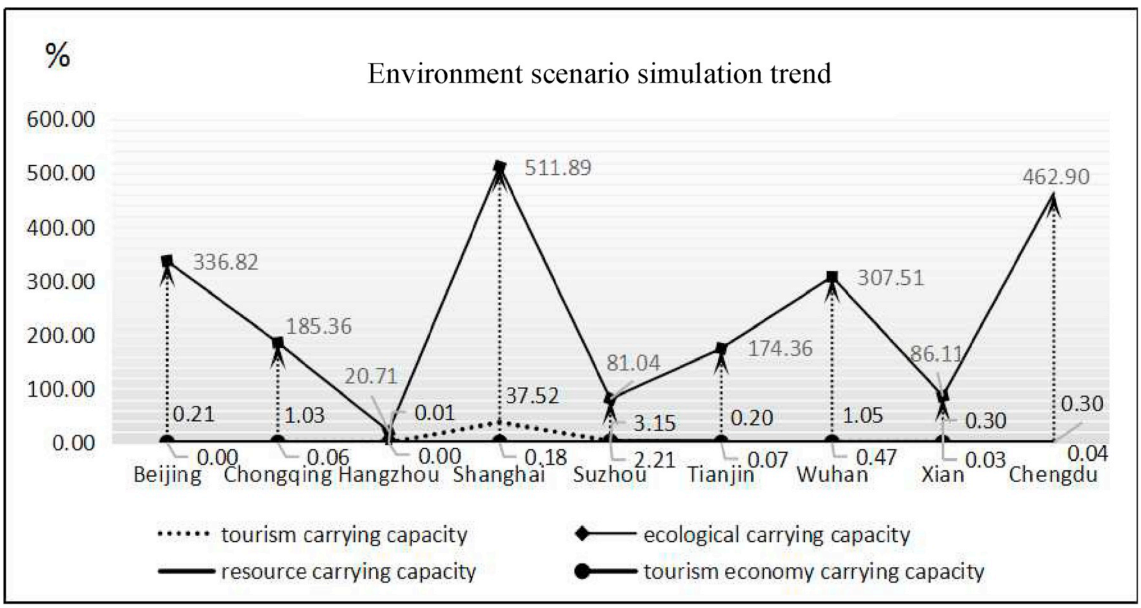

Fig. 6. Relative growth rate in the environment scenario compared with current scenario in 2030.

scenario compared with other scenarios, and its relative growth rate ranked first among the three subsystems in all the scenarios. More specifically, the ecological carrying capacity value of Shanghai, Chengdu, Beijing, Wuhan, Chongqing, Tianjin saw significant growth in environment scenario. Shanghai, Beijing, Chongqing, Hangzhou, and Chengdu ranked as the top five for ecological carrying capacity in the environment scenario.

The resource carrying capacity index has a significant growth in the resource scenario, while simulation results in other scenarios show no change. The relative growth rate in the resource scenario of Beijing, Shanghai, Xian, Chengdu, and Hangzhou was higher than other cities. Chongqing, Wuhan, Suzhou, Hangzhou, and Beijing ranked as the top five of RCC evaluation.

Tourism economy carrying capacity value is seen to be higher in the economy scenario and the environment scenario than in current scenario. The trend of TCC coincides with the tourism economy carrying capacity in the economy scenario. The five highest cities of TECC index were Beijing, Hangzhou, Tianjin, Chengdu, and Chongqing. Shanghai, Suzhou, Wuhan, and Chengdu had a more significant growth of tourism economy carrying capacity in the economy scenario than in the environment scenario.

Consequently, the increment of transportation, or labor, or infrastructure, or environment investment, or green area benefits the TCC of a destination, but the change of tourism resource has no significant impact on TCC. The local government could enhance TCC through improving transportation, reducing pollution, increasing labor, infrastructure, environment investment, and green area, and preventing over exploitation of tourism resource. Furthermore, the impacts of economic, resource and environmental improvement on enhancing TCC of different cities are various, such as environmental improvement is more important to Shanghai, Suzhou, and Chongqing cities to improve their TCC. Economic improvement is contributes most to improving the TCC for Beijing, Tianjin, and Wuhan cities, while tourism resource improvement is the key for Xian, Chengdu, and Hangzhou.

4.3.2. Trend of six main indicators

The relative growth rate of tourism resource value changes in resource scenario compared with current scenario. Fig. 8 represents that

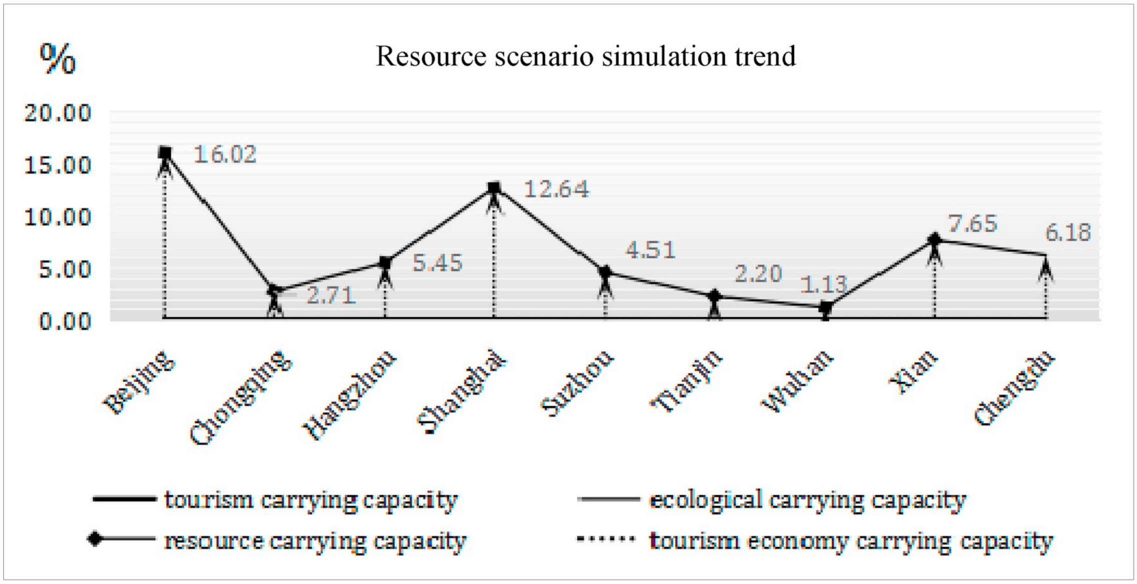

Fig. 7. Relative growth rate in the resource scenario compared with current scenario in 2030.

number of tourism resource in all the cities has a significant growth in the resource scenario than that in other scenarios. Specifically, Beijing, Suzhou, Wuhan, Hangzhou, and Chongqing have the top five highest relative growth rate. The top five cities that have the biggest number of tourism resource in 2030 are changing from Tianjin, Shanghai, Chengdu, Chongqing, and Xian to Beijing, Chongqing, Shanghai, Hangzhou, and Suzhou. The impact of increasing tourism resource amount on TCC is not significant.

As for the tourist simulation results, the number of tourists presents a significant growth in the environment scenario (see Fig. 9). The cities will attract more tourists if they improve environmental investment, protect green area, and decrease industrial waste emission. From the spatial perspective, the amount of tourists visiting the nine cities in the environment scenario in 2030 rank from high to low in the following sequence: Shanghai, Beijing, Suzhou, Chongqing, Tianjin, Wuhan, Hangzhou, Chengdu, and Xian, of which Suzhou, Wuhan, Tianjin, Chongqing, and Shanghai have the highest relative growth rate influenced by environment policy. Consequently, tourists' travel behavior is mainly influenced by the environment quality of urban tourism destination, which indicates that the government and managers of tourism companies need to pay more attention to external environment protection and improvement. In order to enhance the attraction of scenic spots, managers could use low-carbon tourism products and recycled materials, and utilize green facilities (such as resting places, visitor centers, corridors, trails, and parking lots) (Serra-Llobet & Hermida, 2017). For the government, increasing the use of renewable energy and green transportation, minimizing waste, and using biodegradable products can improve the external environment (Pan et al., 2018).

As shown in Fig. 10, tourism economic growth in the economy scenario shows a significant decline compared with those in the other scenarios, which means that an economic improvement strategy is not an effective way to enhance tourism economic growth. Although expanding the infrastructure, increasing labor, or improving transportation could enhance the TCC, tourism income might not fully cover the increasing cost. Thus, improving the tourism economy's conditions cannot really contribute to urban tourism economic growth. Furthermore, the impact of the economy scenario on the tourism economic growth will differ in different cities. The tourism economic growth decreasing rates of Shanghai, Suzhou, Wuhan, Xian, and Chongqing rank as the top five of all the value. Beijing, Hangzhou, Tianjin,

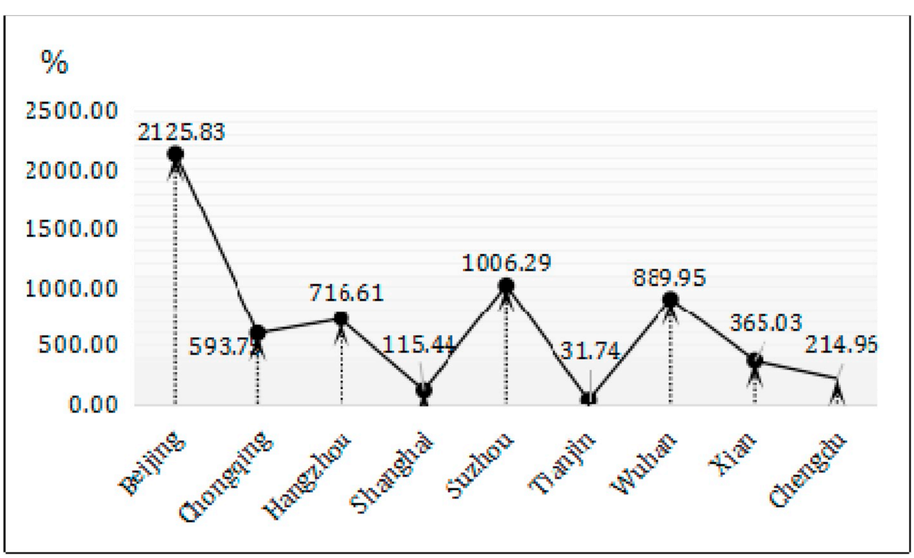

Fig. 8. Relative growth rate of tourism resource in the resource scenario compared with current scenario in 2030.

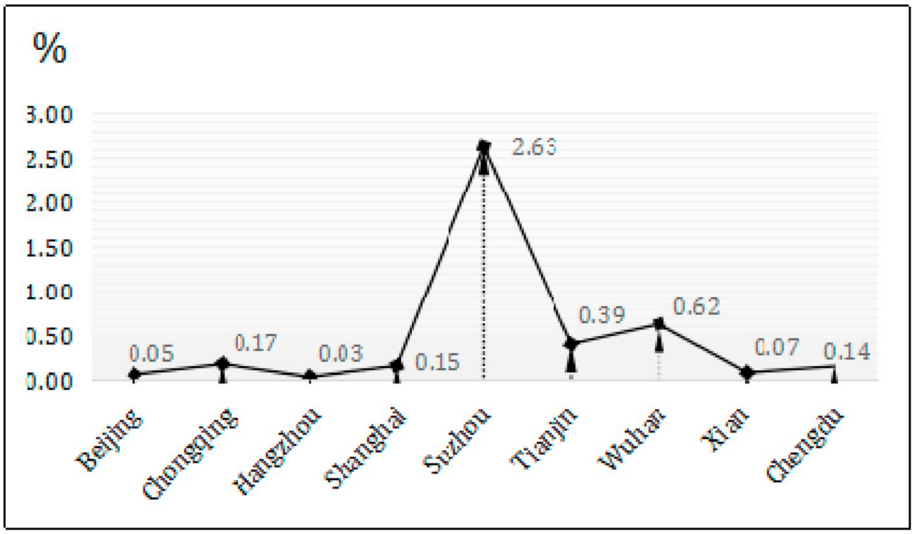

Fig. 9. Relative growth rate of tourists in the environment scenario compared with current scenario in 2030.

Chengdu, and Chongqing will have the highest tourism economic growth value in 2030.

In the environment scenario, both ecological resilience and environmental treatment value are higher than those in the other scenarios while environmental pollution value is lower than those in the other scenarios. The relative growth rate of ecological resilience is higher than that of environmental treatment. Shanghai, Chengdu, Wuhan, Beijing, and Tianjin have the top five highest growth rate of ecological resilience in environment scenario compared with current trend. Environmental treatment in Tianjin, Beijing, Suzhou, Wuhan, and Chengdu will have the top five relative growth rate.

Obviously, ecological resilience and green area of urban tourism destination in the environment scenario are larger than those in the other scenarios, respectively. Thus, the governments and firms should focus on environmental protection to improve TCC.

5. Discussion

This paper has established a dynamic TCC framework and simulates the TCC tendency in four scenarios by SD method. It focuses on urban tourism development from a macroscopic perspective and predict the dynamic change of TCC and tourism growth in the long-run. The following discussion explores interactions among tourism economic growth factors, examines the links with environment, and suggests some policies of TCC management.

5.1. Interactions between tourism economic growth and its impact factors

Considered as a dynamically complex system, the tourism industry is influenced by many interacting components, such as water supply, infrastructure, resorts, labor, capital, and transportation (Mai & Smith, 2018). Scenario simulations show that TCC will have an increase in both the economy scenario and the environment scenario compared with those in the current scenario; tourism economic growth will decline in the economy scenario but will increase in the resource scenario compared with the current scenario. The results indicate that tourism resources and GDP have positive impacts on tourism economic growth, while tourism labor, infrastructure, and transportation have negative impacts. The continued growth of tourism labor, infrastructure, and transportation will incur additional high costs, which lead to a decrease

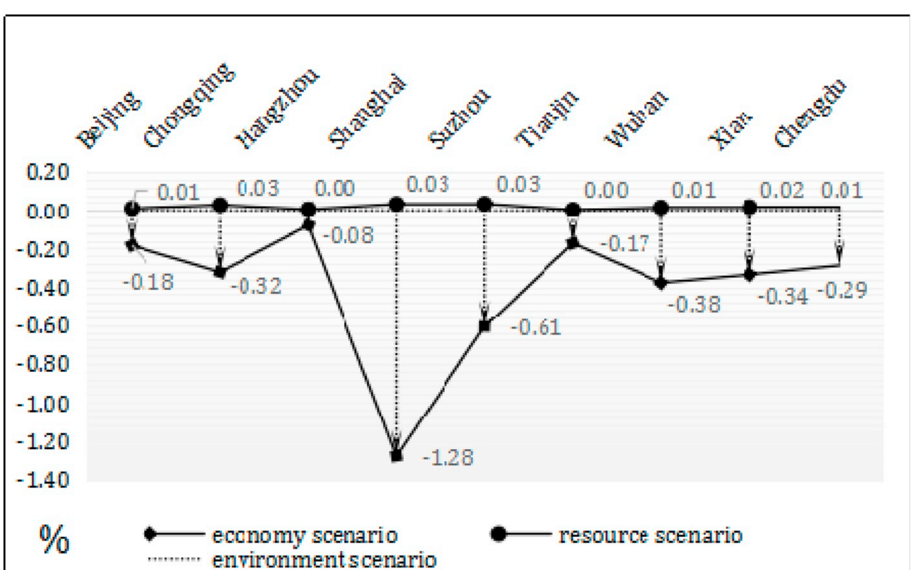

Fig. 10. Relative growth rate of tourism economic growth in three scenarios compared with current scenario in 2030.

in tourism economic growth.

With regard to tourism labor, employees in tourism destination play a critical role in tourism industry: the perception of whom may impact tourists' satisfaction and their pro-tourism behavior (Nunkoo & Gursoy, 2012; Tovar & Lockwood, 2008). An increase in employee can enhance the TCC but might cause harm to the tourism economic growth. If employees' perceived disadvantages of the job, organization and location outweigh any employment advantages (Solnet, Ford, Robinson, Ritchie, & Olsen, 2014), they will more likely to quit. The increasing outflow of workforce will negatively affect tourist satisfaction and cause a rise in costs (e.g. recruitment cost and training expenditure) in the long run. Thus, the top nine tourist cities should focus on the quality of employees and improve workforce strategies for them, rather than to just provide jobs.

With respect to tourism infrastructure, the results indicate that infrastructure has positive impact on TCC, while it has negative influence on tourism economic growth. The relationship between infrastructure and tourism has been discussed in prior studies. Numerous scholars indicate that tourism economic growth can be enhanced through investment in new infrastructure (Bennett, Lemelin, Koster, & Budke, 2012). Imikan and Ekpo (2012) illustrate that tourism infrastructure has contributed positively to tourist arrivals in Niger-Delta where is lack of tourism infrastructure. But according to life-cycle theory, when the tourism destination grows into a mature level in the long run, the increase of infrastructure might negatively affect the tourism competitiveness, such as causing a rise in waste generated by hotels, resorts and restaurants, or increasing capital surplus. That means it is not efficient to expand the scale of tourism enterprises when the development of a tourism destination is at a high growth level. Within a high growth level and mature development situation, the top nine tourist cities will have a rise in the number of tourists but a decline in tourism economic growth when increasing the tourism infrastructure.

In terms of transportation, the interaction between transportation (such as oil price, network, mode, and service) and tourism is widely studied in the literature. Scholars mainly analyze the accessibility and the benefits from tourists but pay little attention to the costs (including time cost and environmental pollution) of road transportation. An increase in road transportation will lead to a significant growth of self-driving tourists along with a rise in oil demand. As Chatziantoniou, Filis, Eeckels, and Apostolakis (2013) note, demand-side oil price arising exerts a negative impact on tourism economic growth, then it can be concluded that transportation will effect tourism economic growth negatively because of the oil price growth. Moreover, improving transportation may attract more tourists, but also bring environmental pollution and increase the vehicle traffic congestion at the same time, which will weaken the accessibility of destinations, and increase tourists' time costs. Promoting road transportation is a vital strategy for the government to capture a higher number of tourists at the beginning of tourism development, but when some cities that are in high level of accessibility will meet with transportation exogenous, governments might be more likely to optimize road transportation system through taxing pollution, utilizing low-carbon vehicles and other environmental modes of transport (Aguiló, Palmer, & Rosselló, 2012). This is what the tourist cities need to do in the future in order to reduce the costs of transportation, and optimize external environmental conditions. In addition, a rise in tourism resources, tourism capital, and GDP will promote tourism economic growth. Similar impacts on tourism economic growth have demonstrated in many studies.

With regard to tourism resources, the relationship between tourism resources and tourism development has been argued for many years without any consensus. A resource curse hypothesis proposed by Chao, Hazari, Laffargue, Sgro, and Yu (2006), Nowak and Sahli (2007) demonstrates that exploitation of tourism resource in tourism-dependent destinations can negatively impact the tourism economic growth because the increase of input costs and wages causes a decrease in the output of traditional industries, and therefore results in Dutch disease (Sheng & Tsui, 2009). However, Zeng and Zhu (2011) and Deng, Ma, and Cao (2014) suggest that large country with non-tourism-dependent economies can resist the Dutch disease effect because the income effect can outweigh negative effect of resource exploitation. This paper supports the conclusion that tourism resource contributes to tourism economic growth in large non-tourism-dependent cities. Moreover, resource curse might occur in the long term in non-tourism-dependent cities because of the crowding out human capital (Deng et al., 2014). Thus, the government should improve the quality of tourism supporting resource and encourage firms to produce diversified tourism products in order to avoid resource curse (Kurecic & Kokotovic, 2017).

In terms of GDP, the literature on the causality between tourism and economic growth has presented three directions: tourism-led growth theory (Tang & Abosedra, 2014), economics-driven tourism growth (Oh, 2005; Rivera, 2017; Tang & Tan, 2015; Wang, 2010), and bidirectional causality (Antonakakis, Dragouni, & Filis, 2015; Tugcu, 2014). The causality depends on the destinations, tourism development stage and tourism indicators. If a country's GDP is not mainly generated by tourism development, or a country relies on economic invest in tourism to establish material tourist attractions to maintain tourist inflow, the causality is from economic growth to tourism (Tugcu, 2014). In the present case, the top nine cities seem to be the ones that rely on economic invest in tourism to support tourism growth, which implies that supply-sides economic policies affect tourism growth positively in high level of urban tourism development.

5.2. Conceptual transform of TCC

Based on historical data and present situation, much literature emphasizes tourist limits from the physical, social, economic or psychological perspectives in beach, resorts, protected areas, national parks, theme parks and other micro studies. But there is no consensus on the standard of tourist limits or growth limits assessment. In this paper we suggest that the concept of TCC need to transform from tourist limits, tourist perceptions, or tourist presence, to a wider context (capability of a destination to absorb and management tourism activities), not only for theory framework expansion but also for practical capability promotion. On one hand, TCC can be strengthened depending on the external factors, such as resilience, facilities, transportation, etc. On the other hand, considered as a significant management approach to sustainable development, TCC should integrate tourist behavior management and environmental management into the a larger tourism and environmental management framework at urban level.

Visitor and environmental management concept have been proposed in previous studies. Anfuso, Williams, Hernández, and Pranzini (2014), Jang, Hong, Lee, Lee, and Shim (2014) indicate that a clean beach environment and environmental education of tourists are vital to tourists' recreational quality. Higgins-Desbiolles (2018) suggests that managing tourism industry in terms of a wider concept of sustainability with cultural, educational, ecological and spiritual purposes are essential to sustainable tourism development. Zhong, Buckley, Wardle, and Wang (2015) indicate that environmental and visitor management in protected areas, country parks are critical components of conservation worldwide. Besides, LAC theory, VIM theory, and the Visitor Activity Management Process has been used in TCC management method through controlling the number of visitors, modifying visitor behavior, enhancing facilities, or changing visitor preferences and behavior. Thus, both environmental and tourist management are critical elements in TCC framework establishment. Environmental management consists of transportation system, waste treatment plan, biological protection system, environmental impact assessment, pollution monitoring, protection investment, online reservation system, rewards and punishment system. Tourist management should not only focus on tourist behavior management, but also emphasize on fostering ecological notion.

Based on systems dynamics analysis, this paper finds that both the number of tourists and TCC keep increasing associated with urban tourism growth. TCC will have a higher growth in the economy scenario and the environmental scenario than in the current scenario, while its tendency in resource scenario is almost the same as in current scenario. Tourism resource creation contributes to tourism attraction but not the capability. Differential relative growth rate in different cities illustrates that urban tourism industry environment can be optimized by economic or environmental policies depending on the local situation. The cities those are more sensitive to environment factors, or have trouble in some environment protection, such as Shanghai, Suzhou and Chongqing, should attempt to use environmental strategies including environmental-protection-investment policy, industrial-waste-reduction policy, natural-resource-protection policy, low-carbon-emissions-reduction policy in the transportation and infrastructure sectors, resident-civilization policy and tourist-environmental-behavior management, which will contribute to the capability of tourism activities and ecological resilience.

The cities that present extra space and resource to develop (e.g. Chengdu, Hangzhou, Xian), and locate in traffic hub region or cultural concentration (e.g. Beijing, Tianjin, and Wuhan) will be more sensitive to economic strategy. With the tourist demand increasing, these cities will be willing to expand infrastructure, transportation and labor sector, the TCC will be enhanced while tourism economic growth rate will become lower in the long run because of the increasing costs and competition in tourism market. These cities should improve the tourism information and reservation system both online and offline in order to provide more information for tourists' decision-making. A formation of good ecological behavior for every individual in cities will benefit both residents and tourists.

5.3. Practical implications

Aiming at coordinating the developments of TCC and tourism economic growth, some practical implications are proposed according to the findings of this study. The results show that environment improvement is the key to improve TCC, thus environment management for tourist cities needs to be optimized through joints efforts of stakeholders, including government, managers, residents and tourists. From the perspective of the government, they should increase investment in green energy development and pollution control (Pan et al., 2018), establish low-carbon tax and carbon cap-and-trade policies, promote the exploitation of new energy vehicles, set up a green path system, construct an intelligent transportation system and an ecological tourism enterprise evaluation institution, and implement an eco-tourism subsidy policy (e.g. green hotel, demonstration area of eco-tourism, demonstration city of ecological civilization). For managers of tourism enterprises, they determine operation strategies in the context of carbon regulation policy and ecological institution, and also build employee and tourist behavior management regulations to manage waste discharge. Managers could design ecological travel routes and products, and utilize new energy (e.g. new-energy vehicles, solar water-heating), recycled materials (e.g. recycled paper, bags, water, garbage), degradable tableware, green facilities (e.g. green buildings, restrooms, corridors, trails, parking lots) (Serra-Llobet & Hermida, 2017). For residents, they should raise their awareness of environmental protection (Chen & Tung, 2014; Simón, Narangajavana, & Marqués, 2004), support new energy products (e.g. vehicles, electric appliances), and insist on green travelling. For tourists, they should obey the behavior rules and show their respect to nature. They should select a reasonable way to travel (e.g. walking and bicycle can be to be the most ecological way), consume green products, reduce trash output, and make a rational choice of tourism destinations (including time, location, and routes).

Furthermore, tourist cities should promote growth strategies based on their carrying capability, stage of development and driving factors to balance tourism development and TCC. At the first stage of tourism development, the government and managers can improve TCC through economic policies. Aiming at sustainable development, environment policies should be carried out in tourist cities in the long run. According to the results of TCC, the nine cities should make different strategies based on local tourism development. For example, Shanghai, Suzhou, and Chongqing which are at a high level of tourism development, should focus on environmental protective policies (e.g. new energy vehicles); Beijing, Tianjin and Wuhan, which are driven by location and accessibility, need to pay more attention to economic policies (using green facilities and intelligent technology, and establishing tourism statistical and data system); Xian, Chengdu and Hangzhou. Which are at a high tourism growth rate, need to improve resource layout, protect heritage and develop time-consuming products.

6. Conclusions

This study establishes a dynamic TCC system containing three subsystems and 47 variables by the SD method. It then compares how government investments in tourism resource, environmental protection, economy and infrastructure may impact the city's tourism growth potential through four scenarios. It also investigates the relationship between tourism and external factors from supply-side perspectives, and suggests a wider framework containing the environmental and tourist management concept.

According to the result of examining how the supply-side factors affect TCC and tourism growth in tourist cities through four scenarios simulation, it was found that the TCC index in environment and economic scenario had a higher value compared with current scenario. The improvement of transportation, labor, facilities could enhance TCC, but would result in a rise in the cost and competition, and finally result in a lower value in tourism economic growth compared with the current scenario. Thus, environmental management and tourist-management strategies are suggested to be the best approach to both TCC and tourism economic growth. The government and managers should focus on the environment protection, ecological system resilience, the improvement of low-carbon facilities, pollution treatment, rewards-and-punishment policy, information-sharing platform, and the promotion of greater environmental awareness. Moreover, the number of tourists is growing associated with tourism development. Tourist management is not just a number constraint, but requires the embedding of behavior rules and the ecological concept in people's everyday lives, so that tourists would make rational decisions, reduce uncivilized behavior and then satisfy both tourists and residents.

There are also several limitations in this paper. First, the data was collected from yearly statistic books in nine cities, ignoring seasonal and daily changing analysis. Further comparative studies in other tourist cities and time zones are required. Second, the focus is on supply-side research, so some endogenous factors, such as tourists' ecological behavior cognition, residents' attitude and perception, stakeholder' willingness to protect environment, which also impact TCC, must be further studied.

Acknowledgement

We would like to thank Professor Alan August Lew for his helpful comments on the earlier drafts of this paper. This work was supported by the National Social Science Fund of China (Grant Nos. 16CGL024; 17BGL115; 19BGL143), the National Natural Science Foundation of China (Grant No. 71801121), the College of Humanities & Social Science Research Base Project of Jiangxi Province (2016) (Grant No. JD16150), the College Humanities and Social Science Key Research Base Project of Jiangxi Province (2018) (Grant No. JD18023), and the Social Science Planning Think-Tank Project of Jiangxi Province (2017) (Grant No. 17ZK33). The first author is also grateful for the support given by China Scholarship Council (File No. 201706825077).

Appendix

The main equations in the SD model.

Take Chengdu as an example, main equations in the SD model are as follows:

(01) Initial time = 2010

Units: Year

(02) Final time = 2030

Units: Year

(03) Time step = 1

Units: Year

(04) Air condition = 57.8

Units: %

(05) Ecology carrying capacity = Pollution + Resilience + Treatment

Units: Dimensionless

(06) Environment protective investment = Environment protective investment rate*GDP

Units: {100 Million Yuan}

(07) Environment protective investment rate = 0.031

Units: %

(08) Forest coverage = WITH LOOKUP (Time, ([(2010, 0)-(2030, 100)], (2010, 39.43), (2011, 39.15), (2012, 39.38), (2014, 35.86), (2016, 41.39), (2030, 41)))

Units: %

(09) GDP = INTEG (GDP growth amount, 5551.33)

Units: {100 Million Yuan}

(10) GDP growth amount = 0.604*Per capita tourism income/1e +008 + 1180

Units: {100 Million Yuan}

(11) GDP weight = 0.0408

Units: Dimensionless

(12) Green area = WITH LOOKUP (Time, ([(2010, 0)-(2030, 700,000)], (2010, 16,734), (2012, 18,519), (2014, 19,757), (2016, 31,084), (2030, 307,203)))

Units: Hectare

(13) Industrial waste gas emission = WITH LOOKUP (Time, ([(2010, 0)-(2030, 20,000)], (2010, 2225), (2011, 2832), (2012, 2971.14), (2013, 3048.83), (2015, 1710.87), (2016, 2105), (2030, 778)))

Units: 10,000 Million Cubic Metre

(14) Industrial waste solid emission = INTEG (Industrial waste solid produce, 283)

Units: 10,000 Ton

(15) Industrial waste solid growth rate = −0.162

Units: %

(16) Industrial waste solid utilized rate = WITH LOOKUP (Time, ([(2010, 0)-(2030, 100)], (2010, 98.76), (2012, 98.65), (2013, 99), (2015, 96), (2030, 86.6)))

Units: %

(17) Industrial waste water emission = WITH LOOKUP (Time, ([(2010, 0)-(2030, 80,000)], (2010, 12,259), (2011, 12,845), (2012, 11,780), (2013, 10,524), (2014, 10,064), (2016, 9262), (2030, 9342)))

Units: 10,000 Ton

(18) Land supply = 14,335

Units: Sq.m

(19) Land supply weight = 0.0448

Units: Dimensionless

(20) Per capita GDP = GDP*10,000/Population

Units: Yuan per person

(21) Per capita tourism income = Tourism economic growth*10,000/Tourists

Units: Yuan per person

(22) Pollution = Industrial waste gas emission*0.0518 + Industrial waste solid emission*0.0515

+Industrial waste water emission*0.049
Units: Dimensionless

(23) Population = INTEG (Population growth amount, 1149.07)

Units: 10,000 Person

(24) Population growth amount = 0.005*Industrial waste solid emission+3.514

Units: 10,000 Person

(25) Residential garbage treatment rate = 100

Units: %

(26) Resilience = Air condition*0.0746 + Forest coverage*0.0401 + Green area*0.0865

Units: Dimensionless

(27) Resource carrying capacity = Land supply*Land supply weight + Tourism resource weight*Tourism resource + Water supply*Water supply weight

Units: Dimensionless

(28) Sewage treatment rate = WITH LOOKUP (Time, ([(2010, 0)-(2030, 100)], (2010, 87.31), (2011, 85.85), (2012, 88.9), (2013, 85.18), (2015, 95.49), (2030, 95.49)))

Units: %

(29) Tourism labor = WITH LOOKUP (Time, ([(2010, 0)-(2030, 80,000)], (2010, 54,739), (2012, 27,369), (2013, 27,866), (2015, 23,443), (2030, 1841)))

Units: Person

(30) Tourism capital = WITH LOOKUP (Time, ([(2010, 0)-(2030, 8.8e+007)], (2010, 867,569), (2011, 950,647), (2012, 963,961), (2014, 1.21882e+006), (2015, 1.46037e+006), (2030, 6.96532e+006)))

Units: 10,000 Yuan

(31) Tourism capital weight = 0.0476

Units: Dimensionless

(32) Tourism carrying capacity = SQRT(Ecology carrying capacity*Ecology carrying capacity + Resource carrying capacity*Resource carrying capacity + Tourism economy carrying capacity*Tourism economy carrying capacity)

Units: Dimensionless

(33) Tourism economic growth = 0.185*Tourism resource-0.034*Tourism labor-0.018*Tourism infrastructure+0.247*Tourism capital-0.093*Transportation+0.715*GDP+0.002

Units: 100 Million yuan

(34) Tourism economic growth weight = 0.053

Units: Dimensionless

(35) Tourism economy carrying capacity = Tourism labor*Tourism labor weight + Tourism capital*Tourism capital weight + Tourism infrastructure*Tourism infrastructure weight + Transportation* Transportation weight + Per capita tourism income*Tourism economic growth weight + Per capita GDP*GDP weight

Units: Dimensionless

(36) Tourism infrastructure = WITH LOOKUP (Time, ([(2010, 0)-(2030, 1000)], (2010, 364), (2011, 281), (2013, 254), (2015, 208), (2030, 26)))

Units: Unit

(37) Tourism infrastructure weight = 0.0483

Units: Dimensionless

(38) Tourism labor weight = 0.0477

Units: Dimensionless

(39) Tourism resource = INTEG (Tourism resource growth amount, 17)

Units: Unit

(40) Tourism resource growth amount = Tourism resource*Tourism resource growth rate

Units: Unit

(41) Tourism resource weight = 0.0479

Units: Dimensionless

(42) Tourist growth amount = 0.002*Per capita GDP+1149.69

Units: 10,000 person

(43) Tourists = INTEG (Tourist growth amount, 6818.5)

Units: 10,000 person

(44) Transportation = WITH LOOKUP (Time, ([(2010, 0)-(2030, 800,000)], (2010, 17,923), (2011, 19,055), (2012, 20,269), (2013, 20,732), (2015, 21,171), (2030, 734,892)))

Units: Km

(45) Transportation weight = 0.0463

Units: Dimensionless

(46) Treatment = Environment protective investment*0.0709 + Industrial waste solid utilized rate

* 0.0565 + Residential garbage treatment rate*0.0529 + Sewage treatment rate*0.0417
Units: Dimensionless

(47) Tourism resource growth rate = WITH LOOKUP (Time, ([(2010, 0)-(2030, 1)], (2010, 0.118), (2011, 0.211), (2012, 0.13), (2013, 0.269), (2014, 0.152), (2015, 0.17), (2030, 0.17)))

Units: %

(48) Water supply = WITH LOOKUP (Time, ([(2010, 0)-(2030, 6000)], (2010, 855), (2012, 698), (2014, 624), (2015, 540), (2016, 627), (2030, 135)))

Units: Cubic meter

(49) Water supply weight = 0.0481

Units: Dimensionless

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jdmm.2019.100383.

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