Ecological Indicators 56 (2015) 218–228

Contents lists available at ScienceDirect

Ecological Indicators

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

Tourism sustainability in Tibet – Forward planning using a systems approach

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A R T I C L E I N F O

Article history:
Received 19 November 2014
Received in revised form 11 March 2015
Accepted 7 April 2015

Keywords:
Tourism sustainability
Evaluation of tourism sustainability
System dynamics
BP neural network

A B S T R A C T

The purpose of this study is to employ a nonlinear dynamic evaluation method to assess the tourism sustainability of Tibet Autonomous Region (TAR), China, a new emerging tourism destination. The methodology draws on system dynamics and Back Propagation (BP) neural network. According to 7 setting principles, this study identifies 13 tourism sustainability indicators including conventional tourism income, tourism resources stock, pollution stock, etc., as well as specific residents' tourism cognition, seasonal difference, accessibility, etc. Then a system dynamics model including the 13 indicators (variables) and other relevant auxiliary variables is established. Based on the numerical simulation, using a three layers BP neural network optimized by genetic algorithm and particle swarm algorithm, this study evaluates the future sustainability dynamically and compares the sustainability evolution from 2014 to 2050 under different development strategies. The research results not only provide information useful for the dynamic control and scientific management of the future sustainable tourism development, but also provide a systems approach to evaluate regional tourism sustainability.

1. Introduction

Since the appearance of the Sustainable Development as an environmental management thought, sustainable development strategies have been gradually formed and widely accepted by the public. In this context, the World Tourism Organization (UNWTO) proposed the concept of Sustainable Tourism Development (STD) in 1993, and then United Nations Educational, Scientific and Cultural Organization (UNESCO), United Nations Environment Programme (UNEP) and UNWTO jointly adopted "Sustainable Tourism Development Charter" and "Sustainable Tourism Development Action Plan" at the World Tourism Sustainable Development Conference held in Spain. Consequently, "sustainable tourism development" and "sustainable tourism" have become high frequency key words in research publications on tourism. Thereinto, the assessment of tourism sustainability has become the focus of the literature on sustainable tourism and its hot topic (Lu and Nepal, 2009).

Sustainable development was defined as development that meets the needs of the present without compromising the ability of future generations to meet their own need, due to the fact that STD is based on the sustainable development (UNWTO, 1998), the assessment of the STD is developed on the regional sustainable development evaluation. Accordingly, the UNWTO defines STD as follows: sustainable tourism development meets the needs of present tourists and host regions while protecting and enhancing opportunities for the future. Generally, a sustainable development evaluation index system includes three domains: economy growth, society development, and environment protection (Li et al., 2009; Yu and Wen, 2010; Tso et al., 2011; Hak et al., 2012). Similar to the evaluation of sustainable development, the evaluation of STD is also based on economic, social and environmental elements, supplemented by other related indicators such as population, resources, etc. (Tsaur et al., 2006; Choi and Sirakaya, 2006; Sharpley, 2009; Castellani and Sala, 2010; Blancas et al., 2011; Wan and Li, 2013; Pérez et al., 2013).

Yet, although considerable and sustained research efforts have contributed to the assessment of tourism sustainability, there has been intense debate about how sustainability should be assessed (reductionist vs. systems approach; Ko, 2005). The dominant research paradigm currently is mainly based on linear methods (reductionist approach) measuring different level indicators such as Analytic Hierarchy Process (AHP) (Tsaur and Wang, 2007; Lee et al., 2010; Park and Yoon, 2011; Crouch, 2011), Touristic Ecological Footprint Model (Gössling et al., 2002; Yang and Li, 2005; Li and Hou, 2011; Castellani and Sala, 2012) and Data Envelopment Analysis (DEA) (Cracolici et al., 2009; Pérez et al., 2013). Unfortunately, the correlation of the impact factors of STD, subjectivity of determining weights, difficulty of calculating quantitative indicators and

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http://dx.doi.org/10.1016/j.ecolind.2015.04.006
1470-160X/

appearance of noise in indicators data, as well as some other factors, lead to that the traditional research paradigm is often difficult for making scientific description of the sustainability. So the reductionist approach is limited. Thus, some improved methods such as the integration of the Delphi technique and network analysis (Melón et al., 2012), genetic algorithms (Huang et al., 2009) and spatial agent-based model (Balbi et al., 2013) demonstrate the applicability of nonlinear evaluation methods in general. In addition, there is still a critical and significant but long-neglected issue: how to assess the tourism sustainability at different development stages and scenarios. Despite the dynamic assessment in some areas such as water scarcity risk (Gain and Giupponi, 2015) and climate change (Giupponi et al., 2013), in the existing literature on evaluation of STD, more attention is paid to the static analysis, and dynamic extensions have long been neglected. Only dynamic evaluation of STD can contribute to the scientific control and management of regional tourism systems (Buhalis and Costa, 2006; Tyrrell and Johnston, 2008). Hence, Zhang et al. (2013) argues that a combination of quantitative and qualitative indexes, nonlinear and linear methods, and static and dynamic evaluations is the future of the sustainable tourism evaluation method.

Given this background, this study employs a systems approach to assess the tourism sustainability and compare the sustainability in different scenarios. Its aim is to resolve the lack of dynamic and comparative assessment of tourism sustainability. The proposed methodological framework will be a basis on which the tourism sustainability can be assessed in various destinations at different development stages and under different scenarios. The methodology presented in this paper draws on system dynamics and BP neural network. The system dynamics is a suitable approach, used to predict dynamic results of interactions in complex systems and analyze policies in different scenarios (Bald et al., 2006; Arquitt and Johnstone, 2008). BP neural network has great advantages in evaluation research with the excellent property of massively parallel distributed processing, great adaptability, self-learning, robustness and fault tolerance (Papale and Valentini, 2003; Yu et al., 2008). So the method combining system dynamics with BP neural network is right competent for this study.

This study is divided into 6 sections. In the next section we describe the case and why we choose it. In Section 3 we explain how the indicators and data were obtained to measure tourism sustainability. In Section 4 we carry out a system dynamics simulation. The results and discussions are presented in Section 5 using BP neural network and the conclusions in the final section.

2. Study area

This study takes the Tibet Autonomous Region (TAR) in China as a case study. TAR is an emerging tourism destination in China with a lot of world-famous historical sites, magnificent plateau landscapes related to Tibetan Buddhism. Since the 21st century, the central and local government have adopted policies to improve the Tibetan tourism industry strategically. In 2000, the TAR government explicitly prioritized the industry to develop tourism. At the "2005 EU-China Tourism Forum" held in Switzerland, Lhasa, the capital of TAR, was rated as the "European tourists favorite tourist city" and Potala Palace as the "European tourists favorite tourist attractions". Besides Potala Palace, Mount Qomolangma, Drepung Monastery, Tashilhunpo Monastery, Yarlung Zangbo Grand Canyon, Mount Namchabarwa, Mount Kangrinboqe, Namtso, Lake Manasarovar, etc. are also very fascinating tourism attractions. In 2010, The Fifth Tibet Work Forum of The CPC Central Committee proposed to build TAR into an important world tourism destination and put Tibetan tourism under the national development strategy. Consequently, in 2013, TAR was visited by 12.91 million tourists (23 times the number in 2000), and the tourism income amounted for RMB 16.52 billion (26 times the number in 2000) (National Tourism Administration of PRC (NTAPRC), 2014). As a result of this rapid development, some research efforts to Tibetan sustainable tourism have been made (Zhang, 2011, 2013; Zhang et al., 2011), nonetheless, few studies contributed to Tibetan tourism sustainability. There are still some critical issues remained: Does the rapid tourism development accord with the sustainable development? What are the key indicators affecting the tourism sustainability? What are the current and future tourism sustainability? What countermeasures should be adopted to improve the tourism sustainability?

Taking this into account, we take TAR as our case study to dynamically evaluate its tourism sustainability and provide important information regarding the sustainable development.

3. Sustainability indicators and data collection

3.1. Setting principles and indicators

Based on the tourism development goals presented in "Tibet Autonomous Region Tourism Development Master Plan (2005–2020)" and "Tibet Autonomous Region Twelfth Five-Year Development Plan", this study focuses on indicators with important decision-making reference values following the fundamental principles of comprehensibility, measurability and availability (Manning, 1999; Miller, 2001; Medina, 2005; Schianetz and Kavanagh, 2008), as well as special principles of independence, dynamics, boundedness and specificity.

(1) Comprehensibility. On the basis of the foregoing analysis, the STD system includes economy, society, environment, population and environment elements, and the essence of STD is to promote the coordinated development of them (Bramwell and Lane, 2013; Edgell, 2013; Liu, 2003; Zhang, 2011). Thus the evaluation indicators of STD is a comprehensive system comprising 5 subsystems: the economy subsystem, population subsystem, society subsystem, resource subsystem and environment subsystem. There will be one or more indicators in every subsystem.
(2) Measurability. The indicators should be quantitative, or qualitative ones that could be converted into quantitative indicators using quantitative methods. For instance, the local culture is a destination's most valuable asset and play an important role in achieving sustainability (George and Reid, 2005), nevertheless, culture change is difficult to be measured quantitatively in STD, hence cultural indicators are excluded in this study.
(3) Availability. It is difficult to obtain some indicators' data due to the existing statistical system in TAR, therefore, considering the tourism development, the evaluation indicators should be available through related literature analysis or field research or some technical methods. Despite the fact that crises have a major impact on STD in TAR (e.g. "SARS" in 2003, "3.14"' Lhasa Riots" in 2008), it is impossible to forecast when they will happen, so crises indicator is unavailable.
(4) Independence. Though completely independent indicators in sustainable development are nonexistent (Hak et al., 2012), there should be weak correlation between selected indicators. In traditional evaluation model (especially the linear model), there was strong correlation between indicators very often, which affects the evaluation accuracy.
(5) Dynamics. Indicators should be sensitive to the changes of the socio-economic environment, otherwise it is difficult to reflect the dynamic changes of the tourism sustainability. Some indicators such as tourism area (Pérez et al., 2013), although it may also constrain the tourism sustainability, it does not work in the

Table 1
Evaluation index system of STD in TAR.

Evaluation index system	Subsystem	Indicators
	Population	Residents' tourism cognition
		Travel congestion index
		Seasonal difference
	Economy	Tourism income
		Tourism enterprise fixed assets
		Tourism employees
		Tourist numbers
	Environment	Pollution stock
	Resource	Tourism resources stock
	Society	Tourism innovation ability
		Highway mileage
		Investment in public service
		Accessibility

evolution of STD and decision-making. So these indicators are ruled out.

(6) Boundedness. This study confines evaluation indicators into the tourism system, and excludes energy consumption, communications, finance and other common indicators found in related research.
(7) Specificity. Compared with other tourism destinations, TAR is very extraordinary. Seasonal differences, traffic restrictions, education level, etc. heavily constraint Tibetan tourism industry. So this study brings seasonal differences, accessibility and innovation ability into evaluation indicators.

According to the above criteria, 13 evaluation indicators of STD in TAR are pre-determined. In order to ensure the validity of indicators, we refer to Gain and Giupponi's (2015) research to finally select the indicators (as shown in Table 1) through involvement of key stakeholders including researchers, tourism operators, policy makers and residents.

3.2. Interpretation and calculation of indicators

(1) Population subsystem. The tourism industry has brought various effects (positive and negative) on the social economy in TAR. So how the residents regard these effects. This study designs "residents' tourism cognition" to measure the residents' overall cognitive status of the tourism development. The data is collected through questionnaire survey. The questionnaire used in this study is given in online supplementary materials (see questionnaire S1 (page 1) of online supplementary materials). This study adopts "tourist numbers/population" to calculate "travel congestion index" instead of the formal "tourist numbers/tourism destination area" (Pérez et al., 2013). The traditional calculation does not objectively reflect the tourism social psychological effect because of the vast 1,230,000 sq km land of TAR. So "tourist numbers/population" could better evaluate the crowding effect brought by the tourism development from the residents' perspective.
(2) Economy subsystem. The plateau climate is an important factor that restricts the sustainable tourism development in TAR, resulting in larger seasonal differences compared with other tourism destinations. In order to change this situation, Tibetan administrations and tourism enterprises have adopted policy innovations to enhance the quality of the public service, and some good results have been achieved. Thus the "seasonal difference" is an important indicator affecting STD in TAR. It is measured as the number of tourists in the peak season to the total numbers of visitors annually. Tourism income, tourism employees and tourist numbers are the common indicators used to evaluate tourism sustainability. Tourism development witnesses the growth of tourism enterprise fixed assets in TAR, which means that more and more capital have entered Tibetan tourism. The participation of capital will benefit the industry's sustainability (Ellison et al., 2007), so the change of tourism enterprise fixed assets could reflect the tourism sustainability in a way.
(3) Environment subsystem. This study uses "pollution" instead of "tourism pollution" to reveal the effects of environmental issues on STD, without distinguishing the pollution caused by tourism and other industries. Because, first, both industrial and tourism pollution have great impact on STD; second, from the evaluation point of view, the tourism pollution is difficult to distinguish from the overall pollution and the share of tourism pollution to pollution stock in TAR is unavailable; third, in the questionnaire survey above, the residents' pollution cognition was very distorted and they almost attributed all pollution to tourism development in spite of the pollution caused by other industries. The pollution include waste water and solid wastes, other pollution in TAR is very little (National Bureau Statistics of PRC (NBSPRC) and Ministry of Environmental Protection of PRC (MEPPRC), 2001–2013). Referring Forrester's (1973) research, we measure "pollution stock" as a whole.
(4) Resource subsystem. The "tourism resources stock" is measured as a whole too by Forrester's (1973) System Dynamics World II. For measurability, the tourism resources in this study refer to tangible ones such as mountains, lakes, buildings, etc. which are the main tourism attractions in TAR. Tourism resources stock is decreasing because of natural and human-caused loss. Natural loss is mainly due to climate change, natural disasters, etc. and we adopt natural loss rate to measure it.
(5) Society subsystem. Until now the tourism innovations has mainly been examined in a piecemeal case-by-case manner (Hjalager, 2010). Hall and Williams (2008) and Hall (2009) find that there is a clear quest for better empirical evidence regarding the innovations and quantitative research in tourism. So, considering some elements are difficult to quantify, such as technology, policy, etc., this study measures the tourism innovation ability of TAR from the macro perspective. In the following model, the "tourism innovation ability" in TAR is set to be a dependent variable affected by the "tourism research outlay" and "proportion of college education in tourism employees". Tourism research outlay is constituted by partial R&D input and tourism income.

The "highway mileage" is to reflect the transportation convenience in TAR where tourists mainly travel depending on highway (although there are air and railway transportation in TAR, the tourists they deliver are reasonable few and the share is approximately 0.5% (Bureau Statistics of TAR (BSTAR), 2001–2013). So in the past 10 years, the highway mileage increased very rapidly (from 22,503 km in 2000 to 65,198 km in 2012) and promoted the flow of tourists effectively in TAR. For "investment in public service", public service refer to the communication, finance, health care, etc. that tourists could enjoy and they help to improve tourism service level.

Especially, such as TAR, a plateau tourism destination, increasing investment in public service can effectively eliminate the dilemma (e.g. altitude sickness and electronic communications) of tourists traveling to Tibet. Considering the great influence of transportation on Tibetan tourism (e.g. when Qingzang railway was completed in 2006, tourists traveling to Tibet increased from 2,512,103 person times in 2006 to 4,029,438 person times in 2007 (BSTAR, 2008)), this study introduces "accessibility", calculated as a negative exponential function with the "travel time" as a variable (Karou and Hull, 2014) ("accessibility" in this study is limited to the transportation convenience degree in or out of TAR, excluding the internal transport, since the internal transport is reflected by "the highway mileage" in the system dynamics model).

In tourism development in TAR, there are always some outstanding problems and weaknesses such as residents' attitude, environment and resources destruction, tourism innovation, climatope and transportation (Chen and Wang, 2005; Liu et al., 2011; Zhang, 2015). The 13 indicators are closely linked to these problems and weaknesses through above analyses, so the indicators system is competent for evaluating tourism sustainability in TAR.

4. System dynamics simulation

4.1. System flow diagram

The above-mentioned 13 indicators are the main variables of system dynamics model of STD in TAR. There are complex positive/negative feedback relationships among the 13 variables. Taking tourist numbers as an example (see Fig. 1), in Tibetan tourism development, it is affected by accessibility, investment in public service, pollution stock, residents' tourism cognition, seasonal difference, the highway mileage, tourism innovation ability and tourism resources stock. And residents' tourism cognition is affected by pollution stock, tourism employees, tourism income and travel congestion index. In addition, tourism income affects pollution stock, tourism resources stock and tourism enterprise fixed assets, tourism enterprise fixed assets affects tourism employees, etc. Thus we draw the casual loop diagram of STD system in TAR (see Fig. 2), where "+" indicates positive effect and "−" indicates negative effect.

Based on Fig. 2, this study establishes a system dynamics model supplemented by other relevant variables using Rate Variable Fundamental In-tree Model (Jia et al., 2001). The In-tree Model in which we could see how the relevant variables are adopted is presented in Fig. S1 (page 2 of online supplementary materials). The system dynamics model is to simulate the trends of these indicators under the current scenario and other different scenarios. The model is composed of 5 subsystems (the population subsystem, economy subsystem, environment subsystem, resource subsystem and society subsystem), 6 level variables (the pollution stock, residents' tourism cognition, tourism employees, tourism resources stock, tourist numbers and tourism enterprise fixed assets), 10 rate variables (the decreased volume of pollution, produced volume of pollution, tourism resources consumption, residents' tourism cognition decrease, residents' tourism cognition increase, tourism employees loss, tourism employees increase, tourist change, tourism enterprise fixed assets increase and tourism enterprise fixed assets loss), 19 table functions[1], auxiliary variables (e.g. GDP, population, travel time, etc.) and constants (e.g. environmental self-purification capacity (0.031), turnover rate of tourism employees (0.180), natural loss rate of tourism resources (0.001), etc.). The model is written in VENSIM software with a time step of 1 year, and time span 51 years from 2000 to 2050. The stock-flow diagram of STD system in TAR is shown in Fig. 3.

The main data for the model evaluation is obtained in a field research. This includes the residents' tourism cognition, tourism research outlay, proportion of college education in tourism employees, turnover rate of tourism employees, proportion of tourism research outlay, research outlay share of tourism income, natural loss rate of tourism resources, environmental self-purification capacity and average lifecycle of tourism enterprise. Data of residents' tourism cognition is collected through questionnaire (see questionnaire S1 (page 1) of online supplementary materials). This study uses sampling survey to calculate turnover rate of tourism employees, proportion of tourism research outlay, research outlay share of tourism income, natural loss rate of tourism resources and environmental self-purification capacity. Proportion of college education in tourism employees is reflected by table function which is obtained by statistical analysis. Through the analysis of tourism enterprise data (including registration time, canceled time, enterprise quantity, new tourism enterprises and exited tourism enterprises) offered by Industrial and Commercial Bureau of TAR, this study determines average lifecycle of tourism enterprise. Some common data, for instance, the GDP, pollution, tourist numbers, highway mileage, public service investment, was taken from the "China Statistical Yearbook on Environment" (NBSPRC and MEPPRC, 2001–2013), "The Yearbook of China Tourism Statistics" (NTAPRC, 2001–2013) and "Tibet Statistical Yearbook" (BSTAR, 2001–2013). The interpolation of each table function is calculated according to the comprehensive analysis of the statistical yearbook and field research. This study selects 2000 as the base year, and uses the data of 2000 as the initial value and reference quantity for measuring the indexes.

4.2. Simulation results

4.2.1. Validation of system dynamics model

It is necessary to empirically calibrate the model to test the reasonability and feasibility of simulation results. This can be fulfilled by a historical test of the 6 level variables, with the time span from 2000 to 2013 (see Table 2). By comparing the simulation results with the historical data, the error range for each year was found to be below 5.5% except for 2003, 2008 and 2009 (in the three years, especially in terms of tourist numbers, the error range reached 9.68%, 79.56% and 9.98% respectively). The reason is that "SARS" (in 2003) and "'3.14'" Lhasa Riots" (in 2008) made a big shock to the tourism development of TAR. Due to this, the study calculates the historical smoothing data in 2003, 2008 and 2009 (are 1.013, 3.810, 4.786 respectively) using the exponential smoothing model. Through comparing the calculation results with the simulation results in these years, the error came to less than 6%. This verifies the validity of this model. So, the developed system dynamics model is reliable to explain the causal feedback relationship and predict dynamical changes of the STD system in TAR.

4.2.2. Simulation under different scenarios

Using the sensitivity test of the parameters in the system dynamics model, some parameters (shown in Table 3) are determined to be sensitive, so that they could significantly influence the STD in TAR. These parameters are the decision variables and each group of them represents a program. In this model, the pollution stock depends on decreased volume of pollution and produced volume of pollution, decreased volume of pollution depends on environmental protection investment and produced volume of pollution depends on GDP. So proportion of environmental protection

[1] Table function is an important component of a system dynamics model (Forrester, 1973). When it is difficult to give precise functional expression between two variables, we could use a table function to make numerical simulation to give an approximate mapping between them. In this model, every table function is given through a lot of statistical analysis.

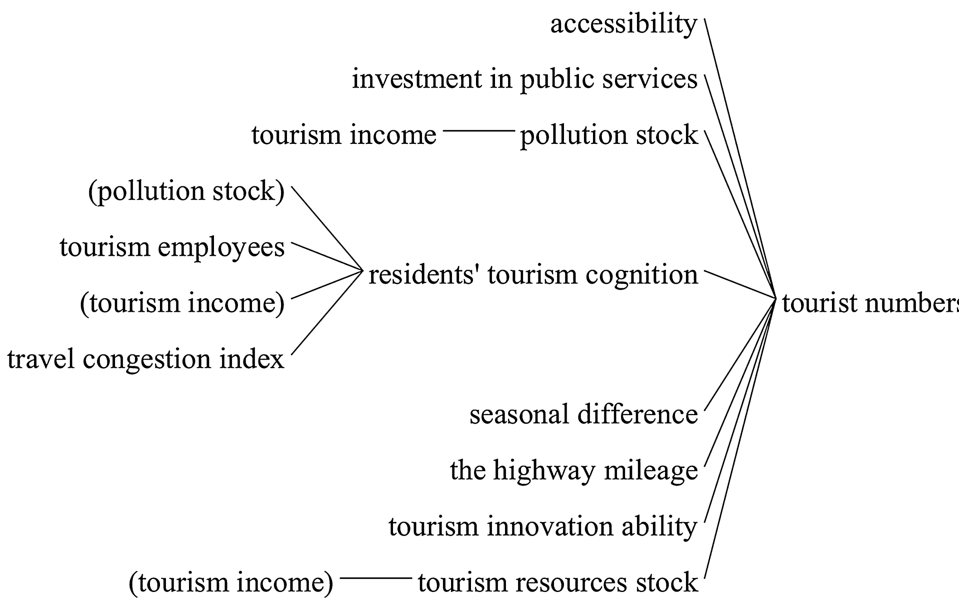

Fig. 1. Causal tree of tourist numbers.

investment and produced volume of pollution per 10,000 Yuan GDP are the important decision variables in environment subsystem. In resource subsystem, natural loss rate of tourism resources is a constant, thus tourism resources consumption depends on tourism income and then tourism resources consumption per 10,000 Yuan tourism income is a decision variable. In society subsystem, tourism innovation ability depends on tourism research outlay and the education level of tourism employees, therefore proportion of tourism research outlay, research outlay share of tourism income and proportion of college education in tourism employees are decision variables. Seasonal difference depends on tourism innovation ability and public service, hence proportion of public service investment is another decision variable. In Tibetan tourism development, high turnover rate is a significant phenomenon, so we investigate the effect of turnover rate on the model. Enterprise lifecycle has a positive effect on industry's sustainability (Ny et al., 2006), so in economy subsystem, lifecycle of tourism enterprise reflects the tourism sustainability to a great extent and average lifecycle of tourism enterprise is also an important decision variable. In "Tibet Autonomous Region Tourism Development Master Plan (2005–2020)" and "Tibet Autonomous Region Twelfth Five-Year Development Plan", economy and resource and environment strategies were proposed and compared. So this study groups the adjustment of these parameters (decision variables) into three different development strategies as shown in Table 3. We can test the performance of STD system in TAR under different development scenarios. The adjustment of parameters under different development scenarios is shown in Table 3.

Developing tendencies of the 13 evaluation indicators are simulated following different scenarios respectively, among which the

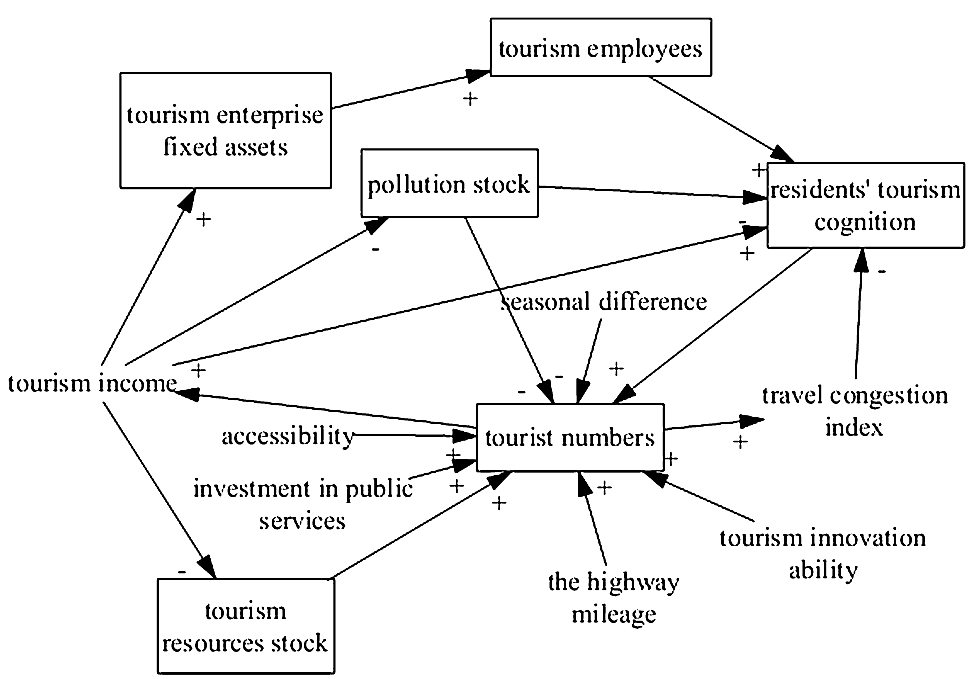

Fig. 2. Casual loop diagram of STD system in TAR with 13 evaluation indicators.

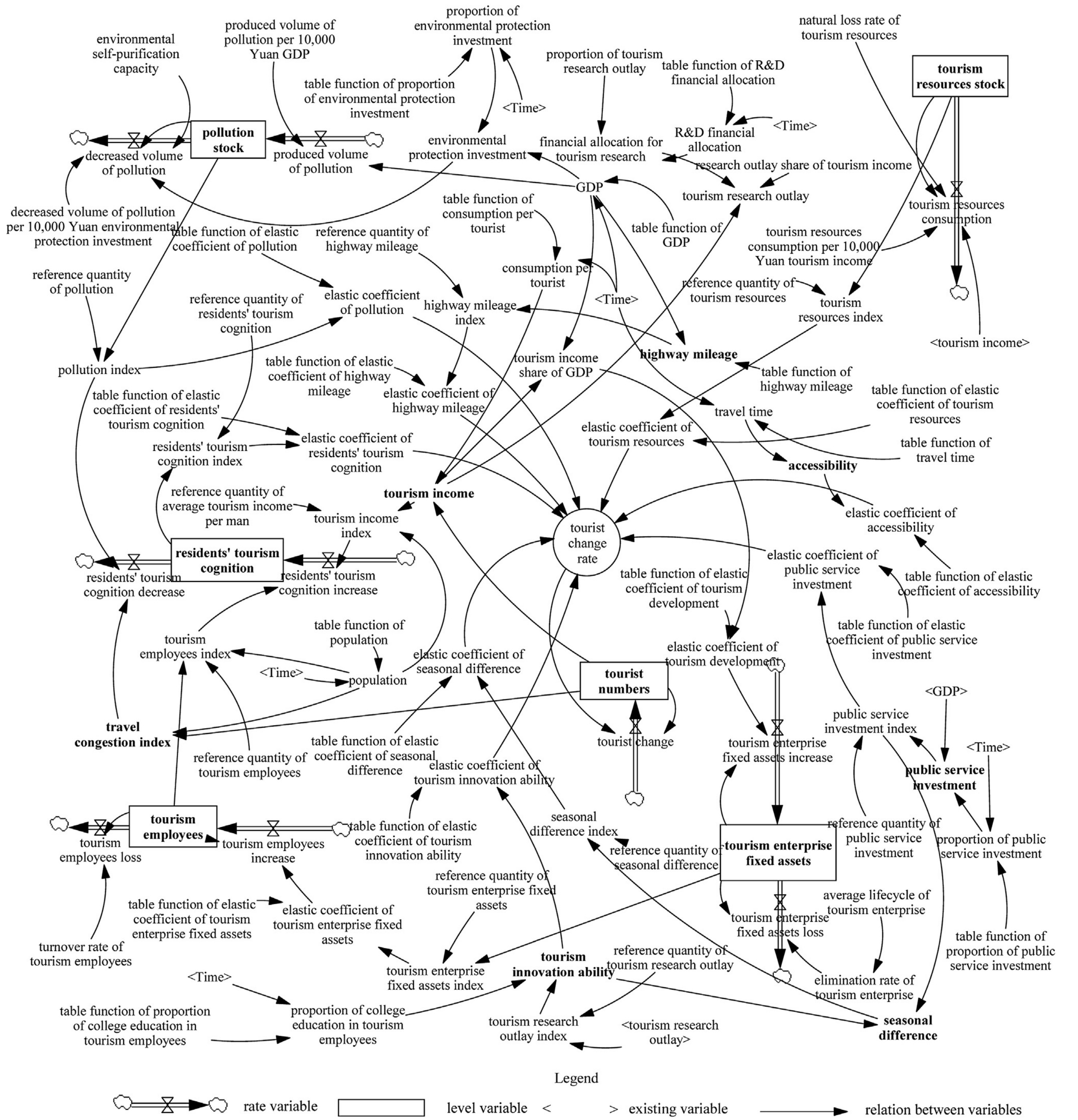

Fig. 3. Stock-flow diagram of STD system in TAR.

6 level variables are shown in Fig. 4 with R1 for the current scenario, R2 for the economy scenario, and R3 for the resource and environment scenario. All the simulated results are given in online supplementary materials (see Table S1 (page 3–7) of online supplementary materials).

5. Evaluation results on a neutral network

5.1. Data normalization

As shown in Table 1, the evaluation indicators of STD in TAR have different properties, leading to different dimensions and magnitudes. So, it is necessary to normalize each indicator. In normalization technique, there are some mature ones such as value function approach (Gain and Giupponi, 2015). This study adopts the linear transformation method to obtain normalized data using Eqs. (1) and (2).

$$I^{+'} = \frac{I_t^+ - I_{\min,t}^+}{I_{\max,t}^+ - I_{\min,t}^+} \quad (1)$$

$$I^{-'} = 1 - \frac{I_t^- - I_{\min,t}^-}{I_{\max,t}^- - I_{\min,t}^-} \quad (2)$$

where $I^{+'}$ (with positive impact) and $I^{-'}$ (with negative impact) are the normalized indicators at time t, I_t^+ and I_t^- are the positive and

Table 2
Historical data and simulation data.

Year	Residents' tourism cognition (Dmnl)		Tourism employees (10,000 persons)		Tourism enterprise fixed assets (100 million RMB)		Tourism resources stock (million resource unit)		Pollution stock (million pollution unit)		Tourist numbers (million person-times)	
	H	S	H	S	H	S	H	S	H	S	H	S
2000	3.65	3.65	13.88	13.88	3.50	3.48	100.00	100.00	8.20	8.20	0.61	0.61
2001	3.79	3.72	14.59	13.88	3.57	3.50	99.99	99.99	9.01	9.01	0.69	0.70
2002	3.67	3.81	14.54	14.20	3.83	3.70	99.98	99.98	10.02	10.02	0.87	0.82
2003	4.03	3.91	15.27	14.74	4.10	3.98	99.97	99.97	11.24	11.24	0.93	1.02
2004	4.07	4.01	14.63	15.35	4.22	4.32	99.96	99.96	12.64	12.64	1.22	1.27
2005	3.89	4.09	15.66	16.04	4.94	4.71	99.95	99.95	14.24	14.24	1.80	1.75
2006	4.00	4.16	17.41	16.77	5.33	5.14	99.94	99.94	16.01	16.01	2.51	2.37
2007	4.43	4.22	18.17	17.46	5.32	5.56	99.93	99.93	18.19	18.19	4.03	3.80
2008	4.45	4.28	17.96	18.12	5.68	5.99	99.92	99.92	20.76	20.76	2.25	4.04
2009	4.12	4.33	17.76	18.76	6.53	6.42	99.91	99.91	23.69	23.69	5.61	5.05
2010	4.28	4.37	19.53	19.38	7.20	6.85	99.90	99.90	26.99	26.99	6.85	6.90
2011	4.60	4.42	20.85	19.93	7.65	7.31	99.89	99.89	30.64	30.64	8.70	8.65
2012	4.61	4.48	21.29	20.65	7.69	7.84	99.88	99.88	34.86	34.86	10.58	10.54
2013	4.30	4.55	21.10	21.46	8.77	8.46	99.87	99.87	39.63	39.63	12.91	12.50

Note: "H" indicates historical data, "S" indicates simulation data.

negative indicators at time t respectively, $I^{+}_{\max,t}$ and $I^{-}_{\max,t}$ are the maximum of positive and negative indicators at time t respectively, $I^{+}_{\min,t}$ and $I^{-}_{\min,t}$ are the minimum of positive and negative indicators at time t respectively. In Table 1, the residents' tourism cognition, tourism income, tourism enterprise fixed assets, tourism employees, tourist numbers, tourism resources stock, tourism innovation ability, highway mileage, public service investment and accessibility are positive indicators, while the travel congestion index, seasonal difference and pollution stock are negative indicators.

5.2. Neural network evaluation model

Taking the classic BP neural network as a basic tool, using the evaluation indicators as the input data and the evaluation results as the output data, this study establishes a three layers BP neural network, including the input layer, hidden layer and output layer, to evaluate the tourism sustainability. The number of nodes in the hidden layer is determined using Eq. (3).

$$s = 2m + 1 \tag{3}$$

where s is the number of nodes, and m is the number of nodes in the input layer. Thus the developed BP neural network contains 13 input nodes, 27 hidden nodes and an output node, and the network structure is 13-27-1. Usually, when the number of nodes in the hidden layer is large, the network has high mapping ability, but it easily converges to a local minimum point and has a longer learning time (Møller, 1993). Keeping the above and some inherent problems of BP neural network in mind, this study combines a genetic algorithm and particle swarm algorithm to optimize it. The process of the hybrid algorithm is as follows.

First, the relevant parameters of the particles are initialized, and the errors of the neural network as the particles' fitness values are calculated. Second, according to the normal particle swarm algorithm, particles' velocities and positions are optimized and updated. Third, according to the selection, the crossover and mutation idea of genetic algorithms, new particles are generated. Finally, the best particles as the results of the hybrid algorithm are selected. The population size is 20, the iteration number is 100. For the mathematical description of the hybrid algorithm, see Appendix.

The evaluation value of STD capability ranging from 0 to 1 is divided into 5 grades: 0–0.2 for very weak (I), 0.2–0.4 for weak (II), 0.4–0.6 for general (III), 0.6–0.8 for strong (IV), 0.8–1 for very strong (V). The study uses TAR tourism development data from 2000 to 2013 as the research sample to test the performance of the neural network, with the data from 2000 to 2010 as the training sample, and the data from 2011 to 2013 as the test sample. Then it evaluates the dynamical development of the future STD capability and explores the evolution characteristics under different development strategies in TAR through the system dynamics simulation data from 2014 to 2050. The evaluation values from 2000 to 2013 are confirmed by three rounds of Delphi survey.

This study implements its computation process using the neural networks toolbox of Matlab 2012b. Training results of the neural network and experts' evaluation results from 2011 to 2013 are shown in Table 4. Results show that the training results are basically in line with the experts' evaluation results. The higher fitting degree indicates that the developed neural network can be used to evaluate the STD capability. Fig. 5 shows evaluation results of STD capability in TAR from 2014 to 2050.

Table 3
Parameters setting under different development scenarios simulation.

Parameter	Scenarios		
	Current scenario	Economy scenario	Resource and environment scenario
Proportion of environmental protection investment	/	↓0.2%	↑0.2%
Produced volume of pollution per 10,000 Yuan GDP	1	1.05	0.95
Tourism resources consumption per 10,000 Yuan tourism income	1	1.1	0.9
Proportion of tourism research outlay	0.014	0.01	0.02
Research outlay share of tourism income	0.000015	0.00001	0.00002
Proportion of college education in tourism employees	/	↓5%	↑5%
Proportion of public service investment	/	↓5%	↑5%
Turnover rate of tourism employees	0.18	0.185	0.175
Average lifecycle of tourism enterprise	9.45	9	10

Note: "↓" indicates decrease, "↑" indicates increase.

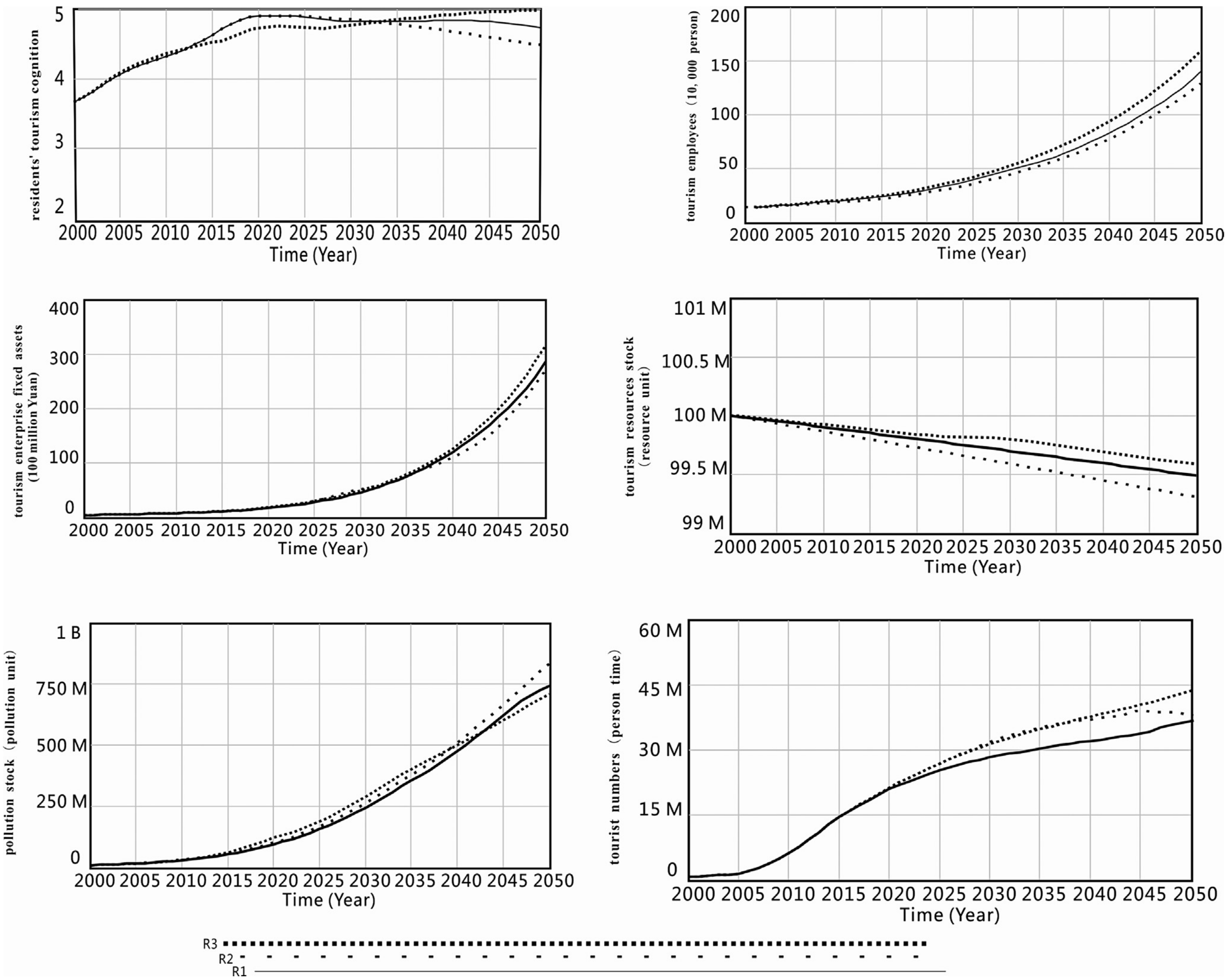

Fig. 4. Simulation under different scenarios. A limitation of the model is that the simulation is run in the common market environment without considering uncertainty. Uncertainty greatly affects sustainable tourism system such as political events (e.g. "3.14" Lhasa Riots), economic crisis (e.g. financial crisis in 2008), natural calamities (e.g. earthquake) and so on. Regarding the unpredictability of uncertain events and the availability of indicators data, the model do not considerate the uncertainty and it is out of the scope of this work to go into it in detail, however, we must recognize its significant influence. In spite of the ignorance, the simulation is also encouraging.

Table 4
Training results of neural network and experts evaluation results.

Year	Training results		Experts evaluation results		Error
	Evaluation value	Grade	Evaluation value	Grade	
2011	0.5175	III	0.5127	III	0.94%
2012	0.5234	III	0.5252	III	0.35%
2013	0.5308	III	0.5306	III	0.03%

5.3. Evaluation results

Fig. 5 shows that, under the current scenario, the Tibetan STD capability increases from 2014, and achieves the peak value (0.7946, IV grade) around 2035. But some time later, the capability begins to decline slowly and persistently. Correspondingly, the evaluation value drops to 0.7359 by 2050. Despite the strong sustainability, the decline is inevitable because of the gradually prominent resource and environment problems after 2035. Even now, we find that in some scenic spots like Namtso, Yarlung Zangbo Grand Canyon, the discharge of waste water and solid wastes increase year after year. As shown in Table S1 (page 3–7 of online supplementary materials), from 2035 to 2050, the tourism resources stock declines from 9.96×10^7 resource units to 9.95×10^7 resource units, the pollution stock increases from 3.38×10^8 pollution units to 7.41×10^8 pollution units. In addition, the residents' tourism cognition begins to decrease when it reaches

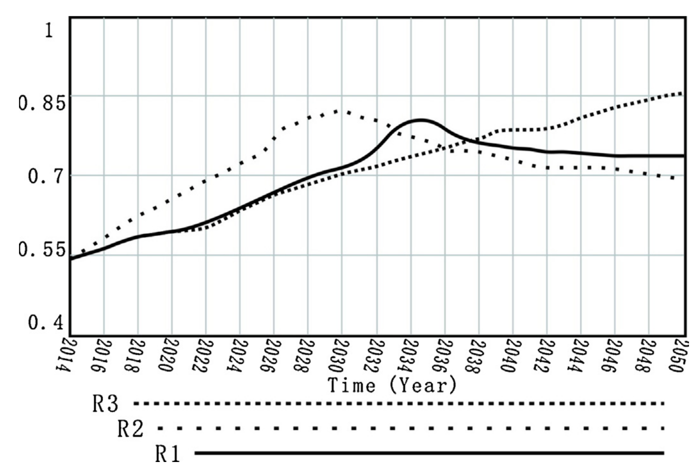

Fig. 5. Dynamic changes of STD capability under different development strategies in TAR.

a maximum value. Although other indicators are still in the state of growth, the tourism sustainability relying heavily on resources and environment in TAR (Chen and Wang, 2005) is greatly influenced by their degradation.

In economy scenario, the results indicate that the STD capability increases rapidly until 2030 and the evaluation value peaks at 0.8304. But after 2030, the capability drops rapidly, and the evaluation value is only 0.6929 in 2050. Tourism sustainability in TAR is divided into two phases: rapid growth (2014–2030) and rapid decline (2031–2050). From the simulation, most of the evaluation indicators' growth begin to slow such as tourist numbers, tourism enterprise fixed assets, tourism employees, etc., simultaneously, tourism resource stock decrease and pollution stock increase begin to accelerate. For Tibet, a plateau ecological tourist destination, overstretching and weak protection of the resources and environment, will easily destroy its sustainability. By 2050, most of the positive indicators lag behind other scenarios, on the contrary, all the negative indicators are greater. From here we see that reducing investment in environment protection, public service, tourism research and education may affect other system indicators through complex feedback relationships, thus reduce the STD system performance in TAR.

In the resource and environment scenario, the capability is in the state of steady growth. Despite the slow pace, the tourism development in Tibet conforms to the sustainable development connotation proposed at the "Rio + 20″ Summit in 2012. The evaluation value of the STD capability increases from 0.5412 in 2014 to 0.8553 in 2050, and the sustainable development grade reaches "very strong (V)" level. So this development scenario is sustainable. Nevertheless, there are still some issues remained in this scenario. As the short-term profits (especially in economy) under such development strategy is limited, would the stakeholders of Tibetan tourism accept it? Keeping the high sustainability requires plenty of investment in all aspects, but it is difficult to gain sufficient financial support in TAR which is the poorest province in China. This development strategy needs rigorous institutional constraint that is almost nonexistent here and now in TAR, so it needs a institution guarantee. Under these restrictions, although the resource and environment scenario is sustainable, the fact is that, in the construction process of world tourism destination, both enterprises and residents and even administrations most likely choose the economy strategy, which is what we really should consider.

6. Conclusion

This study develops a nonlinear dynamic model combining system dynamics with artificial neural network to evaluate tourism sustainability in TAR, a emerging tourism destination and aiming to be a world tourism destination in China. The study explores the dynamical changes in the tourism sustainability from 2014 to 2050 under different development strategies. The research results provide information useful for the dynamic control and scientific management of the future STD system in TAR and provide a new way to evaluate tourism sustainability in other areas.

For Tibet, to resolve the problems in the future tourism development and keep the sustainability, strategies including capital raising, concept renewal and scientific administrative decision need implementation. Since the very weak economic base, Tibetan local government revenue is extraordinary few and its main revenue depends on the subsidies of the central government (approximately 90% of the total revenue every year (BSTAR, 2001–2013)). Thus Tibetan financial expenditure is fixed and limited, which leads to that only a few of the amount is invested in environment protection, public service, scientific research, etc. which benefit the tourism sustainability. For instance, the proportion of environmental protection investments in TAR is far below other provinces of China (NBSPRC and MEPPRC, 2001–2013), typically, only about 1/10 of the country's average in 2011 (NBSPRC and MEPPRC, 2012). We suggest that attracting the external sources of finance especially the foreign direct investment (FDI) should be urgent and effective.

Long-closed geospatial and backward education lead to the deviation between social concept and modern tourism. We find that the value of residents' tourism cognition under resource and environment scenario is smaller than other scenarios by 2035. So for one thing, residents' concept should change for the tourism sustainability. For another, it is necessary to transform the administration and business idea as well as tourist behavior. Zhang (2006) points out that once the ecological environment in TAR is damaged, it will be irreversible. Hence both development first, protection second and development together with protection are infeasible to sustain Tibetan tourism development. The objective, in concept renewal, is to form a social atmosphere of resources and environment protection in decision-making, management and traveling, which could reduce pollution emissions and tourism resource consumption. In addition, employment concept should be changed. In TAR, traditional "officialdom standard thought" lead to that a college student would rather to be a civil servant than a "service worker" such as a tourism employee. Forming a modern employment concept is an important way to reduce turnover rate and improve the proportion of college education in tourism employees.

A comprehensive and efficient tourism administrative department is of great significance for Tibetan tourism sustainability. From above analysis, Tibetan tourism is a complex huge system and when in administrative decision-making, various departments will be involved. Establishing a new administrative department covering tourism, environment, culture, heritage, water conservancy, transport, etc. in TAR is possible. Moreover, the department must be efficient. Government-oriented Tibetan tourism needs a powerful and intelligent lead agency.

One of the main limitations of the current study is that the established indicators system could not include all the elements of STD due to the 7 criteria, even some indicator is important. For instance for climate change, it has significant impact on future tourism industry. The tourism industry may be one of the greatest economic victims of climate change (Pang et al., 2013) and sustainable tourism must address climate change (Scott, 2011). However, future climate change is difficult to forecast and we have used seasonal difference to take place climate change approximately. Nevertheless, future research should pay serious attention to the issue of climate change and tourism. Besides, crisis events also play an important role in Tibetan sustainable tourism development. But considering availability, this study excludes it. Crisis events are involving in crisis management and public opinion analysis which are not our research topic in this paper, and it will be another research area in the future.

Acknowledgements

We thank associate editor and anonymous reviewers for their constructive comments. This work was financially supported by the National Natural Science Foundation of China under Grant (71163038, 71361023); Humanities and Social Sciences Project of Ministry of Education of China under Grant (12XZJA630001); and the Key Project of Base of State Ethnic Affairs Commission of China of Tibet University for Nationalities under Grant (14mwjdz01).

Appendix. Hybrid algorithm description

A.1. Particle swarm optimization

Suppose that a group **X** consisting of n particles is flying in **D**-dimensional search space at a certain velocity, the population $\mathbf{X} = (X_1, X_2, \ldots, X_n)$. The position of the particle i, also standing for a solution to the problem, is represented as a **D**-dimensional vector $\mathbf{X}_i = (x_{i1}, x_{i2}, \ldots, x_{iD})$, the velocity is represented as $\mathbf{V}_i = (v_{i1}, v_{i2}, \ldots, v_{iD})$. According to the objective function, we can calculate the fitness value of the particle position $\mathbf{X}_i$. In the population, the individual extremum is $\mathbf{P}_i = (p_{i1}, p_{i2}, \ldots, p_{iD})$, the global extremum is $\mathbf{P}_g = (p_{g1}, p_{g2}, \ldots, p_{gD})$. When searching, every particle changes its position in accordance with its searched individual extremum and other particles' individual extrema in the population by Eqs. (4) and (5).

$$v_{iD}^{k+1} = \omega v_{kD}^{k} + c_1 \xi (p_{iD}^{k} - x_{iD}^{k}) + c_2 \eta (p_{gD}^{k} - x_{iD}^{k}) \tag{4}$$

$$x_{iD}^{K+1} = x_{iD}^{k} + v_{iD}^{k+1} \tag{5}$$

where ω is inertia weight, $i = 1, 2, \ldots, n$, k is current iteration number, c_1 and c_2 are acceleration factors (nonnegative constant in general), ξ and η are pseudo-random numbers distributed in [0,1]. To prevent the blind search of particles, their position and velocity are limited in a certain interval $[-X_{\max}, X_{\max}]$ and $[-V_{\max}, V_{\max}]$ respectively.

A.2. Particle selection, crossover and mutation

A.2.1. Selection of particles

For individual i, let its fitness value be F_i, and let the population size be NP, the selected probability of the particle is represented as Eq. (6).

$$P_i = \frac{F_i}{\sum_{i=1}^{NP} F_i} \tag{6}$$

Then the wheel method is adopted to implement the selection of particles. Let $PP_0 = 0, PP_i = \sum_{j=1}^{i} PP_j$, rotating NP times. Every time when rotating, we randomly generate $\xi_k \in U(0, 1)$. When $PP_{i-1} \le \xi_k \le PP_i$, the particle i is selected.

A.2.2. Crossover of particles

At each iteration, a certain number of particles in the population are selected and put into a pool. The selected particles cross each other in the pool, generating the same amount of progeny particles that are used to replace the parent particles. So, the population size remains the same. In each dimension, the position of progeny particles is calculated by the arithmetic crossover of parent particles using Eq. (7) (s is a progeny particle, f is a father particle, m is a mother particle).

$$\begin{aligned} s_1(x_i) &= \varphi_i * f(x_i) + (1 - \varphi_i) * m(x_i), \\ s_2(x_i) &= \varphi_i * m(x_i) + (1 - \varphi_i) * f(x_i) \end{aligned} \tag{7}$$

where φ_i is a pseudo-random number distributed in [0,1]. The velocity vector of progeny particle is calculated by normalizing the sum of parents' velocity vector using Eq. (8).

$$s_1(v_i) = \frac{f(v_i) + m(v_i)}{\left|f(v_i) + m(v_i)\right|} * \left|f(v_i)\right|, \; s_2(v_i) = \frac{f(v_i) + m(v_i)}{\left|f(v_i) + m(v_i)\right|} * \left|m(v_i)\right| \tag{8}$$

A.2.3. Mutation of particles

After the selection and crossover phases, a mutation operation is added with a predetermined probability p_v. This study uses Gauss mutation method to update particles' position and velocity by using Eq. (9) (Higashi and Iba, 2003).

$$mut(x) = x * [1 + Gaussian(\sigma)] \tag{9}$$

where $mut(x)$ is the position of mutant particle, σ is the 1/10 length of each dimension of search space.

Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2015.04.006

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