Sustainability **2014**, *6*, 2320-2337; doi:10.3390/su6042320

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

Simulation and Prediction of Decarbonated Development in Tourist Attractions Associated with Low-carbon Economy

Yuyan Luo [1], Maozhu Jin [2,*], Peiyu Ren [2], Zhixue Liao [2] and Zhongfu Zhu [3]

[1] College of Management Science, Chengdu University of Technology, No.3, Dongsan Road, Erxian Bridge, Chengdu 610059, China; E-Mail: luoyuyan13@cdut.cn

[2] Business School, Sichuan University, No.24 South Section 1, Yihuan Road, Chengdu 610065, China; E-Mails: renpeiyu@scu.edu.cn (P.R.); law1219@126.com (Z.L.)

[3] Management Bureau of Jiuzhai Valley Scenic and Historic Interest Area, Zhang Zha Zhen, Aba Zhou 623402, China; E-Mail: zzfandly_418@163.com

* Author to whom correspondence should be addressed; E-Mail: jinmaozhu@scu.edu.cn; Tel.: +86-28-8541-6236; Fax: +86-28-8541-6236.

Received: 29 January 2014; in revised form: 8 April 2014 / Accepted: 9 April 2014 / Published: 21 April 2014

Abstract: In the field of tourism, the development of tourist attractions is gradually playing a crucial role in tourism economy, regional economy and national economy. While tourism economy is stimulated by growing demand, tourist attractions have been facing the situation that ecological environment is becoming fragile and environmental protection is increasingly difficult in China. As low-carbon economy is highlighted more than ever before, how to develop green economy, how to apply theories and technologies, which are related to low-carbon economy, to push forward decarbonation, to protect the ecological environment, and to boost the development of tourism economy have become the core problems for the sustainable development of tourist attractions system. In addition, this system has drawn the attention of scholars and practitioners in recent years. On the basis of low-carbon economy, this paper tries to define the decarbonated development goals and the connotation of tourist attractions system. In addition, it also discusses system structure associated with system dynamics and system engineering, and constructs system simulation model. In the end, a case study is conducted, that is, to predict the development trend of Jiuzhai Valley by adopting the constructed system so as to extend the previous research on low-carbon tourism and to guide the decarbonated development in tourist attractions.

Keywords: tourist attractions system; decarbonated development; system dynamics; Jiuzhai Valley

1. Introduction

The concept of low-carbon tourism dates back to the World Economic Forum "Go to Low-carbon Travel and Tourism Industry" in 2009 [1]. Since the global ecological and environmental problems are highlighted significantly, more are required in terms of tourism development as well as the transformation of the pattern of economic growth. In the process of tourism economy development, to transform the development mode from the traditional extensive one to the emerging intensive one, to promote the decarbonated construction, to decarbonate tourist attractions will become an inevitable choice when taking both the tourism economic development and ecological protection into account. Hopefully, a balanced development of social, economic, and ecological benefits can be realized due to the choice [2].

In 2003, energy white paper "Our Energy Future: Creating a Low-carbon Economy" issued by the U.K. firstly mentioned "low-carbon economy". The term meant that if fewer natural resources were consumed and less pollution were emitted, then more economic output would be gained [3]. With low-carbon economy and its derivative ideas affecting the industrial structure, low-carbon economic development model is established. Scholars have made researches on low-carbon economy and therefore have made some achievements. Those researches initially focused on a small number of industries, such as transportation industry, cement industry, *etc.* [4,5], providing foundations for further researches on national and global carbon emissions, *etc.* [6–8].

As researches on low-carbon economy have progressed theoretically and practically, some documents which integrated low-carbon economy with tourism industry have begun to concentrate on carbon dioxide emissions generated by tourism industry. For example, Lin [9] applied a bottom-up approach to determine the amount of carbon dioxide emissions in domestic tourism transport from 1999 to 2006. Loo and Li [10] stated that the main factor contributed to emission reduction was the lower emission intensity supported by relevant policies, the effect was weak though. Munday [11] examined the carbon footprint associated with tourism spending in a regional economy. Tsai *et al.* [12] conducted an investigation on carbon dioxide emissions from four types of hotels in Taiwan. There are also some researches on constructing and assessing low-carbon tourist attractions based on low-carbon economy, such as Chang and Peng [13], Xu *et al.* [14], Luo *et al.* [15], and Li and Yin [16].

However, the combination of quantitative intention and the goals of low-carbon economy have seldom been given to tourist attractions, which are thought to be of a static, less-consumptive nature. In addition, some early studies of the negative environmental impacts of tourism in the ways of qualitative judgments were made by Mathieson and Wall [17], Mieczkowski [18], Kelly *et al.* [19], and Holden [20]. Moreover, few works have made quantitative researches for tourism sector development, especially tourist attractions system. In fact, tourist attractions system includes several subsystems whose quantitative interrelationships are important for sustainable development. Consequently, a systematic dynamical system model with subsystems, including economic operation subsystem, social development subsystem, environmental representation subsystem, decarbonated control subsystem and constructive guarantee subsystem, will be adopted in this paper to study the trend of developing decarbonated development of tourist attractions.

Based on what has been said above, system dynamics and system engineering will be used to simulate and predict the development trend of tourist attractions system from multiple subsystems. Therefore a dynamic perspective of internal mechanism and mutual impact among the subsystems will be indicated in this paper.

Given the profound effect of low-carbon economy on tourism field, the objective of this study is to simulate and predict decarbonated tourist attractions on the aspects of economic operation, social development, environmental representation, decarbonated control, and constructive guarantee, the research results of which could be sought to provide some references for other tourist attractions, to step well in the low-carbon development road in China. To this end, the following procedure is followed. In Section 2, the low-carbon theory of tourist attractions is briefly introduced to show the goals of decarbonated development and define decarbonated tourist attractions system. Section 3 describes tourist attractions system and analyzes the cause-effect relationship and system flow diagram of the system. The case study of Jiuzhai Valley, which is carried out by means of parameter estimation and validity test, and its result analysis are in Section 4 and a conclusion of the research is in Section 5.

2. Low-Carbon Economy Theory of Tourist Attractions

2.1. Goals of Decarbonated Development

The concept of low-carbon economy, which emerged in the end of last century and the beginning of this century, penetrates into all the industries as a new economic development pattern. Since the application of low-carbon economy concept in tourism industry just takes off, it remains a rather new research area with no specific associated system of low-carbon economy and tourist attractions. In addition, developing decarbonated tourist attractions is both the foundation for an environmentally-friendly ecotourism with low energy consumption and pollution and an important measure to increase the level of ecological civilization.

Based on the connotation of low-carbon economy, decarbonated development of economy in tourist attractions refers to that throughout the whole travelling period including "foods, transportation, accommodations, sightseeing, shopping, and entertainment", services, such as operating management, resource exploitation, tourist reception, and behavior guidance of tourists provided by tourist attractions should adopt a decarbonated development pattern for tourism economy, attach importance to the protection and restoration of ecological environment, reduce the adverse influence of tourists' behaviors on ecology, achieve the maximum economic efficiency brought by carbon emissions per unit, pursue the highly efficient utilization of resources, and promote the harmonious development of human beings and sceneries.

Firstly, it indicates that tourism economy development and environmental protection should coexist. Tourist attractions are both places with beautiful sceneries and promoters of ecological balance; for instance, some national scenic spots shoulder the responsibility of developing tourism industry and promoting tourism economy, and meanwhile function as ecological barrier. The two functions, though contradicting with each other, are vital to tourism industry and national strategic development, and thus the economy shouldn't develop at the cost of ecological environment and *vice versa*. Therefore, decarbonated development of tourist attractions is a win-win act, which protects the ecological environment while developing tourism economy.

Secondly, it advocates decarbonated development of tourist attractions and tourism economic growth. It is known from the connotation of low-carbon economy that the development of decarbonated economy in tourist attractions, promotion of scenic decarbonated construction and development, and control of carbon emissions exert a certain influence on the increase of tourists' quantity, and guidance and restraint on tourists' misbehaviors, to put forward a higher demand on the management and service level of tourist attractions. Considering China's actual conditions that operating fund of tourist attractions from tourism economic growth is used not only for protection of ecological environment and resources and construction of tourist sites, but also for management and development of residents formerly living in the sites, and that decarbonated development and management of tourist attractions cannot be implemented without the support of tourism revenue, it is crucial to treat and handle properly the relationship between tourism economic growth and decarbonated development for the sustainable development of decarbonated tourist attractions and balanced development among economic efficiency, social interests, and ecological benefits.

Thirdly, innovation and development of low-carbon technology and integrated management of tourist attractions are necessary measures to reduce the damage to the ecological environment of tourist attractions brought by tons of tourists out of economic development, to adjust the influential ranges of tourists' quantity during peak periods on tourist attractions, and to realize the integrated management and control on tourists and tourist attractions.

2.2. Decarbonated Tourist Attractions System

As areas related to decarbonated tourist attractions still belong to frontier fields, the proposal and construction of decarbonated tourist attractions remain in early exploration stage with scarce research literature and further researches need to be deepened and completed.

Through field investigation into tourist attractions and researches on low-carbon areas, this paper, guided and supported by complexity science, system engineering, and information technology, claims that decarbonated tourist attractions advocate a new pattern of tourism economic growth with "low energy consumption, low pollution, low emissions" and a highly efficient integrated management concept during operating process in the era of low-carbon economy, which closely combine "low-carbon" and "development" while developing tourism economy and promoting community development, use a variety of advanced science and technology and comprehensive integrated management methods to level up energy saving and environmental protection in tourist attractions, increase vegetation coverage, decrease carbon emissions per tourist, add up the benefit from carbon emissions per unit, strengthen carbon sequestration capacity, enhance energy efficiency, and reduce pollution, and finally promote the harmonious coexistence of tourism economy and ecological environment, of human beings and sceneries to realize the win-win situation of economic, ecological and social benefits. Decarbonated tourist attractions system, of which the development is a decarbonated construction process, contains various kinds of elements, system structure, and low-carbon technology and method that are organically connected to realize decarbonated tourist attractions, and not only focuses on “low-carbon” or “development”, but also realizes the development “decarbonation” and “greenization”, that is, to seek a development pattern of decarbonated tourism economy to promote the full development of scenic compound system.

3. Modeling

3.1. System Description

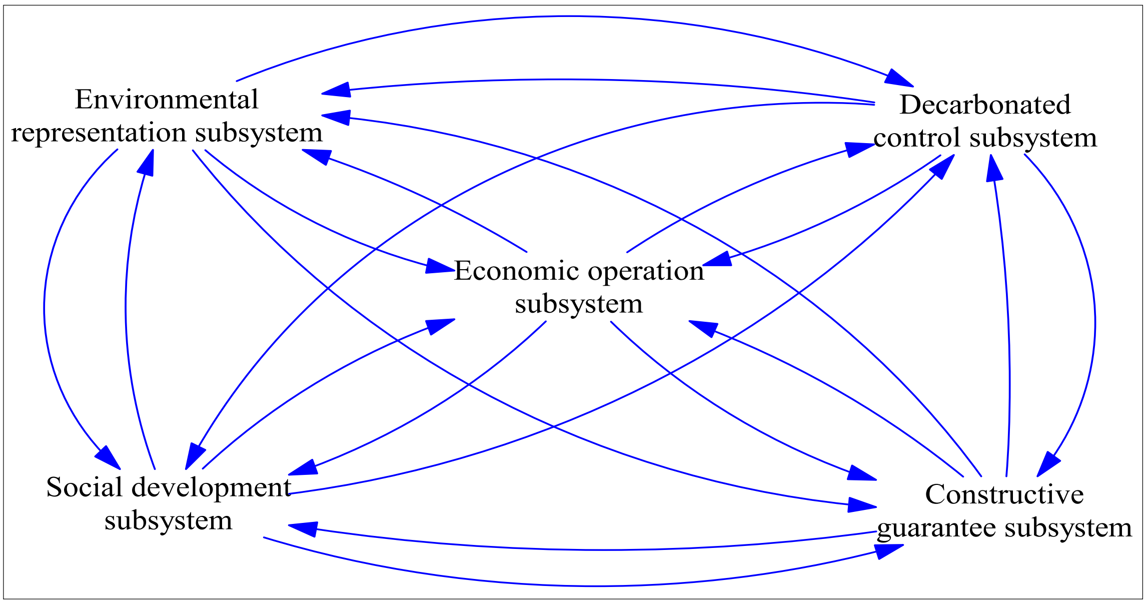
The comprehensive benefits of tourist attractions is better revealed through protecting ecological resources, reducing intensity of energy consumption and carbon emissions, improving the utilization efficiency of carbon per unit and other resources, and leading the compound system of “economy-ecology-society” to develop in a more harmonious and effective status while sustainably develop tourism economy and meet the tourists’ demands at the same time. Under the requirements of such development conditions, decarbonated tourist attractions system is composed of ecological environment, tourism economy, and social environment, among which ecological environment includes atmosphere, water, the Earth’s surface, and flora and fauna in the scenic spot; tourism economy mainly contains various kinds of tourism revenue brought by tourist reception services; social environment involves residents’ living standards, population quantity, and folk culture, *etc.* The factors above interact with each other, develop harmoniously, and further promote the ordinal change of decarbonated tourist attractions system. The assemble of several factors reflect both the status of economic operation, environmental representation, and social development related to ecological, economic, and social benefits of tourist attractions system and the interaction among those factors which is revealed in the impact of decarbonated control and constructive guarantee on the three benefits during decarbonated development process of the compound system.

Upon the basis of symbiosis benefits, decarbonated development of tourist attractions’ adequate to the development requirements of decarbonated economy and society is a specific embodiment of sustainable and protective development, and provides a method for synergetic development, by the utilization of which the subjective initiative of constructers including residents and staff is easy to be manifested in the scenic development process. Therefore, on the basis of refined structure of compound system, the development status of society, environment, and economy is not the only situation to be reflected; furthermore, the achievements gained during decarbonated development process of tourist attractions and infrastructure guarantee made to maintain regular operation should also be revealed. Since tourist attractions system is an integrated system containing various factors, this paper is based on the development of tourist attractions itself. The maximized benefits of the integrated system is reflected in five aspects of economic operation, social development, environmental representation, decarbonated control, and constructive guarantee, which contain various elements and possess an interactive relationship through description of system boundary as Figure 1 shows.

3.2. System Dynamics Model

Based on theories and methods of system modeling, division of boundaries of tourist attractions system, and the interaction among each subsystem of the description system, the internal structure of each subsystem will be determined and causality chains of each subsystem will be designed to parse the feedback structure.

Figure 1. Interactive relationship among subsystems.



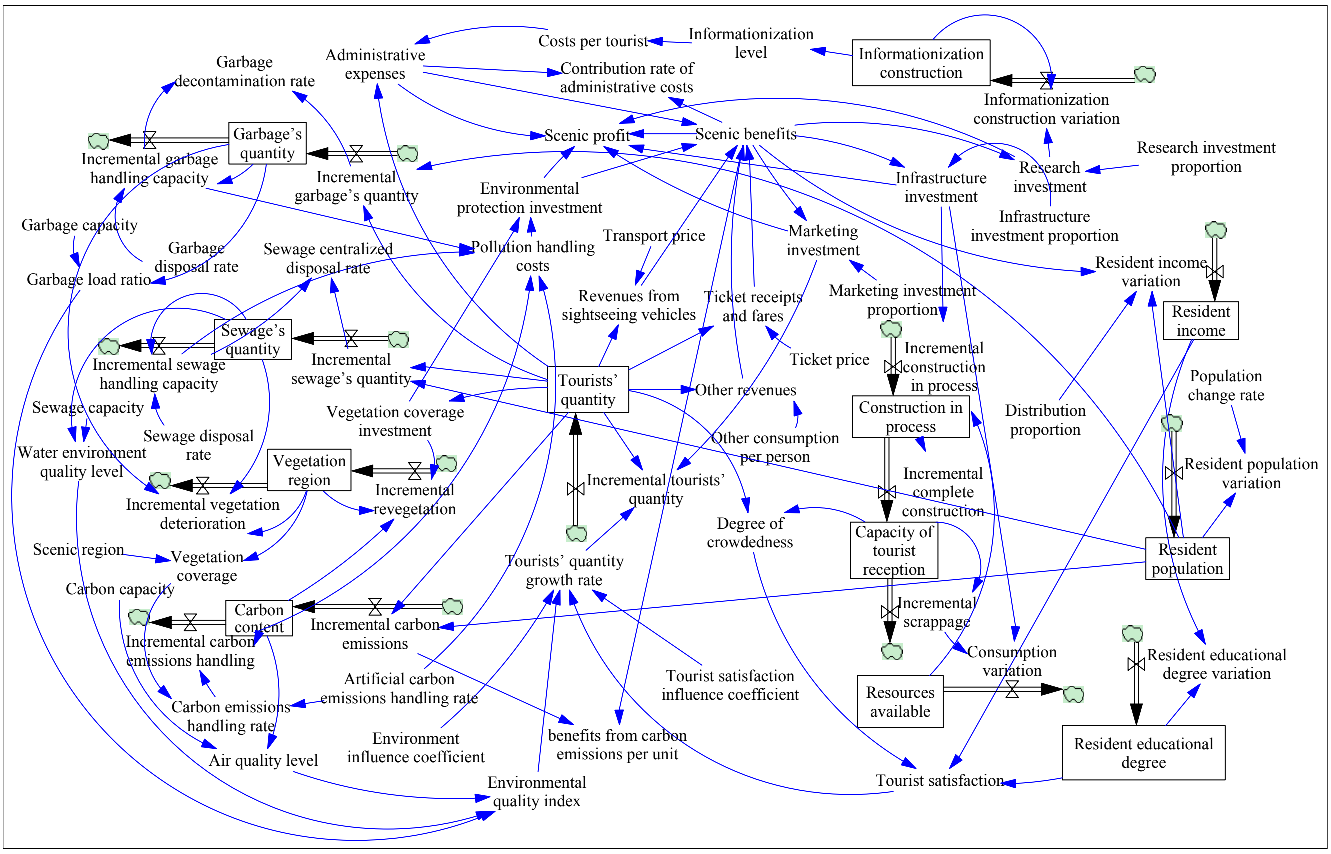
In economic operation subsystem, the revenue of tourist attractions mainly comes from tourists, and the growth of the tourists is bound to increase the revenue, so as to promote the implementation of construction in process, strengthen the capacity of tourist reception and establish an indispensable precondition for the improvement of tourist satisfaction (satisfaction degree of tourists who experience management services of tourist attractions). A good degree of tourist satisfaction will add to the attraction of scenic spots, stimulate the demand of potential tourists, increase tourists' quantity, and further cause a rise in ticket receipts and fares, incomes of sightseeing vehicles, and investment in publicity, infrastructure, environmental protection and other aspects, which will exert both positive and negative effect on the scenic benefits in the short term, and reduce scenic benefits to some extent when the increase of tourists' quantity demands more administrative expenses to maintain daily operation of tourist attractions. And the causation chains of economic operation subsystem are as follows: Scenic benefits → Construction in process → Capacity of tourist reception → Tourist satisfaction → Tourists' quantity → Ticket receipts and fares (Revenues from sightseeing vehicles, Other revenues and Administrative expenses) → Scenic benefits.

In environmental representation subsystem, a good condition of air quality level, water environment quality level, and vegetation coverage will attract more tourists, accompanied by discharge of carbon dioxide, garbage and sewage, putting forward new challenges to the scenic bearing capacity of carbon emissions, garbage and sewage. As carbon content, garbage's quantity, and sewage's quantity increase, the scenic remaining bearing capacity of carbon emissions, garbage and sewage in the scenic spot will be lessened, reducing the air quality level, water environment quality level, and vegetation coverage, and further affecting the experience result of tourists and holding back the increase of tourists' quantity. The causation chains of environmental representation subsystem are as follows: (1) Air quality level → Tourists' quantity → Carbon content → Scenic remaining bearing capacity of carbon emissions → Air quality level; (2) Air quality level → Tourists' quantity → Carbon content → Scenic remaining bearing capacity of carbon emissions → Vegetation coverage → Air quality level; (3) Water environment quality level → Tourists' quantity → Sewage's quantity → Scenic remaining bearing capacity of sewage → Water environment quality level; (4) Water environment quality level → Tourists' quantity → Sewage's quantity → Scenic remaining bearing capacity of sewage → Vegetation coverage → Water environment quality level; (5) Vegetation coverage → Tourists' quantity → Carbon content (Garbage's quantity and Sewage's quantity) → Scenic remaining bearing capacity of carbon emissions → Vegetation coverage.

In social development subsystem, the rising living standards and improving educational degree of residents in scenic area enhance the service consciousness and exert a positive influence on increasing tourist satisfaction. The growth of tourists' quantity provides a prerequisite for an increase in scenic incomes and benefits. According to a certain distribution proportion, residents' incomes will also rise. In addition, the causation chains of social development subsystem are as follows: Living standards of residents (Resident educational degree) → Service consciousness → Tourist satisfaction → Tourists' quantity → Scenic benefits → Resident income → Living standards of residents (Resident educational degree).

In decarbonated control subsystem, quantities of garbage, sewage and carbon content primarily fluctuate with tourists' quantity, the increase of which will directly damage the ecological environment of tourist attractions and the economic, ecological, and social benefits gained by decarbonated tourist attractions system, largely against the direction of decarbonated development. Therefore, pollutants should be controlled and handled within a certain range. That the rise in handling capacity of garbage, carbon emissions and sewage positively affects the pollution handling costs, and the increase of carbon content causes vegetation absorption and stores more carbon dioxide and more investment in vegetation protection positively impacts investment in environmental protection, so as to lessen scenic revenues, exert an adverse effect on investment in tourist reception capacity, and restrain the rising of tourist satisfaction and tourists' quantity beyond a certain limit. What's more, the increase of garbage's quantity, sewage's quantity and carbon content negatively affects environmental quality index and frustrate the rise of tourists' quantity. And the causation chains of decarbonated control subsystem are as follows: (1) Garbage's quantity → Garbage handling capacity → Pollution handling costs → Environmental protection investment → Scenic benefits → Capacity of tourist reception → Tourist satisfaction → Tourists' quantity → Garbage's quantity; (2) Garbage's quantity → Garbage handling capacity → Pollution handling costs → Environmental quality index → Tourists' quantity → Garbage's quantity; (3) Sewage's quantity → Sewage handling capacity → Pollution handling costs → Environmental protection investment → Scenic benefits → Capacity of tourist reception → Tourist satisfaction → Tourists' quantity → Sewage's quantity; (4) Sewage's quantity → Sewage handling capacity → Pollution handling costs → Environmental quality index → Tourists' quantity → Sewage's quantity; (5) Carbon content → Carbon emissions handling capacity → Environmental protection investment → Scenic benefits → Capacity of tourist reception → Tourist satisfaction → Tourists' quantity → Carbon content; (6) Carbon content → Carbon emissions handling capacity → Environmental protection investment → Environmental quality index → Tourists' quantity → Carbon content; (7) Carbon content → Carbon emissions handling capacity → Environmental protection investment → Tourists' quantity → Carbon content; (8) Carbon content → Carbon emissions handling capacity → Environmental protection investment → Vegetation coverage → Tourist satisfaction → Tourists’ quantity → Carbon content.

Figure 2. System flow diagram of decarbonated tourist attractions.



In constructive guarantee subsystem, the growth of tourists’ quantity raises the need of infrastructure and informationization construction, impels tourist attractions to enhance investment in infrastructure and scientific research, and further speeds up the construction in progress and reinforces tourist reception capacity. Therefore, the reduction of tourism and land resources available would limit infrastructure construction to some extent; resources available exceeding a certain degree would put on an evident inhibition effect. The scenic integrated management level and efficiency improve as the informationization degree of tourist attractions rises, which reduces administrative expenses, increases scenic benefits, enhances input in scientific research, strengthens the capacity of tourist reception and informationization degree, and further attracts tourists. The causation chains of constructive guarantee subsystem are as follows: (1) Infrastructure investment → Construction in process → Capacity of tourist reception → Resources available → Infrastructure investment; (2) Infrastructure investment → Construction in process → Capacity of tourist reception → Tourists’ quantity → Infrastructure construction demand (Scenic benefits) → Infrastructure investment; (3) Scientific research input → Informationization construction → Management efficiency → Capacity of tourist reception → Tourists’ quantity → Scenic benefits → Scientific research input; (4) Scientific research input → Informationization construction → Management efficiency → Scenic benefits → Scientific research input; (5) Informationization construction → Management efficiency→ Capacity of tourist reception → Tourists’ quantity → Scenic benefits → Scientific research input → Informationization construction; (6) Informationization construction → Management efficiency → Scenic benefits → Scientific research input → Informationization construction.

According to the system structure and analysis on causal feedback relations among five subsystems, the system flow diagram of decarbonated tourist attractions is seen as Figure 2.

4. Simulation and Prediction

4.1. System Dynamics Equations

Combined with the logic relations and system structure of variables reflected in the constructed cause-effect diagram and system flow diagram, the system dynamics equations are created to show the quantitative relations. The process equals to that of translating system model structure into mathematical equations.

Economic Operation Subsystem: *Tourists' quantity.K = Tourists' quantity.J + Tourists' quantity variation.JK*; *Tourists' quantity variation.KL = Tourists' quantity change rate.KL × Tourists' quantity.K = Tourists' quantity growth rate.KL × Tourists' quantity.K*; *Tourists' quantity growth rate.K = Environment influence coefficient.K × Environmental quality index.K + Tourist satisfaction influence coefficient.K × Tourist satisfaction.K*; *Scenic benefits.K = Ticket receipts and fares.K + Revenues from sightseeing vehicles.K + Other revenues.K − Administrative expenses.K − Environmental protection investment.K*; *Contribution rate of administrative costs.K = Administrative expenses.K/Scenic benefits.K.*

Environmental representation Subsystem: *Garbage load ratio.K = Garbage's quantity.K/Garbage capacity.K*; *Water environment quality level.K = 1 − Sewage load ratio.K = 1 − Sewage's quantity.K/Sewage capacity.K*; *Air quality level.K = 1 − Carbon emissions load ratio.K = 1 − Carbon content.K/Carbon content.K*; *Environmental quality index.K = (1/exp(Garbage load ratio.K) + 1/exp(Sewage load ratio.K) + 1/exp(Carbon emissions load ratio.K))/3.*

Decarbonated Control Subsystem: *Environmental protection investment.K = Pollution handling costs.K + Vegetation coverage investment.K*; *Garbage decontamination rate.K = Garbage handling capacity.K/Garbage discharge.K*; *Sewage centralized disposal rate.K = Sewage handling capacity.K/Sewage discharge.K*; *Vegetation coverage investment.K = Tourists'quantity.K × Vegetation coverage investment per tourist.K*; *Garbage's quantity.K = Garbage's quantity.J + Garbage discharge.JK − Garbage handling capacity.JK*; *Garbage discharge.KL = Garbage discharge per tourist.K × (Tourists'quantity.K + Resident quantity.K)*; *Garbage handling capacity.KL = Garbage disposal rate.K × Garbage's quantity.K*; *Sewage's quantity.K = Sewage's quantity.J + Sewage discharge.JK − Sewage handling capacity.JK*; *Sewage discharge.KL = Sewage discharge per tourist.K × (Tourists'quantity.K + Resident quantity.K)*; *Sewage handling capacity.KL = Sewage disposal rate.K × Sewage's quantity.K*; *Carbon content.K = Carbon content.J + Carbon emissions.JK − Carbon emissions handling capacity.JK*; *Carbon emissions.KL = Carbon emissions per tourist.K × (Tourists'quantity.K + Resident quantity.K)*; *Carbon emissions handling capacity.KL = Carbon emissions handing rate.K × Carbon emissions.K.*

Social Development Subsystem: *Resident income.K = Resident income.J + Resident income variation.JK*; *Resident income variation.K = Scenic benefits.K/Resident quantity.K × Distribution* *proportion.K*; *Resident population.K* = *Resident population.J* + *Resident population variation.JK*; *Resident educational degree.K* = *Resident educational degree.J* + *Resident educational degree variation.JK.*

Constructive Guarantee Subsystem: *Construction in process.K* = *Construction in process.J* + *Incremental construction in process.JK* − *Incremental complete construction.JK*; *Capacity of tourist reception.K* = *Capacity of tourist reception.J* + *Incremental capacity of tourist reception.JK* − *Decremental capacity of tourist reception.JK* = *Capacity of tourist reception.J* + *Incremental complete construction.JK* − *Incremental scrappage.JK*; *Degree of crowdedness.K* = *Tourists' quantity.K/Capacity of tourist reception.K*; *Resources available.K* = *Resources available.J* – *Utilisation of resources.JK*; *Informationization construction.K* = *Informationization construction.J* + *Informationization construction variation.JK.*

4.2. Parameter Estimation

During the research process of tourist attractions system based on the system boundary of Jiuzhai Valley and the data from 2002 to 2012, the system flow diagram and the causal feedback relations, this paper, excluding price variation, confirms two factors influencing tourists' quantity growth rate in the system dynamics model, that is, environmental quality index and tourist satisfaction. The environmental quality index is mainly influenced by garbage, sewage, and carbon emissions, thus, the calculation of its value through variables like garbage load ratio, water environment quality level, and air quality level, *etc.*

Tourist satisfaction is mainly affected by scenic service quality, which is closely related to staff (resident), supplier of scenic service, and crowdedness degree. Therefore, resident income and educational degree, and crowdedness degree of scenic spots indirectly or directly impact tourist satisfaction. Since environmental quality index and tourist satisfaction exert an uncertain impact on tourists' quantity growth rate, this paper will estimate environment influence coefficient and tourist satisfaction influence coefficient by regression analysis.

Due to "SARS" in 2003 and Wenchuan Earthquake in 2008, there was a sharp decrease in tourists' quantity, especially in 2008, with 74.47% cut. In 2011, tourists' quantity restored to pre-quake levels. Thus, this paper amends the data of tourists' quantity by taking average growth rate before and after the year as the incremental tourists' quantities of the middle year so as to exclude influence of emergencies like "SARS" and Wenchuan Earthquake.

Tourists' quantity growth rate refers to the ratio of incremental quantity to tourists' quantity in the previous year, that is, $\frac{dy}{dt} = r(a,b)y$, where y refers to tourists' quantity and $r(a,b)$ refers to the tourists' quantity growth rate. $r = \frac{dy/dt}{y} = \frac{\Delta y}{\bar{y}}$, where Δy and $\bar{y}$ can be calculated through $\bar{y} = (y_i + y_{i+1})/2$, $\Delta y = y_{i+1} - y_i$ $(i = 2002, 2003, \cdots, 2010, 2011)$. Thus, tourists' quantity growth rate per year can be estimated through tourists' quantity every year as Table 1 shows.

Environmental quality index, a number used to evaluate environmental quality of scenic areas, is mainly reflected by garbage, sewage and carbon emissions, and its function expression is defined as $x_1 = \frac{1}{3}\left(\frac{1}{e^{k_1}} + \frac{1}{e^{k_2}} + \frac{1}{e^{k_3}}\right)$, and the value range of the measuring function of environmental quality index is [0, 1], where k_1 refers to garbage load ratio, k_2 refers to sewage load ratio, and k_3 refers to carbon emissions load ratio. Tourist satisfaction, a synthetical measurement index of the scenic management service conditions tourists experience when travelling, varies with crowdedness degree and service quality, which is evaluated by variables of staff (resident) income and educational degree. Accordingly, this paper claims that tourist satisfaction should mainly explore its relationship with scenic crowdedness degree, resident income and educational degree, defining its function equation as $x_2 = \frac{1}{3}\left(\frac{1}{e^{s_1}} + \frac{1}{e^{1/s_2}} + \frac{1}{e^{1/s_3}}\right)$, and the value range of measuring function of tourist satisfaction is [0, 1], where s_1 refers to crowdedness degree, s_2 refers to resident income, s_3 refers to resident educational degree. Processing results of environmental quality index and tourist satisfaction from 2002 to 2012 can be gained through the calculation as Table 1 shows.

Table 1. Tourists' quantity growth rate, environmental quality index and tourist satisfaction.

Year	Tourists' quantity growth rate	Environmental quality index	Tourist satisfaction
2002	0.17	0.84	0.81
2003	0.16	0.76	0.83
2004	0.15	0.73	0.84
2005	0.14	0.69	0.84
2006	0.12	0.66	0.84
2007	0.11	0.62	0.84
2008	0.10	0.59	0.84
2009	0.09	0.56	0.85
2010	0.08	0.53	0.85
2011	0.08	0.51	0.85
2012	0.07	0.49	0.86

Table 2. Parameters of decarbonated tourist attractions system simulation model.

Parameters	Value	Units	Source
Environment influence coefficient	0.092	Dimensionless	Data analysis
Tourist satisfaction influence coefficient	1.083	Dimensionless	Data analysis
Average consumption per tourist	290	Yuan	Field Research
Distribution proportion	5%	Dimensionless	Field Research and review of literatures
Research investment proportion	3%	Dimensionless	Review of literatures
Marketing investment proportion	10%	Dimensionless	Review of literatures
Infrastructure investment proportion	15%	Dimensionless	Field Research and review of literatures
Garbage emissions per tourist	1.112	Kilogram	Review of literatures
Sewage emissions per tourist	0.100	Cubic meter	Review of literatures
Carbon emissions per tourist	4.196	Kilogram	Field Research and review of literatures
Garbage disposal rate	97%	Dimensionless	Field Research and review of literatures
Sewage disposal rate	99%	Dimensionless	Field Research and Review of literatures
Artificial carbon emissions handling rate	8%	Dimensionless	Field Research

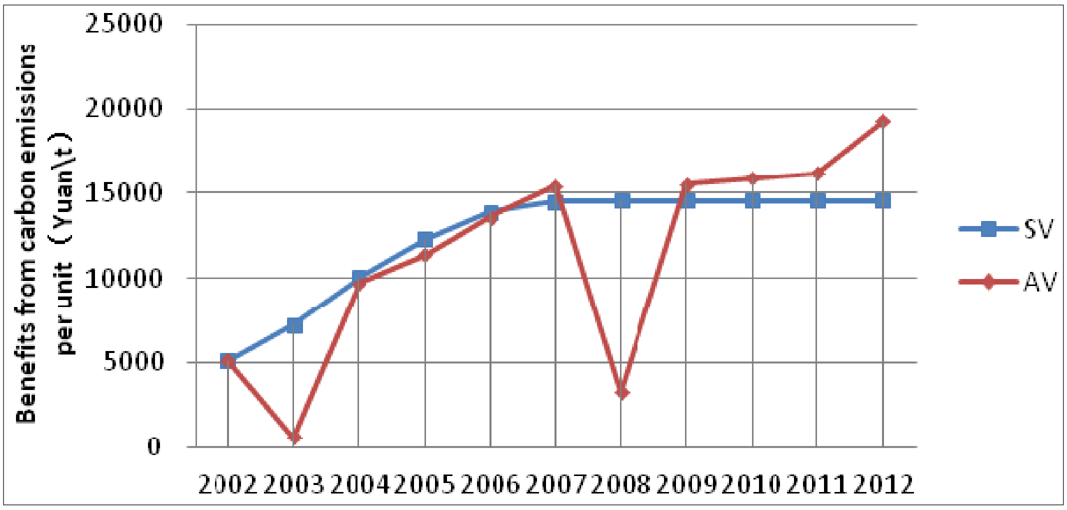
Taking tourists' quantity growth rate as a dependent variable, and environmental quality index and tourist satisfaction as an independent variable, test parameters R^2 = 0.998 can be obtained through regression analysis by SPSS. That the significance level of F is 0.038 < 0.05 and the variables of environmental quality index and tourist satisfaction T are 0.036 < 0.05 and 0.000 < 0.05, respectively illustrating that the regression model is of statistical significance. Therefore, environment influence coefficient and tourist satisfaction influence coefficient can be obtained and other parameters can be gained through field research and referring to the related literature as Table 2 shows [2]. As for carbon emissions per tourist, they are different in each scenic area, influenced by the attributes of travel distance and transport mode [9]. In addition, carbon emissions per tourist are estimated within the scenic area in this paper. Taking the actual data searched from Jiuzhai Valley into account, carbon emissions per tourist are mainly calculated from carbon dioxide emission factor generated by different energy consumption of sightseeing vehicles from 2002 to 2012 and the respiration of tourists in Jiuzhai Valley.

4.3. Parameter Estimation

To test the validity of the model, this paper compares the simulation value and actual value of vital variables of benefits from carbon emissions per unit, tourists' quantity, sewage centralized disposal rate, garbage decontamination rate, resident income per capita, scientific research input, and environmental protection investment in the five subsystems from 2002 to 2012.

As Figure 3 reveals, it can be seen that simulation value (SV) curve and actual value (AV) curve of benefits from carbon emissions per unit take on the same trend, and the calculated average relative error is 6.9% excluding the data of 2003, 2008, 2009, and 2010, that are affected by "SARS" and the earthquake.

Figure 3. Simulation value (SV) and actual value (AV) of benefits from carbon emissions per unit.



Simulation value curve and actual value curve of tourists' quantity in the mid-term of observation diverge a lot, which is strongly affected by the earthquake. In 2011, tourists' quantity restored to pre-quake levels. Therefore, this paper excludes the data of 2003, 2008, 2009, and 2010 and obtains an average relative error 11%.

Simulation value curve of sewage centralized disposal rate nearly overlapped with the actual curve, and the calculated average relative error is 2%. Simulation value curve of garbage decontamination rate nearly overlapped with the actual curve, and the calculated average relative error is 2.6%.

Excluding the data of 2003, 2008, 2009, and 2010 affected by "SARS" and earthquake, the average relative error between simulation value and actual value of resident income per capita is 10%, that of scientific research input is 8.6%, and that of environmental protection investment is 8.1%.

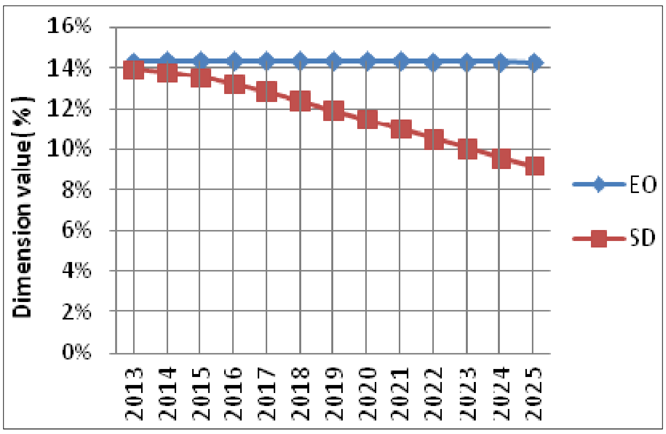
In conclusion, excluding adverse effects of incidents like "SARS" and earthquake, the error between the simulation value and actual value of major variables is controlled within 11%. Considering the particularity and complexity of tourist attractions, such kind of precision can meet the requirements of the model. What's more, the development tendency of simulation value and actual value almost stays the same, reflecting the action mechanism of economy, environment, and society in the scenic spots. Therefore, the model is reliable, effective, and can be used for system simulation and prediction of Jiuzhai Valley.

4.4. Result Analysis

According to the result of simulation run of Jiuzhai Valley previously stated, the future development process and tendency can be calculated in the dimensions of economic operation, social development, environmental representation, decarbonated control, and constructive guarantee as follows.

On the dimension of economic operation (EO), it mainly explores the lumped effect of benefits from carbon emissions per unit, contribution rate of administrative costs, and tourists' quantity growth rate. As benefits from carbon emissions per unit and contribution rate of administrative costs keep increasing constantly, the dimension values rise slowly since 2013, while benefits from carbon emissions per unit and contribution rate of administrative costs slow down its growth speed and the declining tourists' quantity growth rate becomes more obvious after 2008, slowly decreasing the dimension value. It reveals that the growth momentum of economic operation in Jiuzhai Valley wanes gradually, and the dimension value shows a trend of slight decline, but remains flat, as Figure 4 shows.

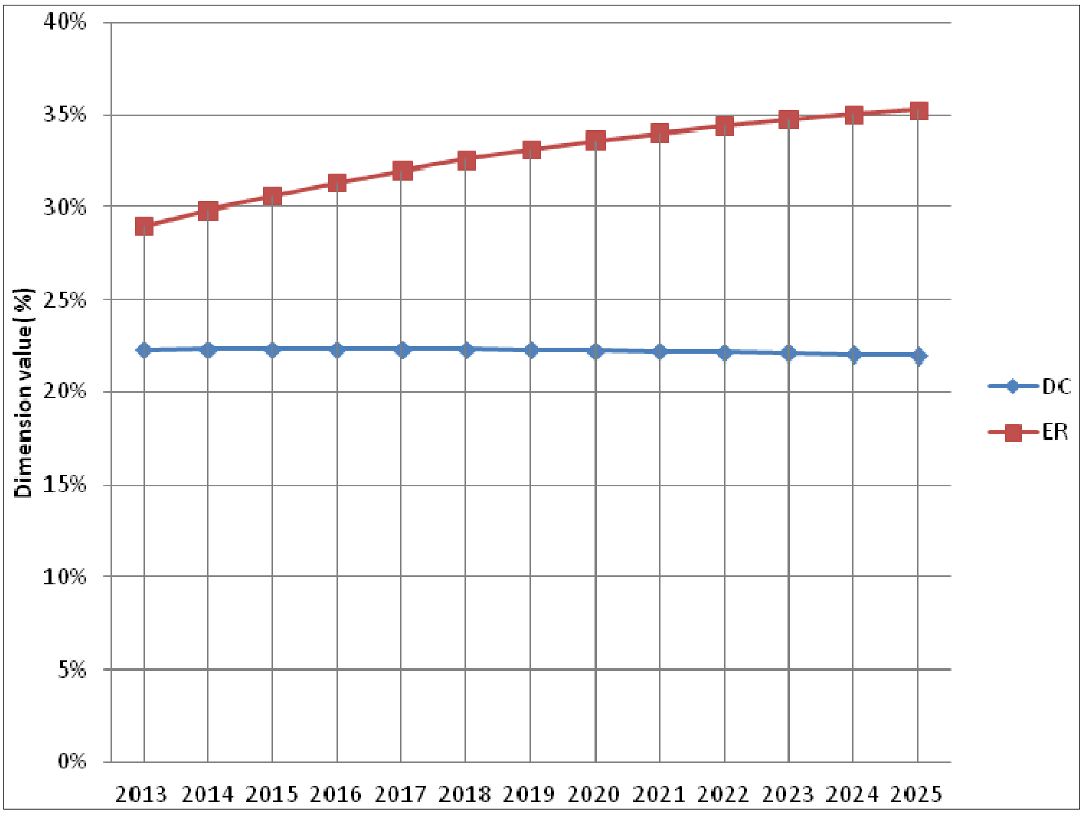
Figure 4. Development tendency of economic operation (EO) and social development (SD) dimensions.



On the dimension of social development (SD), as shown in Figure 4, it mainly reveals the lumped reflection of social development level through investigating into resident income and educational degree. When the growth rate of resident income exceeds zero, resident living standards present a rising tendency in absolute amount with a declining growth momentum. As the growth rate of resident income decreases, and the educational degree descends, the dimension value keeps declining in small amplitude, reflecting that the social development of Jiuzhai Valley tend to be saturated.

On the dimension of environmental representation (ER), it mainly researches the situation of natural environment and ecological benefits reflected by vegetation coverage, air quality level, and water environment quality level. With the strengthened protection on ecological environment and constant improvement of water environment quality level and air quality level, the change rate slows down gradually. Meanwhile, due to the limitation on scenic covering areas, differences in the nature of land utilization, the vegetation coverage maintains a steady state. Under the joint efforts of factors above, environmental representation dimension tends to stabilize gradually, as Figure 5 shows.

Figure 5. Development tendency of environmental representation (ER) and decarbonated control (DC) dimension.



On the dimension of decarbonated control (DC), it reveals the situation of decarbonated control implemented in the scenic areas, mainly including growth rate of environmental protection input, garbage decontamination rate, sewage centralized disposal rate, and decline rate of carbon emissions per tourist. Due to the increase in garbage decontamination rate and sewage centralized disposal rate and the control of carbon emissions per tourist in earlier stage, decarbonated control strength of tourist attractions will raise slightly compared with 2016. As the garbage decontamination rate, sewage centralized disposal rate, and decline rate of carbon emissions per tourist tend to be stable, and growth rate of environmental protection input declines obviously, the growth situation of decarbonated control dimension value will decline slightly after 2016, as Figure 5 reveals.

On the dimension of constructive guarantee (CG), it mainly presents the condition of scenic constructive guarantee, including the application of advanced technologies like informationization construction, infrastructure and service facilities construction, and growth rate of scientific research input. During transition process of Jiuzhai Valley from digital scenic to wisdom scenic, the scenic spot emphasizes on informationization construction and facilities construction and highly demands scientific research input at preliminary stage, while at later stage, scientific research input declines and maintenance becomes the key point, and, thus, influenced by the gradual decline of growth rate of facilities construction, informationization construction, and scientific research input, the growth momentum of scenic guarantee force decline, and its development trend tends to be stable, as Figure 6 shows.

As lumped tendency of scenic system shows (see Figure 7), under the compound effect of dimensions as economic operation, social development, environmental representation, decarbonated control, and constructive guarantee, the scenic system will reach its fastest development speed around 2015, followed by a falling tendency in lumped dimension value and then a stable tendency. Even though the absolute value presents a tendency of slow rise, the increasing or enhancing speed declines gradually according to the major factors within each dimension. From the angle of quantity, major factors of the scenic system increases slightly, or remains stable, while from the angle of the quality, the force enhancing the decarbonated development also weakens, which shows that tourist attractions develop towards low-carbon development with a declining speed.

Figure 6. Development process and tendency of constructive guarantee (CG) dimension.

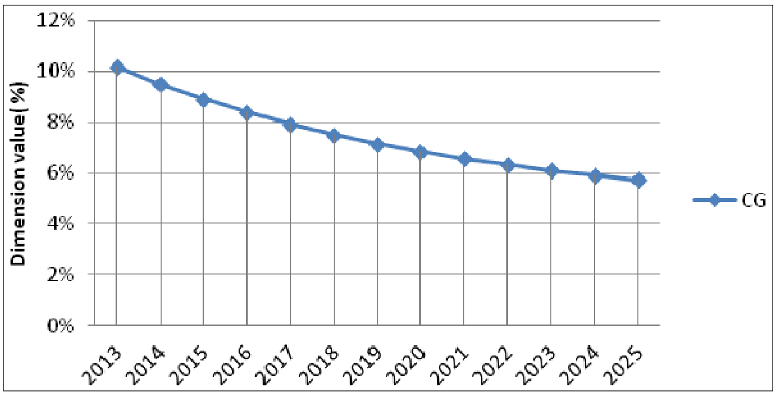
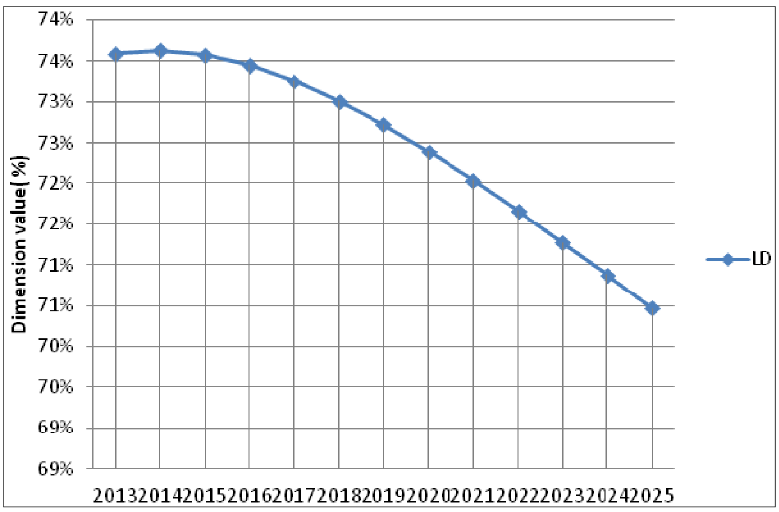


Figure 7. Lumped tendency (LD) of tourist attractions system.



5. Conclusions

This paper has discussed tourist attractions system-by-system dynamics, systematology and other related theories and methods from the perspective of decarbonated development. Within the context of decarbonated tourist attractions system, this study has found that low-carbon tourism is the key motivating aspect of sustainable tourism. Furthermore, according to the simulation of Jiuzhai Valley from the perspectives of economic operation, social development, environmental representation, decarbonated control, and constructive guarantee, this paper indicates that, the economic growth will weaken gradually, social development will tend to be a saturated state, environmental representation will become stable, decarbonated control will take on a tiny drop in growth, and the enhancement of constructive guarantee will be less in future process of decarbonated development in Jiuzhai Valley. All these can offer insights to relevant future decision-making.

For Jiuzhai Valley, introducing advanced management technologies, improving integrated management level, exploring innovative community management, promoting environmental protection and energy saving technologies would be better choices to strengthen ecological and environmental protection, and maintain a harmonious relationship between human beings and tourist attractions.

To change the extensive mode of tourist attractions system into an intensive mode, and to realize the significance of decarbonated development and sustainable development indeed could be an academic and scientific problem nowadays, as the theoretical system and its application are still on the way. Due to the limitation of subjective and objective conditions, data acquisition tends to be difficult and the model accuracy cannot be guaranteed to be a perfect state in conducting the research process, so further in-depth researches would be needed.

Acknowledgments

This work was supported by the Major International Joint Research Program of the National Natural Science Foundation of China (Grant no. 71020107027), the National Natural Science Foundation of China (Grant no. 71001075 and 71371130), Doctoral Fund of Ministry of Education of China (Grant no. 20110181110034), Central University Fund of Sichuan University (Grant no. SKQY201112), Social Sciences Program of Chengdu (Grant no. SKNHR13-07).

Author Contributions

The study was designed by Yuyan Luo in collaboration with all co-authors. Data was collected by Yuyan Luo and Zhixue Liao with assistance from Zhongfu Zhu. The first and final drafts were written by Yuyan Luo and Zhixue Liao. The draft questions were critiqued by Maozhu Jin and Peiyu Ren. The results were analyzed by Maozhu Jin and Yuyan Luo. The project and key elements of the research were reviewed by Peiyu Ren. The writing work of corresponding parts and the major revisions of this paper were completed by Maozhu Jin and Yuyan Luo.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Cheng, Q.; Su, B.R.; Tan, J. Developing an evaluation index system for low-carbon tourist attractions in China: A case study examining the Xixi wetland. *Tour. Manag.* **2013**, *36*, 314–320.
2. Luo, Y.Y.; Liao, Z.X.; Ren, P.Y.; Jin, M.Z.; Wang, J.; Zhang, Y. Decarbonated development of tourist attractions based on system dynamics. *Int. J. Environ. Pollut.* **2013**, *51*, 192–205.
3. Department for Business Innovation & Skills-GOV.UK. *Energy White Paper: Our Energy Future: Creating a Low-Carbon Economy*; Department for Business Innovation & Skills: London, UK, 2003.
4. Mazzarino, M. The economics of the greenhouse effect: Evaluating the climate change impact due to the transport sector in Italy. *Energy Policy* **2000**, *28*, 957–966.
5. Rehan, R.; Nehdi, M. Carbon dioxide emissions and climate change: Policy implications for the cement industry. *Environ. Sci. Policy* **2005**, *8*, 105–114.
6. Dalton, M.; O'Neill, B.; Prskawetz, A.; Jiang, L.W.; Pitkin, J. Population aging and future carbon emissions in the United States. *Energy Econ.* **2008**, *30*, 642–675.
7. Soytas, U.; Sari, R. Energy consumption, economic growth, and carbon emissions: Challenges faced by an EU candidate member. *Ecol. Econ.* **2009**, *68*, 1667–1675.
8. Söderholma, P.; Hildingssonb, R.; Johanssonc, B.; Khanc, J.; Wilhelmssond, F. Governing the transition to low-carbon futures: A critical survey of energy scenarios for 2050. *Futures* **2011**, *10*, 1105–1116.
9. Lin, T.P. Carbon dioxide emissions from transport in Taiwan's national parks. *Tour. Manag.* **2010**, *31*, 285–290.
10. Loon. B.P.Y.; Li, L. Carbon dioxide emissions from passenger transport in China since 1949: Implications for developing sustainable transport. *Energy Policy* **2012**, *50*, 464–476.
11. Munday, M.; Turner, K.; Jones, C. Accounting for the carbon associated with regional tourism consumption. *Tour. Manag.* **2013**, *36*, 35–44.
12. Tsai, K.T.; Lin, T.P.; Hwang, R.L.; Huang, Y.J. Carbon dioxide emissions generated by energy consumption of hotels and homestay facilities in Taiwan. *Tour. Manag.* **2014**, *42*, 13–21.
13. Chang, B.; Peng, J.J. Construction of low-carbon tourist attractions based on low-carbon economy. *Energy Procedia* **2011**, *5*, 759–762.
14. Xu, J.P.; Yao, L.M.; Mo, L.W. Simulation of low-carbon tourism in world natural and cultural heritage areas: An application to Shizhong District of Leshan City in China. *Energy Policy* **2011**, *39*, 4298–4307.
15. Luo, Y.Y.; Ge, P.; Ren, P.Y.; Liang, X.D.; Qiu, Y.Q. Integrated evaluation of decarbonated tourist attractions based on IEME. *Resour. Sci.* **2011**, *33*, 2182–2190. (In Chinese)
16. Li, X.Q.; Yin, Y. A conceptual model of low-carbon scenic spots and construction of evaluation index system. *Tour. Trib.* **2012**, *27*, 84–89. (In Chinese)
17. Mathieson, A.; Wall, G. *Tourism: Economic, Physical and Social Impacts*; Longman Publishing: London, UK, 1982.
18. Mieczkowski, Z. *Environmental Issues of Tourism and Recreation*; University Press of America Landham: Landham, MD, USA, 1995.

19. Kelly, J.; Haider, W.; Williams, P. A behavioral assessment of tourism transportation options for reducing energy consumption and greenhouse gases. *J. Travel Res.* **2007**, *45*, 297–309.
20. Holden, A. *Environment and Tourism*; Routledge: London, UK, 2008.