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Research on Evaluation Model of Regional Low Carbon Competitiveness based on Analytic Hierarchy Process & Entropy Method Co-weighting and System Dynamics Modeling Method: The Case of Chongqing, China

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Abstract: In this study, regional low carbon competitiveness evaluation system was established, and analytic hierarchy process (AHP) and entropy method (EM) were combined as the co-weighting method so that the subjective and objective weighting methods can be synthetically considered to determine the weight values of the indicators selected in the evaluation system. Based on theevaluation system, the system dynamics (SD) method was used to build the regional low carbon competitiveness evaluation model in which factors may influence the low carbon competitiveness were connected together in a whole system. Six proposed scenarios were taken to evaluate and stimulate the variation tendency of low carbon competitiveness in Chongqing from 2001 to 2020 if different policies and regulations could be put into practice. The stimulationresults and trend lines showed that low carbon competitiveness in Chongqing would develop continuously stable but relatively gentle if the current development policies remained unchanged. However, the low carbon competitiveness would be promoted to a large extent and the results of which in 2020 could be nearly twice (0.8417) than that in the Primary scenario (0.4425) in 2020 if Scenario 5 could be applied, which is an integrated panning scenario that includes policies in energy conservation, economy transition, industry optimization, society promotion and environment protection.

Keywords: Regional low carbon competitiveness; AHP-EM co-weighting method; System dynamics

1. Introduction

The rapid development of global economy has been resulting in the consequences of global climate warming and natural environment deteriorating, however, the alteration of human thought and innovation of science technology play dominant role in leading human society to rethink about the grab of the natural resources. Hence, the environment-friendly economy development models, such as green economy, cyclic economy, low carbon economy, have been proposed on the agenda from tentative idea, and which also have been deeply studied by researchers all over the world. Low carbon competitiveness is a core concept which can be used to evaluate and promote low carbon economy development in a certain region. For this reason, it is quite essential to make a profound study on the evaluation of regional low carbon competitiveness.

Integration of analytical hierarchy process (AHP), a relatively subjective weighting method (RSWM) which is usually according to the experts'evaluations,and the entropy method (EM), a relatively objective weighting method (RCWM) which is mainly based on data calculation is an effective method to co-weight the indicator values in the low carbon competitiveness evaluation (LCEE) system. The system dynamics (SD) method is used in this paper to establish the LCEE model and the stimulation of which will be realized to compare the LCEE results of 6 different scenarios by using the data in Chongqing, a municipal city in China. Based on the stimulation results, we will make a profound discussion on the development tendency of low carbon competitiveness in Chongqing.

2. Literature Review

The definition of regional low carbon competitiveness varies a lot due to the fact that there has no authoritative definition being put forward by government or official authority. The Climate Institute and the E3G (2009) defined it as the ability of a country to generate economic-prosperity while simultaneously reducing greenhouse gas emission in the G20 low carbon competitiveness report. Climate competitiveness is the ability of an economy to create during economic value through low carbon technology, products and services (Lee, H. et al., 2010). Urban low carbon competitiveness is the ability for a city to create material fortune for its residents and promote the sustainable development of the society, and the target of which is to reduce energy consumption and cut down carbon emission (Guo, 2013). By analyzing different definitions of regional low carbon competitiveness, in this paper, we define it as the comprehensive capacity of a certain region from the aspects of energy, economy, industry, society and environment, in which the economy develops smoothly in low consumption, low pollution and low emission model.

There are many successful LCCE systems have been built, and the weighting method used in these systems can be roughly divided as RSWM such as Delphi, AHP (Ma, 2011; Xiao, 2011), and ROWM, for example, entropy method, principal component analysis, and factor analysis method (Jin and Du, 2013; Lu and Shi, 2013; Zhu and Chen, 2011). However, both the RSWM and the ROWM have deficiency in weighting the value of a certain indicator by reason that the RSWMs have close relationship with the subjective judgments which can inevitably lower the objectivity and scientificity of the indicator system, while the ROWMs are data-orientated weighting methods in which data analysis is the only resource to determine the value of the indicators, and the subjectivity and predictability have been ignored in the evaluation system. To compensate the deficiencies of both kinds weighting methods, in this paper, we will put forward a co-weighting method in which the AHP and EM are combined to determine the weight of the indicators in the regional LCCE system.

System dynamics (SD) is an effective modeling method fluently used to analyze and evaluate interactions between key factors in a dynamic and complex system. Zhang et al. (2014) made a research on the development tendency analysis and evaluation of water ecological carrying capacity in the Siping area of Jilin province in China based on SD and AHP. Trappey et al. (2012) established an evaluation model for low carbon island policy and the Penghu island, in Taiwan, was taken as a case study by using SD. LCCE is a complicate evaluation system which includes energy, economy, industry, society and environment, and SD has great advantage in modeling complex system using a quantitative approach to lead to new insights that have never been achieved thus far by traditional and established models. So, the SD modeling method will be used in this paper to establish the LCCE model, and the results by stimulation will be used to analyze and put forward regional low carbon competitiveness strategies.

3. Methodology

3.1. Establishment of regional low carbon competitiveness evaluation index system

The establishment of a scientific and reasonable index system would be helpful to provide a fundamental basis for a scientific and accurate assessment of the regional low carbon competitiveness. Based on the principles of establishing LCCE system (Cheng at el., 2013; Zhang, 2011; Pan and Wang, 2012), we establish the regional LCCE system by searching literature (Cheng and Chen, 2013; Li and Zhou, 2011; Chen et al., 2012), counting indexes, and consulting experts. The evaluation system (Table 1) we built was classified into 5 sub-systems: energy sub-system, economy sub-system, industry sub-system, society sub-system and environment sub-system, and from which hierarchy, we also divided 20 indexes on the index hierarchy to make an overall and through evaluation on the current performance of regional low carbon competitiveness. Based on the evaluation and stimulation by SD, we will analyze the stimulation results and put forward promotion strategies to improve regional low carbon competitiveness.

Table 1. Regional LCCE indicator system

Object hierarchy	Rule hierarchy	Index hierarchy	Unit
Regional low carbon competitiveness (A)	Energy sub-system (B_1)	Total energy consumption ($C_{1,1}$)	10^4tce
		Proportion of coal in energy consumption ($C_{1,2}$)	%
		Ratio of clean energy in total consumption ($C_{1,3}$)	%
		Energy consumption intensity ($C_{1,4}$)	tce/10^4 yuan
		Energy consumption elasticity ($C_{1,5}$)	1
	Economy sub-system (B_2)	GDP per capita ($C_{2,6}$)	10^4 yuan/person
		Development rapid of regional economy ($C_{2,7}$)	%
		Value of foreign trade ($C_{2,8}$)	10,000 dollar
	Industry sub-system (B_3)	Industrial structure ($C_{3,9}$)	%
		R&D investment ($C_{3,10}$)	%
		Education investment ($C_{3,11}$)	%
	Society sub-system (B_4)	Natural population growth rate ($C_{4,12}$)	‰
		Sewage treatment rate ($C_{4,13}$)	%

		Public vehicles every 10,000 residents ($C_{4,14}$)	Standard units
		Engel coefficient of residents families ($C_{4,15}$)	%
	Environment sub-system (B_5)	Carbon emission per capita ($C_{5,16}$)	t/person
		Carbon emission intensity ($C_{5,17}$)	t/10^8 yuan
		Forest coverage rate ($C_{5,18}$)	%
		Investment of environment protection ($C_{5,19}$)	10^8 yuan
		Green area per capita ($C_{5,20}$)	m^2

3.2. Determination of the index weightings by using the AHP-EM co-weighting method

(1) Determination of the indexes weightings by using AHP

Due to the ambiguity and uncertainty of various indexes in the evaluation system, the AHP weighting method can be used to effectively solve the complex decision problems with multiple objectives and criteria. By using the scoring method at a scale of 1~9, 14 ecological economy experts, who have deep understandings about the regional ecological and low-carbon economy, have been invited to establish the judgment matrixes according to their own knowledge about the indexes in the low carbon evaluation to analyze the relative importance of system factors on each hierarchy. And those judgment matrixes, which fail to pass the consistency test, will be moved or recalculated before whole correct weighting matrixes are established after calculating the hierarchy weight vectors and combination weight vectors. Finally, the relative weight of each evaluation index in the evaluation system will be obtained, and the weight of index hierarchy relative to object hierarchy is calculated by Eq. (1).

$$w_j^1 = b_i^1 \times c_{i,j}^1 \tag{1}$$

Where w_j^1 is the weight of the index hierarchy relative to the object hierarchy in AHP, b_i^1 is the weight of the rule hierarchy relative to the object hierarchy in AHP, and $c_{i,j}^1$ is the weight of the index hierarchy relative to the rule hierarchy. In addition, $j=1,2,\ldots,20$ while $i=1,2,\ldots,5$ (Note. $j=1,2,\ldots,5$ when $i=1$; $j=6,7,8$ when $i=2$; $j=9,10,11$ when $i=3$; $j=12,13,14,15$ when $i=4$; $j=16,17,\ldots,20$ when $i=5$.

(2) Determination of the indexes weightings by using EM

By comparison to relatively subjective weighting methods, the objective fixed methods are based on the inherent information of indexes which could eliminate man-made disturbances, and the calculation results made by which can be more objective and accord with the facts. In information theory, entropy by Shannon can be used to determine the disorder degree and its utility in system information, and the entropy weighting method (EM), which was built upon the entropy theory, can be adapted to calculate the index weights according to the amount of information reflected by the indexes in the LCCE indicator system. In this paper, the weighting process by EM is treated as follows.

Step1: Normalization of the original data value;

For the optimized maximal data, the following Eq. (2) was applied.

$$a_{j,k} = (x_{j,k} - \min x_{j,k}) \Big/ (\max x_{j,k} - \min x_{j,k}) \tag{2}$$

For the optimized minimal data, the following Eq. (3) was applied.

$$a_{j,k} = (\max x_{j,k} - x_{j,k}) \Big/ (\max x_{j,k} - \min x_{j,k}) \tag{3}$$

Step 2: Calculation of the standardized value of indicators in Eq. (4);

$$p_{j,k} = a_{j,k} \Big/ \sum a_{j,k} \tag{4}$$

Step 3: Calculation of the entropy value of indicators in Eq. (5);

$$e_j = -k \sum_{k=1}^{n} p_{j,k} \bullet \ln(p_{j,k}) \tag{5}$$

Step 4: Calculation of the coefficient of variance of indicators in Eq. (6);

$$g_j = 1 - e_j \tag{6}$$

Step 5: Calculation of the weight of indicators in index hierarchy;

$$c_{i,j}^2 = g_j \Big/ \sum_{j=1}^{20} g_j \tag{7}$$

And, the score of i-index in k-year can be therefore got by Eq. (8);

$$a_{i,k} = \sum_{j=1}^{m} w_j \bullet a_{j,k} \tag{8}$$

By recalculating the Eq. (4) - (7), the weight of indicators on the rule hierarchy can be got by Eq. (9);

$$b_i^2 = g_i \Big/ \sum_{i=1}^{5} g_i \tag{9}$$

And so, the weight of index hierarchy relative to the object hierarchy is given by Eq. (10).

$$w_j^2 = b_i^2 \bullet c_{i,j}^2 \tag{10}$$

In these equations, $a_{j,k}$ is the score of j-index in k-year; $x_{j,k}$ is the value of j-index in k-year; $p_{j,k}$ is the standardized value of j-index in k-year; In Eq. (5), e_j is the entropy value of j-index, and the coefficientkis related to the amount of samples, which reflects the entropy of the whole sample data. Here, due to the sample data are disorderly distributed, we define $k = 1/\ln(n)$; g_i is the coefficient of variance of indicators; $c_{i,j}^2$ is the weight of indicators on the index hierarchy; $a_{i,k}$ is the score of i-index in k-year; b_i^2 is the weight of the rule hierarchy relative to the object hierarchy; w_j^2 is the weight of index hierarchy relative to the object hierarchy calculated by EM. In this study, the value of data from 2001-2012 will be used, so, $k = 1, 2, 3 \ldots, n$ where n=12, and $j = 1, 2, \ldots, 20$ while $i = 1, 2, \ldots, 5$.

(3) Determination of the index weightings by using the AHP-EM co-weighting method

The key metrics of our co-weighting method is adopting AHP method, which can comprehensively take the subjective attributes into consideration, and EM, a weighting method can be objectively determining the weights of the criteria which rest on the basis of the data only. For this, the co-weighting of the LCCE system can be calculated by integrating, b_i^1 and b_i^2 , w_j^1 and w_j^2 in Eq. (11) and Eq. (12).

$$b_i = (b_i^1 + b_i^2)/2 \tag{11}$$

$$w_j = (w_j^1 + w_j^2)/2 \tag{12}$$

Where, b_i is the weight of the rule hierarchy relative to the object hierarchy by AHP-EM co-weighting method, and w_j is the weight of the weight of index hierarchy relative to the object hierarchy by AHP-EM co-weighting method.

3.3. The system dynamics method

System dynamics (SD) is a methodology and mathematical modeling technique for framing, understanding and discussing comprehensive and complex issues, and the basic of this method is the recognition of that the structure of any system includes many circulars, interlocking and sometimes, the time-delayed relationship among its components. For SD, the basic structure unit of the system is a feedback loop that couples the status, the speed (or "decision"), and information in the system (Vincenot et al., 2011). The core of the system dynamics method is to build the casual loop diagram, which shows the cause-result relationship and interaction of each constituent componentin the whole system.Casual loop diagram aids in visualizing a system's structure and behavior, understanding the relationships and interactions, and analyzing the system qualitatively. To perform a more detailed quantitative analysis, a stock and flow model, transformed from the casual loop diagram, is needed in deep studying and analyzing, and with which, models are usually built and stimulated using computer software. The LCCE evaluation system is a comprehensive structure in which all indicators and elements have close relationship to others and significant influence on the evaluation results, so the SD method can be used to establish an evaluation model. In this paper, the low carbon competitiveness evaluation system dynamics model will be built first, and 6 scenarios will be stimulated to make a basis for promoting strategies in improving regional low carbon competitiveness.

4. Establishment of Regional LCCE Model by SD

The regional low carbon competitiveness is affected by many different factors, and most of which are nonlinear variables changing a lot in different time scales, and the SD, a dynamic modeling method which can be used to scientifically monitor how the target system changes as one or several variations inside the whole feedbacks change. According to the evaluation system built before, in this study, we will further use SD to establish the LCCE model and to stimulate the development trend of regional low carbon competitiveness. In this evaluation model, five different sub-systems which coordinate to the five indicators on the rule hierarchy will be firstly established to integrate the whole regional LCCE model.

4.1. Regional low carbon energy competitiveness sub-system

Energy condition is one of the most important factors in evaluating the regional low carbon competitiveness by reason that the amount and distribution of energy consumption are vital to the development of social economy, ecology environment, and the overall competitiveness in a certain area. Energy consumption is affected by many different factors, such as, population, energy reservation, economy development, etc. The flow chart of regional low carbon competitiveness sub-system is shown in Fig. 1.

4.2. Regional low carbon economy competitiveness sub-system

Economy development is the core target in evaluating the comprehensive competitiveness to a region which is crucial to represent the social-economic development. (The flow chart of the regional low carbon economy competitiveness sub-system is shown in Fig. 2). As we can see from the chart, the economy competitiveness is influenced by not only the economy indexes, such as, the GDP, development rapid of regional economy, but also the socialfactors, like, the total population.

4.3. Regional low carbon industry competitiveness sub-system

Industry distribution and the devotion to the low carbon industry are crucial to the development of regional low carbon competitiveness. The evaluation indicators about industry, such as, the proportion of tertiary industry, industry structure, research &development (R&D) in GDP, and devotion to education, can reflect the low carbon industry development level in a region, reflect how low carbon industry influence the regional low carbon competitiveness, and reflect the effects of industry on regional low carbon development. The flow chart of the regional low carbon industry competitiveness sub-system is shown in Fig. 3.

4.4. Regional low carbon society competitiveness sub-system

Society sub-system includes the indicators like population, sewage treatment, public transportation and Engel coefficient, etc. These indicators ware used to evaluate the public's low carbon behavior, the region's low carbon policy and the government's low carbon strategy from both the macro and the micro aspects of people's living society. The flow chart of the regional low carbon society competitiveness sub-system is shown in Fig. 4.

4.5. Regional low carbon environment competitiveness sub-system

The environment sub-system is also a core component of the LCCE system. It reflects the concrete amounts of environment protection and the carbon emission, which are two crucial factors in evaluating a certain region's low carbon competitiveness because environment condition is the basis of the low carbon development. In the feedback loop of environment sub-system, the investment of environment protection, the forest coverage rate, amount of carbon emission and carbon emission intensity are used to evaluate the low carbon environment competitiveness. The flow chart of regional low carbon environment competitiveness sub-system is shown in Fig.5.

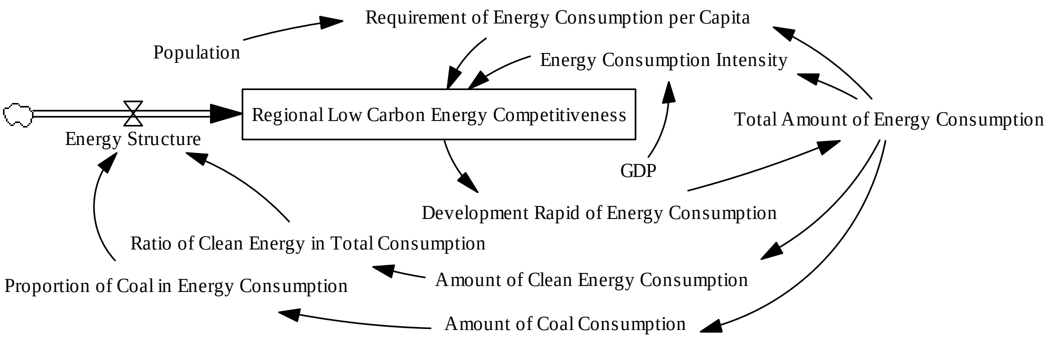

Figure 1. System dynamics flow chart of regional low carbon energy competitiveness sub-system

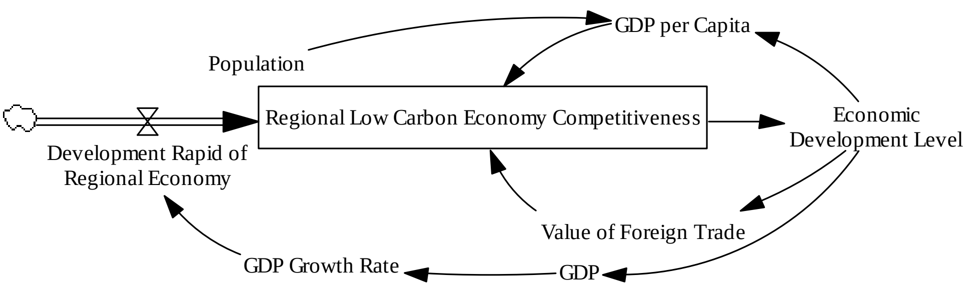

Figure 2. System dynamics flow chart of regional low carbon economy competitiveness sub-system

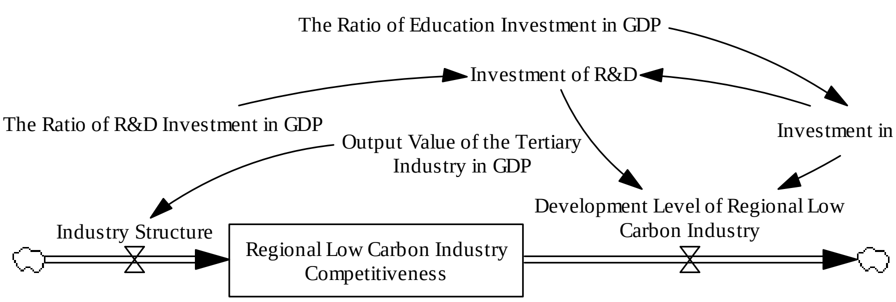

Figure 3. System dynamics flow chart of regional low carbon industry competitiveness sub-system

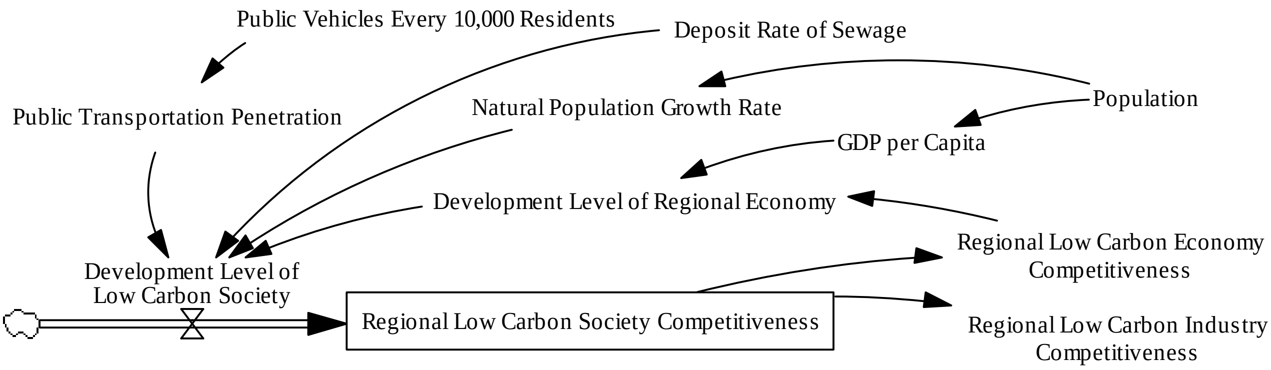

Figure 4. System dynamics flow chart of regional low carbon society competitiveness sub-system

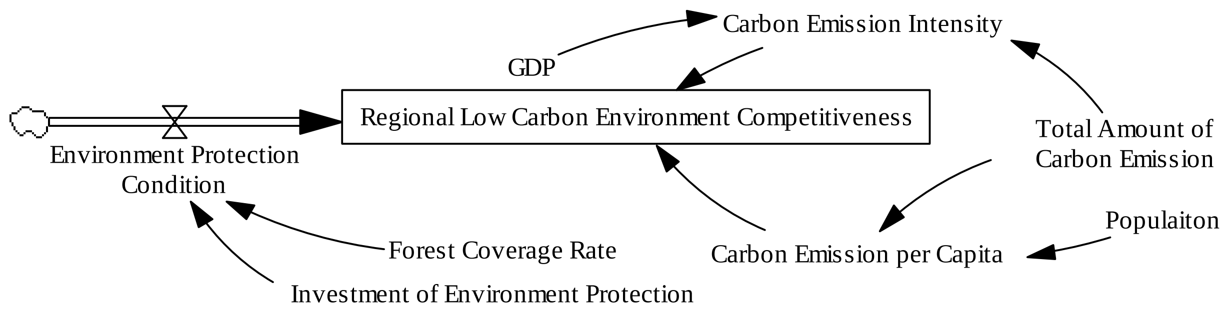

Figure 5. System dynamics flow chart of regional low carbon environment competitiveness sub-system

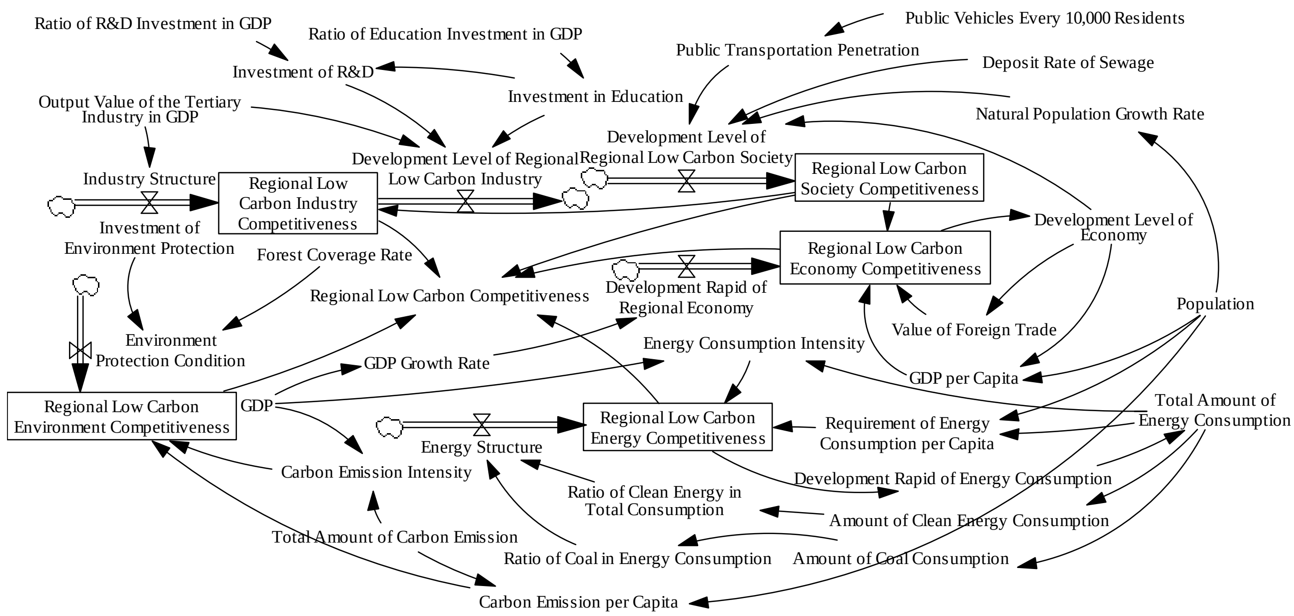

Figure 6. System dynamics flow chart of regional low carbon competitiveness evaluation model

4.6. Regional low carbon competitiveness evaluation model

Based on the regional LCCE system described above (Table 1) and system dynamics, we will build a regional low carbon competitiveness evaluation model in which five sub-systems are included. In this comprehensive evaluation model, the sub-systems are connected by different factors and most which are described in the LCCE system so that the evaluation model and the evaluation system are coordinated to make a basis for evaluating system, stimulating results and making strategies. The regional low carbon competitiveness evaluation model is shown in Fig.6.

5. Case Study

5.1. Study area and data resource

Chongqing (105°11'-110°11' E, 28°10'-32°13' N) locates in the southwest part of China and it covers an area of 82,400 km2with a total population of 33.43 million. As one of the four municipalities in China, Chongqing is not only the financial and economic center in the upper reaches of Yangtze River but also the largest economy in the central and western regions in China. In the rapid process of industrialization and urbanization, Chongqing does witness its boost in economy and trade; however, this boost was realized by consuming large amounts of natural resources which inevitably led to the growing amount of carbon emission. GDP per capita in Chongqing in 2012 is 1.04 times by contrast to that in 2001; however, the carbon emission per capita is 3.05 times and the amount of energy consumption is 3.25 times compared with that in 2001. Based on these data, we can conclude that the economy development model with high energy consumption, high carbon emission and high environment pollution plays a serious hindrance role to the development of low carbon economy and improvement of low carbon competitiveness in Chongqing.

In present study, the data needed in the evaluation system which can be found in the Chongqing statistical yearbook (2001-2012) or National statistical yearbook (2001-2012) will be directly copied, and to those data whichcannot be found directly, we will calculated according to the existing data. Table 2 shows how those data are calculated, and datawhich have not been listed in this table can be directly found in the yearbooks.

Table 2. Variables and expressions in the regional low carbon competitiveness evaluation system

Name of variables	Expression	Unit
Proportion of coal in energy consumption (PECE)	$=CC_k/TEC_k$	%
Ratio of clean energy in total consumption (RCETC)	$=CEC_k/TEC_k$	%
Energy consumption intensity (ECI)	$=TEC_k/GDP_k$	tce/104 yuan
GDP per capita (GDPPC)	$=GDP_k/TP_k$	104 yuan/person
Development rapid of regional economy (DRRE)	$=GDP_k/GDP_{k-1}$	%
Industrial structure (IS)	$=OTI_k/GDP_k$	%
Natural population growth rate (NPGR)	$=TP_k/TP_{k-1}$	‰
Carbon emission per capita (CEPC)	$=CE_k/TP_k$	t/person
Carbon emission intensity (CEI)	$=CE_k/GDP_k$	t/108 yuan

Note. 1. Thevariables in the expressions are the abbreviations of names such as“coal consumption” is expressed as “CC”, “total energy consumption”-“TEC”, “clean energy consumption”-“CEC”, “total population”-“TP”, “output of the tertiary industry”-“OTI”, “carbon emission”-“CE”; 2. The subscript-krefers to the year of the variable, and in this paper, the data from 2001 to 2012 in Chongqing will be used, so $k=1,2,\ldots,12$. 3. The CEin the expressions is calculated in this way: $CE=\sum E_t \times C_t$, where E_t is the amount of t-energy's consumption, C_t is the carbon emission coefficient of t-energy, and the carbon emission coefficient table is presented in Table A of appendices.

Table 3. Weight values of the regional low carbon competitiveness evaluationsystem

Object hierarchy	Rule hierarchy	Weight values b_i^1	Weight values b_i^2	Weight values b_i	Index hierarchy	Weight values w_j^1	Weight values w_j^2	Weight values w_j
A	B1	0.2973	0.1964	0.2469	C1,1	0.0288	0.0422	0.0355
					C1,2	0.0386	0.0488	0.0437
					C1,3	0.0503	0.0589	0.0546
					C1,4	0.0456	0.0300	0.0378
					C1,5	0.0368	0.0201	0.0285
	B2	0.0945	0.2553	0.1749	C2,6	0.1009	0.0541	0.0775
					C2,7	0.0513	0.0264	0.0388
					C2,8	0.0478	0.1195	0.0837
	B3	0.1728	0.1158	0.1443	C3,9	0.1002	0.0814	0.0908
					C3,10	0.0592	0.0631	0.0611
					C3,11	0.0406	0.0556	0.0481
	B4	0.1622	0.1631	0.1626	C4,12	0.0361	0.0018	0.0189
					C4,13	0.0588	0.0936	0.0762
					C4,14	0.0556	0.0319	0.0438

					C4,15	0.0495	0.0726	0.0611
	B5	0.2732	0.2694	0.2713	C5,16	0.0569	0.0315	0.0442
					C5,17	0.0478	0.0336	0.0407
					C5,18	0.0256	0.0363	0.0310
					C5,19	0.0239	0.0557	0.0398
					C5,20	0.0458	0.0429	0.0443

By combination of the AHP and EM weighting methods stated before, we will determine the weight values in the evaluation system on both the rule hierarchy and the index hierarchy. As cited before, the weighting process includes determining the weight values by AHP which can be expressed as b_i^1, w_j^1, the weight values calculated by EM can be expressed as b_i^2, w_j^2 and the co-weight values b_i, w_j are shown in Table 3.

5.2. Stimulation

To evaluate and facilitate the development condition of regional low carbon competitiveness in Chongqing, we will take the current situation in Chongqing as the first scenario and five more scenarios (these six scenarios are expressed as S_lwhere l=1,2,…,6) in which some adjustments have been put in practice will be promoted to stimulate how the results change as relevant index values be fixed. In present study, we will take SD model to stimulate various regional low carbon competitiveness evaluation indices to explore the changes between 2013 and 2020 according to the data from 2001 to 2012 found in the yearbook. Six scenarios are shown in Table 4. The established SD model is used to stimulate various regional low carbon competitiveness evaluation indexes in separate scenarios, and the low carbon competitiveness is calculate based on the stimulation values of evaluation indexes during different time periods. To express the low carbon competitiveness in Chongqing clearly, we will quantitatively state the competiveness by calculating the LCCE index as follows:

$$E_l = \sum_{i=1}^{5} \sum_{j=1}^{20} b_i w_j s_{j,l} \quad (13)$$

Where $s_{j,l}$ is the standardized score of j-index in l-scenario; b_i, w_j are the co-weight values determined by AHP and EM (Table 3). In present study, we will take six scenarios into consideration, so l=1,2,…,6.

5.3. Results and discussion

The development trend of low carbon competitiveness with six different scenarios in Chongqing is shown in Fig.7 based on the results assessed by using Eq. (13), the regional LCCE system and the data found in the yearbook. Upon analyzing the results and trend lines, we will make a profound discussion on the low carbon competitiveness condition in Chongqing.

As shown in Fig.7, if the current development policy is maintained in Chongqing, the low carbon competitiveness will exhibit a continuous increase trend in the following years to 2020 even though there were some fluctuations from 2001 to 2010. There was a dramatic drop from 2001 to 2003 by reason that the energy consumption and structure were in poor condition, and since then, the low carbon competitiveness has inclined gradually The low carbon competitiveness is evaluated as 0.1832 in 2001, and if the development mode unchanged, which will double in 2015 and increase to 0.4425 in 2020. These figures in the graph show that the development of low carbon competitiveness in Chongqing is continuously stable but relatively gentle.

Table 4. Improvement scenarios for the regional low carbon competitiveness in Chongqing

Scenario	Key strategies	Detailed procedures
Primary scenario	Maintaining current situation.	Maintain the current regional development model, do not change any policies related to the indices in the evaluation system, and use this as the reference for other five scenarios
Scenario 1	Energy conservation.	Implement policies to reduce energy consumption, to increase the proportion of clean energy, to decrease coal energy use; to respectively reduce energy consumption intensity and elasticity to 0.7 and 0.4
Scenario 2	Energy conservation; Economy transition.	Besides the strategies stated in Scenario 1, speed up the economy development, and improve the foreign trade value.
Scenario 3	Energy conservation; Economy transition; Industry optimization.	Besides the strategies stated in Scenario 2, implement policies to accelerate the development of tertiary industry and enhance the ratio of output of tertiary industry in GDP, to increase the investment of R&D and education business.
Scenario 4	Energy conservation; Economy transition; Industry optimization; Society promotion.	Besides the strategies stated in Scenario 3, implement policies to control the natural growth rate, to improve sewage treatment and to put more public transportation vehicles into use.
Scenario 5	Energy conservation; Economy transition; Industry optimization;	Besides the strategies stated in Scenario 4, implement regulations and policies to reduce carbon emission, to increase the investment in environment protection, and to enhance the forest coverage rate and green area.

	Society promotion; Environment protection.	

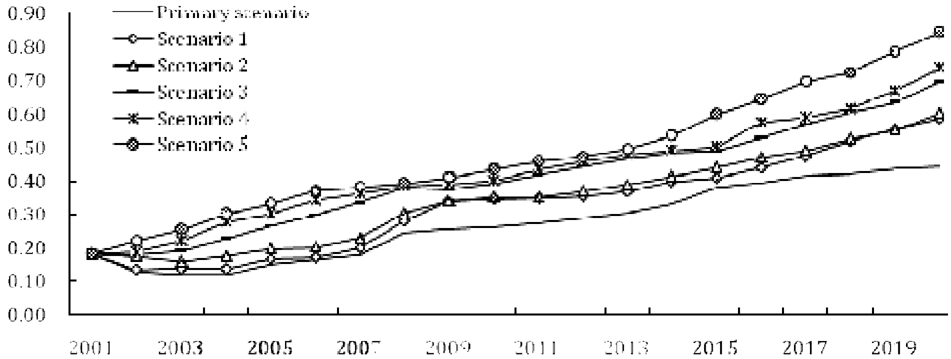

Figure 7. Development trend of low carbon competitiveness in Chongqing with different scenarios

Scenario 1, which is different from the primary scenario, aims to make a promotion in energy conservation and consumption by reducing energy use, increasing the ratio of clean energy, optimizing the development of economy and consumption of energy. As the weight value of regional low carbon energy sub-system is 0.2469 (Table 3), improvement of energy use plays a significant role in promotion of low carbon competitiveness in Chongqing which can be drawn from the trend line of Scenario 1 in Fig.7. Low carbon competitiveness increased a lot each year (the average value gap is 0.0516) and presented a continuous rise. Although the value in 2001 was the same as the primary scenario, it was doubled in 2013, and in 2020 the figure will be over triple than that in 2001. By comparing the trend lines between the Scenario 1 and the primary scenario, we can conclude that implementing the strategies related to the energy conservation indeed promotes the development trend a lot in Chongqing.

Scenario 2 is a strategy based on Scenario 1 which promotes to implement the economy transition into practice by reason that economy is one of the important factors in affecting the low carbon competitiveness. The economy transition scenario includes the practices that speeding up the development of regional economy and increasing the proportion of foreign trade. The implement of economy transition increases the low carbon competitiveness in Chongqing, however, it is obviously in the graph that the trend line of Scenario 2 is close to that of Scenario 1, and even in some years, such as 2009-2011, and 2018-2019, these two trend lines are almost overlapped. The relatively gentle increase from Scenario 1 to Scenario 2 shows that economy transition policies can slightly raise the low carbon competitiveness in Chongqing (the average increased value of each year is 0.0186)

Besides the strategies stated in Scenario 2, Scenario 3 added policies related to industry optimization, such as, enhancing the ratio of tertiary industry and increasing the investment in R&D and education. As we can see from the graph, the trend line of Scenario 3 is much high than that of Scenario 2 (the average increased value of each year is 0.0625) which means that the low carbon competitiveness in Chongqing is much improved by implementing industry optimization policies. Even though regional low carbon industry competitiveness index is least important (the weight value of which is 0.1443 in Table 3), the increase of low carbon competitiveness in Chongqing is obvious and continuous by reason that promotion of tertiary industry ratio and improvement of the investment of R&D and education are crucial not only to the development of industry competitiveness, but also the improvement of energy conservation, economy transition, society promotion and the environment protection. For this reason, the industry optimization policies should be paid much attention in the process of developing regional low carbon competitiveness.

In terms of society promotion, Scenario 4 emphasizes the control of the natural growth rate, improvement of sewage treatment and development of public transport vehicles. The trend line of Scenario 4 is nearly parallel to Scenario 3 with an average data gap of 0.0217 each year. The slight development of low carbon competitiveness in Chongqing between these two scenarios suggests that the policies in society promotion respect can improve regional low carbon competitiveness in a gentler trend. However, by comparison with the Primary scenario, the Scenario 4 still increases in a quite dramatic degree which means that combination of these effective policies, regional low carbon competitiveness can be largely improved even though the rising from Scenario 3 to Scenario 4 is in a slightly gentle trend.

Based on Scenario 4, Scenario 5 incorporates the carbon emission control regulations, investment in environment protection improvement policies, and green area enhancement measures. By analyzing the weight values in Table 3 and comparing the trend lines of Scenario 4 and Scenario 5, we can get conclusions that environment is of utmost significance in promoting regional low carbon competitiveness (the weight value is 0.2713), and low carbon competitiveness can be largely developed and the development trend will increase faster and faster in the future year. If the Scenario 5 can be taken into practice, low carbon competitiveness in Chongqing in 2020 will be twice as much as that in the Primary scenario. For these reasons, Scenario 5 should be considered to improve the low carbon competitiveness in Chongqing based on the weight value table and the development trend line in Fig. 7.

6. Conclusions

The present study established a regional low carbon competitiveness evaluation system based on a new co-weighting method in which the AHP and EM are combined to comprehensively consider the subjective and objective weighting methods. Based in the SD stimulation model built in this paper and the stimulation results of six different scenarios, the development trend of low carbon competitiveness in Chongqing from 2001 to 2020 can be drawn in Fig.7. The main conclusions are as follows.

(1) Based on the principles of establishing LCCE system, this paper built a comprehensive evaluation system of regional low carbon competitiveness by taking literature retrieval method, frequency statistical methods and expert consultation method. This evaluation system consists of three hierarchies: the object hierarchy, the rule hierarchy on which five sub-systems are established, and the index hierarchy which includes 20 concrete indicators. The AHP and EM weighting methods are combined to determine the weight values of indicators so that the balance of subjective and objective weighting methods can be both considered to make a scientific and realisticevaluation system.

(2) The regional low carbon competitiveness evaluation system contains large quantities of factors, and most of which are connected with others in complicate and nonlinear relationship. SD is a much effective modeling method which can be used to analyze the whole complex system and stimulate how the factors in the system interact with each other. We built the regional low carbon competitiveness SD evaluation model based on the indicators in stated in the evaluation system.

(3) Data in Chongqing are used to stimulate in the SD model as the primary scenario and other five scenarios are put forward with the purpose of improving the low carbon competitiveness in Chongqing. The trend lines in Fig.7 show how the low carbon competitiveness can be changed if different scenarios are taken into practice. By analyzing and comparing different scenarios and the results, we can conclude that Scenario 5, in which policies and strategies related to energy conservation, economy transition, industry optimization, society promotion and environment protection are implemented, can effectively improve the low carbon competitiveness and should be considered as main strategies to improve low carbon competitiveness in Chongqing.

(4) The evaluation system and model do have some weaknesses; however, previous researches about regional low carbon competitiveness mainly concentrate on the construction of evaluation system only and the qualitative description with a few quantitative analyses. Therefore, this study may provide a reference as the combination of qualitative and quantitative evaluations for further analysis of regional low carbon competitiveness.

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8. Appendices

Table A. Energy carbon emission coefficient

Energy	Coefficient (104tec/104tec)
Raw coal	0.7559
Cleaned coal	0.7559
Coke	0.855
Other coke chemicals	0.6449
Crude oil	0.5857
Gasoline	0.5538
Kerosene	0.5741
Diesel	0.5921
Liquefied petroleum gas	0.5042
Natural gas	0.4483
Water and nuclear energy	0

Data resource.2006 IPCC guidelines for national greenhouse gas inventories

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