Comprehensive evaluation of low-carbon city in China using intuitionistic fuzzy set theory

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Abstract: Low carbon city is the direction of the development of city in the future. Firstly, this paper constructed the comprehensive evaluation index system of the low carbon economy city that including six primary indexes and 12 secondary indexes by summarizing the recent research of low-carbon connotation and low-carbon evaluation index. These indexes are low-carbon economy, low-carbon energy, low-carbon construction, low-carbon traffic, low-carbon society and low-carbon policy. And then, we discussed the development of low-carbon economy of Beijing, Shanghai and Baoding by using intuitionistic fuzzy set approach for urban low-carbon economy comprehensive evaluation index system. The result that Beijing first and Shanghai second and the last is Baoding, that have important practical significance to regulate and guide the construction of low-carbon cities.

Keywords: Evaluation of Low-Carbon City, Intuitionistic Fuzzy Sets, Fuzzy Evaluation Method

1. Introduction

Energy consumption and emissions of CO_2 were increasing rapidly, and these seriously threaten to the global climate. More countries must consider that how to develop a low-carbon economy and realize the transformation of economic development. In 2009, China committed to reducing its carbon dioxide intensity (CO_2/unit of gross domestic product, GDP) by 40-45% by 2020 from a 2005 baseline. In August 2010, after receiving permission from the State Council, the National Development and Reform Commission (NDRC) of China established a Low-Carbon City policy and announced the selection of 5 provinces and 8 cities to pilot the low carbon development work (NDRC, 2010). The five provinces are: Guangdong, Liaoning, Hubei, Shanxi and Yunnan: and the 8 cities are Chongqing, Shenzhen, Xiamen, Tianjin, Hangzhou, Guiyang, Baoding and Nanchang. Until now, over one hundred Chinese cities have been devoted to the construction of low-carbon city that will contribute to the sustainability goals. Therefore, we need to evaluation to a low carbon economy development ability objectively, and provide the recommendation for scientific decision.

Low-carbon city is a new development pattern as well as a development idea (Dai YX and Liu ZL, 2009). The low carbon idea should be penetrated into all fields of the urban development including economic development, energy consumption, construction field, transportation field and social living. The evaluation of low-carbon city is a complicated process; its indicators of the choice not only conform to general indicators selection principle, and also comply with the requirements of low-carbon economy.

The current low-carbon evaluation systems are mainly focused on the studies of the low-carbon economy. For example, in the field of the low-carbon economy evaluation, based on defining what the low-carbon economy is, Zhuang. et al. (2011) put forward an index system to measure outputs, consumptions, resources and policies of the low-carbon economy. From the perspective of the low-carbon economy's connotation and its industry chain path, Hu. et al. (2010) proposed a low-carbon economy evaluation index system. From the level of the economic development, the technological development and available resources, Ye. Y and Huang. M (2011) invented nine indicators of the low-carbon economic development evaluation system, and then used the comprehensive analysis and synthesis, obtains the corresponding evaluation results. Xiao-yan Li (2010) Chooses 30 indicators from six aspects of economic development system, then uses fuzzy analytical hierarchy process to evaluate the provincial low carbon economy.

This paper is organized to determine the evaluation indicators which should be built from seven aspects. They are low-carbon economics, low-carbon energy, low-carbon construction, low-carbon transportation, low-carbon society, and low-carbon policies respectively. In this paper, the intuitionistic fuzzy set theory has been proved to have the ability to evaluate the level of low-carbon city.

The remainder of the paper is organized as follows: section 2 describes the methodologies about the intuitionistic fuzzy set theory in comprehensive evaluation of low-carbon city. Section 3 introduces the calculation of index in the evaluation system. Section 4 presents the comparative result of different cities under low-carbon evaluation index. At last, key findings and recommendations are summarized in Section 5.

2. Methodologies

2.1. Constructing Evaluation Index System

The evaluation indexes of low-carbon city are not only influenced by the development of economic level, but also by society, energy, transportation and policy and so on. In the design of indicators, it is necessary to consider many factors to meet all needs of the low-carbon development, but the key point is still the economic and energy. The paper follows the basic principles of choosing indicators, such as scientific, systematic operational, dynamic, policy-relevant principles, and forms the target layer, the rule layer and the index layer (Table 1) of the low-carbon economy evaluation index system.

Table 1. The comprehensive evaluation of low-carbon city

The target layer	The rule layer	The index layer	unit
The comprehensive evaluation of low-carbon city	Low-carbon economic	Carbon productivity	Yuan/ ton
		Energy intensity	Tons of standard coal/ million
		Non-fossil fuels rate of primary energy consumption	%
	Low-carbon energy	Intensity of carbon energy	Ton/ yuan
		Elasticity of energy consumption	%
	Low-carbon construction	Energy consumption per unit area in public building	Tons of standard coal /m^2
		Energy consumption per unit area in residential building	Tons of standard coal /m^2
	Low-carbon transportation	The volume of public transport passenger	%
		The proportion of clean energy public transportation	%
	Low-carbon society	The index of air pollution	%
		Carbon emissions per capita	Ton/ person
	Low-carbon policy	The urban management system	

2.2. The Intuitionistic Fuzzy Sets TOPSIS Method

Zadeh (1965) proposed fuzzy set theory, then fuzzy theory has been widely used to study fuzzy decision problem. In 1989, Atanassov (1989) expanded the fuzzy sets, put forward the concept of intuitionistic fuzzy sets, compared with the fuzzy set, which gives the degree of membership and non-membership about the element relative to the set A, and also has a strong ability to express uncertain information. In this paper, we combined intuitionistic fuzzy sets with TOPSIS multi-attribute decision making to resolve the problem of supplier selection.

The intuitionistic fuzzy set A in a finite set X can be written as:

$$A = \{< x, \mu_A(x), \upsilon_A(x) >| \ x \in X\}$$

where $\mu_A(x), \upsilon_A(x)$: X → [0, 1] are membership function and non-membership function,

$$0 \le \mu_A(x) + \upsilon_A(x) \le 1$$

Define $\pi_A = 1 - \mu_A(x) - v_A(x)$
as hesitation degree.

$$\alpha + \beta = \{\mu_A(x) + \mu_B(x) - \mu_A(x)\mu_B(x), v_A(x)v_B(x)\} \quad (1)$$

$$\alpha \otimes \beta = \{\mu_A(x)\mu_B(x), v_a(x) + v_\beta(x), v_A(x)v_B(x) | x \in X\} \quad (2)$$

$$\lambda \alpha = (1 - (1 - \mu_A(x))^\lambda, v_A(x)^\lambda) \quad (3)$$

Model and calculation steps:
Set $A = \{A_1, A_2, ... A_n\}$ is a series of being evaluated

object, $X = \{X_1, X_2, ..., X_n\}$ is a series of evaluate indexes for being evaluated object.

Step 1. Determine the weights of decision makers.

Let $D_k = \{\mu_k, \nu_k, \pi_k\}$ be an intuitionistic fuzzy number for rating of k_{th} decision maker. Then the weight of kth decision maker can be obtained as:

$$\lambda_k = \frac{(\mu_k + \pi_k (\frac{\mu_k}{\mu_k + \nu_k}))}{\sum_{k=1}^{l} \pi_k (\frac{\mu_k}{\mu_k + \nu_k})} \quad (4)$$

$$c_{ij} = [1 - \prod_{k=1}^{l} (1 - \mu_{ij}^{(k)})^{\lambda_k}, \prod_{k=1}^{l} (\nu_{ij}^{(k)})^{\lambda_k}, \prod_{k=1}^{l} (1 - \mu_{ij}^{(k)})^{\lambda_k} - \prod_{k=1}^{l} (\nu_{ij}^{(k)})^{\lambda_k}] \quad (5)$$

$$C = [(\mu(x_1), v(x_1), \pi(x_1))(\mu(x_2), v(x_2), \pi(x_2)) n (\mu(x_n), v(x_n), \pi(x_n))]$$
$$= [c_1, c_2, n, c_n]$$

ii Determine the weight of two indicators

Set $q_j^{(k)} = [\mu_j^{(k)}, v_j^{(k)}, \pi_j^{(k)}]$ is the k_{th} decision maker's intuitionistic fuzzy number about index, then the weights of

Step 2. Construct Level indicators' aggregated intuitionistic fuzzy decision matrix.

i Build two indicators' aggregate intuitionistic fuzzy decision vector according to the views of decision makers.

Set $C^{(k)} = (c_{ij}^{(k)})_{m \times n}$ is each decision maker's intuitionistic fuzzy decision matrix, $\lambda = \{\lambda_1, \lambda_2, ..., \lambda_i\}$ is each decision maker's weight.

the criteria are calculated by:

$$q_j = IFWA_\lambda (q_j^{(1)}, q_j^{(2)}, ..., q_j^{(l)})$$
$$= \lambda_1 q_j^{(1)} \oplus \lambda_2 q_j^{(2)} \oplus \lambda_3 q_j^{(3)} \oplus ... \oplus \lambda_l q_j^{(l)}$$
$$= \left[1 - \prod_{k=1}^{l} (1 - \mu_j^{(k)})^{\lambda_k}, \prod_{k=1}^{l} (v_j^{(k)})^{\lambda_k}, \prod_{k=1}^{l} (1 - \mu_j^{(k)})^{\lambda_k} - \prod_{k=1}^{l} (v_j^{(k)})^{\lambda_k} \right] \quad (6)$$

$$Q = [q_1, q_2, q_3, ..., q_j]$$

iii Construction of weighted summary intuitionistic fuzzy decision matrix

$$C \otimes Q = \{(x, \mu_q(x), v(x) + v_q(x) - v(x) \cdot v(x) \cdot v_q(x)) | x \in X\}$$

$$\pi_q(x) = 1 - v(x) - v_q(x) - \mu(x) \cdot \mu_q(x) + v(x) \cdot v_q(x)$$

$$C' = [(\mu_q(x_1), v_q(x_1), \pi_q(x_1))(\mu_q(x_2), v_q(x_2), \pi_q(x_2))...(\mu_q(x_n), v_q(x_n), \pi_q(x_n))]$$
$$= [c_1', c_2', ... c_j'] \quad (7)$$

where $c_j' = (\mu_j', v_j', \pi_j') = (\mu_q(x_j), v_q(x_j), \pi_q(x_j))$

iv The comparison with intuitionistic fuzzy decision vector and the index level of similarity

Let $A = \{x_i, \mu_a(x_i), v_a(x_i)\}$ is the intuitionistic fuzzy set of index grade.

$$S_w^p(A, C') = 1 - \frac{1}{p\sqrt{n}} \sqrt[p]{\sum_1^n (\frac{1}{3}\varphi(i) + \frac{1}{3}\varphi(i) + \frac{1}{3}\varphi(i))^p} \quad (8)$$

Where $m_a(i) = \frac{1}{2}(\mu_a(x_i) + 1 - v_a(x_i))$

$$m_q(i) = \frac{1}{2}(\mu_q(x_i) + 1 - v_q(x_i))$$

$$\phi_1 = |\mu_q(x_i) - \mu_a(x_i)| \qquad (9)$$

$$\phi_2(i) = |m_q(x_i) - m_a(x_i)|$$

$$\phi_3(i) = |(1 - v_a(x_i)) - (1 - v_q(x_i))|$$

Then we get level index's evaluation level of further get level index' aggregated intuitionistic fuzzy decision matrix.

Step 3. Determine the weights of level index.

Let $w_j^{(k)} = \{\mu_j^{(k)}, v_j^{(k)}, \pi_j^{(k)}\}$ be an intuitionistic fuzzy number assigned to criterion Xj by the kth decision maker. Then the weights of the criteria are calculated by:

$$w_j = \left[1 - \prod_{k=1}^{l}(1 - \mu_j^{(k)})^{\lambda_k}, \prod_{k=1}^{l}(v_j^{(k)})\lambda_k, \prod_{k=1}^{l}(1 - \mu_j^{(k)})\lambda_k - \prod_{k=1}^{l}(v_j^{(k)})^{\lambda_k}\right] \qquad (10)$$

Step 4. Construct aggregated weighted intuitionistic fuzzy decision matrix.

$$r_{ij}' = \{(\mu_{A_i}(x) \cdot \mu_w(x), v_{A_i}(x) + v_w(x) - v_{A_i}(x) \cdot v_w(x),$$
$$1 - \mu_{A_i}(x) \cdot \mu_w(x) - v_{A_i}(x) - v_w(x) + v_{A_i}(x) \cdot v_w(x)) \mid x \in X\} \qquad (11)$$

r_{ij}' is an element of the aggregated weighted intuitionistic

fuzzy decision matrix R'.

Step 5. Obtain intuitionistic fuzzy positive-ideal solution and intuitionistic fuzzy negative-ideal solution.

Then A^+ and A^- which are intuitionistic fuzzy positive-ideal solution and intuitionistic fuzzy negative-ideal solution are obtained as:

$$A^* = (\mu_{A^*_w}(x_j), v_{A^*_w}(x_j)) \qquad A^- = (\mu_{A^-_w}(x_j), n_{A^-_w}(x_j)) \qquad (11)$$

$$\mu_{A^*_w}(x_j) = \max_i \mu_{A_i w}(x_j) \qquad \mu_{A^-_w}(x_j) = \min_i \mu_{A_i w}(x_j) \qquad (12)$$

$$v_{A^*_w} = \min_i v_{Aw}(x_j) \qquad v_{A^-_w}(x_j) = \max_i v_{A_i w}(x_j)$$

Step 6. Calculate the separation measures.

The separation measures Si+ and Si- is calculated as

$$S_{i+} = \sqrt{\frac{1}{2n}\sum_{j=1}^{n}((\mu_{A_1 w}(x_j) - \mu_{A^*_w}(x_j))^2 + (v_{A_1 W}(x_j) - v_{A^*_w}(x_j))^2 + (\pi_{A_1 w}(x_j) - v_{A^*_w}(x_j))^2)} \qquad (13)$$

$$S_{i-} = \sqrt{\frac{1}{2n}\sum_{j=1}^{n}((\mu_{A_1 W}(x_j) - \mu_{A^-_w}(x_j))^2 + (v_{A_1 w}(x_j) - v_{A^-_w}(x_j))^2 + (\pi_{A_1 w}(x_j) - v_{A^*_w}(x_j))^2)} \qquad (14)$$

Step 7. Calculate the relative closeness coefficient.

$$K_i = \frac{S_{i-}}{S_{i+} + S_{i-}} \qquad (15)$$

After the relative closeness coefficient of each alternative is determined, alternatives are ranked according to descending order K_i.

3. Data Collection and Calculation Processing

In this paper, the three cities including Beijing, Shanghai, Baoding as the evaluation objects to verify practicality and reliability of the comprehensive evaluation index system of low-carbon city. Beijing, as the capital, its economic and politics have strong representation in China with rapid development and expedition. The Chongming Dongtan Eco-city in Shanghai was designed from urban planning, ecological development, sustainable energy, waste management, green building, and transportation planning. It is likely to became the first carbon-neutral area in the word, where an ecosystem characterized by low carbon, water saving and energy saving will generated (Fu Y, Wang, 2008). Baoding has put forward the plan of "Electricity Valley of China". Six industrial systems including optic-electricity, wind power, electricity savings, electricity storage, trans-electricity, and power automation have been formed in recent years (Yuan XL, Zhong YY, 2010). So the three cities are choosing as typical cities to process the calculation of low-carbon index and analyze for low-carbon development.

Data in this paper are from China Statistical Yearbook,

China Energy Statistical Yearbook, and Yearbook of China Transportation and Communications, and statistical literature that are compiled by National Bureau of Statistics and Bureau of Energy. The data are collected from the year 2011.

Suppose the three cities are represented by A_1, A_2, A_3, three decision makers DM_1, DM_2 and DM_3. The calculation steps are as follows:

Step 1. Determine the weights of decision makers.

The importance language describe and weights of three experts are shown in Table 4

Table 2. Classification of decision-makers's importance

	DM1	DM2	DM3
Linguistic terms	Very important	medium	important
Weights	0.406	0.238	0.356

Table 3. Linguistic terms description of decision-makers and indicators

Linguistic terms	Intuitionistic fuzzy set
Very important(VI)	(0.90，0.10)
Important(I)	(0.75，0.20)
Medium important(M)	(0.50，0.45)
Unimportant(U)	(0.35，0.60)
Very unimportant(VU)	(0.10，0.90)

According to the Eq (4) calculate the weight of decision-makers as follows:

$$\lambda_{DM1} = \frac{0.9}{0.9+(0.75+0.05\frac{0.75}{0.95})+(0.50+0.05\frac{0.50}{0.95})} = 0.406$$

$$\lambda_{DM2} = \frac{(0.50+0.05\frac{0.50}{0.95})}{0.9+(0.50+0.05\frac{0.50}{0.95})+(0.75+0.05\frac{0.75}{0.95})} = 0.238$$

$$\lambda_{DM3} = \frac{(0.75+0.05\frac{0.75}{0.95})}{0.9+(0.50+0.05\frac{0.50}{0.95})+(0.75+0.05\frac{0.75}{0.95})} = 0.356$$

Step 2. Construct Level indicators' aggregated intuitionistic fuzzy decision matrix.

ⅰ Build two indicators' aggregate intuitionistic fuzzy decision vector according to the views of decision makers.

Table 4. Linguistic terms description of devide index level

Linguistic terms	Intuitionistic fuzzy set
Very good(VG)	(1.00,0.00)
Good(G)	(0.75,0.15)
Medium good(M)	(0.50,0.40)
Bad(B)	(0.25,0.65)
Very bad(VB)	(0.10,0.90)

Table 5. The ratings given by the experts

Supplier	A_1			A_2			A_3		
Criteria	DM_1	DM_2	DM_3	DM_1	DM_2	DM_3	DM_1	DM_2	DM_3
C_1	VG	G	G	G	VG	G	G	G	M
C_2	G	M	G	VG	G	G	VG	G	M
C_3	M	G	G	G	G	G	G	VG	G
C_4	G	G	VG	G	M	G	VG	G	M
C_5	M	M	M	M	G	G	VG	M	G
C_6	VG	G	G	G	G	VG	M	G	G
C_7	M	G	VG	M	B	M	G	G	G
C_8	G	VG	G	M	VG	G	G	VG	G
C_9	M	G	VG	G	G	VG	G	M	G
C_{10}	M	G	G	G	B	G	G	G	G
C_{11}	G	G	VG	VG	G	G	M	VG	M
C_{12}	G	M	B	M	M	G	VG	G	G

The aggregated intuitionistic fuzzy decision matrix according to the Eq(5):

Table 6. Aggregated intuitionistic fuzzy decision matrix

C	A_1	A_2	A_3
C_1	(1.000,0.000,0.000)	(1.000,0.000,0.000)	(0.680,0.213,0.107)
C_2	(0.705,0.189,0.105)	(1.000,0.000,0.000)	(1.000,0.000,0.000)
C_3	(0.669,0.223,0.108)	(0.750,0.150,0.100)	(1.000,0.000,0.000)
C_4	(1.000,0.000,0.000)	(0.705,0.189,0.105)	(1.000,0.000,0.000)
C_5	(0.500,0.400,0.100)	(0.669,0.223,0.108)	(1.000,0.000,0.000)
C_6	(1.000,0.000,0.000)	(1.000,0.000,0.000)	(0.669,0.223,0.108)
C_7	(1.000,0.000,0.000)	(0.449,0.449,0.102)	(0.750,0.150,0.100)
C_8	(1.000,0.000,0.000)	(1.000,0.000,0.000)	(1.000,0.000,0.000)
C_9	(1.000,0.000,0.000)	(1.000,0.000,0.000)	(0.705,0.189,0.105)
C_{10}	(0.669,0.223,0.108)	(0.675,0.213,0.112)	(0.750,0.150,0.100)
C_{11}	(1.000,0.000,0.000)	(0.609,0.282,0.109)	(1.000,0.000,0.000)
C_{12}	(0.564,0.319,0.117)	(0.539,0.344,0.117)	(1.000,0.000,0.000)

ⅱ Determine the weight of two indicators

Table 7. The evaluation of criteria's importance

Criteria	Decision maker		
	DM_1	DM_2	DM_3
C_1	VI	VI	I
C_2	VI	I	I
C_3	I	M	I
C_4	I	VI	I
C_5	I	I	I
C_6	VI	I	VI
C_7	I	VI	VI
C_8	VI	VI	M
C_9	VI	M	I
C_{10}	I	VI	I
C_{11}	M	M	M
C_{12}	M	I	M

$$Q = \begin{pmatrix} 0.861, 0.128, 0.011 \\ 0.828, 0.151, 0.021 \\ 0.705, 0.243, 0.052 \\ 0.799, 0.170, 0.031 \\ 0.750, 0.200, 0.050 \\ 0.876, 0.118, 0.006 \\ 0.855, 0.133, 0.013 \\ 0.823, 0.171, 0.007 \\ 0.797, 0.183, 0.020 \\ 0.799, 0.170, 0.031 \\ 0.500, 0.450, 0.050 \\ 0.576, 0.371, 0.053 \end{pmatrix}^{T}$$

iii Construction of weighted summary intuitionistic fuzzy decision matrix

Table 8. *Summary intuitionistic fuzzy decision matrix*

C	A_1	A_2	A_3
C_1	(0.861,0.128,0.011)	(0.861,0.128,0.011)	(0.586,0.314,0.101)
C_2	(0.584,0.311,0.105)	(0.828,0.151,0.021)	(0.828,0.151,0.021)
C_3	(0.472,0.411,0.117)	(0.529,0.356,0.115)	(0.705,0.243,0.052)
C_4	(0.799,0.170,0.031)	(0.563,0.327,0.110)	(0.799,0.170,0.031)
C_5	(0.375,0.520,0.105)	(0.502,0.378,0.120)	(0.750,0.200,0.050)
C_6	(0.876,0.118,0.006)	(0.876,0.118,0.006)	(0.586,0.315,0.100)
C_7	(0.855,0.133,0.013)	(0.384,0.522,0.094)	(0.641,0.263,0.096)
C_8	(0.823,0.171,0.007)	(0.823,0.171,0.007)	(0.823,0.171,0.007)
C_9	(0.797,0.183,0.020)	(0.797,0.183,0.020)	(0.562,0.337,0.101)
C_{10}	(0.535,0.355,0.111)	(0.539,0.346,0.114)	(0.599,0.294,0.107)
C_{11}	(0.500,0.450,0.050)	(0.305,0.605,0.090)	(0.500,0.450,0.050)
C_{12}	(0.325,0.572,0.103)	(0.310,0.587,0.102)	(0.576,0.371,0.053)

iv The comparison with intuitionistic fuzzy decision vector and the index level of similarity

Table 9. *The index level of similarity*

Criteria	Supplier	VG	G	M	B	VB
	A_1	0.712	0.828	0.868	0.588	0.388
B_1	A_2	0.727	0.875	0.823	0.573	0.373
	A_3	0.755	0.925	0.795	0.545	0.345
	A_1	0.748	0.862	0.740	0.552	0.352
B_2	A_2	0.675	0.816	0.819	0.626	0.426
	A_3	0.731	0.915	0.819	0.569	0.369
	A_1	0.575	0.766	0.876	0.725	0.525
B_3	A_2	0.529	0.720	0.827	0.771	0.571
	A_3	0.598	0.798	0.939	0.702	0.502

Get level indicators' evaluation level based on Table 6.

Table 10. *Level indicators' evaluation level*

Criteria Supplier	B_1	B_2	B_3
A_1	M	G	M
A_2	G	M	M
A_3	G	G	M

Table 11. *Level indicators' aggregated intuitionistic fuzzy decision matrix*

Criteria	A_1	A_2	A_3
B_1	(0.500,0.400,0.100)	(0.750,0.150,0.100)	(0.750,0.150,0.100)
B_2	(0.750,0.150,0.100)	(0.500,0.400,0.100)	(0.750,0.150,0.100)
B_3	(0.500,0.400,0.100)	(0.500,0.400,0.100)	(0.500,0.400,0.100)

Step 3. Determine the weights of level index.

Table 12. *The evaluation of criteria's importance*

	DM_1	DM_2	DM_3
B_1	VI	M	I
B_2	I	I	M
B_3	I	VI	I

$$w = \begin{pmatrix} (0.797,0.183,0.020) \\ (0.680,0.267,0.053) \\ (0.799,0.170,0.031)) \end{pmatrix}^{T}$$

Step 4. Construct aggregated weighted intuitionistic fuzzy decision matrix.

Table 13. Aggregated weighted intuitionistic fuzzy decision matrix

B	A_1	A_2	A_3
B_1	(0.398,0.510,0.092)	(0.598,0.306,0.097)	(0.398,0.510,0.092)
B_2	(0.510,0.377,0.113)	(0.340,0.560,0.100)	(0.340,0.560,0.100)
B_3	(0.599,0.294,0.107)	(0.599,0.294,0.107)	(0.399,0.502,0.099)

Step 5. Obtain intuitionistic fuzzy positive-ideal solution and intuitionistic fuzzy negative-ideal solution.

Table 14. Intuitionistic fuzzy positive-ideal solution and negative-ideal solution

	B_1	B_2	B_3
A^{+}	(0.598,0.306,0.097)	(0.510,0.377,0.113)	(0.399,0.502,0.099)
A^{-}	(0.398,0.510,0.092)	(0.340,0.560,0.100)	(0.599,0.294,0.107)

Step 6. Calculate the separation measures.

Table 15. The separation measures

Supplier	S^{+}	S^{-}
A_1	0.128	0.079
A_2	0.121	0.09
A_3	0.12	0.091

Step 7. Calculate the relative closeness coefficient.

Table 16. The relative closeness coefficient

Supplier	K_i
A_1	0.381
A_2	0.428
A_3	0.432

3 partner were ranked according to the relative closeness coefficient of Ki, The alternatives were ranked as A3>A2>A1, so A3 is the best. According to the result above, it is easy to conclude that the low-carbon economy development capability of Beijing is the strongest, Shanghai is stronger than Baoding, and Baoding has the weakest low-carbon economy development capability.

4. Result and Discussion

Based on the above calculations, we can easily find that comprehensive indicators based on 6 rule layers and 12 index layers can explain the level of low-carbon development effectively. The comprehensive evaluation system can lead to a relative accurate comparisons and conclusions about whether certain cities or provinces are or are not low-carbon. Beijing ranks first in terms of being low-carbon city, as the nation's capital, with a highly-developed, economically-productive commercial sector. Shanghai to Beijing, China's financial hub, ranks well in terms of low-carbon when the indicator is based on low-carbon energy. Also to Beijing, this low-carbon transportation does not rank well in terms of energy consumption and CO_2 emissions. Shanghai also ranks poorly in terms of energy use per capita or per employee for residential and commercial buildings, respectively. Baoding was ranked slightly worse than the other two in terms of comprehensive indexes of low-carbon system. It can be seen that Baoding should make more effort to improve energy efficiency, but also to develop secondary industries with lower carbon intensity.

For the economic sector, the industrial share of regional GDP was used as the denominator, but a better value would be provincial or city industrial sector value added.

For the energy sector, the indicator used is calculated based on total energy demand by province. This approach favors large hydropower producers and exporters such as Hebei province. It accords more closely with supply region for consumption.

For the transport sector, it would be helpful to have more detailed information on usage of all public transportation modes, and the total person trip- kilometers for all private travel in cars and taxis, as well as the total energy consumption of these travel modes in order to develop more detailed indicators and metrics. This information, however, is also not readily available at the provincial and city level for China.

5. Conclusion

The results presented above for China illustrate that comprehensive evaluation indicators of low-carbon city based on intuitionistic fuzzy set theory which could explain and reflect the low-carbon development of cities or provinces effectively. This paper constructed the comprehensive evaluation index system of the low carbon economy city that including six primary indexes and 12 secondary indexes by summarizing the research in domestic and foreign of low-carbon connotation and low-carbon evaluation index. These indexes are low-carbon economy, low-carbon energy, low-carbon construction, low-carbon transportation, low-carbon society and low-carbon policy. And then, we discussed the development of low-carbon economy of Beijing, Shanghai and Baoding by using intuitionistic fuzzy set approach for urban low-carbon economy comprehensive evaluation index system. The result that Beijing first and Shanghai second and the last is Baoding, that have important practical significance to regulate and guide the construction of low-carbon cities.

City is an important platform of low-carbon development.

Many Chinese cities have made their efforts to construct low-carbon city in recent years, among which some establish the overall low-carbon city strategy planning, some construct demonstrative area, some pay attention to specific such as energy, industry, transportation, and some emphasize the scientific research and international cooperation.

There is still a long way to go before achieving the low-carbon development objective. Certain items need to be concerned in the future.

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