Study on the comprehensive evaluation of low carbon city based on PSR model and normalized index transformation

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Abstract. Referring the "stress-state-response" (PSR) model, the index system of low-carbon city was constructed. The Immune Evolution Chaos Weed Algorithm was used to optimize the Weber Fechner index formula and the universal Carson index formula. A low-carbon city evaluation method was established and applied to evaluate the low-carbon development level of Beijing, Tianjin, Shanghai, and Chongqing in 2015. The results showed that the evaluation results of the Weber Fechner index formula and the universal Carson index formula for the four cities were basically the same. The low-carbon development level (Weber Fechner Composite Index XI) of the four cities in 2015 was ranked as follows: Beijing (0.590), Shanghai (0.499), Tianjin (0.467), Chongqing (0.461).

With the continuous acceleration of urbanization, the continuous growth of economic scale, and the massive consumption of energy, the global catastrophic climate change caused by the increase in the concentration of carbon dioxide in the atmosphere has repeatedly appeared, which has seriously threatened the survival and development of human beings. As an important measure to deal with global climate change, low-carbon city construction is booming.

This article adopts the "pressure-state-response" (PSR) model to establish a low-carbon city evaluation index system. Based on the setting of the reference value of the low-carbon city evaluation index and the standard transformation formula, the immune evolution chaos weed algorithm is used to optimize the parameters of the Weber Fechner index formula and the universal Carson index formula. The equal weight method is adopted to determine the comprehensive index classification standard, and empirical analysis is carried out in four cities of Beijing, Shanghai, Tianjin and Chongqing.

1 Low-carbon city index system construction and evaluation methods

1.1 Construction of PSR model

In the pressure-state-response (PSR) model, pressure refers to the effects of human economic and social activities on the environment, state refers to the environmental state and changes in a specific time period, and response refers to actions taken by humans to reduce, prevent and restore the negative impact of human activities on the environment.

From the perspective of carbon source-carbon flow-carbon sink, this article focused on the availability of

data, the cohesion between indicator systems, and the ease of assessment [1-2]. The pressure layer selects indicators such as energy consumption per unit of GDP and the level of urbanization, the state layer selects indicators such as urban air quality and forest coverage, and the response layer selects indicators such as the proportion of clean energy in energy consumption and the proportion of energy-saving buildings to establish a PSR model.

1.2 Evaluation methods for low-carbon cities

1.2.1 Data standardization

Since the evaluation index system has two types of indicators, forward and reverse, the standard values of different indicators often differ greatly between the same level. Therefore, the data needs to be standardized before evaluation. This article adopts formula (1) and formula (2) to carry out the specification transformation.

Among them, x_j and x_j' are the transformed value and the standard value of index j ; c_{j0} is the reference value of index j ; c_j is the grading standard value or actual value of index j ; n_j is the threshold value of index j ; The power exponent of the set index j , and $n_j > 0$.

Through a lot of practice, the selection method of n_j is summarized as follows. Estimate the most probable value of n_j according to the variation range of the ratio of the maximum value $\max\{c_{jk}\}$ to the minimum value $\min\{c_{jk}\}$ or the ratio of $\max|c_b - c_{jk}|$ to $\min|c_b - c_{jk}|$ in the various standards of index j , as shown in Table 1. Secondly, the standard is divided into 5 levels, and c_{j0} is set based on the preliminary determination of n_j , so that the standard normative value of index j calculated by

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formula (1) and formula (2) can be within the range.

$$x_j = (c_j / c_{j0})^{n_j} \quad (1)$$

$$x'_j = \frac{1}{10} \ln x_j \quad (2)$$

Table 1. Corresponding relation between the value of n_j and the range of $\max\{c_{jk}\} / \min\{c_{jk}\}$ or $\max|c_b - c_{jk}| / \min|c_b - c_{jk}|$

	$\max\{c_{jk}\} / \min\{c_{jk}\}$ or $\max c_b - c_{jk} / \min c_b - c_{jk} $	
	(2,7)	[6,30]
n_j	2	1
		0.5

Table 2. Allowable range of variation of standard values at all levels

	X'_{jk}				
Grade	k=1	k=2	k=3	k=4	k=5
X'_{jk} variation range	[0.10, 0.24]	[0.18, 0.32]	[0.25, 0.40]	[0.33, 0.46]	[0.40, 0.55]

Table 3. Grading standard of low carbon city comprehensive index

Grade	k=1 (level 1)	k=2 (level 2)	k=3 (level 3)	k=4 (level 4)	k=5 (level 5)
X'_{jk}	0.18	0.25	0.33	0.4	0.5
FI_k	0.2498	0.3469	0.4579	0.5551	0.6938
KI_k	0.3050	0.3515	0.4047	0.4512	0.5177

1.2.2 Formula selection and parameter optimization

Based on the normative transformation of indicators, a universal W-F (Weber-Fechner) index formula and universal Carson index formula expressed by index norm values are established [3-5].

Among them, a_0 , a_1 , and b_1 are the parameters to be optimized in formula (3) and formula (4) respectively, which are applicable to all indexes and have nothing to do with the specific index value. FI_j , KI_j are the index values of the two universal index formulas corresponding to index j . The parameters of the above formula are optimized by the immune evolution chaos weed algorithm, and the optimized formulas are shown in formula 5 and formula 6. After verification, the formula is reliable [6].

Weber Fechner(W-F)index formula:

$$FI_j = a_0 \lg x_j \quad (3)$$

Universal Carson Index formula:

$$KI_j = a_1 + b_1 \ln x_j \quad (4)$$

The index specification value X'_{jk} or the corresponding index transformation value X_{jk} ($j = 1, 2, \dots, 100; k = 1, 2, 3, 4, 5$) is taken into formula 5 and formula 6 for calculation. Regarding the value of each index with equal weight, the comprehensive index grading standard value X_{jk} applicable to any M index is calculated by formula (7).

In formula (7), XI is the comprehensive index value of M indicators. XI_j is the index value of a single index calculated by formula (5) and formula (6) respectively. w_j is the normalized weight of index j ,

shown in Table 2.

which satisfies $\sum_{j=1}^M w_j = 1$. If there is little difference in the norm value of each indicator after norm transformation, the form of equal weight is generally adopted.

Otherwise, the index needs to be weighted calculation. If the index needs to be weighted and calculated, the linear weighting method such as formula (8) is generally used to linearly weight the conversion value X_j of each index.

Weber Fechner(W-F)index formula:

$$FI_j = 0.319529 \lg x_j \quad (5)$$

Universal Carson Index formula:

$$KI_j = 0.185365 + 0.066460 \ln x_j \quad (6)$$

$$XI = \sum_{j=1}^M w_j XI_j \quad (7)$$

$$w_j = x_j / \sum_{j=1}^M x_j \quad (8)$$

1.2.3 Grading standard determination

Based on the comprehensive indicators of low-carbon cities and reference standards, the development level of low-carbon cities is divided into 5 levels. The median value of each grading range in Table 2 is taken as the standard value of low-carbon city grading standard, and they are respectively brought into equation (5) and equation (6). The difference between the indexes after the standard transformation is very small. The W-F index formula and the universal Carson index formula are calculated using the equal weight method to obtain the comprehensive index classification standard values FI_k and KI_k as shown in Table 3. In the evaluation process, the pros and cons of all levels of indicators are judged according to the positive and negative indicators.

Summarize the collected data and judge the pros and cons of the 18 indicators. According to the threshold value of index j set by relevant data, the standard transformation formula of 18 indexes is designed.

Calculate the relevant range value of $\max\{c_{jk}\} / \min\{c_{jk}\}$ or $\max|c_b - c_{jk}| / \min|c_b - c_{jk}|$ from the data of each year. It is determined that except for the index C_{18} to be 0.5, the other indexes n_j are all 2, and the reference value C_{j0} of each index is calculated, and the standard value of each level ($k=1 \sim 5$) is calculated inversely. The results are shown in the table below.

Table 4. Corresponding relation between the value of n_j and the range of $\max\{c_{jk}\} / \min\{c_{jk}\}$ or $\max|c_b - c_{jk}| / \min|c_b - c_{jk}|$

Category	Serial NO.	Index	Comprehensive index reference value C_{j0}
Pressure	1	Carbon intensity per unit of GDP(tons of carbon dioxide / 10,000 yuan)	2.08

	2	Energy consumption per unit of GDP (tons of standard coal / 10,000 yuan)	24.4
	3	elastic coefficient of carbon dioxide emission	1.04
	4	The level of urbanization (%)	0.18
	5	Urban air quality (%)	2.88
State	6	Forest cover rate (%)	Mountain13.44 Hilly area7.68 Plain area2.88
	7	Per capita public green area (m ² /person)	0.11
	8	The rate of public's satisfaction with the environment (%)	0.11
	9	The proportion of clean energy in the energy consumption (%)	1.84
Response	10	Urban gasification rate (%)	0.77
	11	Energy processing conversion efficiency (%)	0.92
	12	Energy-saving building proportion (%)	Severe cold and cold regions1.84 Hot summer and cold winter area1.66; Hot summer and warm winter area1.48
	13	Public transportation mode share rate (%)	1.92
	14	The harmless rate of urban municipal solid waste (%)	1.92
	15	The rate of industrial solid waste disposal utilization (%)	1.92
	16	The proportion of compulsory clean production enterprises that have passed the acceptance inspection (%)	1.92
	17	The tertiary industry accounting for the proportion of GDP (%)	0.18
	18	Environmental protection investment accounting for GDP (%)	0.002

whether it is a pilot low-carbon city, etc., four municipalities directly under the Central Government, Beijing, Shanghai, Tianjin, and Chongqing, are selected for empirical analysis. The four municipalities directly under the Central Government are all pilot low-carbon cities, and the required data are easier to obtain, taking into account regional differences (heating areas: Beijing, Tianjin; plain areas: Beijing, Tianjin, Shanghai; hilly areas: Chongqing; severe cold and cold areas: Beijing, Tianjin; hot summer and cold winter areas: Shanghai, Chongqing).

2.2 Data sources

The basic data of the indicators in this study are derived from: ① 2015 statistical yearbook of each city, ② Statistical Bulletin of National Economy and Social Development, ③ Annual Report on Transportation Development, ④ Annual Development Research Report on China's Building Energy Conservation.

The reference standards for each indicator are derived from: ① "Eco-Counties, Eco-Cities, and Eco-Province Construction Indicators (Revised Draft)": Eco-city construction indicators; ② "Ecological Counties, Eco-Cities, Eco-Province Construction Indicators (Trial)" Indicators; ③ "National Environmental Protection Model City Assessment Indicators and Implementation Rules (Phase Six)"; ④ "China Habitat Environment Award Evaluation Index System (Trial)"; ⑤ "National Garden City Standards".

2.3 Result analysis

From Table 5 and Table 6, it can be seen that the index values c_j , the standardized conversion values X'_{jk} of the indicators and the comprehensive index value XI of the two formulas in the four cities of Beijing, Shanghai, Tianjin and Chongqing. The evaluation results of the Weber Fechner index formula and the universal Carson index formula for the four cities of Beijing, Shanghai, Chongqing and Tianjin are basically the same.

Table 5. Index values of various indicators in four cities

Index	Beijing	Shanghai	Tianjin	Chongqing
C ₁	0.3	0.453	0.499	0.618
C ₂	0.3	0.453	0.6	0.51
C ₃	0.28	0.18	0.41	0.15
C ₄	86.5	100	62.44	60.9
C ₅	50.96	70.7	60.3	80
C ₆	41.6	10.74	9.87	45
C ₇	16	15.9	10.1	18.1
C ₈	89.3	89.8	90.5	90
C ₉	73.2	22.2	12.3	27.23
C ₁₀	100	100	100	95.34
C ₁₁	97.63	76.84	77.6	63.05
C ₁₂	89.3	33.6	69.1	29.52
C ₁₃	50	31.6	32	38.5
C ₁₄	99.8	100	92.7	98.6

2 Empirical research

2.1. Overview of the study areas

Considering the comparability between cities, the availability of data, geographical distribution, and

C ₁₅	99.98	96.15	98.58	84.45
C ₁₆	100	100	100	100
C ₁₇	79.7	67.8	52.2	47.9
C ₁₈	4.04	2.82	2.26	2.54

Table 6. Comprehensive evaluation index of each index of four cities

Index	Beijing		Shanghai		Tianjin		Chongqing	
C ₁	0.538	0.443	0.423	0.388	0.397	0.375	0.337	0.347
C ₂	0.61	0.478	0.553	0.45	0.514	0.432	0.537	0.442
C ₃	0.365	0.36	0.487	0.419	0.259	0.309	0.538	0.443
C ₄	0.734	0.537	0.778	0.558	0.584	0.465	0.566	0.456
C ₅	0.111	0.239	0.496	0.423	0.452	0.402	0.589	0.467
C ₆	0.741	0.54	0.365	0.36	0.342	0.349	0.491	0.42
C ₇	0.594	0.47	0.592	0.469	0.408	0.381	0.626	0.485
C ₈	0.421	0.387	0.448	0.4	0.479	0.415	0.458	0.405
C ₉	0.511	0.43	0.345	0.351	0.263	0.312	0.374	0.364
C ₁₀	0.681	0.512	0.681	0.512	0.681	0.512	0.594	0.47
C ₁₁	0.532	0.44	0.439	0.396	0.444	0.398	0.301	0.329
C ₁₂	0.538	0.443	0.417	0.385	0.503	0.426	0.399	0.377
C ₁₃	0.763	0.551	0.499	0.424	0.509	0.429	0.629	0.486
C ₁₄	0.648	0.496	0.65	0.497	0.524	0.437	0.63	0.487
C ₁₅	0.65	0.497	0.591	0.468	0.63	0.487	0.589	0.468
C ₁₆	0.458	0.405	0.458	0.405	0.458	0.405	0.458	0.405
C ₁₇	0.762	0.55	0.719	0.53	0.629	0.487	0.589	0.468
C ₁₈	0.479	0.415	0.416	0.385	0.336	0.346	0.387	0.371
XI	0.59	0.468	0.499	0.424	0.467	0.409	0.461	0.406
Results	4	4	4	4	4	4	3	3

Pressure indicators: The low-carbon development level (Weber Fischner Composite Index XI) of the four cities is ranked: Beijing (0.562), Shanghai (0.56), Chongqing (0.495), Tianjin (0.439). Shanghai's urbanization level reached 100% in 2015; Chongqing had the lowest level of urbanization, with a higher carbon emission intensity per unit of GDP; Tianjin's carbon dioxide emission elasticity coefficient is higher.

Status indicators: the low-carbon development level (Weber Fischner Composite Index XI) of the four cities is ranked: Chongqing (0.541), Shanghai (0.475), Beijing (0.467), Tianjin (0.420). Beijing, Chongqing, and Chengdu had higher forest coverage rates. Chongqing's forest coverage rate in 2015 was 45.4%, and the per capita public green area was relatively high; Tianjin's forest coverage rate and per capita public green area were relatively low. In addition, the air quality indicators of 4 cities, especially Beijing, account for a low proportion of the 4 status indicators, indicating that the air quality of the cities has declined and urgently needs improvement.

Responsive indicators: the low-carbon development level (Weber Fischner Composite Index XI) of the four cities is ranked: Beijing (0.602), Shanghai (0.522), Tianjin (0.498), Chongqing (0.459). Beijing's tertiary industry accounted for the highest proportion of GDP and energy processing and conversion efficiency; Tianjin was relatively dependent on the development of heavy industry, and clean energy accounted for a low proportion of energy consumption; Chongqing's industrial solid waste disposal utilization rate was low.

3 Conclusion

This article established a low-carbon city evaluation index system and evaluation model on the basis of grasping the connotation of low-carbon city development. The optimized universal Carson index formula and Weber Fechner index formula were used in the comprehensive evaluation of low-carbon development in four cities of Beijing, Shanghai, Tianjin and Chongqing. a) Different types of index data were standardized to make the comprehensive evaluation results comparable; b) To ensure the objectivity of the evaluation results, the basic evaluation method adopted the equal weight method; c) To ensure the effectiveness of the combined evaluation results, reliability analysis was carried out during the evaluation process, so as to finally obtained the evaluation result that can comprehensively measure the level of urban low-carbon development. Based on the actual data of the four cities, and the use of optimized evaluation methods for empirical analysis, the results showed that the Weber Fechner index formula and the universal Carson index formula had basically the same evaluation results for the four cities of Beijing, Shanghai, Tianjin and Chongqing.

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