Eco Economic Development Evaluation Model Based on Fuzzy Theory

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Abstract
This paper breaks down the comprehensive evaluation of the economic development into four sub systems, the economic, social, environmental and technological system, and establishes the comprehensive evaluation indicator system for ecological economy development, and then makes use of the fuzzy analytic hierarchy process, to build a comprehensive evaluation model for ecological economy development, and carry out comprehensive evaluation through the established comprehensive evaluation model for ecological economy development.
Key words: ENVIRONMENTAL POLLUTION, ECOLOGICAL ECONOMY DEVELOPMENT, FUZZY ANALYTIC HIERARCHY PROCESS, COMPREHENSIVE EVALUATION.

1. Introduction

The high speed development of the world economy also brings about the resource and environmental problems at the same time, and the concept of ecological economy is put forward accordingly. People would like to realize the reduction of the resource consumption, environmental pollution, and also the high speed development of the economy through the transformation of the economic development mode [1-2].

Fuzzy analytic hierarchy process is a comprehensive evaluation method that makes use of the combination of fuzzy mathematical theory and analytic hierarchy process, to carry out comprehensive evaluation on the data acquired from different sides of the complicated socio-economic and scientific management field [3-4]. This method first makes use of the analytic hierarchy process to analyze the complicated problems in the socio-economic and scientific management field, and breaks down the problems into different constituent factors based on the nature of the problems and the overall objective to be achieved, and in line with the interrelationship that influence the factors with each other, as well as the relationship of affiliation, to cluster the factors into different levels of aggregation, so as to form a multi-layered analytical structure model, and ultimately to analyze and summarize the system into the determination of the relative importance of the lowest level versus the highest level (overall goal) or the ranking of the pros and cons. Secondly, with the foundation of the fuzzy theory, this paper applies the principle of fuzzy relation composition, to quantify some factors with unclear border definition, the factors that are difficult to quantify, and this is applicable to the overall rating of things with uncertainty rules [5]. The document [6] puts forward the fuzzy analytic hierarchy process, namely to convert the fuzzy preferential relation matrix (O-1 three-degree method) into the fuzzy consistent matrix by mathematical transformation, taking the corresponding goodness value of the fuzzy consistent judgment matrix as the consistent dimensionless indicator value of all the objects for evaluation in different indicators. The concept of fuzzy consistent matrix is more in accordance with the consistency of human decision making, therefore it is more reasonable and practical [7-8]. The document [9] makes further studies on this theory, and proposes the principles and procedures for the fuzzy analytical hierarchy method. In respect of the practical applications, document [10] makes use of the fuzzy analytic hierarchy process to study the risks of the insurance fund stock investment, by identifying the risk factors of the stock investment of the insurance funds, to establish the indicator system of the fuzzy hierarchy analytical model, by leveraging the experiences of expert to make judgment and obtain the fuzzy risk judgment matrix, through data processing to acquire elative weight of each evaluation factor, so as to solve the key issues in the risk management of the insurance fund stock investment. Document [11-12] makes use of the fuzzy analytic hierarchy process to study the selection of suppliers. The selection of suppliers is a multi-target evaluation issue that contains quantitative indicators and qualitative indicators, to establish the supplier evaluation system and build the fuzzy analytic hierarchy process model for the selection of suppliers.

As can be seen from the research on the ecological economy in this paper, the majority of the research carried out by experts and scholars on the ecological economy still focus on the macro aspect and the discussion of concepts, while there are relatively less quantitative studies. Through the study of the comprehensive evaluation method, we can see that the fuzzy analytic hierarchy process is more in line with the requirements of the comprehensive evaluation of the low carbon economic development. To establish a ecological economy development the evaluation system can provide quantitative analytical methods for the development of ecological economy. Based on the analysis on the results of the development of ecological economy, this paper evaluates the situation of low carbon economic development, with the help of fuzzy analytic hierarchy process, to carry out quantitative analysis of ecological economy.

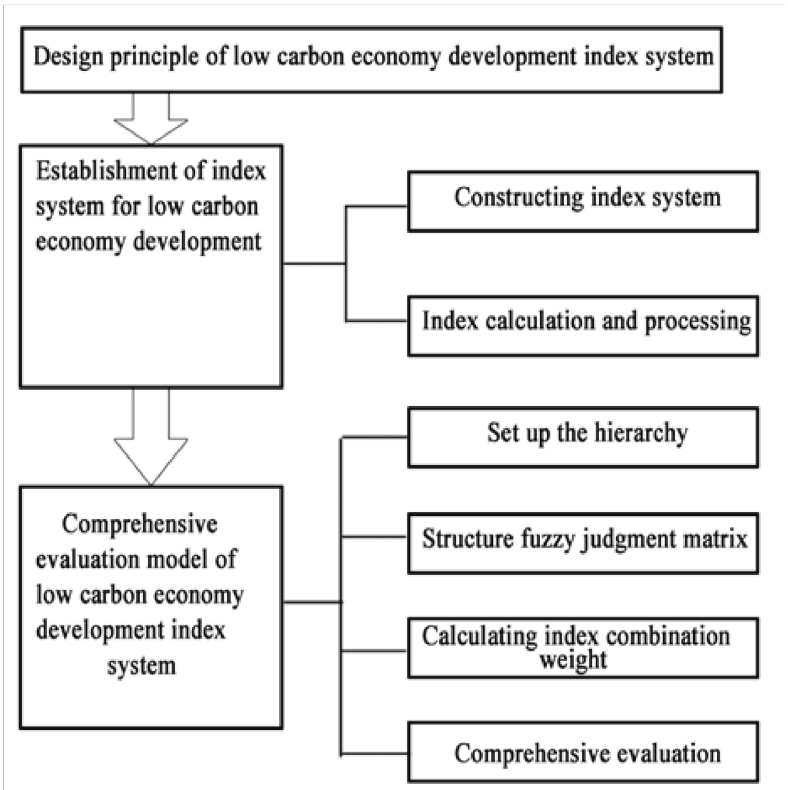

Figure 1. Overall Idea Map of the Comprehensive Evaluation of the Development of Ecological Economy

2. Comprehensive evaluation model of economic development based on fuzzy analytic hierarchy process

2.1 Overall Idea of the Evaluation Model

The comprehensive evaluation of ecological economy is a systematic project, involving a wide range of economic, social, environmental, technological and other aspects of factors; when the indicator system is established, it should reflect as accurately and objectively as possible the development of low carbon economic development in all aspects. The establishment of a multi-level indicator system can perfectly solve this problem, to divide the ecological economy into several subsystems, and set the corresponding evaluation indicator in the subsystems, through the observations on these indicators, to evaluate the development status of the subsystem, and further evaluate the overall low carbon economic development. For the evaluation method, Fuzzy Analytical Hierarchy Process (FAHP) can be selected, which is a combination of analytic hierarchy process and fuzzy mathematical theory, and a method of comprehensive evaluation on complicated social economy. The utilization of this method on the comprehensive evaluation for the ecological economy allows the breaking down of the complicated system of ecological economy into relatively simple evaluation indicators so that the final result of evaluation is more rational and objective, and thus can truly reflect the development status of the ecological economy. The overall idea of ecological economy development evaluation is shown in Figure 1.

2.2 Establishment of the comprehensive evaluation index system

As a complicated system, it is difficult to fully evaluate the status of the system operation with a single indicator for the comprehensive evaluation of ecological economy; therefore, it is necessary to establish an indicator system. The development of ecological economy should coordinate the relationship between government, businesses and the public, and the ecological economy comprehensive evaluation system operational mechanism should also contain the economic activities of the three parties. In order to facilitate the selection of indicators, it can be considered to divide the low carbon economic development comprehensive evaluation system into four smaller subsystems, namely the low carbon economic system, low carbon social systems, low carbon environmental systems and low carbon technological system, and then break down these subsystems into the corresponding indicators. For these four subsystems, the government guides the low carbon environmental system, and also covers the contents of low carbon economic system, the enterprises are involved in the development of ecological economy, and also the main force in low carbon technological system, and the public are mainly involved in the low carbon social system, with the government and businesses together to promote the development of the ecological economy. The comprehensive evaluation indicator system of low carbon economic development is shown in the table as follows:

Table 1. Comprehensive Evaluation Indicator System of Low Carbon Economic Development

System	Sub-system	Indicator
Comprehensive Evaluation Indicator System of Low Carbon Economic Development	Low Carbon Economic System	GDP per capita
		The proportion of tertiary industry
		GDP proportion of high tech industry
		GDP proportion of new energy industry
	Low Carbon Social System	Urbanization rate
		Public traffic passenger volume
		Housing space per capita
		Carbon emissions per capita consumption
	Low Carbon Environmental System	Output value of integrated utilization of the three industrial wastes
		Forest coverage percentage
		Green area per capita
		Proportion of nature reserves in the provincial jurisdiction area
	Low Carbon Technological System	Energy consumption per unit GDP
		Carbon emissions per unit GDP
		Fertilizer application amount per hectare of planting area
		Clean energy proportion in the energy mix structure

2.3 Comprehensive Evaluation Model of Low Carbon Economic Development

2.3.1 Hierarchy of Low Carbon Economic Development Indicator System

(1). The Calculation of the Indicators

In index layer most indicators can be found in the Statistical Yearbook, the carbon emissions related indicators need to be acquired through calculation.

Total carbon emissions calculation formula is as follows:

$$c = \sum_{i} Si \times Fi \times E \tag{1}$$

Where E is the total amount of energy consumption: Fi is the carbon emission intensity of the ith energy: Si means the proportion of the energy consumption of i in the total energy consumption.

Fi value is shown in the following table:

Table 2. Various Energy Emission System

Item	Coal	Oil	Natural Gas	Hydropower, Nuclear Power
Fi(t carbon / million t of standard coal)	0.7476	0.5825	0.4435	0

Carbon emissions per unit of GDP are calculated as follows:

Carbon emissions per unit of GDP = Total carbon emissions / GDP

Carbon emissions per capita consumption is calculated as follows:

Carbon emissions per capita consumption = final consumption proportion in GDP × carbon emissions per unit of GDP

(2). The processing of indicator data

The indicators also have different dimensions and dimension unit, all of which cannot be directly evaluated comprehensively. In order to solve this problem, dimensionless processing should be carried out on the indicators. The most commonly used standardized method of processing is as follows:

$$y_{ij} = \frac{x_{ij} - \overline{x_j}}{\sigma_j} \qquad (2)$$

Where $\overline{x_i}$ is the mean index for x_j, and x_j is the standard deviation of x_j. After the standardization of index data, the mean is zero, and the variance is 1, which has eliminated the influence of dimension and magnitude.

Using fuzzy analytic hierarchy process to develop the comprehensive evaluation of the low-carbon economy, first of all, it is necessary to build the ecological economy development hierarchical index system. Based on the construction of low carbon economic development indicators in the aforementioned section, the entire index system is divided into the target layer, criterion layer and index layer. The index layer is used for the evaluation of the criterion layer, and the criterion layer is to evaluation the final operation status of the low carbon economic development. And the hierarchical diagram can be established as Figure 2.

In the Hierarchical diagram A = {B1, B2, B3, B4} = {Low carbon economic system, low-carbon social system, low-carbon environmental systems, low-carbon technological system}, B1 = {C11, C12, C13, C14} = {per capita GDP, the proportion of tertiary industry, high-tech industry, and the new energy industry in GDP}, B2 = {C21, C22, C23, C24} = {Urbanization rate, total public traffic passenger volume, housing area per capita, carbon emissions per capita consumption}, B3 = {C31, C32, C33, C34} = {Output value of integrated utilization of the three industrial wastes, forest coverage rate, green area per capita, proportion of nature reserves in the provincial jurisdiction area}, B4 = {C41, C42 , C43, C44} = {Energy consumption per unit GDP, carbon emissions per unit GDP, the amount of chemical fertilizer per hectare planting area, clean energy proportion in the energy mix structure}.

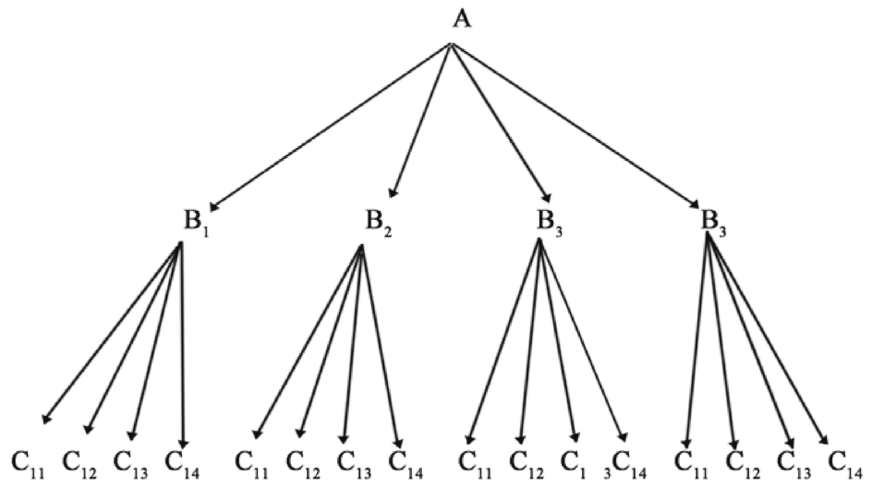

Figure 2. Hierarchical Diagram

2.3.2 Ecological Economy Development Indicator System Fuzzy Judgment Matrix

The key of the fuzzy analytic hierarchy process is to establish the fuzzy judgment matrix (precedence relation matrix) for the factors, as represented by R for the fuzzy judgment matrix (precedence relation matrix) for the importance of factors, the fuzzy judgment matrix (precedence relation matrix) R can be expressed as follows:

$$R = \begin{bmatrix} r11 & r12 & \dots & r1_\pi \\ r21 & r22 & \dots & r2_\pi \\ \dots & & & \\ r_{n1} & r_{n2} & \dots & r_{n\pi} \end{bmatrix} \quad (3)$$

Rij represents the fuzzy relationship in the comparison of element i and element j... "…is much more important than ..." of the degree of membership, in order to quantitatively describe the relative importance between two elements, you can adopt the following scale:

Table 3. Fuzzy Judgment Matrix (Precedence relation Matrix) Degree

0-1Three Degree Method	Meaning
0	The latter is more important than the former
0.5	With the same importance
1	The former is more important than the latter

If R has the following properties:

(1) $r_{ij} = 0.5, i = 1,2,\dots n$,

(2) $r_{ij} = 1 - r_{ij}, i, j = 1,2,\dots n$,

(3) $r_{ij} = rik - rjk, i, j, k = 1,2,\dots n$

Then R is called fuzzy consistent matrix. The consistency shows the consistent thinking and judgment, that is, no conflict will be generated in judging the degree of importance between factors. In the establishment of ecological economy development indicator system fuzzy judgment matrix (precedence relation matrix), the judgment of the importance of factors might have deviation, therefore, we should pay attention and carry out the consistency test on the fuzzy judgment matrix (precedence relation matrix) of the ecological economy development indicator system.

If the requirements for consistency of nature cannot be met, we should make adjustments according to the nature of the fuzzy consistent matrix, until it reaches the requirements of consistency, the adjustment approach is as follows:

1. Firstly, determine an element, and the comparative relationship between this element and other elements is very certain, assuming that the judgment on the first row of R is very certain.

2. Subtract the second row from the first row, to obtain n differences, if the n differences are constant, the second row does not need to be adjusted; if not constant, the adjustment is needed until the difference becomes constant.

3. Subtract the third row from the first row, to obtain n differences, if the n differences are constant, the third row does not need to be adjusted; if not constant, the adjustment is needed until the difference is constant. Repeat the above steps until the difference of first row deducted by the n-th row is constant. To reduce the consistency test for the fuzzy judgment matrix (precedence relation matrix), the precedence relation matrix can be transformed into fuzzy consistent matrix in advance, so that there is no need for consistency test. The method of transformation is as follows: The priority relationship matrix is R, assuming the fuzzy consistency matrix is Q, and

$$Q = \begin{bmatrix} q^{11} & q^{12} & \dots & q^{1\pi} \\ q^{21} & q^{22} & \dots & q^{2\pi} \\ \dots & & & \\ q^{n1} & q^{n2} & \dots & q^{n\pi} \end{bmatrix} \quad (4)$$

$$q_i = \sum_{j=1}^{n} r_{ij}, i = 1,2,\dots n \quad (5)$$

$$q_{ij} = \frac{q_i - q_j}{2n} + 0.5 \quad (6)$$

2.3.4 Calculate the Indicator Weight

(1)Weight Calculation Principle

Fuzzy technology matrix $Q = (q_{ij})_{n \times n}$ for the sum of the element of each row and (excluding self-comparison), and excluding the sum of the diagonal elements:

$$I_i = \sum_{j=1}^{n} q_{ij} - 0.5, i = 1,2,,\dots n \quad (7)$$

$$\sum_j I_i = \frac{n(n-1)}{2} \quad (8)$$

Because Ii refers to the importance of the factor i for the upper level target, perform the normalization to Ii and get the weight for each indicator, the formula is as follows:

$$w_i = \frac{I_i}{\sum_i I_i} = \frac{2I_i}{n(n-1)} \quad (9)$$

2.3.4 Comprehensive Evaluation of Ecological Economy

Comprehensive Evaluation Principle. Combine the indicator weight and dimensionless indicator value to calculate the low carbon economic development comprehensive index:

$$U = \sum_{k=1}^{m} w_k c_k \quad (10)$$

Where U represents the low carbon economic development comprehensive index; Ck represents dimensionless index value: Wk represents the index weight.

3. Evaluation model calculation for certain province

Based on the model proposed above, we performed the evaluation calculation to certain province.

3.1 Basic Data

(1). In recent years, for the exhaust emissions structure in the province, it is mainly sulfur dioxide, soot and dust pollution, and mostly industrial emissions as shown in the following table:

Table 4. 2007-2014 Exhaust Emissions Condition Comparison

Year			2002	2003	2004	2005	2006	2007	2008
Carbon dioxide	Total	Absolute amount (10k ton)	74.32	84.85	87.24	91.93	93.36	90.43	84.0
		Lapse rate (%)	-	14.2	2.82	5.38	1.6	-3.1	-7.1
	Total	Absolute amount (10k ton)	57.59	67.15	71.18	75.50	76.60	73.94	67.5
		Lapse rate (%)	-	16.6	6.00	6.07	1.5	-3.5	-8.7
	Industrial	Absolute amount (10k ton)	16.73	17.70	16.06	16.43	16.76	16.49	16.5
		Lapse rate (%)	-	5.8	-9.26	2.30	2.0	-1.6	0.2
Soot	Total	Absolute amount (10k ton)	43.43	49.25	53.07	53.88	49.14	44.32	40.8
		Lapse rate (%)	-	13.4	7.75	1.53	-8.8	-9.8	-14.8
	Total	Absolute amount (10k ton)	36.72	42.03	45.21	45.26	41.64	37.28	30.6
		Lapse rate (%)	-	14.5	7.56	0.11	-8.0	-10.5	-17.7
	Industrial	Absolute amount (10k ton)	6.71	7.22	7.86	8.62	7.50	7.04	7.1
		Lapse rate (%)	-	7.6	8.86	9.67	-13.0	-6.1	0.6
Dust	Absolute amount (10k ton)		60.83	69.90	72.63	76.87	73.35	65.86	55.4
	Lapse rate (%)		-	14.9	3.9	5.84	-4.6	-10.2	-15.8

As can be seen from the above table, the total amount of industrial solid wastes discharged from Hunan Province in 2009 increased from 27,540,800 tons to 45,590,300 tons in 2014, there was a slight decrease in 2009, which was 45,196,300 tons, where in 2007 and 2012 there was relatively large increase, which was 18.70% and 23.6% respectively. Comprehensive utilization of industrial solid waste has been improved, and the comprehensive utilization rate was increased from 63.040% in 2008 to 78.87% in 2013, with increase rate of 25%, The effect is significant.

(2). Energy Production Analysis

Table 5. 2007 Henan Energy Production Status Table

Energy types	Sub-type	Production (10k tons of standard coal)	Increase/decrease over last year (%)
Primary energy	Total	6180.38	5.12
	Raw coal	5112.2	5.48
	Hydropower	1068.18	3.42

Secondary energy	Total			
	Coal products	Washed coal	415.74	37.87
		Other washed coal	26.94	-0.44
		Briquette	108.06	-26.25
	Petroleum products	Gasoline	191.08	4.56
		kerosene	12.42	5.88
		Diesel fuel	333.3	15.74
		Fuel oil	35.77	-20.19
		Other petroleum products	141.75	31.38
	Thermal power	Thermal power	2012.19	14.13
	Other energy	Coke	483.82	23.04
		Other coking products	24.56	14.96
		Heat	193.86	8.86
		Coke oven gas, coal and other refining dry gas	304.18	59.6

According to the above table, the characteristics of the province's energy supply can be analyzed: Firstly, the total energy supply is rising; secondly, there is insufficient supply for the energy itself, and the energy input has rapid growth; and thirdly, the primary energy supply is singular, without gas or oil, and the crude oil and natural gas mainly relies on the energy input.

3.2 Indicator System Judgment Matrix and Wight Calculation

3.2.1 Comparison Matrix for the Ecological Economy Development Indicator System

(1). The Construction of the Fuzzy Judgment Matrix for the Target Layer A

In the comprehensive evaluation of the development of ecological economy, the most important is the low carbon technological system, followed by the low carbon economic system and low carbon environmental system, both of which are equally important, and the low carbon social system is relatively the least important. Thus, the precedence relation matrix can be established.

Table 6. Target Layer A Precedence Relation Matrix

A	B_1	B_2	B_3	B_4
B_1	0.5	1	0.5	0
B_2	0	0.5	0	0
B_3	0.5	1	0.5	0
B_4	1	1	1	0.5

Transform the target layer A precedence relation matrix into fuzzy consistent matrix:

Table 7. Target Layer A Fuzzy Consistent Matrix

A	B_1	B_2	B_3	B_4
B_1	0.5	0.6875	0.5	0.3125
B_2	0.3125	0.5	0.3125	0.125
B_3	0.5	0.6875	0.5	0.3125
B_4	0.6875	0.875	0.6875	0.5

(2). The Construction Criterion for Fuzzy Judgment Matrix Layer B1

In the ecological economy system, the indicator of new energy industry GDP proportion is the most important, followed by the high-tech industries GDP proportion, followed by the tertiary industry, which relatively speaking, has the lowest per capita GDP importance. Thus, the precedence relation matrix can be established.

Table 8. Criterion Layer B1 Precedence Relation Matrix

B_1	C_{11}	C_{12}	C_{13}	C_{14}
C_{11}	0.5	0	0	0
C_{12}	1	0.5	0	0

C_{13}	1	1	0.5	0
C_{14}	1	1	1	0.5

Transform the criterion layer Bi precedence relation into fuzzy consistent matrix:

Table 9. Criterion Layer B1 Fuzzy Consistency Matrix

B_1	C_{11}	C_{12}	C_{13}	C_{14}
C_{11}	0.5	0.375	0.25	0.125
C_{12}	0.625	0.5	0.375	0.25
C_{13}	0.75	0.625	0.5	0.375
C_{14}	0.875	0.75	0.625	0.5

3.2.2 Indicator Weight of the Ecological Economy Development

(1). Target Layer A Indicator Weight Calculation

Table 10. Target Layer A Indicator Weight Calculation Table Weight

A	B_1	B_2	B_3	B_4	li	Weight
B_1	0.5	0.6875	0.5	0.3125	1.5	0.25
B_2	0.3125	0.5	0.3125	0.125	0.75	0.125
B_3	0.5	0.6875	0.5	0.3125	1.5	0.25
B_4	0.6875	0.875	0.6875	0.5	2.25	0.375
$\sum_i \lambda$					6	-

(2). Criterion Layer B1 Indicator Weight Calculation

Table 11. Criterion Layer B1 Indicator Weight Calculation Table

B_1	C_{11}	C_{12}	C_{13}	C_{14}	li	Weight
C_{11}	0.5	0.375	0.25	0.125	0.75	0.125
C_{12}	0.6875	0.5	0.375	0.25	1.25	0.208
C_{13}	0.6875	0.625	0.5	0.375	1.75	0.292
C_{14}	0.875	0.75	0.625	0.5	2.25	0.375
$\sum_i \lambda$					6	-

(3) Criterion Layer B2 Indicator Weight Calculation

Table 12. Criterion Layer B2 Indicator Weight Calculation Table

B_2	C_{21}	C_{22}	C_{23}	C_{24}	li	Weight
C_{21}	0.5	0.3125	0.3125	0.125	0.75	0.125
C_{22}	0.6875	0.5	0.5	0.3125	1.5	0.25
C_{23}	0.6875	0.5	0.5	0.3125	1.5	0.25
C_{24}	0.875	0.6875	0.6875	0.5	2.25	0.375
$\sum_i \lambda$					6	-

For the quantitative evaluation of the development of ecological economy, the key is to obtain the comprehensive evaluation score for the ecological economy. After getting the ecological economy development comprehensive evaluation standardized data, the comprehensive evaluation formula can be utilized:

$$\begin{aligned} U &= 0.03125C_{11} + 0.052C_{12} + 0.073C_{13} + 0.09375C_{14} + 0.015625C_{21} + 0.03125C_{22} \\ &+ 0.03125C_{23} + 0.046875C_{24} + 0.09375C_{31} + 0.04175C_{32} + 0.0725C_{33} + 0.04175C_{34} \\ &+ 0.124875C_{41} + 0.124875C_{42} + 0.046875C_{43} + 0.078C_{44} \end{aligned} \quad (11)$$

Hunan comprehensive evaluation of low carbon economic development is shown in the following table

Table 13. Hunan comprehensive evaluation score of low carbon economic development

Year Score	Low carbon economic system score	Low carbon social system score	Low carbon environmental system score	Low carbon technological system score	Total score of the comprehensive evaluation

2009	-0.1373	-0.16806	-0.36367	-0.3168	-0.98583
2010	-0.15024	-0.06764	-0.15825	-0.23629	-0.61243
2011	-0.07463	-0.00099	-0.04845	-0.13964	-0.26371
2012	-0.00221	-0.0068	0.070119	0.157001	0.218115
2013	0.234066	-0.08456	0.209349	0.198145	0.726121
2014	0.130306	0.158938	0.290893	0.337591	0.917729

According to the low carbon economic development comprehensive evaluation score, the province low carbon economic development operation can be analyzed. Although from 2009 - 2011 the development of the ecological economy, it was not good enough, in terms of the low carbon economic, low carbon social, low carbon environmental, or low carbon technological systems are in progress. In 2012, for the four subsystems of ecological economy development evaluation score, the low carbon economic and low carbon social system score was still smaller than 0, and the low carbon environmental system and low carbon technological system score was more than 0 for the first time, and the improvement rate was larger than that of the low carbon economic and low carbon social system score, indicating that in this year, the province was focused more on the low carbon environment construction and low carbon technological transformation, and have made great achievements. In 2013 and 2014 the low carbon economic development comprehensive evaluation total scores were greater than 0.5, compared to the province's ecological economy development status in 2012, the ecological economy development and operation condition has been further improved to another level.

4. Conclusion

This paper focuses on the central task of the low carbon economic development, and draws on the research of the domestic and foreign scholars for the development of the ecological economy, adopting the fuzzy analytic hierarchy process, to establish the comprehensive evaluation model for the low carbon economic development, and performs the comprehensive evaluation on the ecological economy with certain principle of the low carbon economic development comprehensive evaluation model as illustrated in this paper. Firstly, according to the system theory, the comprehensive evaluation of the ecological economy system is broken into four sub-systems including the low carbon economic system, low carbon social system, low carbon environmental system and low carbon technological system. Then based on the fuzzy hierarchy analysis, this paper calculates the weight of each indicator system, and ultimately establishes the comprehensive evaluation model for the low carbon economic development. The analysis on the low carbon economic development in certain province has been carried out, and research was done on the changes in the situation from 2009 to 2014 in respect of the development of the ecological economy.

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