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Construction and Application of Low-Carbon Audit Evaluation Index System Based on Low-Carbon Economy*

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Abstract

Low-carbon economy is the future development direction. Facing the current situation of high pollution and high energy consumption, low-carbon audit emerges as The Times require. Firstly, the connotation of low carbon economy, green economy and circular economy is analyzed, and the relation and difference among them are pointed out. Based on the low-carbon economy, the article elaborated on the meaning and significance of low-carbon audit. The article uses the analytic hierarchy process to construct a low-carbon audit evaluation index system. The indicator system includes four indicators of low-carbon environment, low-carbon economy, low-carbon energy and carbon dioxide benefits. The Saaty 1 - 9 scale method is used when calculating the criterion layer, index layer and comprehensive weight. The efficiency coefficient method is used in the standardization of indicators in the low-carbon audit evaluation indicator system. On this basis, the standardized scores of each indicator are calculated. The low-carbon economy score of Henan Province was finally calculated. Through the score, we can understand the development of the low-carbon economy in Henan Province. At the end of the article, relevant suggestions are put forward.

Keywords

Low-Carbon Economy, Low-Carbon Audit, Evaluation Index System

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1. Low-Carbon Economy, Green Economy and Circular Economy

1.1. Connotation of Low-Carbon Economy

In 2003, the concept of a low-carbon economy was first proposed by former British Prime Minister Blair in "Our Energy Future: Creating a Low-Carbon Economy" to achieve better economic benefits while minimizing the consumption of natural resources and environmental pollution (Department of Trade and Industry, 2003). The proposal of this concept has attracted widespread attention from all walks of life, and many experts and scholars have studied it from different angles. However, there is no unified understanding of the connotation of low-carbon economy. Zhuang Guiyang proposed: energy efficiency and clean energy structure are the essence of low-carbon economy, and mitigation of climate change is the goal of low-carbon economy (Zhuang, 2009). Low-carbon economy is based on three lows and three highs. Low-carbonization is its development direction. The development method is energy saving and emission reduction. Energy consumption is another understanding of low-carbon economy. Energy consumption is a form of economic development to a certain period. It is the common desire of the world to reduce greenhouse gas emissions. Energy efficiency and non-fossil energy account for energy consumption. The problem of proportion is its core content (Zhang, 2011).

1.2. Low-Carbon Economy, Green Economy and Circular Economy

The green economy is people-oriented; and the feature is to protect the environment for human survival and rational use of resources.

Circular economy is the general term for reducing, reusing and reusing activities in the process of production, circulation and consumption. Circular economy is an important way to implement the scientific development concept. Circular economy is an important way to implement the scientific development concept. It appeared in "Earth Economics of Future Spaceships" in 1966 and was proposed by the American economist Paulding (Zhang, 2012).

As a low-carbon economy with low energy consumption, low pollution and low emissions, it is an important change in human society driven by technologies such as energy saving and emission reduction, and a major innovation after agricultural and industrial civilization (Xiao et al., 2020).

The core of a low-carbon economy is to reduce greenhouse gas emissions, with special attention to clean energy utilization and energy efficiency. The main purpose of the China Council for International Cooperation is to promote the environment and development. Its definition of a low-carbon economy is: in terms of production and consumption, a low-carbon economy can achieve the purpose of energy conservation and greenhouse gas emission reduction. A low-carbon economy is also a difference. Based on the technical and social system of the traditional economy, this system can promote economic and social development (Fu, 2014).

1.3. The Connection and Difference between Low-Carbon Economy, Green Economy and Circular Economy

1.3.1. Contact

Green economy includes circular economy and low-carbon economy. All three have achieved economic development based on the concept of sustainable development. The three have the same guiding ideology and the same goals in terms of development, consumption, and production.

1.3.2. Difference

The three have certain differences in specific methods, problems and functions. Green economy refers to the harmonious economic activities and results between man and nature. It includes all aspects of economic activities such as production, circulation, distribution, consumption, ecology and environmental protection, and it contains a wide range of content. Circular economy refers to the economic form of a virtuous cycle of the ecological economic system, with particular emphasis on the protection and utilization of natural resources, the reuse of commodities and the recovery of waste. The main goal of a low-carbon economy is to reduce greenhouse gas emissions, requiring low-carbon industry, low-carbon consumption and low-carbon energy. The low-carbon economy mainly focuses on energy consumption and greenhouse gas emissions.

2. Overview of Low Carbon Audit

2.1. Meaning

The concept of low-carbon audit related to low-carbon issues was first mentioned in the UK's 2008-2009 work report. This report is a comprehensive low-carbon audit report, which reflects the development and direction of low-carbon audit (Wang, 2010). Combining audits with low-carbon production, new energy development, and energy utilization is the development direction of low-carbon auditing (Yuan, 2011). Regarding the definition of low-carbon audit, different experts have different views. The generally agreed view is that The goal of low carbon audit is to audit and supervise the carbon activities of the audit objects, comprehensively evaluate the low carbon performance, promote the reasonable and effective application of low carbon economic activities and low carbon technologies, promote energy conservation and emission reduction, and promote the healthy and orderly development of low carbon economy (Zhao, 2017). As a part of environmental audit, low-carbon audit has an important supervisory role in the construction of a low-carbon economic environment and plays an important role in energy conservation and emission reduction (Chen & Peng, 2010).

China currently lacks carbon audit standards, and it is difficult to calculate relevant data about carbon audit. Carbon audit talents are not enough to undertake carbon audit tasks, and relevant training for carbon audit talents should be increased. Lu Xiangjun and others believe that low-carbon audits should include auditing the formulation and implementation of low-carbon policies, auditing

the efficiency of low-carbon funds, and auditing low-carbon behaviors (Lu, et al., 2011). And Wang Aiguo believes that carbon audit includes a wide range of content, including performance audits of carbon-related emission reduction policies, compliance audits, and audits of carbon emission reduction activities (Wang, 2012). Yue Fengxian identified the motivations for low-carbon audits, which mainly included auditing the formulation and implementation of low-carbon policies and carbon trading activities (Yue, 2014). Chen Yangyang constructed a low-carbon audit evaluation index system from several aspects such as economic benefits, low-carbon consumption, low-carbon technology, environmental resources and low-carbon policies (Chen & Wang, 2016). At present, some researches mainly define the objectives and content of low-carbon audits and initially build a low-carbon audit framework.

2.2. Significance of Low-Carbon Audit

Conducting a low-carbon audit in the context of a low-carbon economy is conducive to the evaluation and supervision of the low-carbon environment. It can also evaluate the effects of energy conservation and emission reduction (Li, 2016), which is helpful to the transformation of economic development models, and Promoting the construction of an environmentally friendly and resource-conserving society, at the same time, provides a certain theoretical basis for the adjustment of the industrial structure, and ultimately promotes the optimization of the human living environment.

3. Construction of Low-Carbon Audit Evaluation Index System

Low-carbon audit involves a wide range, a large amount of content, and a large amount of work. Due to the complexity of the low-carbon economy and the limitation of auditors' knowledge, it is more difficult than traditional audits. A low-carbon audit evaluation index system is established and the indicators are evaluated (Li, 2017).Quantification can improve audit efficiency, contribute to the development of low-carbon audit, and at the same time increase the government and enterprises' intuitive understanding of the low-carbon economy.

3.1. Selection of Low-Carbon Audit Evaluation Indicators

The energy technology system on energy policy, index system, evaluation standard and audit is a low carbon audit evaluation index system established by the World Energy Organization; The British government has established a low-carbon audit system based on energy, transportation, procurement, and waste utilization. Song Meng built a low-carbon performance evaluation system based on power companies from the perspective of energy consumption, including three indicators: energy consumption and output, low-carbon consumption, and low-carbon management (Song et al., 2012); Zhang Caiping and Xu Xiaoxu constructed it through the input-output method A corporate carbon performance

indicator system including carbon intensity, carbon dependence, carbon exposure and carbon risk (Zhang & Xiao, 2011).

The low-carbon economy is characterized by energy consumption and carbon emissions. Therefore, when establishing a low-carbon audit evaluation index system, these two important factors should be included. At the same time, the low-carbon audit evaluation index needs to be quantified (Gao, 2016). It is necessary to construct a low-carbon audit evaluation index. The availability of indicator data should be considered when auditing and evaluating the indicator system (Zhang et al., 2017).

3.2. Construction of Low-Carbon Audit Evaluation Index System

Low-carbon environmental indicators mainly include the proportion of environmental pollution control investment in GDP, forest coverage, the proportion of research and experimental development funding in GDP, and the growth rate of research and experimental development funding. The indicator to measure a country's environmental protection is usually the proportion of environmental pollution control investment in GDP. One of the key factors in tackling climate change is the forest system. Forest resources play an important role in reducing carbon dioxide emissions and mitigating climate change. Technological innovation is an important driving force for energy conservation and emission reduction. Various wastes discharged by industrial enterprises are the main source of environmental pollution. Industrial enterprises should use technology research and development and technological innovation to achieve energy conservation and emission reduction (Zhi et al., 2013). The proportion of research and experimental development funds in GDP can reflect the level of development of the low-carbon environment from a technical perspective; the growth rate of research and experimental development funds reflects the efforts made by the government, enterprises and other departments to develop low-carbon economy.

The development of the low-carbon economy depends on the development of the national economy. The evaluation indicators of the low-carbon economy mainly include the proportion of the added value of the tertiary industry in GDP and the growth rate of per capita GDP. The industrial structure has a great impact on regional energy efficiency and is an important factor in determining the level of carbon emissions. Compared with the primary and secondary industries, the development of the tertiary industry is greener and has low energy consumption. The growth rate of per capita GDP directly affects a country's investment orientation, investment capacity and investment level in terms of residents' income and social construction.

The test of energy consumption is reflected in low-carbon energy indicators. Low-carbon energy indicators mainly include energy consumption per unit of GDP, reduction rate of energy consumption per unit of GDP, proportion of non-fossil energy in primary energy consumption, and growth rate of non-fossil energy consumption. Energy consumption per unit of GDP can explain the ex-

tent of energy use, and it can also reflect changes in energy efficiency and economic structure; the reduction rate of energy consumption per unit of GDP can indirectly reflect the effect of various energy-saving policies and play a certain role in testing the effectiveness of energy-saving and consumption-reducing. Petroleum, natural gas, and coal are now the main fossil energy sources, and their use is the main source of carbon dioxide emissions in environmental pollution. Therefore, increasing the proportion of non-fossil energy in energy consumption can effectively reduce greenhouse gas emissions and protect the ecological environment.

Carbon dioxide emissions per unit of GDP, reduction rate of carbon dioxide emissions per unit of GDP, and reduction rate of carbon dioxide emissions per unit of energy are used as indicators to reflect carbon dioxide emissions, which can reflect greenhouse gas emissions to a certain extent.

On the basis of the above analysis, the Analytic Hierarchy Process (AHP) is used to construct a low-carbon audit indicator system as shown in Table 1.

Table 1. Low-carbon audit evaluation index system framework.

Criterion layer	Index layer	Influence direction
Low carbon environment	Investment in environmental pollution control as a percentage of GDP	+
	Forest cover rate	+
	Research and experimental development expenditure as a percentage of GDP	+
	Research and experimental development expenditure growth rate	+
Low-carbon economy	GDP growth rate per capita	+
	The added value of the tertiary industry as a proportion of GDP	+
Low carbon energy	Energy consumption per unit GDP	–
	Reduction rate of energy consumption per unit GDP	+
	Proportion of non-fossil energy in primary energy consumption	+
	Non-fossil energy consumption growth rate	+
CO_2 benefits	Carbon dioxide emissions per unit of energy	–
	Carbon dioxide emissions per unit of GDP	+
	Reduction rate of carbon dioxide emissions per unit of GDP	–

4. Weight Calculation of Low-Carbon Audit Evaluation Index System

The Saaty 1 - 9 scaling method is used to determine the weight of the criterion layer and the target layer.

4.1. Calculation of Criterion-Level Weight

The basic characteristics of a low-carbon economy are low energy consumption and low emissions. Therefore, when determining indicator weights, indicators such as carbon dioxide emissions and energy consumption have higher weights. Combined with the relevant regulations of green development indicators, low-carbon energy indicators contain two important indicators. The importance is determined to be 3, the economic benefit of carbon dioxide contains an important index, the importance is 2, and the importance of the other two criterion-level indicators is determined to be 1.

The weighting table of the criterion layer is calculated according to the pairwise importance of each criterion layer as shown in Table 2.

4.2. Determining the Weight of the Index Layer

The weight calculation method of each indicator in the indicator layer is the same as that of the criterion layer.

4.2.1. Determination of the Weight of Low-Carbon Environmental Indicators

The proportion of investment in environmental pollution control in GDP reflects the government's efforts to control environmental pollution; the level of forest coverage reflects the ability of the forest environment to absorb harmful gases; the proportion of research and test funds in GDP can reflect the low-carbon economy to a certain extent Growth quality; the growth rate of research and experiment funding is a dynamic reflection of research and experiment funding. The importance of forest coverage rate is determined as 1. The proportion of environmental pollution control investment in GDP and the proportion of research and experimental development expenditure in GDP are the main monitoring and evaluation indicators in the green development indicators,

Table 2. Low-carbon audit evaluation index system criterion layer weight coefficient table.

Criterion layer	Low carbon environment	Low-carbon economy	Low carbon energy	CO_2 benefit
Low carbon environment	1	1	1/3	1/2
Low-carbon economy	1	1	1/3	1/2
Low carbon energy	3	3	1	3/2
CO_2 benefit	2	2	2/3	1
WeightsR1i	0.1429	0.1429	0.4286	0.2856

and the degree of importance is determined to be 2; The importance of the growth rate of research and experiment funding is determined to be 3. The calculation results of the low-carbon environment weight table are as shown in Table 3.

4.2.2. Determination of the Weight of Low-Carbon Economic Indicators

The growth rate of per capita GDP reflects a country's economic development and changes; the increase in the proportion of tertiary industry added value in GDP means that the industry-led economy is gradually shifting to a service-led economy, and the degree of importance is determined to be 1. After calculation, the per capita GDP growth rate and the added value of the tertiary industry accounted for 0.5.

4.2.3. Determination of the Weight of Low-Carbon Energy Indicators

Energy consumption per unit of GDP reflects the energy consumed per 10,000 yuan of GDP, and the degree of importance is determined to be 1. The reduction rate of energy consumption per unit of GDP reflects energy consumption from a dynamic perspective. The proportion of non-fossil energy in primary energy consumption reflects whether the economic structure is an economic structure with high energy consumption. It and the reduction rate of energy consumption per unit of GDP belong to the key monitoring indicators in the green development indicators, and its importance is determined to be 3; the growth rate of non-fossil energy consumption reflects the growth of non-fossil energy consumption determined as 2. After calculation, the energy consumption per unit of GDP, the reduction rate of energy consumption per unit of GDP, the proportion of non-fossil energy in primary energy consumption, and the weight of non-fossil energy consumption growth rate are: 0.1111, 0.3333, 0.3333 and 0.2223.

Table 3. Low-carbon environment weight table.

Index layer	Investment in environmental pollution control as a percentage of GDP	Forest cover rate	Research and experimental development expenditure as a percentage of GDP	Research and experimental development expenditure growth rate
Investment in environmental pollution control as a percentage of GDP	1	2	1	2/3
Forest cover rate	1/2	1	1/2	1/3
Research and experimental development expenditure as a percentage of GDP	1	2	1	2/3
Research and experimental development expenditure growth rate	3/2	3	3/2	1
Weights R2ij	0.2875	0.1187	0.2375	0.3563

4.2.4. Determination of the Weight of Carbon Dioxide Benefit Index

Carbon dioxide emissions per unit of energy reflect the degree of impact of energy consumption on the climate, and its importance is determined to be 1; carbon dioxide emissions per unit of GDP is a measure of carbon dioxide emissions from a development perspective, and its relative importance is determined to be 2; The reduction rate of carbon dioxide emissions per unit of GDP is an important indicator reflecting greenhouse gas emissions and efforts to mitigate climate change, and its importance is determined to be 3. The weights of carbon dioxide emissions per unit of energy, carbon dioxide emissions per unit of GDP, and carbon dioxide emissions reduction rate per unit of GDP are calculated as follows: 0.1667, 0.3333, 0.5.

4.3. Determination of the Comprehensive Weight of the Low-Carbon Audit Evaluation Index System

The comprehensive weight results of the evaluation index system are shown in Table 4.

Table 4. Comprehensive weight table of low-carbon audit evaluation index system.

Criterion layer	Weights	Index layer	Weights	Total ranking weight
Lowcarbon environment	0.1429	Investment in environmental pollution control as a percentage of GDP	0.25	0.0357
		Forest cover rate	0.125	0.0180
		Research and experimental development expenditure as a percentage of GDP	0.25	0.0357
		Research and experimental development expenditure growth rate	0.375	0.0535
Low-carbon economy	0.1429	GDP growth rate per capita	0.5	0.0715
		The added value of the tertiary industry as a proportion of GDP	0.5	0.0715
Low carbon energy	0.4286	Energy consumption per unit GDP	0.1111	0.0476
		Reduction rate of energy consumption per unit GDP	0.3333	0.1429
		Proportion of non-fossil energy in primary energy consumption	0.3333	0.1429
		Non-fossil energy consumption growth rate	0.2223	0.0952
CO_2 benefit	0.2856	Carbon dioxide emissions per unit of energy	0.1667	0.0476
		Carbon dioxide emissions per unit of GDP	0.3333	0.0952
		Reduction rate of carbon dioxide emissions per unit of GDP	0.5	0.1428

5. Application of Low-Carbon Audit Evaluation Index System

5.1. Data Source and Processing

Use the low-carbon economic data of Henan Province in 2017 and use the constructed low-carbon audit evaluation index system to score the low-carbon economic status. The original data used comes from the "Henan Provincial Statistical Yearbook", "China Statistical Yearbook", BP World Energy Statistics, World Bank WDI database or compiled based on other public data.

The standardization of the index adopts the efficiency coefficient method. The low-carbon economic data of the United States is selected as the satisfactory value of the evaluation index, and the average data of the national low-carbon economy is regarded as the unacceptable value.

5.2. Standardized Scores of Low-Carbon Audit Evaluation Indicators in Henan Province

Based on the collection of low-carbon economic data in the United States, China and Henan Province, the standardized scores of low-carbon audit evaluation indicators calculated by the efficiency coefficient method are shown in Table 5.

Table 5. Standardized scores of evaluation indicators.

Evaluation index	Indicator attributes	The United States	China	Henan Province	Standardized score
Investment in environmental pollution control as a percentage of GDP	+	2%	1.15%	1.97%	98.59
Forest cover rate	+	33.93%	21.63%	24.5%	69.33
Research and experimental development expenditure as a percentage of GDP	+	2.79%	2.13%	1.31%	10.30
Research and experimental development expenditure growth rate	+	7.45%	12.3%	17.78%	100
GDP growth rate per capita	+	1.55%	6.3%	5.94%	63.03
The added value of the tertiary industry as a proportion of GDP	+	77%	51．6%	43.3%	46.93
Energy consumption per unit GDP	−	0.27	0.57	0.54	64
Reduction rate of energy consumption per unit GDP	+	3.72%	3.7%	7.9%	100
Proportion of non-fossil energy in primary energy consumption	+	15.8%	13.8%	6.8%	0
Non-fossil energy consumption growth rate	+	5.89%	6.9%	8.86%	100
Carbon dioxide emissions per unit of energy	−	1.59	2.06	2.28	41.28
Carbon dioxide emissions per unit of GDP	−	0.43	1.12	1.17	57.10
Reduction rate of carbon dioxide emissions per unit of GDP	+	5.01%	5.19%	7.64%	100

It can be seen from Table 5 that the forest coverage rate, per capita GDP growth rate, and unit GDP energy consumption score are between 60 and 70, indicating that the low-carbon economy embodied by these indicators is lower than the national average. Carbon work is relatively good; the proportion of environmental pollution control investment in GDP, the growth rate of research and experimental development funding, the reduction rate of energy consumption per unit of GDP, the growth rate of non-fossil energy consumption, and the reduction rate of carbon dioxide emissions per unit of GDP have all exceeded 90 points. However, the proportion of non-fossil energy in primary energy consumption is very low, which results in a low score. The proportion of research and experimental development funds in GDP, the added value of the tertiary industry in GDP, the proportion of non-fossil energy in primary energy consumption, the carbon dioxide emissions per unit of energy and the carbon dioxide emissions per unit of GDP scores are low.

5.3. Comprehensive Scores and Results Analysis of Low-Carbon Audit Evaluation Indicators in Henan Province

It can be seen from Table 6 that from the scores of the criteria level, the highest score is the carbon dioxide benefit, but the score is only 75.913 points, followed by the low carbon environmental criteria level, with a score of 73.375 points, The low-carbon economic criteria level has the lowest score, only 55.018 points. The comprehensive low-carbon economy score of Henan Province calculated according to the low-carbon audit evaluation index system is 66.885 points.

Table 6. Comprehensive scores of low-carbon audit evaluation indicators.

Criterion layer	Criterion level score	Index layer	Index relative to target layer score
Lowcarbon environment	73.375	Investment in environmental pollution control as a percentage of GDP	3.520
		Forest cover rate	1.248
		Research and experimental development expenditure as a percentage of GDP	0.368
		Research and experimental development expenditure growth rate	5.350
Low-carbon economy	55.018	GDP growth rate per capita	4.507
		The added value of the tertiary industry as a proportion of GDP	3.355
Low carbon energy	62.661	Energy consumption per unit GDP	3.046
		Reduction rate of energy consumption per unit GDP	14.290
		Proportion of non-fossil energy in primary energy consumption	0.000
		Non-fossil energy consumption growth rate	9.520
CO_2 benefit	75.913	Carbon dioxide emissions per unit of energy	1.965
		Carbon dioxide emissions per unit of GDP	5.436
		Reduction rate of carbon dioxide emissions per unit of GDP	14.280
		Composite score	66.885

The highest score in the indicator layer is the reduction rate of energy consumption per unit of GDP, followed by the reduction rate of carbon dioxide emissions per unit of GDP, and the growth rate of non-fossil energy consumption ranks third. The indicators with a score of 5 or more also include the growth rate of research and experimental development funding and carbon dioxide emissions per unit of GDP. The scores of other indicators are basically concentrated between 1 and 3 points.

The reduction rate of energy consumption per unit of GDP, the reduction rate of carbon dioxide emissions per unit of GDP, and the proportion of non-fossil energy in primary energy consumption are among the key monitoring indicators in Henan's green development indicators. The scores of the first two indicators are relatively good, and energy conservation and emission reduction work is relatively effective. However, judging from the comprehensive score of the proportion of non-fossil energy in primary energy consumption, Henan Province still needs to increase its efforts in the development and utilization of new energy.

Judging from the comprehensive low-carbon audit results, there is still room for decline in the low-carbon economic development of Henan Province. It is necessary to further improve the industrial structure and energy consumption structure, increase the development of energy technologies, and improve energy efficiency.

6. Conclusion

This article first sorts out the relevant research results of low-carbon economy and low-carbon audit. On this basis, the analytic hierarchy process was used to build a low-carbon audit evaluation index system based on the low-carbon economy of Henan Province, including low-carbon environment, low-carbon economy, low-carbon energy, and carbon dioxide benefits. And the weights of the criterion layer and the index layer are calculated using the Saaty 1 - 9 scale method, and the comprehensive weight of the evaluation index system is calculated. Finally, the article collects low-carbon economic data of Henan Province, China and the United States based on the low-carbon audit evaluation index system. According to the efficiency coefficient method, the indicators in the low-carbon audit evaluation index system are standardized, and the standardized scores of each indicator of the low-carbon audit evaluation index of Henan Province are calculated, and then it uses the constructed low-carbon audit evaluation index system to score Henan Province's low-carbon economy, which can give a more comprehensive understanding of the development status of Henan Province's low-carbon economy. Due to my incomplete knowledge and experience, the selection of indicators for evaluating the low-carbon economy may not be comprehensive enough; in the future, the comparison can be further extended to other provinces in China, which may be more instructive.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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