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Evaluation of Energy-Economy-Environment System Coordination in Southwest China under the Perspective of Carbon Neutrality and Its Influencing Factors Research

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ABSTRACT

Driven by the "carbon neutrality" policy, the coordinated development of energy, economy and environment has become an important part of sustainable development. In this paper, four provinces and cities in southwest China, including Yunnan, Guizhou, Sichuan, and Chongqing from 2011 to 2021, were taken as the research objects, and the coupling coordination model was used to construct a comprehensive evaluation index system of energy, economy, and environment, and the coupling coordination level of the three systems was empirically analyzed, and the influencing factors were analyzed. The final results show that the coordinated development level of energy-economy-environment system in the four provinces is greater than 0.5 in 2021, which has entered the coordination stage, but there is still a distance from high-quality coordination. Based on this, this paper puts forward policy suggestions to promote the coordinated development of energy, economy and environment in four provinces in southwest China.

KEYWORDS

Energy; Economy; Environment; Coupling coordination

1. INTRODUCTION

In recent years, the Chinese government has paid more and more attention to the coordinated development of energy, economy and environment. Energy is a powerful driving force for economic growth and social development, and it is also an important component of the coordinated development of the green economy. There is a significant positive correlation between economic growth and energy consumption, and the total energy consumption is also showing a rapid growth trend while economic growth, and the result is that the level of CO2 emissions based on coal, oil and natural gas energy consumption exceeds the standard, and a large number of carbon emissions have caused huge harm to the environment, and low-carbon transformation has become an urgent problem. To this end, in September 2020, President Xi Jinping proposed the goal of "achieving carbon peak by 2030 and carbon neutrality by 2060" at the 75th United Nations Development Conference. On the one hand, the development of low-carbon emission reduction is conducive to adjusting the economic structure and improving the efficiency of energy utilization. On the other hand, it can reduce the harm caused to the environment. Therefore, in order to implement the "double carbon" goal, China must improve the ecological and environmental protection system on the basis of promoting economic development, and coordinate the coordinated development of energy, economy and environment.

As a strategic fulcrum to achieve China's coordinated regional development, the southwest region has excellent ecological endowments and abundant energy and minerals. However, at present, due to the multiple constraints of economy, energy and industrial structure, there are still many difficulties in achieving carbon peak and carbon neutrality. Based on the current development status, this paper takes four provinces and cities in southwest China as the research object to empirically analyze the current situation of the coordinated development level of energy, economy and environment, so as to provide a theoretical source for the region to embark on a low-carbon path and sustainable economic development.

2. ENERGY, ECONOMY AND ENVIRONMENT ARE INTERRELATED

Economic development depends on the efficient use of energy and the effective protection of the environment. From the perspective of economic development, economic development is inseparable from the input of supply factors such as energy and environment. If energy elements can be rationally allocated, clean and efficient utilization can be achieved, and energy development can gradually shift from "high carbon" to "green and low-carbon" through green innovation, it is of great significance for China to achieve the dual carbon goal. High-quality economic development is inseparable from the protection of the environment, and environmental protection helps to reduce the environmental costs of economic development. At the current stage, China's annual economic losses caused by environmental pollution and ecological damage account for about 6% of GDP that year. If environmental pollution continues to be produced, it will lead to the problem of "high environmental pollution", and the environmental carrying capacity may be on the verge of limit, which will seriously restrict the sustainable and high-quality development of the economy.

The efficient use of energy is inseparable from the rapid development of the economy and the efficient protection of the environment. The economy provides financial support for energy technology innovation by virtue of its material basis, and on the basis of this condition, more advanced science and technology can be developed to improve energy efficiency, and promoting the low-carbon transformation and upgrading of the energy structure and accelerating the energy efficiency are important ways to achieve economic development and environmental protection. From the perspective of efficient environmental protection, protecting the ecological environment is the only way to achieve sustainable development. The report of the 20th National Congress of the Communist Party of China pointed out that it is necessary to promote "carbon reduction, pollution reduction, green expansion, and growth" in a coordinated manner, develop the concept of intensive conservation, green and low-carbon ecology, and force the efficient use of energy by making up for the shortcomings of the ecological environment.

Efficient environmental protection is closely related to economic development and efficient use of energy. Based on the relationship between the environment and the economy, the degree of environmental pollution will show an inverted U-shaped curve with the growth of GDP, and the environment is the material condition for economic development, and the economic activities of human society will be at the cost of environmental pollution to a certain extent, which brings certain pressure to the environment. However, economic development provides financial resources and technical support for environmental protection. Starting from the relationship between environment and energy, green energy development and green supply structure play an important role in the demand for environmental quality, which needs to accelerate the transformation of energy development to clean and low-carbon, and achieve energy security and efficient use.

3. STUDY DESIGN

3.1. Study Area and Data Sources

In this paper, four provinces and cities in southwest China (Yunnan, Guizhou, Sichuan, and Chongqing) were selected as the research objects, and the original data of energy, economy and environment-related index data were the statistical yearbooks of each province and city, local statistical bulletin and China Statistical Yearbook, and some of the missing data were supplemented by mean substitution method.

3.2. Research Methodology

3.2.1. Entropy Weight Method

The entropy weight method uses entropy to judge the dispersion of the index, the smaller the entropy value, the greater the dispersion of the index, and the greater the weight of the index. Therefore, the weight of each index can be calculated through information entropy, which provides a basis for the accuracy and objectivity of the comprehensive evaluation of multiple indicators, and is an objective weighting method. The main calculation steps of the entropy weight method are as follows:

Step 1: Select the indicator. If there is an i system, the j indicator, Xij represents the raw data of the j indicator of the i system.

Step 2: Standardise the indicators using the extreme variance method. In order to make the results of the subsequent calculations meaningful, it is necessary to process the data with a value of 0. After the overall panning dimensionless data, in order to avoid destroying the data and have a minimal impact on the original data, so this paper selects 0.0001.

Positive indicators: $$Y_{ij} = \frac{X_{ij} - \min(X_{ij})}{\max(X_{ij}) - \min(X_{ij})} + 0.0001 \quad (1)$$

Negative indicators: $$Y_{ij} = \frac{\max(X_{ij}) - X_{ij}}{\max(X_{ij}) - \min(X_{ij})} + 0.0001 \quad (2)$$

In equations (1) and (2), Xij denotes the raw data of the jth indicator of the i-system; max (Xij) and min (Xij) are the maximum and minimum values of the jth index, respectively. The value of the normalized metric for it.

Step 3: Calculate the ratio of the value of the i system indicator under the jth indicator Pij.

$$P_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}} \quad (3)$$

Step 4: Calculate the entropy of the jth indicator Ej.

$$E_j = \frac{\sum_{i=1}^{n} P_{ij} \ln P_{ij}}{\ln(n)} \quad (4)$$

Step 5: Calculate the weights by calculating the information redundancy Dj.

$$D_j = 1 - E_j \quad (5)$$

Step 6: Calculate the metric weight Wj.

$$W_j = \frac{D_j}{\sum_{i=1}^{n} D_j} \quad (6)$$

3.2.2. Coupling Coordination Model

The coupling coordination model is used to analyze the level of coordination development between systems. This paper involves three subsystems: energy, economy and environment, so this paper uses the coupling coordination model to measure the coupling coordination degree between the energy-economy-environment systems in four provinces in southwest China, so as to judge the coordination status between the systems. The coupling coordination function is shown below:

$$C = \frac{3*\sqrt[3]{U_1*U_2*U_3}}{U_1+U_2+U_3} \tag{7}$$

$$T = \alpha U_1 + \beta U_2 + \gamma U_3 \tag{8}$$

$$D = \sqrt{C*T} \tag{9}$$

Where C is the coupling degree of the three systems, and C∈[0, 1], the closer the C value is to 0, the smaller the coupling degree between the systems. Conversely, the closer the C value is to 1, the better the coupling state between the individual systems. U1 is the comprehensive energy evaluation index, U2 is the comprehensive economic evaluation index, U3 is the comprehensive environmental evaluation index, T is the comprehensive coordination index of the three systems, α, β and γ are the corresponding weights, and the weights of the three subsystems are the same, indicating that the contribution of energy, economy and environment to the coupling coordination degree is the same, that is, α=β=γ=1/3.

According to the value of coupling coordination degree D, the following classification is carried out, and a total of 10 types are divided, as shown in Table 1.

Table 1. Coupling coordination degree classification criteria

Coupling coordination type	Coupling coordination	Coupling coordination type	Coupling coordination
Extreme disorder	(0, 0.1]	Barely coordination	(0.5, 0.6]
Severe disorder	(0.1, 0.2]	Elementary coordination	(0.6, 0.7]
Moderate disorder	(0.2, 0.3]	Intermediate coordination	(0.7, 0.8]
mild disorder	(0.3, 0.4]	Good coordination	(0.8, 0.9]
on the verge of a disorder	(0.4, 0.5]	Quality coordination	(0.9, 1]

3.3. Construction Of Evaluation Index System

Based on the background of "carbon neutrality" and referring to the relevant research results of existing scholars, combined with the actual situation of low-carbon waste treatment and carbon sink foundation in four provinces and cities in southwest China, three subsystems of energy, economy and environment and 20 index evaluation systems were constructed, as shown in Table 2 below.

Table 2. Energy-economy-environment development indicator system

System	Indicators	Units	Attributes
Energy	Total energy production	million tonnes of standard coal	+
	Total Energy Consumption	million tonnes of standard coal	−
	Energy consumption per unit of GDP	million tonnes of standard coal/billion dollars	−
	Elasticity coefficient of energy consumption	-	+
	Energy consumption per capita	Kilograms of standard coal/person	−
	Raw Coal Production	million tonnes of standard coal	+
	Share of coal energy in energy consumption	%	−
economy	GDP per capita	Yuan	+
	Gross Domestic Product	billion	+
	Disposable income per capita	Yuan	+
	Total freight transport	million tonnes	+
	Share of tertiary industry	%	+
	Total import and export trade	Billions of dollars	+
environ ment	Water resources per capita	Cubic metres per person	+
	Forest Cover	%	+
	Public green space per capita	Square metres per person	+
	Comprehensive utilisation rate of industrial solid waste	%	+
	Investment in industrial pollution control	million	+
	Harmless treatment of domestic rubbish	million tonnes	+
	Total industrial waste gas emissions	billion cubic metres	−

4. EVALUATION OF ENERGY-ECONOMY-ENVIRONMENT COORDINATION

4.1. Comprehensive Development Evaluation Index Analysis

In this paper, the entropy weight method and the linear weighting method are used to calculate the comprehensive evaluation index of energy, economy and environment of the four provinces in southwest China, and the comprehensive development evaluation index is analyzed.

Table 3. Evaluation index of energy-economy-environment system development

		2011	2013	2015	2017	2019	2021
Energy	Yunnan	0.235	0.314	0.160	0.175	0.206	0.198
	Guizhou	0.230	0.268	0.238	0.194	0.186	0.234
	Sichuan	0.125	0.076	0.125	0.265	0.273	0.269
	Chongqing	0.295	0.233	0.211	0.126	0.123	0.130
economy	Yunnan	0.002	0.080	0.126	0.203	0.274	0.312
	Guizhou	0.045	0.099	0.155	0.191	0.264	0.327
	Sichuan	0.012	0.092	0.085	0.213	0.312	0.372
	Chongqing	0.021	0.055	0.123	0.225	0.299	0.375
environment	Yunnan	0.145	0.306	0.465	0.439	0.477	0.547
	Guizhou	0.090	0.214	0.346	0.386	0.613	0.753
	Sichuan	0.073	0.143	0.128	0.178	0.357	0.296
	Chongqing	0.364	0.437	0.266	0.514	0.279	0.473
Comprehensive evaluation index	Yunnan	0.127	0.233	0.250	0.272	0.319	0.352
	Guizhou	0.122	0.194	0.246	0.257	0.354	0.438
	Sichuan	0.070	0.104	0.113	0.219	0.314	0.312
	Chongqing	0.227	0.242	0.200	0.288	0.234	0.326
	Southwest as a	0.136	0.193	0.202	0.259	0.305	0.357

Table 3 shows the evaluation index of energy-economy-environment comprehensive development in each province in southwest China, because of the limited space, this paper only shows the 2011, 2013, 2017, According to the relevant data in 2019 and 2021, observing the energy system, it can be found that all provinces, especially Chongqing, basically show a downward trend, which may be due to the fact that Chongqing, as the only province and city in the western region with a net energy input, has gradually exhausted the development of conventional hydropower resources, and at the same time, its wind and solar resources are limited, and it is facing a situation of "poor coal, little water, gas, and no oil". Sichuan Province has the best evaluation index for energy system development, with an evaluation index of 0.269 in 2021.

From the perspective of the economic system, the upward trend of all provinces is relatively obvious, Sichuan Province has a rich consumer market, tourism, catering and retail industries, Chongqing has obvious competitive advantages in manufacturing, foreign trade and finance, and Guizhou Province and Yunnan Province are relatively rich in tourism resources, which are the reasons for the good economic development momentum in the southwest region.

Based on the environmental subsystem, it can be found that the growth trend of the four provinces has been steadily rising, especially Guizhou Province, which has obvious development advantages, and the environmental quality evaluation is continuously rising, with an environmental system evaluation index of 0.753 in 2021, which is mainly due to Guizhou's unique climate and ecology, and the forest coverage rate has been in a leading position in the country, with a coverage rate of up to 60%, which provides superior conditions for Guizhou's environmental development. The comprehensive environmental evaluation index of Yunnan Province and Chongqing Municipality both reached 0.4, and the quality of the environmental system in Sichuan Province was worse than that of the other three provinces, with a comprehensive development evaluation index of 0.296 in 2021, mainly due to the fact that the industrialization of Sichuan Province promoted economic development at the same time, it also caused harm to environmental development, resulting in the relatively lagging development of environmental system quality.

From the perspective of the energy-economy-environment comprehensive evaluation index, the overall comprehensive evaluation index of Southwest China increased from 0.136 in 2011 to 0.357 in 2021, and the fluctuation range was not obvious.

4.2. Coupling Coordination Analysis

According to equations (7)-(9), the coupling coordination degree of energy, economy and environment of the four provinces of Yunnan, Guizhou, Sichuan and Chongqing is calculated to judge the overall coupling and coordination level of each province and the southwest region.

Table 4. Coordination degree and type of energy-economy-environment coupling

	Yunnan		Guizhou		Sichuan		Chongqing	
	Coordination	Coordination type	Coordination	Coordination type	Coordination	Coordination type	Coordination	Coordination type
2011	0.206	Moderate disorder	0.312	on the verge of a disorder	0.220	Moderate disorder	0.362	mild disorder
2012	0.345	mild disorder	0.352	on the verge of a disorder	0.315	mild disorder	0.384	mild disorder
2013	0.442	on the verge of a disorder	0.422	on the verge of a disorder	0.317	mild disorder	0.422	Barely
2014	0.425	on the verge of a disorder	0.484	on the verge of a disorder	0.348	mild disorder	0.461	on the verge of a disorder
2015	0.459	on the verge of a disorder	0.483	on the verge of a disorder	0.333	mild disorder	0.436	on the verge of a disorder
2016	0.474	on the verge of a disorder	0.444	on the verge of a disorder	0.364	mild disorder	0.458	on the verge of a disorder
2017	0.500	Barely coordination	0.492	on the verge of a disorder	0.464	mild disorder	0.494	on the verge of a disorder
2018	0.533	Barely coordination	0.534	Barely coordination	0.510	Barely coordination	0.483	on the verge of a disorder
2019	0.547	Barely coordination	0.557	Barely coordination	0.559	Barely coordination	0.466	on the verge of a disorder
2020	0.555	Barely coordination	0.568	Barely coordination	0.573	Barely coordination	0.504	Barely coordination
2021	0.568	Barely coordination	0.622	Elementary coordination	0.556	Barely coordination	0.533	Barely coordination

Table 4 shows that the energy-economy-environment coupling coordination degree in Yunnan Province increased from 0.206 in 2011 to 0.568 in 2021, the energy-economy-environment coupling coordination degree in Guizhou Province increased from 0.312 in 2011 to 0.622 in 2021, the energy-economy-environment coupling coordination degree in Sichuan Province increased from 0.220 in 2011 to 0.556 in 2021, and the energy-economy-environment coupling coordination degree in Chongqing increased from 0.362 in 2011 to 0.622 in 2021.533, and all four provinces have continued to rise, showing good momentum. Among them, Guizhou Province has reached primary coordination and is in the stage of running-in adaptation. The main reason is that the carbon neutrality goal is proposed, in order to implement the "national one bureau" policy, the local level has begun to implement energy conservation and emission reduction, and the Guizhou provincial government's 14th Five-Year Plan and key work focus also mainly around the efficient conversion of energy and the promotion of clean and effective use of coal, which also shows that Guizhou Province has achieved certain results in energy emission reduction, economic development and environmental protection in recent years. However, there is still an imbalance in the energy, economy and environmental subsystems of the four provinces, especially Chongqing, which was basically on the verge of imbalance before 2019, and has the lowest degree of coupling and coordination among the four provinces in the southwest.

5. CONCLUSIONS AND RECOMMENDATIONS OF THE STUDY

5.1. Research Conclusion

This paper constructs the index system of green logistics and low-carbon economic development in four provinces in southwest China, and analyzes the coupling relationship between energy, economy and environmental development by using the coupling coordination degree. The main conclusions are as follows:

First, based on the comprehensive energy development evaluation index, it can be found that all provinces have fluctuations, especially Chongqing, which basically shows a downward trend. From the perspective of economic system and environmental system, the comprehensive economic and environmental evaluation index of all provinces of Yunnan, Guizhou, Sichuan and Chongqing has an obvious upward trend. Observing the energy-economy-environment comprehensive evaluation index, the overall comprehensive evaluation index of Southwest China increased from 0.136 in 2011 to 0.357 in 2021.

Second, from the perspective of the coupling and coordination level of energy, economy and environment, there are certain fluctuations in the level of coordinated development of energy-economy-environment system in various provinces, but the overall trend is upward.5.2 Recommendations

In order to be able to carry out the implementation path of low-carbon development, in order to achieve the regional carbon neutrality goal and sustainable economic development, this paper combines the development characteristics of the four provinces in the southwest region and the results of empirical analysis to put forward the following countermeasures recommendations:

(1) Break Down Regional Barriers and Promote Shared Development in the Southwest Region

The provinces and cities in the southwest region have excellent internal ecological endowments and very rich energy resources. For example, Sichuan Province is rich in water resources and has very limited coal resources, while Guizhou Province is rich in coal resources. Chongqing is "coal-poor, water-poor, gas-poor, oil-poor", with the exception of natural gas resources, other resources are relatively scarce. Yunnan Province is rich in water power and wind resources. Comprehensive view of the above, several provinces in the southwest region energy characteristics of significant differences, in order to achieve a reasonable allocation of energy resources, it is necessary to break the regional barriers to accelerate the construction of the Southwest natural gas distribution support system centred on Sichuan-Chongqing, to achieve the sharing of natural gas resources. In addition, the introduction of advanced concepts of green development, improve the subjective willingness of the Southwest provinces and cities to share the development of energy, and in this way to drive the integration of the regional economy in the Southwest region as well as the sustainable development of the ecological environment.

(2) Increase Investment in Technological Innovation, Forcing Green Energy Development to Promote Industrial Restructuring

Focus on scientific and technological empowerment to improve industrial technical equipment and management level. For Sichuan and Chongqing, we can fully rely on the siphon effect of Sichuan and Chongqing talents, give full play to the advantages of talents, and strengthen the research and development of energy-saving and environmental protection technologies. For example, Guizhou Province, which is rich in coal resources, promotes the "intelligent" mining of coal resources through technological innovation, promotes the clean and efficient use of coal, and then promotes the development of high-tech intensive industries, actively promotes the low-carbon transformation and upgrading of high-energy-consuming industries, and reduces the constraints of environmental pollution on economic development at the greatest level, so as to coordinate the coordinated development of the economy and the ecological environment.

(3) Accelerate the Realisation of Rfficient Transformation of Energy Resources, Strengthen the Supply Chain Security Resilience

Based on the energy system, it can be found that the energy consumption of the provinces in the southwest region is mainly concentrated in the high-energy-consuming industries, and there are problems such as low value-added outputs and high-carbon energy structure, etc. To solve the above problems, there are the following suggestions: firstly, from the source, we should vigorously promote the green and low-carbon means of transport, especially for the ports, postal logistics and distribution, etc. We should give priority to the use of clean energy modes of transport, which will be able to deal with the carbon emission control of the means of transport. Secondly, we should vigorously develop energy resources efficient transformation projects, give full play to the advantages of fossils, ores and other resources, and then drive the regional economic development, especially in resource-based areas like Sichuan; finally, we should strengthen the supply chain security and resilience, give full play to the role of supply chain collaborative service platforms, guide the industry and enterprises to build a green, low-carbon and safe supply chain system, strengthen the monitoring and control of potential supply chain risks, and promote carbon neutrality. Finally, strengthen supply chain security and resilience, play the role of supply chain co-operation service platform, guide industries and enterprises to build a green, low-carbon and safe supply chain system, strengthen the monitoring and control of potential risks in the supply chain, and push forward the goal of carbon neutrality and peak carbon.

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