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Study on the Coupled Urbanization-Carbon Emission-Ecological Environment Coordinated Development of Chinese Provinces

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Abstract

This paper takes 30 provinces in China from 2011 to 2020 as research objects, constructs the evaluation index system of urbanization-carbon emission-ecological environment ternary system, and quantitatively analyzes the coupling coordination degree of urbanization-carbon emission-ecological environment of 30 provinces in China with the help of improved entropy value method and coupling coordination degree model. The results show that: (1) the comprehensive evaluation index of the ternary system of urbanization-carbon emission-ecological environment in China has been increasing, and the comprehensive evaluation indexes of the three are gradually approaching;(2)the level of coupling coordination of the ternary system of urbanization-carbon emission-ecological environment is still not high, only Guangdong has reached the intermediate coordination level, and most provinces are at the primary coordination or barely coordination level, with significant regional differences and spatially showing The spatial development pattern is "East > Central > Northeast > West".

Keywords

Urbanization; Carbon Emission; Ecological Environment; Coupling Coordination Degree.

1. Introduction

The 18th and 19th National Congresses of the Party attached great importance to the construction of ecological civilization and advocated green development and low-carbon urbanization [1], and the ecological environment is playing an important role in measuring the comprehensive development of the country. However, as an inevitable product of economic development, the development of urbanization will lead to a sharp increase in carbon emissions from energy sources, which will cause the greenhouse effect and lead to environmental problems, and the contradiction between energy conservation and emission reduction, urbanization development and ecological environment is becoming increasingly prominent. At this stage, dealing with the relationship between urbanization, carbon emission and ecological environment, and promoting the coordinated and orderly development of the three is a major issue that needs to be solved to fully implement the sustainable development strategy and achieve high-quality development.

The current research on the relationship between urbanization, carbon emission and ecological environment has achieved rich academic results, mainly focusing on "urbanization and carbon emission", "urbanization and ecological environment" and "carbon emission and ecological environment". The relationship between "urbanization and carbon emission", "urbanization and ecological environment", and "carbon emission and ecological environment" has been studied from qualitative and quantitative perspectives. In the study of the relationship between urbanization and carbon emissions, scholars have used the case study method, STIRPAT model, and Tapio decoupling model to find linear and non-linear relationships between the two [2,7]. The research on urbanization and ecological environment is mainly carried out in three aspects:

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first, the study of coupling relationship, with the help of coupling coordination model, it is found that the level of coupling coordination between the two is still low [8,10]; second, the study of interaction, which is mainly reflected in the establishment of "urbanization and environmental carrying capacity relationship" model, and the evolution of factors affecting ecological and environmental carrying capacity The second is the study of interaction, which is mainly reflected in the establishment of the model of "urbanization-environmental carrying capacity relationship" and the evolution of factors affecting the ecological carrying capacity [11], and the discussion of the impact of urbanization on ecological footprint with the help of modified urban ecological footprint model [12]; the third is the qualitative analysis from the perspective of legal level and literature review [13,14]. Research on carbon emissions and ecological environment mainly focuses on empirical analysis of the relationship between carbon emissions and ecological environment from a quantitative perspective using various methods, such as analyzing the relationship with the help of VAR dynamic model and finding that environmental management inputs are conducive to reducing carbon emissions [15], and empirically analyzing the impact of ecological and environmental civilization on carbon emissions with the help of STIRPAT model and concluding that ecological and environmental civilization helps reduce carbon emissions [16].

Through combing the relevant literature, it is found that there is less research literature on the relationship between urbanization, carbon emission and ecological environment, especially the analysis of coupling and coordination is still in the initial stage, and most of the previous research results focus on the study of the coupling and coordination of the binary system of urbanization, carbon emission and ecological environment, and few scholars study the coupling and coordination of the ternary system of urbanization, carbon emission and ecological environment. Therefore, this paper introduces the improved entropy method and the improved coupling coordination model from the perspective of geospatial and temporal view to study the coupling coordination relationship among the three systems, in order to contribute to the improvement of the coordinated development of urbanization, carbon emission and ecological environment.

2. The Index System Construction and Research Methods

2.1. Construction of Index System

In this paper, the urbanization-carbon emission-ecological environment evaluation index system is constructed with sustainable development as the theme (see Table 1). 15 indicators are selected to measure the comprehensive evaluation index of urbanization level in terms of population urbanization, economic urbanization, spatial urbanization and social urbanization; 4 indicators are selected to measure the comprehensive evaluation index of carbon emission in terms of the current situation of carbon emission; 11 indicators are selected to measure the comprehensive evaluation index of ecological environment in terms of ecological environment status, ecological environment pressure and ecological environment response. From the aspects of ecological environment status, ecological environment pressure and ecological environment response, 11 indicators are selected to measure the comprehensive evaluation index of ecological environment.

Table 1. Urbanization-carbon emission-ecological environment evaluation index system

Subsystems	Tier 1 Indicators	Tier 2 Indicators	Indicator Properties
Urbanization Subsystem	Population urbanization	Urban population	Positive
		Urbanization rate	Positive
		Share of employment in secondary	Positive

		industry	
		The proportion of employment in the tertiary sector	Positive
	Economic Urbanization	GDP per capita	Positive
		Per capita disposable income of urban residents	Positive
		Share of secondary industry in GDP	Positive
		Share of tertiary sector in GDP	Positive
	Spatial urbanization	Urban Population Density	Positive
		Area of built-up area	Positive
		Urban road area per capita	Positive
	Social urbanization	Retail sales of social consumer goods per capita	Positive
		Number of health technicians per 10,000 people	Positive
		Number of beds in medical institutions per 10,000 people	Positive
		Average number of students enrolled in higher education per 100,000 population	Positive
Carbon Emissions Subsystem	Status of carbon emissions	Carbon emissions per capita	Negative
		Carbon intensity	Negative
		Carbon emission intensity	Negative
		Carbon productivity	Positive
Ecosystem subsystem	Ecosystem Status	Forest cover	Positive
		Green space per capita	Positive
		Greening coverage of built-up areas	Positive
		Water resources per capita	Positive
	Ecological and environmental pressure	Industrial wastewater discharge per capita	Negative
		Industrial SO_2 emissions per capita	Negative
		Industrial fume and dust emissions per capita	Negative
		Industrial solid waste generation per capita	Negative
	Ecological Response	Comprehensive utilization rate of industrial solid waste	Positive
		City sewage daily treatment capacity	Positive
		Harmless disposal rate of domestic waste	Positive

2.2. Research Methods

2.2.1. Improved Entropy Method

In order to better reflect the basic situation of urbanization-carbon emission-ecological environment, the entropy value method is improved by adding time variables with reference to Liu Bo [17] and others, thus making the assignment results more comparable. The calculation principle of the improved entropy method is as follows.

Step1:Indicator selection: Let there be m years, a provinces and b indicators, then Xtij denotes the jth indicator for province i in year t.

Step2: Standardized treatment:Positive indicators: $X'_{tij} = \frac{X_{tij}-X_{min}}{X_{max}-X_{min}}$;Negative indicators: $X'_{tij} = \frac{X_{max}-X_{tij}}{X_{max}-X_{min}}$

Step3: Calculate the weight of indicator j for province i in year t, then $P_{tij} = \frac{X'_{tij}}{\sum_{t=0}^{m}\sum_{i=0}^{a} X'_{tij}}$

Step4:Calculate the entropy value of the jth indicator, then $e_j = -k\sum_{t=0}^{m}\sum_{i=0}^{a} P_{ij}\ln(P_{tij}), k > 0, k = \ln(ma)$

Step5: Calculate the information utility value of the jth indicator, then $g_j = 1 - e_j$

Step6: Calculate the weights of each indicator, then $w_j = \frac{g_j}{\sum g_j}$

Step7: Calculate the comprehensive evaluation index of urbanization-carbon emission-ecological environment for each province, then $U_{ti} = \sum w_j \times X'_{tij}$

2.2.2. Coupling Coordination Model

The coupling degree can reflect the level of interconnection between subsystems. In analysing the coupling and coordination of urbanisation-carbon emissions-ecological environment in various provinces across China, the coupling degree model of urbanisation-carbon emissions-ecological environment is constructed by drawing on the study of Wang Shujia [18].

$$C = \sqrt{\left[1 - \frac{\sqrt{(U_3-U_1)^2}+\sqrt{(U_2-U_1)^2}+\sqrt{(U_3-U_2)^2}}{3}\right] \times \left(\prod_{i=1}^{3}\frac{U_i}{maxU_i}\right)^{\frac{1}{2}}} \quad (1)$$

where U1 denotes the urbanization subsystem evaluation index, U2 denotes the carbon emission subsystem evaluation index, U3 denotes the ecological environment subsystem evaluation index, and C denotes the coupling degree. The higher the C value, the higher the level of coupling of the subsystems; conversely, the lower the level. Although the coupling degree can reflect the interconnectedness of each subsystem, it is still lacking in the study of the coordination between each subsystem. In order to better analyse the coordination situation between subsystems, a coupling coordination degree model is established on the basis of the coupling degree model as follows:

$$D = \sqrt{C \times T}, T = a_1U_1 + a_2U_2 + a_3U_3, a_1 + a_2 + a_3 = 1 \quad (2)$$

Table 2. Classification of coupling coordination levels and evaluation levels

Coherence D	Coordination level	Coherence D	Coordination level
[0.000-0.099)	Extreme disorders	[0.499-0.599)	Reluctantly coordinated
[0.099-0.199)	Severe disorders	[0.599-0.699)	Primary coordination
[0.199-0.299)	Moderate disorder	[0.699-0.799)	Intermediate coordination
[0.299-0.399)	Mild disorders	[0.799-0.899)	Good coordination
[0.399-0.499)	On the verge of disorder	[0.899-1.000]	Quality coordination

The higher the value of D, the higher the level of coordination, and T represents the comprehensive evaluation index of the ternary system of urbanization-carbon emission-ecological environment. a1, a2, and a3 represent the coefficients to be determined for each subsystem, and here they are all taken as 1/3. The degree of coordination of the coupling of urbanization-carbon emission-ecological environment is classified according to existing research results [18], as shown in Table 2.

2.2.3. Data Sources

The research time series of this paper is 2011-2020, and 30 provinces across China are used as research objects, excluding Tibet, Hong Kong, Macao and Taiwan. The data in this paper are obtained from the China Statistical Yearbook, China Energy Statistical Yearbook, China Environmental Statistical Yearbook and the statistical yearbooks of various provinces.

3. Analysis of Urbanization-Carbon Emission-Ecological Environment Coupling Coordination

3.1. Analysis of Urbanization-Carbon Emission-Ecological Environment Integrated Index

The comprehensive evaluation indices of the three subsystems of urbanization (U1), carbon emission (U2) and ecological environment (U3) in Table 1 are measured using the improved entropy value method, as shown in Figure 1 and Table 3.

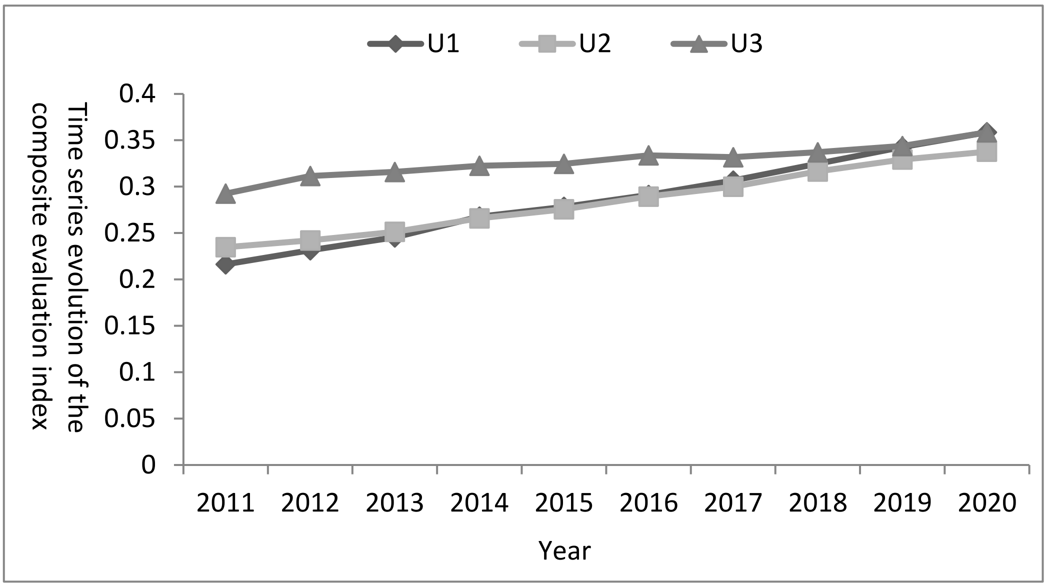

Figure 1. Time series evolution of urbanization-carbon emission-ecological environment integrated evaluation index

In terms of time series evolution (Figure 1), China's urbanization subsystem, carbon emission subsystem and ecological environment subsystem have all been improving from 2011 to 2020, but their respective rates of increase are different. Compared with the urbanization subsystem, the increase in the carbon emission subsystem is slightly lower, from 0.235 to 0.338, with an increase of 43.83%; the increase in the ecological environment subsystem is the lowest, from 0.292 to 0.358, with an increase of 22.60%. From the starting and ending two years, after 10 years of development, the evaluation index of urbanization subsystem has increased from the lowest to the highest, the evaluation index of ecological environment subsystem is in the second place, and the evaluation index of carbon emission subsystem is the lowest.

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Table 3. Average values of urbanization-carbon emission-ecological environment integrated evaluation index (2011-2020)

Region	Province	Urbanization	Carbon Emissions	Ecology	Region	Province	Urbanization	Carbon Emissions	Ecology
East	Beijing	0.472	0.670	0.343	Northeast	Liaoning	0.299	0.193	0.293
	Tianjin	0.393	0.259	0.237		Jilin	0.240	0.240	0.288
	Hebei	0.273	0.203	0.261		Heilongjiang	0.269	0.225	0.332
	Shanghai	0.471	0.325	0.269		Northeast average	0.269	0.219	0.304
	Jiangsu	0.428	0.333	0.396	West	Inner Mongolia	0.242	0.111	0.243
	Zhejiang	0.403	0.365	0.450		Guangxi	0.188	0.304	0.431
	Fujian	0.327	0.371	0.433		Chongqing	0.271	0.388	0.362
	Shandong	0.368	0.230	0.349		Sichuan	0.267	0.376	0.336
	Guangdong	0.411	0.408	0.536		Guizhou	0.165	0.233	0.318
	Hainan	0.190	0.297	0.382		Yunnan	0.191	0.303	0.353
	Eastern average	0.374	0.346	0.366		Shaanxi	0.276	0.237	0.288
Central	Shanxi	0.258	0.114	0.197		Gansu	0.185	0.227	0.176
	Anhui	0.259	0.297	0.333		Qinghai	0.195	0.247	0.404
	Jiangxi	0.275	0.332	0.399		Ningxia	0.203	0.084	0.189
	Henan	0.291	0.297	0.273		Xinjiang	0.218	0.170	0.234
	Hubei	0.289	0.338	0.342		Western average	0.218	0.244	0.303
	Hunan	0.270	0.350	0.371	National average		0.284	0.274	0.323
	Central average	0.274	0.288	0.319					

From Table 3, it can be seen that the comprehensive evaluation index of urbanization-carbon emission-ecological environment ternary system in 30 provinces nationwide is low and unbalanced in regional development, and the comprehensive level of the ternary system varies significantly among provinces. Specifically, the national average value of urbanization subsystem evaluation index is 0.284, of which 11 provinces are above the average value, 8 in the eastern region, 1 in the northeastern region, 2 in the central region, and none in the western region. This indicates that the urbanization in the eastern region has made great progress, while the urbanization in the central, northeastern and western regions is lagging behind, and the overall evaluation index of urbanization is lower than the national average. The national average value of carbon emission subsystem comprehensive evaluation index is 0.274, of which 16 provinces are above the average value, 7 in the eastern region, 0 in the northeastern region, 5 in the central region and 4 in the western region. In terms of the four regions, the carbon emission subsystem comprehensive evaluation index is ranked from highest to lowest as "East - Central - West - Northeast", with the lowest carbon emission subsystem comprehensive evaluation index in Northeast China, which is 0.055 and 0.127 lower than the national average and the eastern average respectively, indicating that the carbon emission subsystem comprehensive evaluation index is lower in other regions except for the eastern region, among which the western region and Northeast China are both lower than the national average. The overall evaluation index of carbon emission subsystem is lower than the national average. In terms of the four regions, the average value of the ecological environment subsystem in the eastern region is the highest, 0.043 higher than the national average, while the average value of the ecological environment subsystem in the remaining three regions is lower than the national average. In general, the provinces with relatively high indexes of urbanization-carbon

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emission-ecological environment ternary system are mainly located in the eastern region, such as Beijing, Jiangsu, Shanghai, Zhejiang, Fujian, and Guangdong. Guangdong, while the rest of the regions have a lower comprehensive evaluation index of urbanization-carbon emission-ecological environment system, and most of them are lower than the national average.

3.2. Spatial and Temporal Analysis of Urbanization-Carbon Emission-Ecological Environment Coupling Coordination Degree

The coupling coordination degree model was used to measure the coupling coordination degree of urbanization-carbon emission-ecological environment in China from 2011 to 2020, as shown in Figure 2 and Table 4.

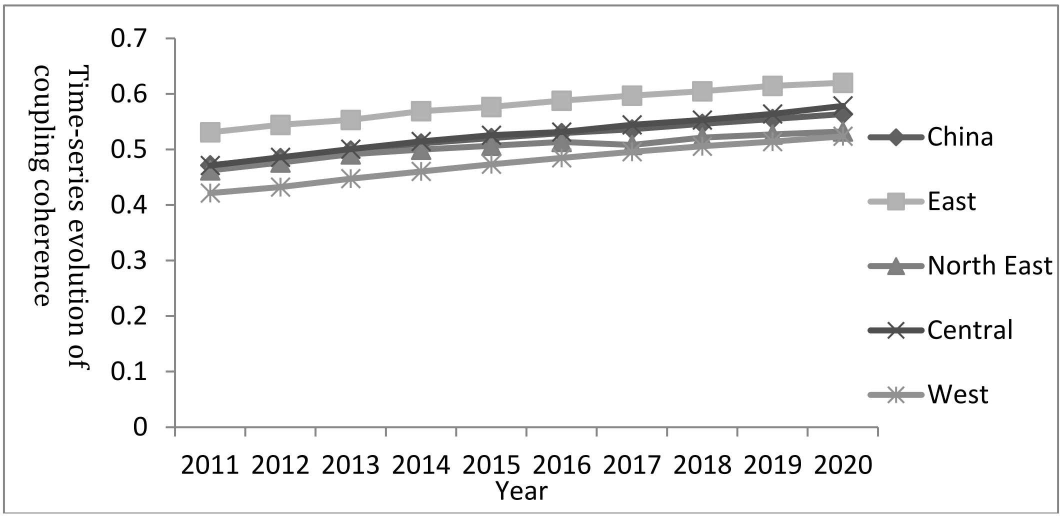

Figure 2. Time series evolution of urbanization-carbon emission-ecological environment coupling coordination degree

Table 4. Evolution of the spatial pattern of urbanization-carbon emission-ecological environment coupling coordination

Year	Coordination level	Eastern Region	Northeast Region	Central Region	Western Region
2011	Mild disorders			Shanxi	Inner Mongolia, Gansu, Ningxia
	On the verge in disorder	Tianjin, Hebei, Hainan	Liaoning, Jilin, Heilongjiang	Anhui, Henan, China	Guangxi, Guizhou, Yunnan, Shaanxi, Qinghai, Xinjiang
	Reluctantly coordinated	Beijing, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong		Jiangxi, Hubei, Hunan	Chongqing, Sichuan
	Primary coordination	Guangdong			
2020	On the verge of disorder			Shanxi	Inner Mongolia, Gansu, Ningxia, Xinjiang
	Reluctantly coordinated	Tianjin, Hebei, Shandong, Hainan	Liaoning, Jilin, Heilongjiang	Anhui, Henan	Guangxi, Guizhou, Yunnan, Shaanxi, Qinghai
	Primary coordination	Beijing, Shanghai, Jiangsu, Zhejiang, Fujian		Jiangxi, Hubei, Hunan	Chongqing, Sichuan
	Intermediate coordination	Guangdong			

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From the perspective of time evolution (Figure 2), the overall coordination degree of urbanization-carbon emission-ecological environment coupling in China is low, and from 2011 to 2020, it shows an increasing and stabilizing trend, and the coordination degree of the triadic system coupling reaches 0.564, an increase of 0.092 or 19.56% compared with 2011. By 2020, the coupling coordination degree of the eastern region reaches 0.620, the northeastern region reaches 0.532, the central region reaches 0.579, and the western region reaches 0.524, with an increase of 16.81%, 15.14%, 22.83%, and 24.83% respectively compared with 2011. and 22.83% and 24.23%, respectively, compared with 2011. Among them, the ternary system coupling coordination of the eastern region is in two levels of barely coordinated and primary coordination, while the ternary system coupling coordination of the central, northeastern and western regions is in two levels of near coordination and barely coordinated.

In order to better analyze the spatial variation characteristics of the urbanization-carbon emission-ecological environment coupling coordination degree in China, the coupling coordination degree in 2011 and 2020 is analyzed.

In terms of spatial evolution (Table 4), in 2011, the coordination degree of urbanization-carbon emission-ecological environment ternary system coupling in 30 provinces nationwide was in the range of mild disorder to primary coordination, with significant differences in coordination levels among provinces. Specifically, Guangdong has the highest ternary system coupling coordination, breaking the 0.6 threshold, and is the only province in the primary coordination stage, while Beijing, Shanghai, Jiangsu, Zhejiang, Fujian, and Shandong are in the barely coordinated stage, and Tianjin, Hebei, and Hainan are in the near-disordered stage; the ternary system coupling coordination of the three northeastern provinces fluctuates in the range of 0.4-0.5, and all of them are in the near-disordered stage; the central In the central region, Jiangxi, Hubei and Hunan have a coupling coordination degree of 0.5 or higher, and are at the stage of barely coordinated, while Anhui and Henan are at the stage of near disorder, and Shanxi is even at the stage of mild disorder; in the western region, most provinces are at the stage of near disorder, only Chongqing and Sichuan have a coupling coordination degree of 0.5 or higher, and are at the stage of barely coordinated, while Inner Mongolia, Gansu and Ningxia have the lowest coupling In 2020, the coordination degree of urbanization-carbon emission-ecological environment ternary system in 30 provinces across China has definitely improved compared with that in 2011, and the coordination level of most provinces has improved by one grade and completed the leap of coordination level. The coordination degree of the three-tier system coupling is in the range of near disorder to intermediate coordination, and the inter-provincial differences are slightly reduced and tend to improve. Specifically, compared with 2011, except for Shandong, which is still in the barely coordinated stage, the ternary system coupling coordination level of all the eastern provinces has improved by one grade, and the ternary system coupling coordination of Guangdong has reached more than 0.7, entering the intermediate coordination stage from the primary coordination, while Beijing, Shanghai, Jiangsu, Zhejiang and Fujian have also broken through the bottleneck of the barely coordinated stage and entered the primary coordination stage, and Tianjin, Hebei and Hainan have entered the intermediate coordination stage from the borderline disorder. Hebei and Hainan have entered the stage of barely coordinated from near disorder; the three northeastern provinces have all seen a small increase in the three-way system coupling coordination, entering the stage of barely coordinated from near disorder; the three central provinces of Jiangxi, Hubei and Hunan have broken the threshold of 0.6 in the three-way system coupling coordination, entering the stage of primary coordination from barely coordinated, Anhui and Henan have entered the stage of barely coordinated from near disorder, and Shanxi has entered the stage of mild disorder from Near disorder; in the western region, except for Xinjiang, which is still at the stage of near disorder, the coupling coordination level of the remaining provinces has also improved by one grade, especially Chongqing and Sichuan, which have entered the stage of primary coordination from barely coordinated, Guangxi, Guizhou, Yunnan, Shaanxi and Qinghai, which have entered the stage of barely coordinated from near disorder, and Inner Mongolia, Gansu and Ningxia, which have entered the stage of near disorder from mild disorder. From a comprehensive point of view, the coupling coordination degree of urbanization-carbon emission-ecological environment system in most of the provinces from 2011 to 2020 has been rapidly improved, and the coupling coordination degree level of most of the provinces has been crossed, and the inter-provincial differences of the coupling coordination degree are gradually reduced, and the development trend of equilibrium has been revealed, and spatially it shows The development pattern of "East > Central > Northeast > West" has emerged.

4. Conclusion

This paper constructs the urbanization-carbon emission-ecological environment evaluation index system, measures the index weights with the improved entropy value method, and further obtains the comprehensive evaluation index of urbanization-carbon emission-ecological environment of 30 provinces nationwide from 2011 to 2020 by combining linear weighting coefficients, and analyzes the coupling and coordination evolution trend of urbanization-carbon emission-ecological environment with the help of coupling coordination degree model, and draws the following conclusions: (1) In terms of the comprehensive evaluation index, the comprehensive index of urbanization-carbon emission-ecological environment of all provinces nationwide shows an increasing trend and good development from 2011 to 2020. Horizontally, the comprehensive development level varies significantly among provinces, and the development level of Beijing, Shanghai, Guangdong and Jiangsu among eastern provinces is significantly better than that of northeastern, central and western provinces. (2) In terms of coupling coordination, although the level of coupling coordination of urbanization-carbon emission-ecological environment has definitely improved in all provinces from 2011 to 2020, the overall level of coupling coordination of the three is still low, especially only Guangdong has reached the intermediate coordination stage nationwide, and the level of coupling coordination is still gradually decreasing from east to west.

Based on the above findings, the following policy recommendations are proposed: (1) Differentiate development according to local conditions. The urbanization level in the western region is low, and urbanization construction needs a large amount of energy resources as material guarantee, coupled with the lack of capital, technology and talent support, so the western region should optimize the industrial structure, actively introduce capital, technology and talent, improve the comprehensive utilization rate of energy resources, and break through the bottleneck of economic development. The urbanization level in the central and northeastern regions is at a medium level, and most provinces are gradually transforming their economic structures, actively introducing advanced low-carbon technologies, optimizing industrial structures and promoting high-quality development. The eastern region, with a higher level of urbanization, should strengthen regional cooperation, realize complementary advantages, and actively provide assistance in terms of capital, technology and talents to provinces with a lower degree of coupling and coordination, giving full play to their leading demonstration role to drive the development of the rest of the region. (2) Protect and improve the ecological environment and take the green development path. For example, introduce corresponding policies to restrict the development of high energy-consuming and high emission industries, while the government should actively cooperate with enterprises to promote the green transformation of industries, actively cultivate energy-saving and environmental protection industries, and further reduce the ecological and environmental costs of development.

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