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Original Research Paper

A Study on Coupling and Coordinating Development Mechanism of China's Low-carbon Development and Environmental Resources System

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ABSTRACT

With the rapid development of China's modern industry, human beings have consumed enormous amounts of high-carbon energy resources. This has caused huge destruction to the systems of environmental resources. Low-carbon development is the best solution to the irrational demand for natural resources, environmental pollution and other associated problems. This study discusses the coupling and coordinating mechanism of low-carbon development and environmental resource system. Herein, we argue that low-carbon development is a necessary requirement for the improvement of environmental resource system and it can promote an effective utilization of environmental resource. The improvement of environmental resource system is also conducive to low-carbon production. This paper studies 31 provinces, municipalities and autonomous regions in China, establishes index system, comprehensively applies entropy evaluation method and coupling coordination model, measures the coupling and coordination degree of two systems, and arrives at the following conclusions. From 2000 to 2013, the comprehensive level and the coordinating degree of China's low-carbon development and environmental resource system generally increased, Shandong and Guangdong rank at the top of provincial-level administrative region, the two provinces also have a high coordinating degrees. Also, this study puts forward several policy recommendations to upgrade the coupling and coordinating development of low-carbon and environmental resource system.

INTRODUCTION

In recent years, the increase of population and the rapid development of China's modern industry, including the fast growth of iron and steel, energy, building materials, automobile, and chemical sectors along with other industries with high energy demands, have led to the consumption of enormous amounts of high-carbon energy resources in the process of development and utilization of natural resources. This consumption has been carried out with a low utilization rate and has resulted in pollution and destruction to the ecological environment and thus the destruction of the environmental resource system. In addition, human beings emit a large number of carbon dioxide and other greenhouse gases while burning fossil fuels and conducting other activities in daily life. These activities pollute the atmosphere and cause global warming, a disastrous trend. At present, the global temperature is generally increasing, the sea level continues to rise, the ecological environment continually deteriorating, and environmental pollution becoming increasingly serious. These factors affect the survival and living conditions of the mankind. Therefore, low-carbon development has become a necessary trend and a crucial component in mitigating climate change and environmental pollution.

Low-carbon development is the best solution for human beings to address climate warming, uncontrolled development, irrational demand for natural resources, environmental pollution, and other associated problems. Low-carbon development can promote the exploitation of new energy resources, reduce production cost, and improve the utilization rates of resources through a series of energy-saving and emission-reduction technologies. In this way, it can alleviate the problem of environmental pollution and realize environmental protection. Therefore, low-carbon development is conducive to the improvement of the environmental resource system, promotion of effective utilization and resource utilization rates, and the protection of environmental resources. It can thus speed up the process of China's sustainable development.

Low-carbon development is an effective way to solve environmental pollution and protect the environmental resource system, and it is also a critical choice for China in the context of global climate change. At present, China boasts abundant research findings on low-carbon development. These studies have mainly focused on the conceptualization and evaluation index system of low-carbon development (Kuang et al. 2013, Shi et al. 2015, Lu et al. 2010), the framework of low-carbon development (Liu et al. 2010), evaluation of low-carbon development levels (Tang et al. 2011, Sasima et al. 2014), spatial differences in low-carbon development (Zhang et al. 2014, Nazmiye et al. 2013), influential factors of low-carbon development, and the corresponding policy recommendations (Wang et al. 2014, David 2012).

With continued low-carbon development in China, awareness about environmental protection is growing, the environmental resource system has tended towards improvement, and academia has conducted in-depth discussions and extensive research on the low-carbon development and the coupled development of the environmental resource system (Toshihiko et al. 2011, Vito et al. 2014, Aumnad et al. 2013). Ghaffar Ali et. al (2013) and Roberto et al. (2014) have expounded the relationship between low-carbon development and environmental protection, and they revealed the importance of low-carbon development to environmental protection.

The present study on low-carbon development and the environmental resource system generally focuses on the construction of an index system, model prediction, and the empirical analysis of medium and small sized areas such as the Yangtze River Delta and the Beijing-Tianjin-Hebei metropolitan region. Few studies have been conducted to investigate the coupling between low-carbon development and the environmental resource system and analyse the coupling coordination mechanism and its spatial differentiation in large-scale provincial areas in China. Therefore, this study attempts to reveal the coupling development mechanism and the spatial distribution of China's low-carbon development and environmental resource system based on the coupling model in physics. Mainland China is adopted as a case study and 31 provincial regions were selected as the research areas. We then attempted to quantitatively measure coupling degree and coordinating degree of low-carbon development and environmental resource system in the 31 provincial areas from 2000 to 2013 via the construction of a measurement system that provides a comprehensive value for low-carbon development and the environmental resource system. The coupling mechanism of low-carbon development and the environmental resource system in the 31 provincial areas in China are then analysed based on their coupling and coordinating relations. Based on this analysis, the paper puts forward several policy recommendations to promote coupling and coordination in China's low-carbon development of the environmental resource system.

ANALYSIS OF COUPLING MECHANISM BETWEEN LOW-CARBON DEVELOPMENT AND THE ENVIRONMENTAL RESOURCE SYSTEM

Definition of Low-carbon Development

Low-carbon development is the organic combination of low-carbon and development. The purpose of low-carbon is to reduce carbon emissions, mitigate global climate change, and construct a sustainable and low-carbon country; development includes social development and economic development, and its purpose is to better coordinate the development of the ecological environment. Therefore, low-carbon development is proposed in the context of the increasingly serious global climate warming and environmental problems. Its purpose is to alleviate environmental problems, reduce emissions of carbon dioxide and other greenhouse gases, and thus mitigate the problem of global climate change; and to build environment-friendly and resource-saving societies.

Low-carbon development, in essence to a change of the development mode of China, aims to develop new clean energy resources, improve effective utilization of energy, take effective control of greenhouse gas emissions, and mitigate climate warming through technological innovation. With the rapid development of China's urbanization and industrialization, energy consumption is growing and human demand for natural resources continuously increasing. Natural resources are inefficiently developed and utilized with emissions of carbon dioxide, carbon monoxide, and other pollutant gases, which harm the atmosphere and cause global warming. The concept of low-carbon development is thus put forward in response to such problems. It is a sustainable development mainly characterized by low energy consumption, low pollution and low carbon emissions.

Low-carbon development is a crucial component to solve environmental problems in China. It is an effective way to improve the environmental resource system and effectively utilize resources. The concept of low-carbon development lays a solid foundation to build China into an environment-friendly and resource-conserving society.

Low-carbon Development Can Promote Effective Utilization and Improvement in the Environmental Resource System

Low-carbon development: A necessary requirement to improve the environmental resource system: At the current middle stage of industrialization, environmental pollution, destruction of ecological environment, and inefficient use of natural resources have become the bottlenecks, restricting the development of China's national economy. Therefore, the change to a low-carbon development mode is a crucial component for the development of China's economy. As a kind of economic mode based on low energy consumption, low pollution, and low carbon emission, low-carbon development has become an unavoidable requirement for environmental protection, and it is also conducive to the improvement of the environmental resource system.

Low-carbon development will improve the environmental resource system: It can provide strong financial support for technological innovation and development of new energy sources, which together will reduce pollutant emissions and alleviate environmental pollution. Meanwhile, the utilization rate of natural resources will be improved and solutions to shortages in natural resources will become available. The low-carbon development will also promote the development of human resources, technology, and other social resources.

In general, low-carbon development has become a necessary choice for environmental protection. It promotes the effective utilization and improvement of the environmental resource system.

Improvement of the Environmental Resource System Promotes Low-carbon Development

The improvement of the environmental resource system can help produce low-carbon development: With the increasingly serious environmental problems, higher requirements have been created to effectively control environmental pollution and waste of natural resources. The government and the society must pay close attention to environmental governance and protection so as to enhance the speed and strength of solutions, reduce the waste of natural resources, conserve resources, and try to build China into an environment-friendly and resource-conserving society. The improvement of the environmental resource system provides good environmental and resource conditions for the economic development mode to transform to a low-carbon mode. This transformation is conducive to producing effective solutions for environmental pollution, destruction of the ecological environment, and waste of natural resources.

The improvement of environmental resource system is a guarantee of low-carbon development: The environmental resource system includes natural resources, social resources, and environmental system. Economic development needs the support of both natural resources and social resources. Natural resources are the basic raw materials for economic development, and the low-carbon mode is the most effective way of the economic development. The improvement of environmental resource system is guaranteed by low-carbon development, by providing it with strong resource support and promoting its development.

In summary, a benign cycle of low-carbon development-improvement of environmental resources-low-carbon development will take shape between low-carbon development and the environmental resource system, reflecting the feedback and promotion effect between the systems. Therefore, the two systems are mutually supplementary, influential, and restrictive.

RESEARCH METHODOLOGIES DESIGN OF INDEX SYSTEM AND RESEARCH METHODS

Construction of Index System

Table 1: Comprehensive evaluation index system for low-carbon development and environmental resources.

Target tier	Standard tier	Index tier
A: Low-carbon development	A_1: Investment of low-carbon	A_{11}: GDP per capita; A_{12}: Per capita disposable income of urban A Level of residents; A_{13}: Science and technology expenditure per capita; A_{14}: Value added of industry
	A_2: Low-carbon output	A_{21}: Proportion of tertiary industrial output in GDP; A_{22}: Proportion of secondary industrial out put in GDP; A_{23}: Comprehensive utilization of industrial solid wastes; A_{24}: harmless treatment rate of household garbage
	A_3: Low-carbon consumption	A_{31}: Electricity consumption per capita; A_{32}: Bus number per ten thousand people; A_{33}: Natural gas consumption per capita
	A_4: Low-carbon construction	A_{41}: Forest coverage; A_{42}: Park and green area per capita;A_{43}:Investment in industrial pollution governance
B: Level of environmental resources	B_1: Natural resources	B_{11}: Proportion of natural protection zone in the area under jurisdiction; B_{12}: Water resources per capita; B_{13}: Urban population density
	B_2: Social resources	B_{21}: Number of public libraries; B_{22}: Number of doctors per ten thousand people;B_{23}:Fixed asset investment; B_{24}: Number of colleges and universities
	B_3: Environmental quality	B_{31}: 2 days of air quality reaching 2-level standard; B_{32}: Annual average temperature; B_{33}: Sun shine hours annually
	B_4: Environmental pressure	B_{41}: COD emissions; B_{42}: Sulfur dioxide emission; B_{43}: Industrial wastewater emissions

To measure the comprehensive development level of the two systems of low-carbon development and environmental resources, a comprehensive evaluation index system for the two system needs to be constructed. According to the connotation and characteristics of low-carbon development and environmental resources, this study follows systematic, objective and dynamic principles within the limitations of data availability to construct the comprehensive evaluation index system for low-carbon development and environmental resources respectively, as is depicted in Table 1. For our analysis, we combine the viewpoints of the relevant scholars and utilize a multi-index comprehensive evaluation method.

Research Methods

Entropy evaluation method: The entropy evaluation method is a comprehensive calculation of the multi-index system by using a variation of the information entropy measurement index. This study uses the entropy evaluation method to calculate index weights, and further calculate comprehensive evaluation indices of the two subsystems of low-carbon development and environmental resources. The procedures of this method are as follows:

1. Construction of original index matrix: Construct the original index matrix $X=\{x_{ij}\}_{m\times n}$ with n comprehensive evaluation indices in m research regions, of which x_{ij} is the index j in region i.
2. Non-dimensionalization of indices: In order to eliminate the dimensional difference of indices, indices are divided into positive and negative classes for non-dimensionalization, of which $x_{ij}= (x_{ij}\text{-}min\ (x_{ij}))\ /\ (max\ (x_{ij})\text{-}min\ (x_{ij})$ is the positive index and $x_{ij} = (max\ (x_{ij})\text{-}x_{ij})\ /\ (max\ (x_{ij})\ \text{-}\ min\ (x_{ij}))$ is the negative index.
3. Synchronous quantification of indices

$$p_{ij} = x_{ij} / \sum_{i=1}^{m} x_{ij} \quad ...(1)$$

4. Calculate entropy H_j of index j :

$$H_j = -k\sum_{i=1}^{n} p_{ij} \ln p_{ij} \quad ...(2)$$

In formula (2) k > 0, ln p_{ij} is the natural logarithm, and Hj > 0. If x_i is equal to any given j, then $p_{ij} = 1/m$. At this time, H_j is maximum, i.e.:

$$H_j = -k\sum_{i=1}^{m}\left(\frac{1}{m}\right)\ln\left(\frac{1}{m}\right) = k \ln m \quad ...(3)$$

If $k = 1/\ln m$, then $0 \leq H_j \leq 1$.

5. Calculate the differentiation coefficient F_j of index j: The smaller the value of x_{ij} of index j, the bigger the value of H_j, and the smaller the effect of the index on the inter-regional comparison, the bigger the difference of the index, the smaller the H_j. Smaller values of H_j indicate larger effects of the index on the inter-regional comparison; if there is no difference with x_{ij}, $H_j = 1$, then the index is meaningless. Thus, the formula of differentiation coefficient is defined as follows:

$$F_j = 1 - H_j \quad ...(4)$$

6. Determine weight λ_j

$$\lambda_j = F_j / \sum_{j=1}^{n} F_j \quad ...(5)$$

7. Comprehensively evaluate index calculation: After the weights are determined through the entropy evaluation method, the comprehensive evaluation indices of both low-carbon development and the environmental resource system can be calculated by the following formula:

$$U_s = \sum_{j=1}^{n} \lambda_{sj} u_{sj} \quad ...(6)$$

In formula (6): U_s is the comprehensive evaluation index of subsystem S, which reflects the comprehensive development level of the subsystem; u_{sj} is the value of index j of subsystem S; and λ_{sj} is the weight of the index.

Coupling coordination model: This study draws on the capacity coupling model in physics and constructs the coupling degree model which can reflect the mutual influence and interaction of multi-subsystems. The formula is as follows:

$$C = \left\{ \left(\prod_{i=1}^{n} U_i\right) \Big/ \prod_{\substack{i=1,2,\dots,n-1 \\ j=i+1,i+2,\dots,n}} \left(U_i + U_j\right) \right\}^{1/n} \quad ...(7)$$

In formula (7): C is the coupling degree; U_i is a product of the comprehensive evaluation index of each subsystem, U_j is any subsystem except U_i; n is the total number of subsystems, and here $n = 2$.

Coupling degree is used to reflect the interaction degree among various subsystems, but it cannot judge whether the coupling is benign. This study introduces the coordinating degree model to better judge the coordination of inter-coupling between low-carbon development and the environmental resource system, and the formula is as follows:

$$D = \sqrt{C \times T}$$
$$T = aU_1 + bU_2 + cU_3 \quad ...(8)$$

In formula (8): D is the coordinating degree; C is the coupling degree; T is the coordinating index between low-

Table 2: The grade classification of coupling and coordinating degree.

	Value range	Stage
The coupling degree:*C*	*C=0*	Extraneous state and disordered development
	0<C≤0.3	Low-level coupling stage
	0.3<C≤0.5	Equally matching stage
	0.5<C≤0.8	running-in stage
	0.8<C<1	High-level coupling stage
	C=1	Benign resonant coupling with tendency of new orderly structure
The coordinating degree:*D*	*0<D≤0.4*	Low-level coordinated coupling
	0.4<D≤0.5	Medium-level coordinated coupling
	0.5<D≤0.8	High-level coordinated coupling
	0.8<D≤1	Extreme-level coordinated coupling

Table 3: Comprehensive evaluation index of China’s low-carbon development and environmental resource system.

	Comprehensive evaluation index in China’s low-carbon development				Comprehensive evaluation index in China’s environmental resource system			
	2000	2007	2013	average values	2000	2007	2013	average values
Beijing	0.4127	0.2796	0.3669	0.3532	0.2337	0.2166	0.2743	0.2453
Tianjin	0.2239	0.2274	0.3499	0.2491	0.1997	0.1997	0.2280	0.2059
Hebei	0.2045	0.2805	0.5114	0.2879	0.2412	0.3191	0.4235	0.3291
Shanxi	0.1299	0.2651	0.4848	0.2399	0.1812	0.2655	0.3302	0.2697
Neimenggu	0.1140	0.2374	0.5033	0.2283	0.1668	0.2493	0.3370	0.2542
Liaoning	0.2337	0.3246	0.4492	0.2906	0.2593	0.3095	0.4348	0.3221
Jilin	0.2192	0.1696	0.2775	0.2024	0.1853	0.2051	0.2777	0.2150
Heilongjiang	0.1951	0.1833	0.2838	0.2116	0.1667	0.2405	0.3572	0.2442
Shanghai	0.3593	0.2612	0.3396	0.2894	0.2431	0.2494	0.2824	0.2654
Jiangsu	0.2758	0.3567	0.5927	0.3603	0.2952	0.3706	0.5223	0.3848
Zhejiang	0.3952	0.3645	0.5500	0.3841	0.1974	0.2742	0.3859	0.2871
Anhui	0.1542	0.1696	0.3990	0.1960	0.1755	0.2257	0.3543	0.2445
Fujian	0.3325	0.3005	0.4844	0.3377	0.1605	0.2276	0.3428	0.2353
Jiangxi	0.1915	0.2101	0.3483	0.2252	0.1523	0.2573	0.3557	0.2621
Shandong	0.5630	0.4276	0.6473	0.4406	0.2720	0.3705	0.5543	0.3892
Henan	0.2196	0.2436	0.4469	0.2482	0.2217	0.3439	0.4967	0.3492
Hubei	0.2248	0.2014	0.3637	0.2342	0.2062	0.2623	0.3904	0.2798
Hunan	0.1826	0.2299	0.3705	0.2303	0.2195	0.3086	0.4217	0.3098
Guangdong	0.3271	0.3699	0.5870	0.4149	0.2653	0.3782	0.5765	0.3960
Guangxi	0.1957	0.1848	0.3358	0.2132	0.2282	0.2930	0.3336	0.2855
Hainan	0.2202	0.1835	0.2580	0.1974	0.1531	0.1419	0.2011	0.1785
Chongqing	0.1591	0.1639	0.3073	0.1886	0.1626	0.1906	0.3032	0.2088
Sichuan	0.3023	0.2697	0.3715	0.2758	0.2691	0.3363	0.4725	0.3452
Guizhou	0.1738	0.1520	0.2742	0.1738	0.1567	0.2030	0.2457	0.2017
Yunnan	0.2208	0.1990	0.3415	0.2242	0.1723	0.2374	0.3223	0.2420
Xizhang	0.2103	0.0830	0.1246	0.1159	0.2762	0.2010	0.2657	0.2443
Shanxi	0.1669	0.1880	0.3939	0.2245	0.1700	0.2703	0.3631	0.2627
Gansu	0.0912	0.1253	0.2398	0.1264	0.1628	0.2316	0.2627	0.2350
Qinghai	0.2203	0.1733	0.3537	0.2290	0.1361	0.1949	0.2373	0.2097
Ningxia	0.2311	0.1752	0.3779	0.2136	0.1127	0.1370	0.1911	0.1474
Xinjiang	0.1496	0.1088	0.3319	0.1565	0.1615	0.2428	0.3084	0.2330

carbon development and environmental resource system, reflecting the effect and contribution of the comprehensive evaluation index of the two subsystems to their coordinating degree; and a, b and c are undetermined coefficients. In the process of coupling and coordinating development, we find that the two systems of low-carbon development and environmental resources are of equal importance. Based on previous studies and interviews of 9 experts in the field of spatial economics, this study adopts the coefficient values of a = 0.4, b = 0.4, and c = 0.2.

Both coupling degree and coordinating degree are a quantified reflection of coupling coordination of certain systems, but there is no consensus within the literature on the classification of coupling degree and coordinating degree.

Therefore, based on past experience, the research findings of Liu Yaobin et al. (2005), Wu Yuming et al. (2011), and other scholars, and the actual situation of this study, we divide the coupling degree into 6 stages and the coordinating degree into 4 grades (Table 2).

Data Sources

This research studies 31 Chinese provinces, municipalities and autonomous regions; measures the coupling degree and coordinating degree of China's low-carbon development and environmental resource system from 2000 to 2013; and analyses their coupling coordination. All the data have come from the China Statistical Yearbook (2001-2014), the China Statistics Yearbook on Science and Technology (2001-2014), the China City Statistical Yearbook (2001-2014), the China Statistical Yearbook on Environment (2001-2014), and the website of the National Bureau of statistics of China.

EVALUATION OF COUPLING DEGREE OF CHINA'S LOW-CARBON DEVELOPMENT AND ENVIRONMENTAL RESOURCE SYSTEM

Comprehensive evaluation of China's low-carbon development and environmental resource system: Based on the corresponding index system, we standardized the index values, fed them sequentially into formulas (1)-(5), obtained the index weight via the entropy evaluation method, and acquired the comprehensive evaluation indices of low-carbon development and environmental resource system for 31 Chinese provincial administrative regions from 2000 to 2013 using formula (6). Due to the limitations of paper length, we only list the results for 2000, 2007 and 2013 (Table 3).

It can be seen from Table 3 that from 2000 to 2013, Shandong boasted the highest comprehensive evaluation index in China's low-carbon development. Guangdong had the second highest value with an average index of 0.4149, though the gap between comprehensive evaluation index of low-carbon development of Shandong and Guangdong generally increased during those years. The low-carbon development of other provincial administrative regions was generally at a low level.

It can be seen from Table 3 that Guangdong's comprehensive development level of environmental resources system, with the comprehensive evaluation index of environmental resources system significantly increased from 0.2653 in 2000 to 0.5765 in 2013, and was higher than that of other Chinese provincial administrative regions from 2000 to 2013. This indicates that during this period, Guangdong had significantly improved its environmental resources system. From 2000 to 2013, the average values of comprehensive evaluation indices of environmental resource system in Shandong and Jiangsu were 0.3892 and 0.3848, respectively, indicating a relatively sound environmental resource system despite the gap with Guangdong. The comprehensive development of environmental resource system in other provincial administrative regions was at a relatively low level.

According to the comparison of average values of comprehensive evaluation indices of low-carbon development and environmental resource system from 2000 to 2013, the ten provincial-level administrative regions of Beijing, Tianjin, Shanghai, Zhejiang, Fujian, Shandong, Guangdong, Hainan, Qinghai and Ningxia had comprehensive evaluation indices of low-carbon development that were larger than those of the environmental resources system. The comprehensive evaluation indices of environmental resource system of other provincial-level administrative regions were more than those of the low-carbon development. Beijing and Fujian had a larger gap than the other 8 provincial-level administrative regions. This shows that from 2000 to 2013, the low-carbon development of the ten provincial-level administrative regions was better than the environmental resource system, while in other provincial regions the reverse was true.

Evolution characteristics of overall coupling coordination in low-carbon development and environmental resource system: Based on the coupling model, this study further calculates the coupling degree and coordination degree of China's low-carbon development and environmental resource system from 2000 to 2013. The average values of the coupling degree and coordinating degree respectively were calculated according for the time series from 2000 to 2004, from 2005 to 2009, and from 2010 to 2013 in order to better reflect the periodical characteristics of coupling coordination (Table 4).

It can be seen from Table 4 that the average values of coupling degrees between China's low-carbon development and the environmental resource system from 2000 to 2013 were between 0.4520 and 0.4990. The coupling degree of Jiangsu was 0.4990, ranking the highest, and that of Tibet was 0.4520, the lowest. This shows that the coupling of China's low-carbon development and environmental resource system, equally matched in this period. The 31 Chinese provincial-level administrative regions were at this stage, indicating that the coupling development was still extensive with a large gap from the benign resonant coupling. From the perspective of time series, the coupling degrees of the provinces, municipalities, and autonomous regions did not change significantly, indicating that the coupling development of China's low-carbon development and environmental resource system from 2000 to 2013 was relatively stable.

Table 4: The coupling degree and coordination degree of China's low-carbon development and environmental resource system from 2000 to 2013.

	2000-2004 year average values		2005-2009 year average values		2010-2013 year average values		2000-2013 year average values	
	Coupling degree C	Coordination degree D	Coupling degree C	Coordination degree D	Coupling degree C	Coordination degree D	Coupling degree C	Coordination degree D
Beijing	0.4828	0.3972	0.4872	0.3725	0.4967	0.3729	0.4883	0.3814
Tianjin	0.4977	0.3239	0.4970	0.3347	0.4952	0.3517	0.4967	0.3357
Hebei	0.4982	0.3495	0.4984	0.3877	0.4961	0.4420	0.4976	0.3896
Shanxi	0.4908	0.3024	0.4978	0.3599	0.4970	0.4045	0.4950	0.3521
Neimenggu	0.4872	0.2810	0.4975	0.3441	0.4971	0.4112	0.4937	0.3407
Liaoning	0.4996	0.3609	0.4977	0.3865	0.4956	0.4277	0.4978	0.3891
Jilin	0.4984	0.3191	0.4972	0.3070	0.4967	0.3429	0.4975	0.3216
Heilongjiang	0.4960	0.3151	0.4947	0.3253	0.4881	0.3682	0.4933	0.3339
Shanghai	0.4978	0.3792	0.4990	0.3665	0.4985	0.3686	0.4984	0.3716
Jiangsu	0.4992	0.3867	0.4991	0.4290	0.4985	0.4819	0.4990	0.4290
Zhejiang	0.4826	0.3865	0.4965	0.3989	0.4976	0.4376	0.4919	0.4055
Anhui	0.4976	0.2963	0.4946	0.3165	0.4940	0.3811	0.4955	0.3277
Fujian	0.4747	0.3553	0.4928	0.3654	0.4973	0.4043	0.4876	0.3730
Jiangxi	0.4987	0.3215	0.4953	0.3431	0.4947	0.3815	0.4963	0.3464
Shandong	0.4921	0.4169	0.4977	0.4442	0.4987	0.5046	0.4960	0.4517
Henan	0.4945	0.3398	0.4904	0.3792	0.4895	0.4334	0.4916	0.3806
Hubei	0.4999	0.3354	0.4942	0.3433	0.4947	0.3969	0.4964	0.3558
Hunan	0.4966	0.3311	0.4924	0.3610	0.4929	0.4072	0.4940	0.3635
Guangdong	0.4973	0.4118	0.4976	0.4377	0.4994	0.5036	0.4980	0.4473
Guangxi	0.4964	0.3335	0.4902	0.3471	0.4936	0.3745	0.4934	0.3501
Hainan	0.4962	0.3128	0.4969	0.2959	0.4983	0.3073	0.4971	0.3052
Chongqing	0.4978	0.2913	0.4986	0.3073	0.4994	0.3489	0.4986	0.3135
Sichuan	0.4992	0.3741	0.4934	0.3839	0.4903	0.4209	0.4946	0.3910
Guizhou	0.4984	0.2925	0.4955	0.2989	0.4980	0.3279	0.4973	0.3049
Yunnan	0.4978	0.3238	0.4954	0.3297	0.4956	0.3703	0.4963	0.3392
Xizhang	0.4913	0.3265	0.4187	0.2561	0.4445	0.2674	0.4520	0.2845
Shanxi	0.4992	0.3091	0.4945	0.3420	0.4986	0.3966	0.4974	0.3459
Gansu	0.4597	0.2623	0.4640	0.2856	0.4911	0.3309	0.4702	0.2902
Qinghai	0.4947	0.3304	0.4970	0.3125	0.4969	0.3480	0.4961	0.3290
Ningxia	0.4843	0.2786	0.4958	0.2861	0.4886	0.3298	0.4896	0.2959
Xinjiang	0.4977	0.2823	0.4711	0.2918	0.4864	0.3507	0.4850	0.3052

From the perspective of coordinating degree, the average values of coordinating degrees of China's provinces, municipalities and autonomous regions from 2000 to 2013 were between 0.2845 and 0.4517, a low and medium coordinated coupling. The coordinating degree of Shandong was 0.4517, ranking the highest, while Tibet had the lowest with only 0.2845. From the perspective of time series, the coordinating degrees of China's provinces, municipalities, and autonomous regions changed obviously. With the passage of time, the coordinating degree increased to different extent, indicating that China's low-carbon development and environmental resource system generally developed towards a benign coordinated interaction. From 2010 to 2013, the average values of coordinating degrees for Shandong and Guangdong were 0.5046 and 0.5036, respectively, rising from the medium-degree coordination to the high-degree coordination. This indicates that starting from this stage, the coupling coordination of China's low-carbon development and environmental resource system qualitatively leapt forward with some of the provincial-level administrative regions gradually entering into the stage of high-level coordination.

The average value of the coupling degree and coordinating degree of China's low-carbon development and environmental resource system from 2000 to 2013 is used to represent the overall situation and the evolution characteristics in this period (Fig. 1).

As we can see from Fig. 1, the coupling degrees and coordination degrees of China's low-carbon development and environmental resource system from 2000 to 2013 were between 0.3 and 0.5. In 2013, the overall coupling degree of China's low-carbon development and environmental resource system was the highest with the value of 0.4953, while in 2009 the coupling degree was the lowest with the value of 0.4882. It follows that the coupling degrees of China's low-carbon development and environmental resource

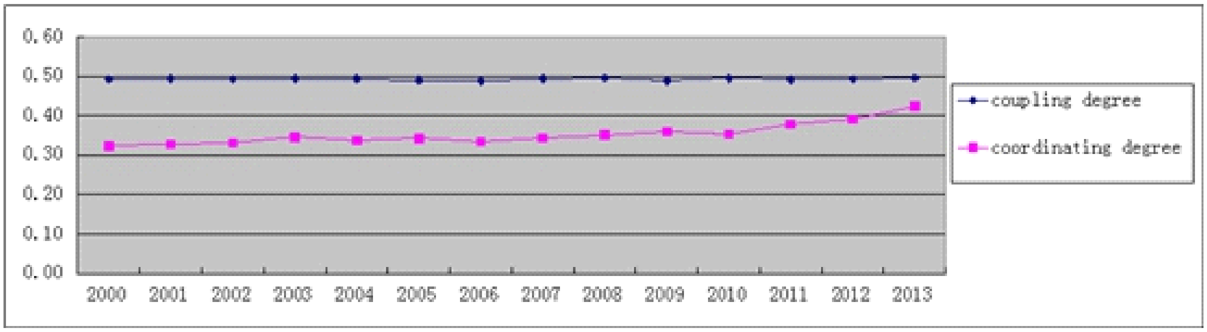

Fig. 1: The condition of the coupling degree and coordinating degree of China's low-carbon development and environmental resource system from 2000 to 2013.

system equally matched in this period, and they did not obvious change over time with a relatively stable coupling situation. As far as the coordinating degree is concerned, the value in 2013 was the highest (0.4244), while that in 2000 was the lowest (0.3241). This shows that from 2000 to 2013 the overall coordinating degree of China's low-carbon development and environmental resource system was at the low and medium coordination stage. Except for 2011, 2012, and 2013 in which the overall coordinating degree increased slightly, other years exhibited relative stability. This shows that in this period China's low-carbon development and environmental resource system generally developed in a stable fashion and at a medium-degree coordination.

CONCLUSION AND RECOMMENDATIONS

This study investigates 31 provinces, municipalities, and autonomous regions in China as examples, combines the comprehensive evaluation model and the coupling model, calculates their comprehensive evaluation index as well as the coupling degree and coordination degree of low-carbon development and environmental resource system, and comes to the following conclusions. First, there were significant differences in the comprehensive development of the low-carbon development and the environmental resource system of China's provincial-level administrative regions from 2000 to 2013. In addition to the individual provinces, the low-carbon development and environmental resource system of other provincial administrative regions was generally at a relatively low level. Second, from 2000 to 2013, the coupling of China's low-carbon development and environmental resource system, equally matched. Their coupling development was still extensive with a large gap from the benign resonant coupling. According to the time series, the coupling degree of China's provinces, municipalities, and autonomous regions did not change significantly, indicating that their coupling development was relatively stable. Overall, both China's low-carbon development and environmental resource system developed towards benign coordinated interaction.

In view of the trend of coupling and coordinating development between low-carbon development and the environmental resource system, this study puts forward some counter-measures and recommendations on how to promote the coordination of low-carbon development and the environmental resource system of China's provincial administrative regions:

First, we should strengthen research and development of new technologies. We should vigorously develop new energy sources, such as solar energy, wind energy, and geothermal energy. Research and promotion of new energy resources can effectively address energy shortages, mitigate environmental pollution, and promote low-carbon production. In addition, the state should strengthen investment in science and technology as well as vigorously develop low-carbon technologies and products. Meanwhile, we can also introduce advanced energy saving technologies from abroad and improve energy efficiency to promote low-carbon development. Independent research and development of carbon-capture technology and secondary innovation of introduced technologies can lay a solid foundation for China's transformation to a low-carbon growth mode.

Second, we should improve the utilization rate of resources. The effective utilization of resources and the environmental system supports and results from low-carbon development. We must attach importance to the protection of local resources and environment as well as promote the coordinating development of the two systems. At present, however, China faces difficulties in quickly addressing the shortage of resources and the serious environmental pollution, in a short period of time. Thus, we must take measures to conserve resources and improve the utilization rate of resources. We can enhance the intensity of the development of clean energy, develop new energy resources, reduce consumption of non-renewable resources, apply renewables in actual production as soon as possible, avoid emission of greenhouse gases, realize the low-carbon production and ensure energy security.

Third, we should establish and develop laws and regulations for low-carbon development. The law is an important pathway to promote the coordinating development of low-carbon development and the environmental resource system. The relevant authorities should establish and improve the laws and regulations on low-carbon development, formulate environmental policies aimed at energy-conservation and emission reduction, develop detailed rules and regulations on pollution supervision and punishment, enhance punishment on pollution, improve pollution evaluation and supervision systems, and promote the protection of resources and environmental systems.

To sum up, optimization of industrial structure, promotion of development and utilization of new energy resources, innovation in low-carbon technologies, reduction of energy consumption, improvement of utilization rate of resources, enhancement of environmental pollution governance, and energy conservation will lower pollution and lower emissions. These efforts can promote sustainable economic development, so that China can realize healthy and rapid low-carbon development.

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