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Original Research

Dynamic Comprehensive Evaluation of the Development Level of China's Green and Low Carbon Circular Economy under the Double Carbon Target

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Abstract

At present, a new pattern of world economic development is taking shape, and different development models featuring a green, low-carbon, and recycling economy have become the goals pursued by all countries. China is in a critical period of economic transformation. Establishing a sound financial system for green, low-carbon, and recycling economic development is an essential initiative for China to realize the dual-carbon goal, build a modern financial system for sustainable development, and promote the construction of a community of human destiny. Therefore, it is of great practical significance to dynamically monitor the development of China's green, low-carbon, and recycling economy and explore regional development differences to realize coordinated and sustainable regional development. This paper measures the level of green, low-carbon, and recycling economy development in 30 provinces and cities in China by constructing a dynamic evaluation system for green, low-carbon, and recycling economy development and utilizing a dual incentive model. The empirical results show that since 2014, the level of green, low-carbon, and recycling economy development in China's provinces and cities has been on an upward trend. Still, the level of action needs to be balanced. Therefore, it is imperative to create an institutional environment conducive to advancing green and low-carbon technologies, promoting structural adjustment and energy efficiency, and reducing regional differences in green, low-carbon, and recycling development.

Keywords: green and low carbon, circular development, green low-carbon circular economy, dynamic comprehensive evaluation, double incentive model

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Introduction

Since the 18th National Congress of the Communist Party of China, China has dramatically appreciated green development. The construction of ecological civilization in China has undergone historic turning and overall changes. The Party Central Committee, with General Secretary Xi Jinping at its core, has introduced many policies to support ecological priority and green development. The green and low-carbon circular economic development system not only integrates Xi Jinping's thoughts on socialism with Chinese characteristics for a new era but also aligns with the global concept of sustainable development [1-3]. At present, China is in a crucial period of economic transformation. Establishing and perfecting a green and low-carbon circular development financial system is essential in building a sustainable and modern economic system and an important measure to construct a Community of Shared Future for Mankind. At the same time, it plays a vital role in promoting economic upgrading and transformation, improving quality and increasing efficiency. General Secretary Xi Jinping has repeatedly stressed the importance of the circular economy. He has elaborated on the role of the circular economy in the construction of ecological civilization, its relationship with economic and social development, and the role it plays in areas such as major national strategies and the achievement of carbon peaking and carbon neutrality, and has put forward requirements and work plans [4-6]. In this context, it is of great practical significance to accurately measure the level of green and low carbon cycle development in China's provinces and to study the regional differences in green and quiet carbon cycle development to implement the national "double carbon" target and the high-quality growth of China's economy.

Theoretical Basis and Research Framework

Evolution of the Concept of Green Low Carbon Circular Economy

Kenneth et al. creatively proposed the circular economy concept in his article. He believed that circular economy referred to a green development model that reduced waste emissions, maximized resource recycling and reduced environmental burden through reduction, reuse and recycling [7-8] The concept of a green economy was first introduced by Pearce et al. Pearce et al. consider the green economy to be the same as the sustainable economy and use environmental economics as an entry point to explore the issue of sustainable development [9]. The concept of a low-carbon economy was first proposed in the 2003 UK Energy White Paper "Our Energy Future: Creating a Low-carbon Economy". Low-carbon economy is the general term for low-carbon development, low-carbon industry, low-carbon technology, low-carbon life and other economic forms. It considers that the essential requirement of a low-carbon economy is to deal with the impact of carbon-based energy on climate change, and the basic purpose is to achieve sustainable economic and social development [10]. Makower et al. linked the concepts of green and low carbon and believed that green and low carbon were the inevitable choices facing the new energy and climate crisis [11].

Developing a green and low-carbon circular economy is an organic combination of green, low-carbon and circular economy. It is significant progress to achieve high-level development by breaking through the shackles of resources and the environment. It is a synergistic relationship that promotes and strengthens each other. Green growth, low-carbon development and circular development share the same development objectives: promoting resource conservation, protecting and improving the natural environment, enhancing energy efficiency and pursuing sustainable human development [12-14].

Relevant Studies on Green Low-Carbon Circular Economy Evaluation

In the research of green index systems, foreign scholars' research on developing the green low-carbon economy is mainly from the input and output perspective. A. Druckman & P. Bradley et al. have changed the traditional accounting framework by proposing a consumption-based accounting framework - using a bi-regional environmental input-output (EIO) model - to measure carbon reduction in the UK and compare it with a production perspective. However, the model is applied without energy substitution and cannot be used for long-term evaluation [15]. A.S. et al. used the macro econometric mixed model E3MG (Energy-Economy-Environment Model at the global level) for their study [16].

China's research on related fields is conducted at the national, provincial and city levels. At the national indicator system construction level, Li et al. analyzed the green development index values of 123 countries by constructing the Human Green Development Index [17]. It is concluded that China's HGDI rank is 86, which belongs to the light green development level stage. Cai et al. measured the green economic growth efficiency of 30 provinces and cities in China using a directional distance function model with non-radial, non-directed relaxation measures and established a new urbanization model based on green development by combining the urbanization processes of different regions [18].

At the level of constructing local indicator systems, Zhao et al. established a dynamic and comprehensive evaluation method that combined a dual incentive model with minimum variance to measure and analyze the causes of the level of green, low-carbon and cyclic development in 30 provinces and cities [19]. Yang et al. studied in depth the evolutionary characteristics of China's green development efficiency and regional disparities by building an SBM-DEA model and verifying its convergence [20]. Zhou et al. focus on establishing an indicator system from green growth, using the connotation and extension of inclusive green growth to establish an indicator system to study the level of green growth, change trends, regional differences and convergence within each province and city and three major regions in China [21].

At the urban indicator system construction level, Wang et al. used Shenzhen as a case study to explore the path of modern cities to build a green, low-carbon and circular development economic system using theoretical analysis methods [22]. By constructing a comprehensive evaluation system for green growth, Huang et al. selected 20 urban agglomerations as research objects and applied the projection tracing model, Pearson correlation, coefficient of variation and Thiel index to systematically study the spatial and temporal characteristics and heterogeneity of green development of urban agglomerations in China [23]. Zhang et al. comprehensively evaluated the green governance capacity of 11 provinces and cities in the Yangtze River Economic Belt by constructing an evaluation index system for green governance capacity [24]. Ma et al. used the entropy-TOPSIS method to assess the green development index of 31 cities in the middle reaches of the Yangtze River urban agglomeration and used the GWR model to investigate their spatial spillover [25]. Li et al. combined DEA static analysis with Malmquist index dynamic analysis to dynamically evaluate and compare the green efficiency of 36 cities in the Central and Yangtze River Delta [26].

Di Fabio considers ecological generativity as the ability of an individual to contribute to the protection of the environment and the promotion of sustainable practices for the benefit of future generations [27]. Ecological generativity includes ecological generativity, social generativity, and aspects of environmental identity and perceptions about achieving goals through the development of successful programs (institutions/pathways). Environmental identity is also part of ecological generativity because generativity, environmental issues, and concerns related to the natural world are closely related and interact [28]. Ecological generativity differs from other concepts or measures of environmental attitudes or behaviors, such as ecological concerns, pro-environmental behaviors, environmental values, and environmental attitudes [29]. Environmental concern consists of two concepts. One is responsible for caring for the environment that arises from the perspective of affecting health and well-being [30]. The second is the study of the impact of human behavior on environmental problems and related solutions from the concern about the severity of environmental issues [31]. Ecological generativity focuses on maintaining a healthy environment and the continuity of life. Ecological generativity is the predecessor of pro-environmental behavior, defined as behavior that consciously protects and enhances its sustainability [32]. Thus, environmental generativity and pro-environmental attitudes can be considered related. The construct of ecological generativity extends the mental processes encompassed by the concept of generativity to the environment and the natural world [33].

A review of relevant studies reveals that there are more studies related to green, low-carbon and circular economy indicator systems by Chinese and foreign scholars, but fewer studies have combined the three. Due to the regional imbalance and regional differences in the development of China's socio-economic and technological levels, the indicator system is not universal, and the research framework is relatively incomplete, so most of the research subjects are studied for a specific region or the whole country as a whole, and there are few studies about the entire country at the same time and quantitative analysis of spatial and temporal differences. In this paper, we will reasonably construct an evaluation index system for the green low-carbon circular economic development system, make simultaneous measurements of the economic level statistics of green low-carbon circular development in each province of China, and give corresponding suggestions.

Interactive Mechanism of Green and Low-Carbon Circular Development Elements

Relationship between Green Economy, Low-Carbon Economy and Circular Economy

Green economy, low-carbon economy and circular economy all conform to the economic development model of sustainable development theory [34]. The three have their characteristics but complement each other. They share the same background, theoretical basis and ultimate development goals. There are differences in the focus of problem-solving, the focus of theoretical basis and the core content. The similarities and differences between them are as follows:

A. The same background and theoretical basis

The green economy, low-carbon economy and circular economy all emerged from a background of excessive sacrifice of resources and the environment due to a crude economic growth model [35-36]. All three are based on ecological-economic and systems theory, focusing on the sustainable development of resources and the environment and reconciling economic development with natural ecology.

B. The same ultimate development goals

All three forms of economy share the same ultimate development goal of achieving sustainable development of human society. The green economy, circular economy and low carbon economy all emphasize the harmonious co-existence between humans and nature and improve the efficiency of utilization; they emphasize moderate consumption and improved reuse of materials to promote sustainable human development [37].

C. Different focus on problem solving

The focus of the green economy is on caring about life, balancing material and spiritual needs; the direction of the low-carbon economy is on carbon emissions, emphasising the reduction of greenhouse gas emissions and lowering carbon emissions; the focus of the circular economy is on the material cycle of society as a whole, emphasising the realisation of resource conservation and environmental protection in economic activities.

D. Different focus on theoretical foundations

The green economy focuses on the use of ecology, sociology and environmental economics to achieve economic development while protecting the human living environment; the theoretical basis of the low-carbon economy focuses on economics, resource and ecological economics, ecology and other theories, mainly economics; the theoretical basis of the circular economy focuses on ecology, systematics, thermodynamics and different ideas, primarily ecology [38].

E. Different core content

A green economy is a balanced economy that uses energy and resources wisely to protect the ecological environment on which humanity depends. At the heart of a low-carbon economy are technological innovations in energy technology and emissions reduction, innovations in industrial structure and systems, and fundamental changes in human survival and development [39]. The core of a circular economy is the efficient use and recycling of resources.

Interaction between the Elements of Green Low- Carbon Circular Economy Development

A. Mechanism for interaction with economic and social development

Economic and social development and the development of a green, low-carbon circular economy influence, promote and constrain each other. The higher the level of green, low-carbon circular economy, the stronger the impetus to the level of social and economic development, the more significant the effect on the improvement of resource allocation efficiency and the improvement of social and economic quality and efficiency, which is the higher-order form of social and economic development. The formation of a green, low-carbon circular financial system is an inevitable requirement for improving the level of economic and social development. As the level of economic and social development rises and the conditions for sustainable economic and social development become higher and higher, a green, low-carbon and circular industrial system has emerged as a new industry and model for economic development.

B. Mechanisms for interaction with green development

Green low, circular carbon economy development and green development are mutually supportive and collaborative. The essence of green, low-carbon circular economic growth is the comprehensive, coordinated and sustainable development of people and nature. Green product is aimed at sustainable development, matching and adapting resources, production and consumption to achieve a harmonious coexistence of society and ecology as the final result so that people and nature can live together in harmony [40]. Under the "double carbon" goal, establishing a green, low-carbon circular economic system is an inevitable requirement for green development. The higher the level of green growth, the higher the green low-carbon circular economy development. Establishing a green, low-carbon and circular economic development system is of great significance to achieving high-quality economic growth and improving the level of green development.

C. Mechanisms of interaction with low carbon development

Low carbon development and green low carbon circular economy development are mutually influential, mutually reinforcing and complementary. Joint carbon development is a sustainable development paradigm and a comprehensive issue that involves synergies across multiple sectors. Suppose joint carbon development is not linked to green and circular development. In that case, it may lead to new ecological damage and environmental pollution, so there is a complementary relationship between it and green low, carbon-circular economic development. The increased level of low-carbon development will also contribute to green and low-carbon circular economy development.

D. Mechanisms of interaction with circular development

The green, low-carbon circular economic development system is a financial system that places equal importance on economic, ecological and social benefits. Circular development is an integral part of driving up the level of economic and social development and is a crucial way to achieve sustainable development of human society, facilitating the development of a green, low-carbon circular economy. Green low-carbon circular economy development promotes green low-carbon development and high-quality economic growth, thus stimulating a new increase in circular development. The level of circular development and the level of development of a green, low-carbon circular economy influence and complement each other.

Construction of Green Low-Carbon Circular Economy Development Index System

Principles of Construction

The primary purpose of constructing a green, low-carbon circular economy development evaluation index system is to objectively reflect the actual situation

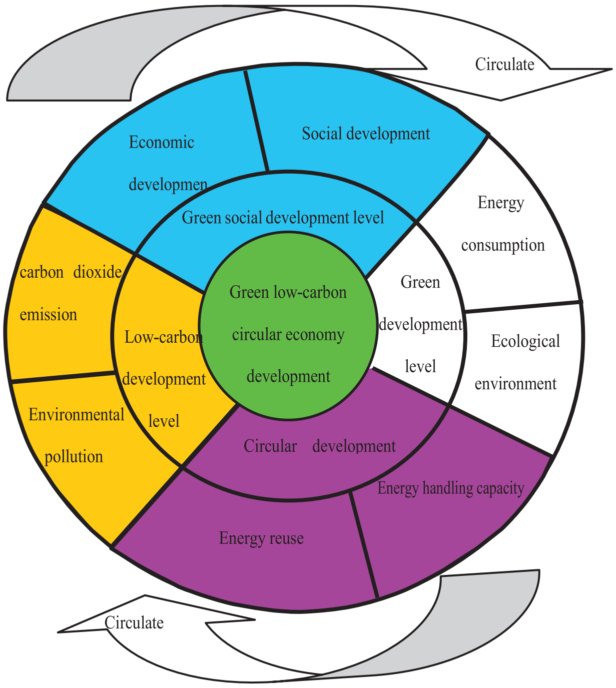

Fig. 1. Interaction between the elements of green low carbon circular economy development.

of China's green, low-carbon circular economy and scientifically judge the level of green, low-carbon circular economy development in each province and region of China. Therefore, the following principles should be followed in selecting specific indicators.

A. The principle of feasibility

Indicators should be collected in a way that is consistent with the provincial and municipal situation and representative, in accordance with the principles of accuracy, simplicity and operability, and that the meaning of the indicators, statistical calibre, calculation methods and data sources of each indicator are easy to collect and calculate. The targets for each indicator are well targeted, realistic, objective and actionable.

B. Principle of universality

The selected indicators should be compatible with the existing policy indicator system and representative so that each hand is universally applicable to the evaluation target without reducing the accuracy of the indicator system due to spatial and systematic errors, and thus comprehensively and effectively measuring the total capacity of China's green low carbon cycle development.

C. The principle of comprehensiveness

The construction of the green low-carbon circular economy development evaluation index system should cover the connotation and characteristics of the green low-carbon circular economy and be able to scientifically and accurately measure the construction level of the green low-carbon circular economy development system.

Selection of Indicators

This research relies on the scientific connotation of the green and low-carbon circular economy development system and constructs a representative index system that can comprehensively reflect the green and low-carbon circular economy from the three dimensions of green, low-carbon and circular, drawing on the existing research results [41-42]. The system consists of three tiers: the guideline tier includes economic and social, green, low-carbon and recycling development levels, respectively; the guideline tier is further subdivided into ten sub-criterion stories of economic development, social development, energy consumption, ecological environment, carbon emissions, environmental pollution, recycling, energy reuse, recycling capacity and energy treatment capacity; and finally implemented into 26 specific evaluation indicators such as per capita GDP (Yuan) and the proportion of tertiary industry (%), as shown in Table 1.

Statistical Measurement of China's Provincial Green Low-Carbon Circular Economy Development Level

Sample Selection

This paper collects data from 30 provinces and cities in China from 2014-2019 (excluding Hong Kong, Macao, Taiwan and Tibet). Relevant data are obtained from the Guotaian database, the National Bureau of Statistics and the China Statistical Yearbook, the China Energy Statistical Yearbook and the China Environmental Statistical Yearbook in different years.

Data Processing

This paper correlates the data through the entropy weighting method and measures the indicator weights of each provincial area [43-44]. The specific steps are as follows:

(a) Setting indicators

There are n provinces and cities, m evaluation indicators, and r year is the j indicator value of area i in the year.

(b) Dimensionless processing of data

Depending on the data, attributes can be divided into positive and negative indicators, and this paper eliminates the effect of negative numbers and zeros by simultaneously panning the data.

For positive indicators, the treatment adopted is

$$a_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} + 1$$

For inverse indicators, the approach taken is

$$a_{ij} = \frac{x_j^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}} + 1$$

Table 1. Table of evaluation indicators for green low carbon circular economy development system.

Target	Criterion level	Sub-criterion layer	Index layer	Indicator type
Green Low Carbon Circular Economy Development Evaluation Index System	Green social development level	Economic development	GDP per capita (yuan)	Positive
			Proportion of tertiary industry (%)	Positive
			Per capita financial expenditure (yuan)	Positive
			Proportion of R&D expenditure in GDP (%)	Positive
		Social development	Per capita disposable income of residents	Positive
			Proportion of urban population (%)	Positive
			Proportion of national financial education expenditure in GDP (%)	Positive
			Registered urban unemployment rate (%)	Reverse
	Green development level	Energy consumption	Energy consumption per unit of GDP (10,000 tons/billion yuan)	Reverse
			Energy consumption per capita (ton/person)	Reverse
			Per capita consumption of coal (tons/person)	Reverse
		Ecological environment	Forest coverage rate (%)	Positive
			Water resources per capita (m^3/person)	Positive
			Urban built-up area green coverage rate (%)	Positive
	Low carbon development level	Carbon dioxide emission	Per capita carbon emission (ton/person)	Reverse
			Carbon emission intensity (ten thousand tons/billion yuan)	Reverse
			Carbon emission growth rate (%)	Reverse
		Environmental pollution	Sulphur dioxide emissions (10,000 tonnes)	Reverse
			Output of general industrial solid waste (ten thousand tons)	Reverse
			Investment in industrial pollution control completed (ten thousand yuan)	Positive
			Removal of municipal solid waste (10,000 tons)	Positive
	Circular development level	Recycle Energy reuse	Comprehensive utilization of general industrial solid waste (10,000 tons)	Positive
			Reuse rate of industrial water (%)	Positive
			Urban sewage daily treatment capacity (10,000 cubic meters)	Positive
		Circulation capacity Energy handling capacity	Harmless treatment capacity of municipal solid waste (ton/day)	Positive
			Harmless Treatment Rate of Municipal Domestic Waste (%)	Positive

Where is the maximum value taken by x_j^{max} for that indicator and x_j^{min} is the minimum value taken by that indicator.

(c) Determining indicator weights:

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}$$

(d) Calculate the entropy value of the jth indicator.

$$e_j = -\frac{1}{\ln n}\sum_{i=1}^{n} p_{ij}\ln(p_{ij}),\ 0 \le e_j \le 1$$

(e) Calculate the information utility value of the j index: $g_j = 1 - e_j$

(f) Calculate the weights for each indicator:

$$W_j = \frac{g_j}{\sum_{j=1}^{m} g_j},\quad j = 1,2,\ldots,m$$

Model Construction

This study measures the green low, carbon circular economy development level by constructing a dual incentive model. With n evaluated objects $S = \{s_1, s_2, ..., s_n\}$, m evaluation indicators $X = \{x_1, x_2, ..., x_n\}$, and T times $T = \{t_1, t_2, ..., t_n\}$. $X_{ij}(t_k)$ represents the observations of the considered object $s_i(i = 1, 2, ..., n)$ indicator at time $x_i(j = 1, 2, ..., m)$, and it is completed with indicator type consistency and dimensionless processing.

(a) Due to the different amount of information contained in each indicator, it is necessary to first determine the weights of the hands at each moment through the entropy weighting method and then derive the static comprehensive evaluation value p of the evaluated object at each moment through the linear complete weighting method (as shown in Table 3), the inert comprehensive evaluation value matrix of the considered thing at each moment is:

$$Y = \begin{bmatrix} y_1(t_1) & y_1(t_2) & \dots & y_1(t_T) \\ y_2(t_1) & y_2(t_2) & \dots & y_2(t_T) \\ \vdots & \vdots & \dots & \vdots \\ y_n(t_1) & y_n(t_2) & \cdots & y_n(t_T) \end{bmatrix} \tag{1}$$

(b) According to the following equation, the average maximum gain of the evaluated object is $\eta^{\max} = 0.0142$, the average minimum gain $\eta^{\min} = -0.0113$ and the average gain is $\eta = 0.0006$

$$\eta^{\max} = \max_i \left(\frac{1}{T-1}\sum_{K=1}^{T-1}(y_i(t_{K+1}) - y_i(t_k))\right) \tag{2}$$

$$\eta^{\min} = \min_i \left(\frac{1}{T-1}\sum_{K=1}^{T-1}(y_i(t_{K+1}) - y_i(t_k))\right) \tag{3}$$

$$\eta = \frac{1}{n(T-1)}\sum_{i=1}^{n}\sum_{K=1}^{T-1}(y_i(t_{K+1}) - y_i(t_k))) \tag{4}$$

(c) Where K^+, $K^- \in (0,1]$, denote the float coefficients corresponding to the indicators. This study refers to the floating coefficient used by Zhang Invention et al. (2019) [45]. i.e. $k^+ = k^- = 0.5$. Substituting into the following equation yields superior and inferior gain levels of $\eta^+ = 0.0074$ and $\eta^- = -0.0053$, respectively.

$$\begin{cases} \eta^+ = \eta + \left(\eta^{\max} - \eta\right)k^+ \\ \eta^- = \eta - \left(\eta - \eta^{\min}\right)k^- \end{cases} \tag{5}$$

Among them, ($k = 2, 3, ..., T$)

(d) An incentive control model is developed to incentivize the evaluated subject's gain level. The amount of superior excitation obtained by the evaluated object s_i at time t_k is $v_k^+(t_k)$, and the amount of inferior excitation is $v_k^-(t_k)$.

$$v_i^+(t_k) = \begin{cases} y_i^+(t_k) - y_i(t_k), y_i^+(t_k) > y_i(t_k) \\ 0, other \end{cases} \tag{6}$$

$$v_i^-(t_k) = \begin{cases} y_i(t_k) - y_i^-(t_k), y_i(t_k) > y_i^-(t_k) \\ 0, other \end{cases} \tag{7}$$

(e) In incentive control models, the dynamic composite evaluation value considers the reward and punishment for deviations from the superior and inferior incentives [46-47]. This results in the dynamic integrated evaluation value $z_i(t_k)$ of the evaluated object s_i at time t_k.

$$z_i(t_k) = h^+ v_i^+(t_k) + y_i(t_k) - h^- v_i^-(t_k) \tag{8}$$

Where the only incentive factor is h^+, the inferior incentive factor is h^- and (h^+, $h^- < 0$), $h^+v_i^+(t_k)$ and $h^-v_i^-(t_k)$ the superior and inferior incentive penalty components are $h^+v_i^+(t_k)$ and $h^-v_i^-(t_k)$, respectively. If $v_i^+(t_k)$ $v_i^-(t_k) = 0$, then $h^+v_i^+(t_k)$ and $h^-v_i^-(t_k)$ cannot take values simultaneously. The importance of h^+ and h^- needs to be determined to achieve the adjustment of rewards and penalties. h^+, h^- is calculated as follows.

Rule 1: Proportionality rule for a total incentive

$$r = \frac{h^+ \sum_{i=1}^{n} \sum_{K=1}^{T} v_i^+(t_k)}{h^- \sum_{i=1}^{n} \sum_{K=1}^{T} v_i^-(t_k)} = 1 \tag{9}$$

Rule 2: The Rule of Moderate Incentives

$$h^+ + h^- = 1 \tag{10}$$

Combining the two equations above, the superior and inferior incentive factors are $h^+ = 0.5562$ and $h^- = 0.4438$.

(f)The dynamic composite measure of the study population is z_i, calculated as

$$z_i = \sum_{k=1}^{T} \tau_k z_i(t_k) \tag{11}$$

Considering the time factor, the appraised object's total dynamic composite appraisal value at each point in time ($\tau_k = 2$) can be derived from the above formula and ranked in numerical order (as shown in Table 4).

Empirical Analysis

A. Dynamic and comprehensive evaluation value of the level of green low carbon circular economy development in each province and region

Based on the above research methods and essential data, the weights of indicators for measuring the level of green low-carbon circular economy development of each provincial region from 2014 to 2019 can be obtained (Table 2), and the static comprehensive evaluation value $y_i(t_k)$ of the level of green low-carbon economy development of each provincial region can be derived by the linear complete weighting method (see Table 3).

As shown in Table 2, in the guideline tier, the weights are in descending order: level of economic and social development, level of green growth, level of low

Table 2. Weights of indicators for measuring the level of development of green, low-carbon and circular economy.

Criterion level		Sub-criterion layer		Index layer	
Green social development level	0.3776	Economic development	0.1956	GDP per capita (yuan)	0.0510
				Proportion of tertiary industry (%)	0.0315
				Per capita financial expenditure (yuan)	0.0558
				Proportion of R&D expenditure in GDP (%)	0.0572
		Social development	0.1820	Per capita disposable income of residents	0.0476
				Proportion of urban population	0.0459
				Proportion of national financial education expenditure in GDP (%)	0.0542
				Registered urban unemployment rate	0.0343
Green development level	0.1508	Energy consumption	0.0309	Energy consumption per unit of GDP	0.0309
				Energy consumption per capita	0.0422
				Per capita consumption of coal	0.0262
		Ecological environment	0.1199	Forest coverage rate	0.0567
				Water resources per capita	0.0358
				Urban built-up area green coverage rate	0.0273
Low carbon development level	0.2067	carbon dioxide emission	0.0937	Per capita carbon emission	0.0331
				Carbon emission intensity	0.0292
				Carbon emission growth rate	0.0314
		Environmental pollution	0.1131	Sulphur dioxide emissions	0.0393
				Output of general industrial solid waste	0.0003
				Investment in industrial pollution control completed	0.0385
				Removal of municipal solid waste	0.0350
Circular development level	0.1965	Recycle	0.1261	Comprehensive utilization of general industrial solid waste	0.0496
		Energy reuse	0.0496	Reuse rate of industrial water	0.0352
				Urban sewage daily treatment capacity	0.0413
		Circulation capacity	0.0703	Harmless treatment capacity of municipal solid waste	0.0387
		Energy handling capacity	0.0703	Harmless Treatment Rate of Municipal Domestic Waste	0.0317

carbon development and status of circular product. In the sub-criteria group, the weights are in descending order: economic development, social development, recycling, ecology, environmental pollution, energy consumption, carbon emissions, recycling capacity, energy treatment capacity, and energy reuse. Of these, the largest weighting is given to economic development, mainly due to the effective implementation of China's sustainable development strategy, laying a solid foundation for constructing a green, low-carbon and cyclical development system. The lowest weighting of circularity indicates that we still need to improve and that there has been no significant improvement in our country's circularity. In the indicator tier, six indicators, namely the proportion of R&D expenditure to GDP, forest coverage, GDP per capita, the balance of state financial expenditure on education to GDP (%), fiscal spending per capita and the amount of general industrial solid waste comprehensively utilised, all carry a greater weight than 5%. Overall, the combined evaluative effect of the indicators is relatively reliable.

Table 3. Static composite assessment values for the level of green low carbon economy development by province, 2014-2019.

	2014	2015	2016	2017	2018	2019
Region	Score	Score	Score	Score	Score	Score
Beijing	0.6844	0.6734	0.6551	0.6310	0.6358	0.6279
Tianjin	0.4794	0.4719	0.4778	0.4323	0.4265	0.4589
Hebei	0.3483	0.3556	0.3942	0.3878	0.3880	0.4047
Shanxi	0.2781	0.2774	0.3193	0.3060	0.3227	0.3385
Inner Mongolia	0.2903	0.2957	0.3188	0.3093	0.2656	0.2565
Liaoning	0.4270	0.4134	0.4186	0.4127	0.3939	0.3827
Jilin	0.3430	0.3891	0.3837	0.3419	0.3441	0.3623
Heilongjiang	0.3274	0.3699	0.3666	0.3173	0.3201	0.3436
Shanghai	0.5864	0.5847	0.6005	0.5933	0.6017	0.5820
Jiangsu	0.5368	0.5479	0.5775	0.5553	0.5466	0.5465
Zhejiang	0.5742	0.5878	0.6053	0.5750	0.5925	0.5843
Anhui	0.4169	0.4319	0.4685	0.4476	0.4548	0.4549
Fujian	0.4767	0.5124	0.5228	0.5115	0.4792	0.4780
Jiangxi	0.4189	0.4313	0.4471	0.4308	0.4311	0.4566
Shandong	0.4447	0.4447	0.5051	0.4984	0.5042	0.4906
Henan	0.3810	0.3933	0.4404	0.4252	0.4391	0.4519
Hubei	0.4334	0.4557	0.4887	0.4546	0.4618	0.4507
Hunan	0.4085	0.4198	0.4245	0.4096	0.4163	0.4379
Guangdong	0.6009	0.6266	0.6461	0.6261	0.6466	0.6474
Guangxi	0.4255	0.4500	0.4509	0.4367	0.4395	0.4309
Hainan	0.4369	0.4351	0.4614	0.4182	0.4362	0.4426
Chongqing	0.4085	0.4450	0.4341	0.4241	0.4443	0.4220
Sichuan	0.3814	0.4144	0.4193	0.4033	0.4304	0.4117
Guizhou	0.3581	0.3665	0.3740	0.3436	0.3855	0.3883
Yunnan	0.4051	0.4098	0.4268	0.3928	0.3872	0.3964
Shaanxi	0.3870	0.4024	0.4127	0.3833	0.3859	0.3682
Gansu	0.3206	0.3344	0.3556	0.3511	0.3535	0.3557
Qinghai	0.3801	0.3715	0.3591	0.3807	0.3766	0.4028
Ningxia	0.2505	0.2446	0.2740	0.2381	0.2334	0.2427
Xinjiang	0.2395	0.2626	0.2762	0.2777	0.2763	0.3005

From the above dual incentive model, the dynamic and comprehensive evaluation results and ranking of the green, low carbon and circular economy development level of 30 provinces and cities in China from 2014-2019 can be derived (see Table 4). Through the dynamic comprehensive evaluation results and ranking of the development level of green low-carbon economy of each province and municipality, it can be seen that the level of green low-carbon and circular economy development system of each region and city can be roughly divided into four groups according to the size of the dynamic comprehensive evaluation results of each province and municipality: The first tier includes Beijing and Guangdong, which indicates a high level of development of their green low carbon circular economy and a high growth rate maintained from 2014-2019; the second tier includes 7 provinces and cities such as Shanghai and Zhejiang; the third tier contains 11 towns and regions such as Anhui and Guangxi, and it can be seen that there is very little difference in the measured values between

Table 4. Results and ranking of the dynamic and comprehensive evaluation of the level of development of green and low-carbon economy in each province.

Region	Result	Ranking	Region	Result	Ranking
Beijing	3.2707	1	Henan	2.1148	15
Tianjin	2.2916	9	Hubei	2.3101	8
Hebei	1.9047	21	Hunan	2.0933	16
Shanxi	1.5377	27	Guangdong	3.1727	2
Inner Mongolia	1.4766	28	Guangxi	2.2155	11
Liaoning	2.0618	18	Hainan	2.1961	12
Jilin	1.8219	24	Chongqing	2.1760	14
Heilongjiang	1.7190	26	Sichuan	2.0721	17
Shanghai	2.9734	3	Guizhou	1.8451	23
Jiangsu	2.7783	5	Yunnan	2.0239	19
Zhejiang	2.9459	4	Shaanxi	1.9699	20
Anhui	2.2420	10	Gansu	1.7352	25
Fujian	2.5141	6	Qinghai	1.8905	22
Jiangxi	2.1806	13	Ningxia	1.2488	30
Shandong	2.4310	7	Xinjiang	1.3626	29

the provinces and cities in this second and third tier; the fourth echelon has 10 towns and regions such as Hebei, Qinghai and Guizhou, indicating that their green low carbon circular economy is developing at a slower pace. Although there are minor differences between these ten provinces and cities, it is more challenging to raise the level of green and low carbon cycles compared to the first tier. Overall, the first and second echelons appear to have higher measured values. Developing a green, low-carbon circular economy is uneven across regions, with most provinces and territories still having significant room for improvement. It is mainly due to the regional differences in resource endowment, environmental conditions and the level of economic development among provinces and municipalities in China.

The spatial differences in the dynamic and comprehensive evaluation results and rankings of each province and city's green and low-carbon economic development show significant gaps in the story of green and low-carbon cyclic development of each region and city. Among them, the highest dynamic, comprehensive evaluation result of each province and city is Beijing, with an evaluation result of 3.2707. The higher ranking of the emotional evaluation of the green low carbon cycle development level are Beijing, Guangdong, Shanghai, Zhejiang, Jiangsu, Fujian, Shandong, Hubei, Tianjin and Anhui. It can be seen that the top-ranked provinces and cities, except Hubei and Anhui, are all in the eastern region, with a large and relatively developed economy and a relatively high GDP per capita. As a result, they have a strong capacity for scientific and technological innovation, can quickly obtain economic benefits, and are more likely to develop a green and low-carbon circular economy. Other dynamic overall evaluation results ranked 21-30 primarily in the significant energy-consuming provinces or western regions, mainly because most enterprises in the western areas are smaller, less technologically advanced and have fewer sources of capital, and are therefore unable to achieve both energy savings and economic benefits. Ningxia has the lowest dynamic, comprehensive evaluation result, with only 1.2488, and a significant gap with Beijing, which has the highest emotional, complete evaluation result. Because Ningxia is a coal-producing region, its energy use is dominated by coal, its energy utilisation rate is low, its economic and social base is poor, and its industrial structure is unreasonable, which restricts the development of its green, low-carbon circular economy.

B. Analysis of evaluation results at the four guideline levels

Based on the above data, the ranking of the combined assessed value of the four guideline tiers was further calculated for each province from 2014-2019 (Table 5).

As shown in Fig. 1, the combined measure values of the provinces and municipalities are influenced differently by these four guideline layers. In some areas and cities, the composite measure is mainly influenced by a single guideline layer (for example, Shandong's composite measure is determined by the level of green development). Some provinces and municipalities are mainly influenced by the dual-criteria layer (for example, Guangdong's composite measure is influenced by both

Table 5. Ranking of the combined assessment value of each provincial guideline tier for 2014-2019.

	Green social development level	Green development level	Low carbon development level	Circular development level
Region	Ranking	Ranking	Ranking	Ranking
Beijing	1	7	3	20
Tianjin	3	26	13	19
Hebei	25	21	24	5
Shanxi	21	27	28	10
Inner Mongolia	14	29	29	15
Liaoning	16	19	26	6
Jilin	26	16	15	26
Heilongjiang	30	17	20	25
Shanghai	2	23	4	11
Jiangsu	5	20	6	2
Zhejiang	4	6	2	4
Anhui	18	14	14	8
Fujian	10	1	9	14
Jiangxi	19	2	18	22
Shandong	9	22	8	3
Henan	28	18	5	7
Hubei	15	13	7	9
Hunan	23	8	11	18
Guangdong	6	5	1	1
Guangxi	27	3	16	12
Hainan	11	4	17	27
Chongqing	8	10	12	29
Sichuan	29	11	10	13
Guizhou	22	12	25	23
Yunnan	24	9	21	17
Shaanxi	20	15	23	16
Gansu	17	24	22	24
Qinghai	7	25	19	28
Ningxia	13	30	30	21
Xinjiang	12	28	27	30

the low-carbon development level and the recycling development level), while similar levels of each criterion influence others.

(a) Level of economic and social development

As can be seen in Table 5, the top ranking is Beijing, and the last ranking is Heilongjiang, with a large gap between the two. Among them, Beijing, Shanghai, Tianjin, Zhejiang and Jiangsu are more advanced in economic and social development, while Jilin, Guangxi, Henan, Sichuan and Heilongjiang are less advanced. It is clear from this that there is still a wide gap between the economic and social development levels in the East and West. The coefficient of variation of the level of economic and social development of each province and city from 2014-2019 is 0.4785, which is larger than the coefficients of interpretation of the other three guideline layers, indicating that the level of economic and social development is the main reason for the different levels

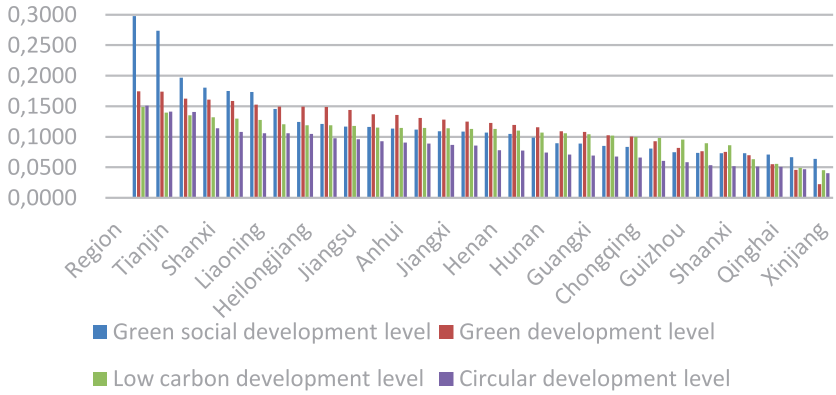

Fig. 2. Combined measure values at the guideline level for each province.

of green and low carbon cycle development between provinces and municipalities.

(b) Level of green development

As can be seen from Table 5, the highest level of green development is in Fujian, and the lowest is in Ningxia, with a massive gap between the two. Fujian, Jiangxi, Guangxi, Hainan and Guangdong are the top-ranking provinces and cities. The bottom-ranking regions and cities are Tianjin, Guangxi, Inner Mongolia, Xinjiang and Ningxia. As can be seen, green development is no longer higher in the East than in the West and is relatively stable across China's provinces. In contrast, the coefficient of variation for the level of green development in each area from 2014-2019 is 0.333, which is lower than the level of green social development, indicating that the level of green social development in each province and city is relatively more balanced.

(c) Low-carbon development level

As seen in Table 5, Guangdong Province has the highest level of low-carbon development. Guangdong, Zhejiang, Beijing, Shanghai and Henan are ranked higher, while Liaoning, Xinjiang, Shanxi, Inner Mongolia and Ningxia are ranked lower. These provinces and cities are ranked low mainly because of their higher carbon emissions. The coefficient of variation of 0.2398 for the average low carbon development level score is the smallest compared to the coefficient for the other guideline tiers, with less variation between provinces and municipalities.

(d) Level of circular development

From Table 5, Guangdong Province is the province with the highest level of recycling development, with Guangdong, Jiangsu, Shandong, Zhejiang and Hebei at the top, and Jilin, Hainan, Qinghai, Chongqing and Xinjiang at the bottom of the list. The difference between those ranked high and those ranked low in terms of the level of circular development is still significant. The coefficient of variation of the average score for the level of circular development is 0.3416, which is slightly lower than the level of green social development and has a more significant impact on the overall provincial and municipal scores.

Conclusions and Implications

Conclusions

In this paper, from the scientific connotation of green, low-carbon and circular economic system and combining the definition of green, low-carbon and circular dimensions, we construct a green, low-carbon and circular development index system and adopt the double incentive method to dynamically measure the level of green, low-carbon and circular development in China's provincial areas. The findings of the study are as follows:

Overall, the overall green and low-carbon cycle development level of each province has been on an upward trend from 2014 to 2019, but there is a wide gap in the green and low-carbon cycle development level between areas and regions, with the green and low-carbon cycle development level in the central-eastern region being higher than that in the western place. Thanks to the development of our economy and the national emphasis on green, low-carbon and circular development, the gap between provinces and municipalities has been gradually reduced during this period. Specifically, Guangdong, Zhejiang and Beijing have higher overall scores for green and low-carbon cycle development, while Inner Mongolia, Xinjiang and Ningxia have lower levels of green and joint carbon cycle development.

For the four guideline tiers, the level of contribution to the level of green, low-carbon and circular development is, in order, the level of green social development, the level of green growth, the level of low-carbon development and the level of circular development. In terms of green social development level, Shanghai, Beijing, and Jiangsu ranked in the top three; in terms of green development level, Fujian, Jiangxi and Guangxi were higher; in terms of low carbon development level, Guangdong, Zhejiang, and Beijing were ahead; and in terms of recycling development level, Guangdong, Jiangsu and Shandong were higher. It is also possible to see the strengths and weaknesses of each province in the different guideline tiers based on the scores and rankings of the guideline tiers. It leads to the conclusion that each province and territory should develop a green, low-carbon and circular development path according to the level of development of each aspect.

Implications

(a) Create an institutional environment conducive to the advancement of green and low-carbon technologies.

The governments of provinces and cities have formulated targeted pollution and energy consumption control policies, created an institutional atmosphere conducive to innovation and development, strengthened the status of enterprises as the main body of the invention, and pushed enterprises to break through the critical green and low-carbon technologies and promote the transformation of production methods in the direction of energy conservation and carbon reduction. At the same time, the government should strengthen the construction of supporting technologies and industrial symbiotic technology platforms, enhance the construction of national engineering technology centers, and increase the supply of green, low-carbon, and recycling innovation technologies. Improve the market transformation rate of innovative technologies through practical system design. Accelerate the transformation of scientific and technological achievements to improve the development of China's green, low-carbon, and circular economy. Finally, the governments of provinces and cities should also pay close attention to implementing and enforcing policies related to sustainable development based on the ever-improving environmental regulatory system and so on.

(b) Promoting structural adjustment and energy efficiency

Provinces and cities should promote energy structure adjustment and accelerate the construction of a clean and low-carbon energy system. They should adhere to the development of energy conservation and strengthen the dual control of total energy consumption and intensity. In industrial structural adjustment, strictly control new production capacity in key industries and promote green, circular, and low-carbon transformation. In energy restructuring, strictly govern the use of fossil energy, improve energy utilization efficiency, expand the scale of clean energy, actively promote the exploration and development of clean energy, and provide financial and technical guidance and assistance to enterprises developing green technologies and industries. The regions have established green development partnerships to plan and share advanced green technologies jointly. High-energy-consuming provinces and cities such as Shanxi, Inner Mongolia, Xinjiang, Hebei, Shandong, and Guangxi should fully develop and utilize renewable energy resources and design relevant regulatory systems. The eastern region should maintain high economic growth, accelerate the formation of a new industrial structure, vigorously adjust and optimize the financial network, promote the high-quality development of the open economy, and leverage and innovate institutional advantages to support economic growth. In the industrial restructuring of the western region, resource advantages should be effectively combined with corresponding capital and technology. For example, Guizhou, Xinjiang, Yunnan, and Guangxi should promote technological progress and innovation in energy, chemical industry, and transportation to advance industrial transformation and upgrading. Yunnan, Sichuan, Chongqing, and other provinces and municipalities should actively develop modern new types of agriculture and biomedical industries.

(c) Reducing inter-provincial differences and developing a low-carbon economy across the board

From the above analysis, there are differences in the level of development of the green, low-carbon economy in China's provinces and cities, and to comprehensively develop the low-carbon economy, it is necessary to narrow the differences between regions. Each region should combine its reality and formulate corresponding development goals and paths. According to their own resource endowment and development stage, they give full play to their strengths and advantages, in which the eastern region can provide an entire space to its advanced project management technology and experience. The western part can rely on its rich natural resources and undeveloped green development potential to enhance green, low-carbon, and circular development. Specifically, Beijing, Shanghai, Tianjin, Jiangsu, Zhejiang, and Guangdong should continuously improve their economic and social development capacity, increase investment in environmental management, and reduce pollution; Inner Mongolia, Hubei, Liaoning, Anhui, Jiangxi, Shaanxi, Guizhou, Hunan, Shanxi, and Gansu should continuously improve their capacity for green and low-carbon development, adhere to the concept of green development, and scientifically develop tourism resources and optimize the industrial structure; Chongqing, Shandong, Fujian, and Hainan, Ningxia, Xinjiang should continuously improve the level of green development by strengthening technological transformation and institutional innovation, and enhance the construction level and market conversion rate of China's green low-carbon and recycling economic development system. For Guangxi, Henan, Sichuan, and Heilongjiang, where the overall story is lagging, they should vigorously adjust the industrial structure, reduce the proportion of high-pollution industries and promote the development of a green, low-carbon, and recycling economy.

Research Shortcomings and Prospects

By constructing a representative indicator system and a dual incentive model, this paper further provides a dynamic and comprehensive evaluation of China's green, low-carbon, and recycling economy development level under the dual-carbon goal. It gives its understanding of China's efforts to carry out sustainable development and the challenges and opportunities it faces in carrying out green sustainable development. This paper demonstrates the importance of green, low-carbon, and recycling economic development and environmentally friendly product. However, the research in this paper also has shortcomings due to the large gap in the data published by Chinese officials after 2020; to ensure the availability and completeness of the data, the data in this paper is only taken up to 2020, so the data in this paper is not the most recent. Most of the studies in this paper establish the indicator system from the three dimensions of green, low-carbon, and recycling fail to cover multiple areas involved in green development, such as economy, society, and environment. The research in this paper further clarifies the differences in the development of green, low-carbon, and circular economies in various regions of China as the research in green development is constantly extending and developing. Therefore, we will further study the relationship between the environment and economic and social development in the future and pay more attention to the study of green sustainable development.

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Conflict of Interest

The authors declare no conflict of interest.

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