

Research on the Relationship Between Green Finance and Low-Carbon Economy in the Yangtze River Basin

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Abstract. Against the backdrop of accelerating global carbon neutrality and the in-depth advancement of China's "dual carbon" strategy, green finance has been positioned as a core tool to support the green transformation of the economy and society. However, there is still a lack of systematic empirical verification on whether it has achieved truly effective synergy with the low-carbon economy and how efficient the synergy is. Based on panel data of 11 provinces in the Yangtze River Basin from 2014 to 2024, this paper uses the entropy method to measure the development levels of green finance and low-carbon economy in each province, and constructs a coupling coordination degree model to systematically analyze the co-evolution characteristics and regional differentiation patterns of the two. The study finds that both present a spatial pattern of "strong in the lower reaches, average in the middle reaches, and weak in the upper reaches", with completely consistent regional rankings. The coupling coordination degree has evolved from moderate coordination to high coordination, but regional gradient differences are significant and show no sign of narrowing, with a conspicuous gap between the upper and lower reaches. Its improvement is mainly driven by the synchronous growth of the development levels of the two systems themselves. This paper reveals the regional imbalance characteristics and internal driving mechanism of the coordinated development of the two, fills the research gap on the coupling relationship between green finance and low-carbon economy in the Yangtze River Basin, and can provide theoretical basis and decision-making reference for formulating differentiated coordination policies according to local conditions, optimizing cross-regional green finance resource allocation, and bridging the gap of regional coordinated development.

Keywords: Yangtze River Basin, green finance, low-carbon economy, entropy method, coupling coordination degree model

1. Research background

Due to the frequent extreme weather events caused by global warming, carbon neutrality has become a broad global consensus. From the *Paris Agreement* to the *Glasgow Climate Pact* of the United Nations, countries are accelerating the transition to a low-carbon economy [1]. In this process, as the core of the modern economy, finance needs to transform its resource allocation in line with the low-carbon trend to better achieve deep emission reduction [2].

Against this global background, China put forward the dual carbon goals of "carbon peaking by 2030 and carbon neutrality by 2060" in 2020, marking that green and low-carbon development has officially risen to a national strategy [3]. Since then, the national-level policy system has been rapidly constructed. In 2021, the Central Committee of the Communist Party of China and the State Council issued top-level design documents, clarifying the overall deployment of the "dual carbon" work. Subsequently, implementation plans for key areas such as energy, industry, and transportation were introduced one after another, forming a "1+N" policy system with clear objectives and distinct levels [4]. In 2022, green finance was formally incorporated into the "dual carbon" policy system and became a core tool to support the green transformation of the economy and society. This series of policy orientations clearly shows that green finance and low-carbon economy are not independent and unrelated to each other, but a community of mutual influence and coordinated progress. However, at the practical level, whether the two have achieved effective cooperation and how efficient their synergy is have become core scientific issues that need to be further verified to test policy effectiveness.

China is still in the middle and late stages of industrialization, and it is difficult for the economic development of various regions to truly adapt to the needs of the dual carbon strategy. On the one hand, there are still many high-energy-consuming industries, and regional development is extremely uneven. For example, the Yangtze River Delta region has a developed economy but scarce resources, while the central and western regions have strong energy-dependent economic characteristics. This structural contradiction makes the low-carbon transition face a huge capital gap, and it is urgent for green finance to play its financing function to provide sustained impetus for the green upgrading of traditional industries [5].

On the other hand, green finance also faces the dilemma of "mismatch between supply and demand" in practice. A large number of low-carbon technology projects have typical characteristics such as long investment cycles and uncertain short-term returns, leading traditional financial institutions dominated by banks to prefer to allocate green credit resources to large enterprises with lower risks, while small, medium and micro low-carbon innovation entities that truly need financial support face the problem of difficult and expensive financing. Meanwhile, the problems of single structure of green financial products and imperfect carbon pricing mechanism also restrict the overall effectiveness of its support for low-carbon transition [2]. Therefore, green finance and low-carbon economy do not exist in isolation. The two need to achieve deep coupling and coordination to realize China's dual carbon goals while maintaining China's economic development, which constitutes the most direct practical motivation of this study.

At present, the academic circle has rich research results on green finance and low-carbon economy, but there are still research gaps. Most existing studies focus on one-way analysis, either exploring the effect of green finance on carbon emissions or analyzing the influencing factors of low-carbon economic development, but few studies couple the two and analyze their coordinated development [6]. Although some scholars have begun to pay attention to the coordinated development of green finance and low-carbon economy, most studies remain at qualitative description, simple measurement of the coordination level of the two or overall large-scale description, lacking differentiated analysis of different regions [7]. Especially in the Yangtze River Basin, which spans the three major zones of eastern, central and western China and has an extremely important ecological status, research on the coupling relationship between green finance and low-carbon economy and its optimization path is still blank.

Therefore, this study takes the Yangtze River Basin as the research object, aiming to fill the research gap on the coupling relationship between "green finance and low-carbon economy". By

constructing a scientific evaluation index system, quantitatively measuring the coupling coordination level of the two, and conducting differentiated analysis on the upper, middle and lower reaches of the Yangtze River Basin, this study provides a solid theoretical basis and decision-making reference for national and local governments to formulate sound policies for the coordinated development of green finance and low-carbon economy, which constitutes the core academic value and practical significance of this study.

2. Literature review

At present, the academic circle holds that green finance is a financial issue carried out in response to a series of climate, resource and environmental problems. Compared with traditional finance, it pays more attention to environmental protection and pursues low-carbon environmental protection. Jiang Bo et al. [8] studied that its measurement indicators cover credit, investment, insurance, bonds, support, funds, equity and other indicators, and the main research methods include entropy method, Dagum Gini coefficient and its decomposition method, kernel density estimation, Markov chain model, etc. Studies have confirmed [9] that the low-carbon effect of green finance can be strengthened through government intervention means such as market-oriented reform and land planning. It can also promote the process of low-carbon economic transformation through technical means such as artificial intelligence [10]. However, China's regional development is unbalanced: the eastern region has higher policy and technical levels and more significant development, while the western region develops slowly due to resource problems and technical level limitations. Most previous studies [11] mostly focused on the one-way research on the influencing factors of green finance and the impact of green finance on low-carbon economy, but rarely studied "what low-carbon economy has done to green finance". In fact, the two promote each other and evolve together, rather than a one-way relationship.

Existing studies believe that energy use efficiency, industrial structure and energy structure adjustment [12], urbanization and economic development level, as well as the development of emission reduction technology [13] are the main driving factors for the development of low-carbon economy. The development levels of low-carbon economy in various regions are significantly differentiated, mainly due to different driving factors such as technical level, government intervention and energy efficiency [14]. Li Min et al. argued that China attaches great importance to the role of financial support in promoting low-carbon economy, with particularly remarkable effects in terms of capital and product innovation [15]. Yao Deli et al. proved that green finance is an important driver of low-carbon development, both directly and indirectly [16]. Most of these studies on low-carbon economy focus on the one-way impact of financial support on low-carbon economy, and do not explore the reverse effect of low-carbon economy on finance or the two-way coupling analysis between it and green finance.

Research on coupling coordination covers a wide range, and most people conduct coupling research on major directions such as society, economy and ecology. However, in recent years, people have gradually refined the selection of two factors for coupling analysis, and gradually turned to issues compatible with China's policies. Many have extended their research to the coupling research in fields such as green finance and ecological environment, digital finance and low-carbon economy [17]. At present, a small number of studies mention the synergy effect between green finance and low-carbon economy [6], and most perspectives focus on whether green finance can promote the development of low-carbon economy [18] and how green finance promotes the development of low-carbon economy [19], which is only a perspective for the development of low-carbon economy. The existing coupling coordination theory provides a theoretical basis and research methods for the study

of the relationship between the two, but there is a serious lack of in-depth analysis and regional differentiated analysis on the coupling coordination of the two at present [20].

To sum up, existing studies have a single perspective, mostly focus on one-way impact analysis, lack of discussion on the coupling relationship between the two, and do not carry out differentiated analysis by region, which is not targeted. This study is committed to clarifying the interaction between green finance and low-carbon economy, using the coupling coordination model to study the dynamic relationship and coordination level of the two, then comparing the differences between the upper, middle and lower reaches of the Yangtze River Basin, and putting forward targeted suggestions.

3. Research methods

3.1. Entropy method

As an objective weighting method, the basic idea of the entropy method is derived from the entropy concept in information theory. In the field of information theory, entropy measures the amount of information contained in data. Specifically, the smaller the information entropy, the greater the difference in the observed data of the indicator, the richer the information it can provide, and the higher its importance in comprehensive evaluation. On the contrary, the larger the information entropy, the smaller the data difference, and the weaker the discrimination ability of the indicator. Based on this, by calculating the information entropy and difference coefficient of each indicator, the indicator weight can be objectively determined, thus avoiding the uncertainty caused by subjective weighting to a certain extent.

With the help of the entropy method, this study calculates the green finance development level and low-carbon economic development level of each province in the Yangtze River Basin each year. First, the collected original indicator data are standardized to eliminate the influence of different indicators due to dimension and magnitude differences. Considering that zero values may appear after standardization, to ensure the effective progress of subsequent logarithmic operations, the standardized values will be shifted slightly as a whole. Then, the proportion matrix of each indicator is calculated based on the standardized data, and then the information entropy value and difference coefficient of each indicator are obtained. After normalization, the entropy weight of each indicator can be obtained. Finally, the entropy weight is used as the weight to conduct linear weighted summation of each indicator, and the comprehensive scores of the two systems of green finance and low-carbon economy are obtained respectively.

3.2. Coupling coordination degree model

The coupling coordination degree model is a mature tool for measuring the synergy effect between systems. Its advantage lies in that it can simultaneously consider the two dimensions of the intensity of interaction between systems and the level of overall development. The coupling degree, namely C , reflects the tightness of correlation and mutual influence between the two subsystems of green finance and low-carbon economy. However, its limitation is that it can only describe the strength of interaction, but cannot distinguish whether this interaction is benign mutual promotion or low-level mutual restriction. In view of this, the coordination index, namely T , is introduced to characterize the overall development level of the two subsystems, and then the coupling coordination degree, namely D , is used to comprehensively judge whether the systems have achieved coordinated progress. The specific calculation formulas are as follows:

$$C = \left\{ \frac{F_1 F_2}{[(F_1 + F_2)/2]^3} \right\}^{\frac{1}{2}} \quad (1)$$

$$T = a_1 F_1 + a_2 F_2 \quad (2)$$

$$D = \sqrt{CT} \quad (3)$$

The green finance development level index and the low-carbon economic development level index are obtained by weighted summation through the entropy method. Since green finance and low-carbon economy are in an equal position in the process of promoting ecological civilization construction, and they help each other and are equally important, the undetermined coefficients α and β are both assigned a value of 0.5. Referring to existing research classification standards, the coupling coordination degree is divided into multiple grades: extremely low coordination (0, 0.3], low coordination (0.3, 0.4], primary coordination (0.4, 0.5], moderate coordination (0.5, 0.6], high coordination (0.6, 0.7], and extremely high coordination (0.7, 1.0].

According to the calculated results, the temporal evolution law of the coupling coordination degree from 2014 to 2024 is first investigated from the perspective of the whole basin, and then its overall trend and phased characteristics are analyzed. The 11 provinces in the Yangtze River Basin are spatially divided into upper reaches (Guizhou, Yunnan, Sichuan, Chongqing), middle reaches (Hunan, Hubei, Jiangxi) and lower reaches (Anhui, Zhejiang, Jiangsu, Shanghai). The average values of the coupling coordination degree of each region over the years are calculated respectively, and the difference patterns and change trends among the upper, middle and lower reaches are systematically compared, so as to reveal the spatial differentiation law of the coupling coordination level in the Yangtze River Basin.

4. Research results

4.1. Calculation and analysis of the entropy method

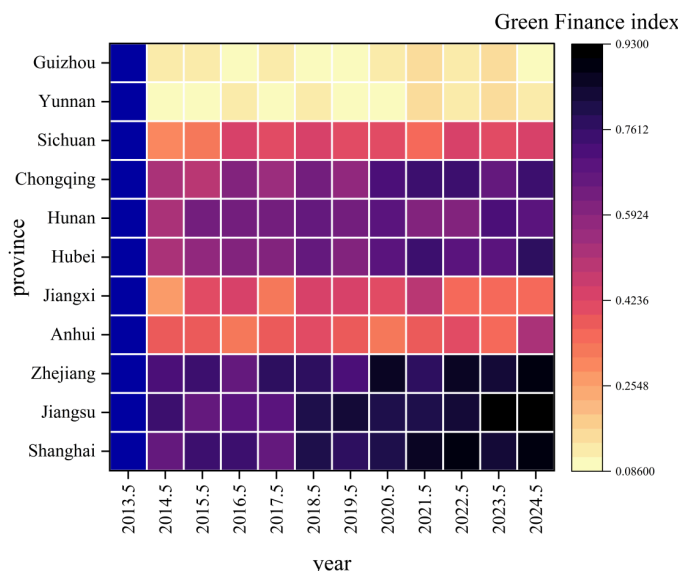


Figure 1. Comprehensive scores of green finance development level of provinces in the Yangtze River Basin, 2014—2024

Based on the weights calculated by the entropy method, we comprehensively measured the green finance and low-carbon economy levels of 11 provinces in the Yangtze River Basin from 2014 to 2024 respectively. The results are shown in the diagrams of each province.

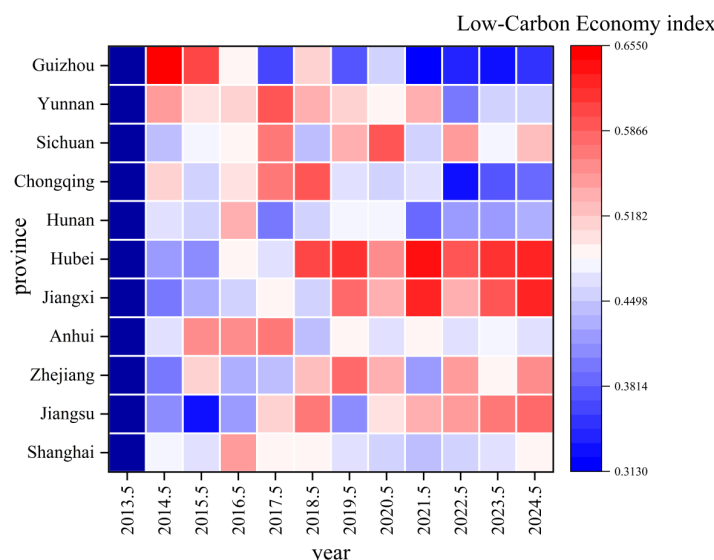


Figure 2. Comprehensive scores of low-carbon economic development level of provinces in the Yangtze River Basin, 2014—2024

In terms of green finance, the lower reaches provinces such as Shanghai, Jiangsu, Zhejiang and Anhui, as well as Hubei and Jiangxi in the middle reaches, have maintained values around 0.9300 in most years, indicating that the financial markets in these places are relatively mature, and green credit, green bonds and other products are promoted rapidly. Hunan is slightly weaker, with lower scores in some years. Sichuan fluctuates around 0.9300 with poor stability. Chongqing has declined significantly in some years. Yunnan and Guizhou have been hovering at a low level for a long time, and directly reach zero in some years. The problems in the upper reaches are not only low level, but also large fluctuation and unstable development.

In terms of low-carbon economy, Shanghai, Jiangsu and Zhejiang are basically stable at around 0.5000. Anhui is different, with some years exceeding 1.00, which is relatively advantageous. Hubei, Jiangxi and Hunan are mostly around 0.5000, but there are negative or zero values in some middle years, with certain fluctuations. Among the four provinces in the upper reaches, Sichuan performs better but is also unstable. Chongqing has zero or even negative values for many years. Yunnan basically remains unchanged. Guizhou gradually decreases from 0.6550 in the early stage to 0.5000, and zero values also appear later. The upper reaches have a thin foundation at the low-carbon level and large fluctuations.

Overall, the regional distribution of the two systems is consistent: strong in the lower reaches, average in the middle reaches, and weak in the upper reaches. The two sides are relatively balanced in the lower reaches, green finance is slightly better than low-carbon economy in the middle reaches, and both are poor with large fluctuations in the upper reaches. This regional difference explains why the coupling coordination degree presents a pattern of high in the east and low in the west.

4.2. Measurement and analysis of coupling coordination between green finance and low-carbon economy

4.2.1. Evolution characteristics of coupling degree (C), coordination index (T) and coupling coordination degree (D) in each province

Using the entropy method to calculate the green finance and low-carbon economic development level indices of each province, and substituting them into the coupling coordination degree model, the coupling degree (C), coordination index (T) and coupling coordination degree (D) of 11 provinces in the Yangtze River Basin from 2013 to 2022 are calculated. The evolution trends of C, T and D in each province are shown in the diagrams of each province.

4.2.1.1. Lower reaches

The C curves of Shanghai, Jiangsu and Zhejiang are all at a relatively high position and operate stably, which reflects that the interaction intensity between green finance and low-carbon economy has been maintained at a high level. Both the T curve and the D curve show a steady upward trend, and their trends are relatively similar. Among them, the D values of Shanghai and Zhejiang have entered the category of extremely high coordination at the end of the period, and Jiangsu has reached the upper limit of high coordination. The distance between the D curve and the T curve of Zhejiang is closer, which means that the matching degree of its two subsystems is relatively high. The spacing between the C curve and the T curve of the three provinces and cities has narrowed to a certain extent, and the coordination structure has been gradually optimized. The C curve of Anhui shows a slight fluctuation trend at a high level, and T and D rise synchronously. Although the starting level is lower than that of the other three provinces in the lower reaches, the upward trend is relatively significant, and D has entered the high coordination range by the end of the period.

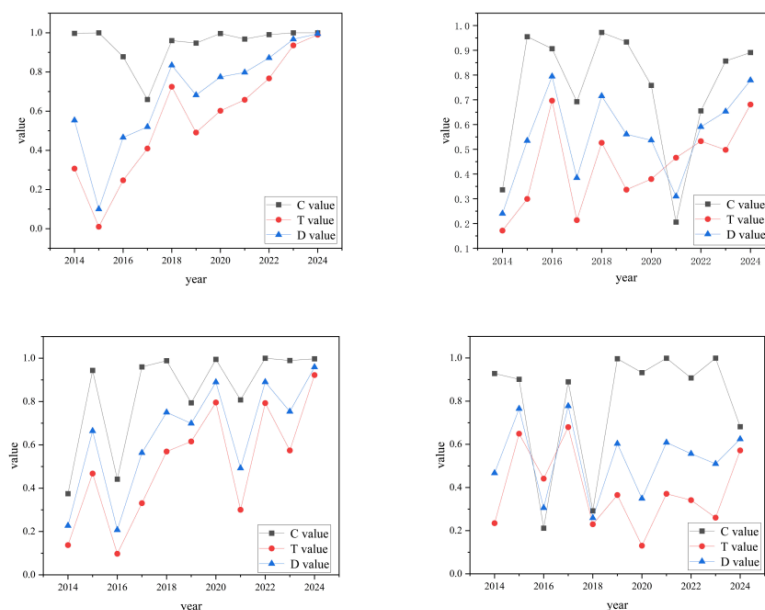


Figure 3. Evolution trends of coupling degree (C), coordination index (T) and coupling coordination degree (D) in the lower reaches (Shanghai, Jiangsu, Zhejiang, Anhui)

4.2.1.2. Middle reaches

The C curves of Hubei, Jiangxi and Hunan are all at a high level and maintain stable operation. T and D simultaneously show a steady upward trend. D is between C and T, and its trend is highly similar to T. Among the three provinces, Hubei holds an absolute leading position in the levels of T and D, while Jiangxi and Hunan have relatively close levels. The spacing between C and T in the three provinces all shows a narrowing trend, which indicates that the coordination structure is gradually being improved.

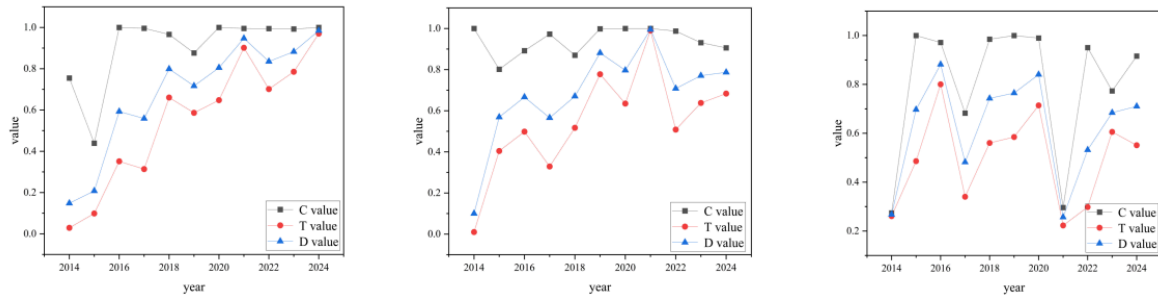


Figure 4. Evolution trends of coupling degree (C), coordination index (T) and coupling coordination degree (D) in the middle reaches (Hubei, Jiangxi, Hunan)

4.2.1.3. Upper reaches

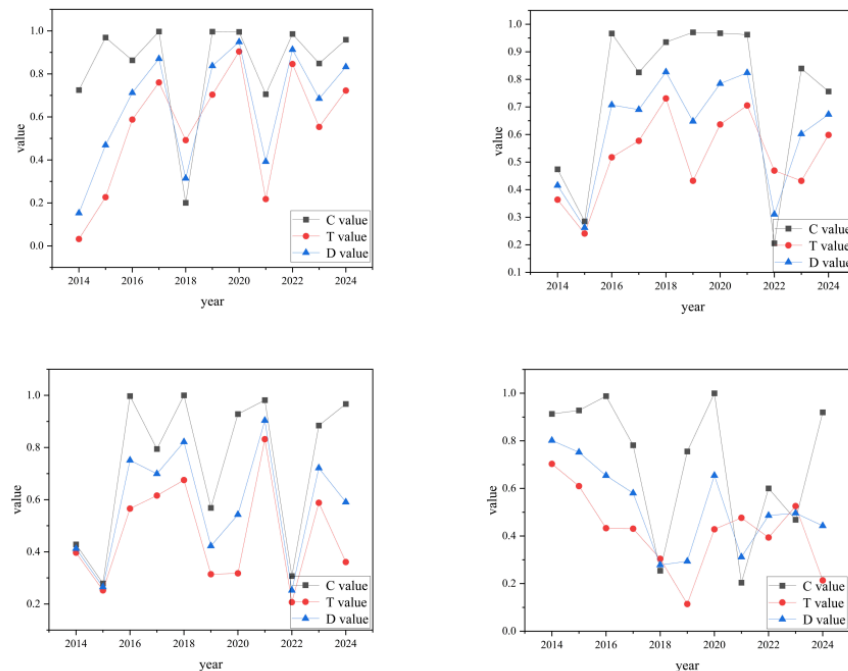


Figure 5. Evolution trends of coupling degree (C), coordination index (T) and coupling coordination degree (D) in the upper reaches (Chongqing, Sichuan, Yunnan, Guizhou)

The C curves of Chongqing, Sichuan, Yunnan and Guizhou have been at a high position. T and D show an upward trend at the same time. Among the four provinces, the absolute levels of T and D in

Chongqing and Sichuan are higher than those in Yunnan and Guizhou. The slope of T rise in the upper reaches as a whole is slightly lower than that in the middle and lower reaches, resulting in a relatively low absolute level of D. The starting level and final level of T in Guizhou are the lowest among the 11 provinces, and D has been near the lower limit of the moderate coordination range. None of the four provinces in the upper reaches has broken through the threshold of high coordination.

From the perspective of the upper, middle and lower reaches of the Yangtze River Basin, the C curves of all provinces are at a high position above 0.85 with small variation range, which indicates that the interaction intensity between the two subsystems of green finance and low-carbon economy is generally strong, and the coupling relationship is relatively close. What really creates gaps between regions is T (coordination index). The absolute level and rising slope of T in the lower reaches are in the leading position, followed by the middle reaches, and the upper reaches are the lowest, making D present a gradient pattern of "high in the east and low in the west". The trends of T and D in each province within the upper, middle and lower reaches are very synchronous, and the convergence degree of T level in the same region is relatively high, which reflects that the overall regional development environment has a decisive impact on the coordination level of the two subsystems.

4.2.2. Regional comparison of coupling coordination degree (D) in the upper, middle and lower reaches

The D of the whole basin shows an overall upward trend, moving from moderate coordination to high coordination, but the regional gradient difference is relatively significant: the lower reaches are in a leading position, the middle reaches are in an intermediate state, and the upper reaches are relatively lagging behind. Shanghai and Zhejiang in the lower reaches have taken the lead in entering the extremely high coordination range, followed by Jiangsu. Among the three provinces in the middle reaches, Hubei is in a leading position, and Jiangxi and Hunan are relatively close. Among the four provinces in the upper reaches, Chongqing and Sichuan are higher than Yunnan and Guizhou, and Guizhou has been in the last position. The gap between the lower reaches and the upper reaches has not been effectively narrowed during the study period, which indicates that the regional coordination gap has obvious inertia.

4.2.3. Relationship between T and D

The D curve has always been between C and T, and its trend is similar to that of T, which indicates that the change of D is mainly driven by T, and the difference of D among provinces is determined by T. The T of each province continues to rise without decline or fluctuation, which shows that the overall development level of the two subsystems has been continuously improved during the study period, laying a solid foundation for the steady improvement of the coupling coordination degree.

5. Conclusions and suggestions

5.1. Main conclusions

Using the data of 11 provinces in the Yangtze River Basin from 2014 to 2024, this paper calculates the specific scores of green finance and low-carbon economy in each province through the entropy

method, and uses the coupling coordination degree model to examine how well the two systems cooperate. The main conclusions are drawn as follows.

1. From the perspective of development level, both green finance and low-carbon economy present a pattern of "strong in the lower reaches, average in the middle reaches, and weak in the upper reaches", and the regional rankings of the two systems are almost identical. During the study period, the green finance scores of lower reaches provinces are basically stable at around 0.93, and the low-carbon economy is also above 0.5; the two indicators in the middle reaches are between 0.5 and 0.93 and around 0.5 respectively; the upper reaches are much worse, with some years directly dropping to zero. The rankings of the two systems in the upper, middle and lower reaches are completely consistent, indicating that their development is actually restricted by the common regional economic foundation.

2. From the perspective of coupling coordination degree, the coupling degree C is generally higher than 0.85, indicating that the two systems do interact frequently, but the regional differentiation of coupling coordination degree D is quite obvious, and this gap has not converged much during the study period. The gap is mainly stuck on the coordination index T . Shanghai and Zhejiang in the lower reaches have entered the extremely high coordination range ($D > 0.7$), and Jiangsu and Anhui have also reached the upper limit of high coordination; the three provinces in the middle reaches are still hovering between moderate and high coordination, with Hubei being relatively better; none of the four provinces in the upper reaches can reach the threshold of high coordination, and Guizhou is always at the bottom. This gap between the upper and lower reaches has not narrowed for more than ten years. Once the gap of regional coordination is formed, it is relatively difficult to bridge.

3. From the perspective of driving factors, the improvement of coupling coordination degree is mainly driven by the synchronous growth of the development levels of the two systems, rather than the change of coupling intensity. The trend of D is basically synchronized with T , but has little to do with the change of C , which indicates that the improvement of coordination level ultimately depends on the continuous improvement of the two subsystems themselves.

5.2. Policy suggestions

First, formulate differentiated strategies for the coordinated development of green finance and low-carbon economy according to local conditions, and avoid the "one-size-fits-all" policy rollout. For the lower reaches provinces and cities (Shanghai, Jiangsu, Zhejiang, Anhui) where both systems are already in the forefront, the next focus should be to further advance green financial products and deepen the carbon financial market. For the middle reaches provinces (Hubei, Jiangxi, Hunan), low-carbon economy is still a short board. It is necessary to rely on green credit to promote the clean transformation of traditional high-energy-consuming industries, and at the same time, consider building a regional green project library to make it easier for green funds to find projects. The upper reaches provinces (Chongqing, Sichuan, Yunnan, Guizhou) need to proceed step by step, first consolidating the basic capacity before considering other aspects. The policies of central financial transfer payment and green finance reform pilots need to be further tilted, and more investment should be made in green financial infrastructure to gradually cultivate low-carbon industries, so as to avoid falling deeper into the low-level trap.

Second, improve the carbon pricing mechanism and green finance standard system, and unblock the financing blockages of low-carbon technology projects. At present, the industries covered by the carbon market are not enough, and the carbon price signal is too weak, so financial institutions do not know how to price low-carbon projects. It is suggested that the national carbon market should

speed up its expansion and gradually introduce carbon quota auctions, so that carbon prices have a clear and stable expectation, which can be used as a reference for financial institutions. In addition, the identification standards and information disclosure of green credit and green bonds should also be unified, so as to avoid institutions spending too much cost on identifying green projects as much as possible, and guide financial resources to small, medium and micro low-carbon innovation entities.

Third, strengthen the regional coordination mechanism and build a cross-provincial linkage platform for the coordinated development of green finance and low-carbon economy in the Yangtze River Basin. The regional gap has not been significantly narrowed during the study period, and it is difficult to break this situation by the independent development of each province. It is suggested that under the framework of the Yangtze River Economic Belt, a basin-level green finance cooperation mechanism should be formed to connect systems such as mutual recognition of green projects, carbon sink trading, and cross-provincial flow of green credit. Financial institutions in the lower reaches can guide green funds to the middle and upper reaches through syndicated loans, asset securitization and other means. The upper reaches should do a good job in ecological protection, and the lower reaches should export capital, forming a cross-regional cycle of "capital empowerment from the lower reaches, ecological feedback from the upper reaches".

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