

Research on the Coupling of Green Finance and Ecological Efficiency from the Perspective of Dual Carbon

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Abstract

A set of green finance and ecological efficiency evaluation system was constructed based on panel data of three major regions, provinces and cities in China, and the overall national level from 2014 to 2023. The current status of green finance in China was analyzed, and ecological efficiency was evaluated. By establishing a coupling degree model, the degree of coupling between the two was analyzed, revealing the complex relationship between them. Analysis shows that there is a relatively small gap in the development level of green finance among different regions in China, while there are significant differences in ecological efficiency. The coupling and coordination degree between green finance and ecological efficiency is in a challenging stage under the evaluation criteria in this article, showing a phenomenon of "high in the east and low in the west".

Keywords

Green Finance; Ecological Efficiency; Coupling Degree; Regional Development.

1. Introduction

The "dual carbon" target is of great significance for China to achieve sustainable development. Green finance is one of the important tools for financial services, ecological civilization construction, and green development. It is also an important means to guide funds to flow into the field of energy conservation and emission reduction under the background of the "dual carbon" goal, promote the green transformation and upgrading of traditional industries, and help build a green, low-carbon, and circular economy system. Meanwhile, ecological efficiency, as a core concept, not only focuses on economic growth, but also emphasizes the harmonious coexistence between economic development, environmental protection, and resource conservation. Green finance effectively alleviates the contradiction between environmental protection and economic development by promoting the sustainability of the ecological environment, accelerating industrial upgrading, and social progress, thereby enhancing ecological efficiency and providing important support for achieving the dual carbon goals.

The development of green finance conforms to the trend of green development, but it is necessary to deepen the concept of sustainable development and continuously improve the top-level design of green finance in order to ensure that green finance plays a positive role in improving ecological efficiency and achieves coordinated development with it. Ultimately, guiding the improvement of ecological efficiency through the development of green finance and achieving coordinated development between the two will be an effective path to promote China's timely achievement of the "dual carbon" goal. In this context, utilizing green finance to enhance ecological efficiency is an important development model for China to address the challenges faced by economic development, enhance environmental carrying capacity, and promote the achievement of dual carbon goals. This development model not only benefits contemporary people, but also demonstrates our responsibility to the next generation and

future society, demonstrating respect and care for nature and life. Therefore, focusing on the background of China's dual carbon goals, keeping up with the forefront, conducting in-depth analysis, clarifying viewpoints, and proposing suggestions are of great theoretical and practical significance.

In summary, utilizing green finance to enhance ecological efficiency is an important development model for China to address the challenges faced by economic development, enhance environmental carrying capacity, and promote the achievement of dual carbon goals. This development model not only benefits contemporary people, but also demonstrates our responsibility to the next generation and future society, demonstrating respect and care for nature and life.

Although there has been some discussion in the academic community on the concepts of green finance and ecological efficiency, there are still shortcomings in path research and mechanism verification, as well as issues such as dimension selection. Based on the theory of ecological economy, this article constructs a set of indicators and proposes corresponding methods to systematically analyze the quantitative impact of green finance on ecological efficiency. This not only enriches the definition of relevant indicators, but also provides a new perspective for a deeper understanding of the relationship between the two.

This article studies the impact mechanism of green finance on ecological efficiency, and specifically analyzes the effects achieved through three paths: capital scale, technological progress, and industrial structure. The research aims to explore how to effectively integrate green finance into the process of improving ecological efficiency, and how to promote the growth of ecological efficiency through green finance. We will combine the construction of green finance with the ecological efficiency system, systematically examine the problems faced by China's ecological economic development, explore the establishment of an effective ecological economic development path under China's national conditions, and promote sustainable development.

There are several viewpoints on the relationship between green finance and ecological efficiency among domestic scholars. The first viewpoint is based on the inherent operational logic of green finance. Wen et al. (2022) internalized emission reduction technologies on the basis of sustainable growth theory, established an economic growth model with environmental constraints and including the financial sector, and explained the internal mechanism of green finance in improving the quality of economic growth by supporting green innovation; Liang Gang (2021) provided feasible suggestions for the benign interaction between green finance and ecological civilization through theoretical analysis of the coordinated development strategy of green finance and ecological environment coupling. The second viewpoint is from the perspective of regional development. Dong Haoyun (2020) used spatial econometric models based on relevant data from 30 provinces in China from 2001 to 2017, and the research results showed that green finance in China has a significant promoting effect on the ecological transformation of the local economy, gradually transforming the economy of each province from a resource consuming type to an ecological resource recycling type, and also promoting the ecological transformation of the surrounding provincial economy.

There are several viewpoints on the relationship between green finance and ecological efficiency among foreign scholars. The first viewpoint is to explore the positive impact of green finance on the development of ecological efficiency from a regional macro perspective. Adeel Farooq et al. (2022) used data from five ASEAN developing economies from 2003 to 2016 to empirically analyze the positive impact of financial development on the overall environmental performance of the five ASEAN developing economies from the perspective of environmental performance, using fixed effects, random effects, Neway West, and generalized least squares estimators; Xueqing K et al. (2021) used a coupled coordination model based on relevant data from a province in China from 2005 to 2019, and the results showed that the coordination

degree between regional ecological environment and financial support in the process of urbanization in the study area gradually increased. The second perspective is to analyze the impact of green finance on ecological efficiency development from a variable perspective. Zhou et al. (2020) used principal component analysis to establish a green finance development index, with industrial smoke, industrial solid waste, and carbon dioxide emissions as environmental variables. They proposed a model of the impact of green finance on environmental quality and concluded that green finance has a positive effect on environmental improvement.

Based on a comprehensive review of literature, it has been found that existing studies have conducted sufficient research on green finance and ecological efficiency, analyzing the development of green finance and the influencing factors of regional ecological efficiency from different perspectives, providing certain directions and ideas for the writing of this article. This article selects an appropriate indicator system to measure the level of green finance and ecological efficiency using a coupled approach, and analyzes the relationship between green finance and ecological efficiency using software such as SPSS and EvIEWS.

Although there have been many achievements in research on green finance and ecological efficiency, there is still room for further exploration. The innovation of this article is reflected in the following aspects: firstly, the measurement of green finance and ecological efficiency involves the integration of complex economic, environmental, and social three-dimensional factors. How to construct scientifically reasonable measurement indicators and evaluation systems, as well as how to apply modern financial and economic theories for quantitative analysis, are technical challenges.

Secondly, in terms of research methods, this article is based on the "dual carbon" goal and uses 30 provinces and cities across the country as samples to comprehensively evaluate the development level of green finance and ecological efficiency, and obtain the Green Finance Index and Ecological Efficiency Index. Subsequently, a coupling degree model was established to analyze the coupling level between the two, which differed from existing literature in terms of methodology and made a unique contribution.

Although the research on green finance and ecological efficiency is receiving increasing attention, due to its late start, various industries still lack sufficient data statistics on green development, and there are obvious gaps in relevant information. Therefore, this study made necessary trade-offs when selecting empirical methods and variable data, and some variables used alternative options. There may be certain errors in the analysis, which limits the depth and breadth of the analysis. In addition, both green finance and ecological efficiency require long-term observation, but the empirical analysis time range of this article is only from 2014 to 2023, and the sample size is relatively small. Furthermore, due to the impact of the epidemic, there are certain difficulties in obtaining and ensuring the accuracy of data in some years, which may affect the reflection of the long-term impact trend of green finance on ecological efficiency.

2. Data Measurement and Analysis

2.1. Measurement and Analysis of Green Finance in China

2.1.1. Indicator Construction

In order to construct a green finance indicator system, we first defined the concept of green finance and evaluated the current development status of green finance in China based on five green finance tools. When selecting secondary indicators, we referred to the relevant research of Yin Yetian (2021)^[1] and ultimately established a comprehensive evaluation system consisting of nine tertiary indicators. These indicators cover five major areas: green credit, green securities, green insurance, green investment, and carbon finance.

Table 1. Green Finance Evaluation System

First level indicator	Secondary indicators	Definition of indicators	attribute
Green Credit	Proportion of interest in high energy consuming industries	Interest expenses for high energy consuming industries/industrial interest expenses	-
	Proportion of green credit scale	Total amount of green credit/total amount of loans	+
Green Securities	Proportion of market value of high energy consuming industries	Market value of A-shares/total market value of A-shares in high energy consuming industries	-
	Proportion of market value of environmental protection enterprises	Total output value of environmental protection enterprises/total market value of A-shares	+
Green Insurance	Agricultural insurance payout ratio	Agricultural insurance expenditure/Agricultural insurance income	-
	Depth of agricultural insurance	Agricultural insurance income/total agricultural output	+
Green investment	Proportion of environmental protection investment	Investment in pollution control/GDP	+
	Proportion of public expenditure on energy conservation and environmental protection	Energy conservation and environmental protection fiscal expenditure/total fiscal expenditure	+
Carbon finance	Carbon emission intensity	Carbon emissions/GDP	-

2.1.2. Measurement Methods

This article uses the entropy method to calculate the weight of indicators for the development level of green finance, which is more objective in calculating weights and takes into account the degree of difference between indicators, making it more accurate^[2].

·Standardization of positive indicators: $X_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})}$

·Standardization of negative indicators: $X_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})}$

·Weight of evaluation indicators: $p_{ij} = x_{ij} / \sum_{i=1}^n x_{ij}$

·Calculate the entropy value of the indicator:

Where k is the adjustment coefficient, $H_j \geq 0$.

·Calculate the coefficient of difference: $U_j = 1 - H_j$

·Calculate weight results: $\delta_j = U_j / \sum_{i=1}^n U_j$

The larger the positive indicator value, the better, and the smaller the negative indicator value, the better, x_{ij} indicating the assignment of the j th indicator under the i -th sample.

2.1.3. Horizontal Measurement

Table 2. Measurement of Green Finance Level in China

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
east	0.212	0.221	0.224	0.231	0.232	0.240	0.251	0.252	0.270	0.265
central section	0.226	0.239	0.239	0.219	0.233	0.252	0.240	0.233	0.243	0.234
west	0.216	0.218	0.219	0.221	0.227	0.213	0.215	0.188	0.189	0.196
whole country	0.202	0.207	0.214	0.213	0.222	0.227	0.228	0.222	0.234	0.234

The overall development of green finance in the country is showing a slow upward trend. Before 2015, the levels of green finance development in the eastern, central, and western regions of China were relatively balanced, with no significant differences. However, since 2015, regional differences in the development of green finance have gradually emerged, especially in the eastern region where the development is more prominent compared to the western region. Specifically, the level of green finance in the eastern region has achieved rapid growth in the past few years, with a strong upward trend in the scale of green credit issuance, the number of green bonds issued, and the coverage of green insurance. At the same time, some regions in the central and western regions are facing severe challenges, with significant declines in various indicators of green finance. This not only hinders the improvement of the local ecological environment, but also to some extent restricts the sustainable development of the regional economy.

It should be pointed out that although the capital Beijing leads the country in the field of green finance and has become a testing ground for various innovations and policy implementation, the development level of green finance in most regions is still relatively low. This indicates that many regions still have enormous development potential and opportunities in the field of green finance in the future. At present, the development of green finance in most regions has not been effectively aligned with the local economic level. This disconnect not only reflects the shortcomings of the green finance system construction, but also reveals the challenges faced by local governments in promoting the transformation of the green economy.

More noteworthy is that the promotion of green finance by regional economic development is relatively limited, exacerbating the imbalance in resource allocation. The main reason for the slow growth rate of green finance is closely related to the significant decline in the central and western regions. This decline is particularly evident in areas such as green credit, securities, and insurance. Taking green credit as an example, many banks in the central and western regions have reduced their loan approval efforts for green projects due to risk control considerations, resulting in multiple environmental and sustainable development projects being difficult to implement due to funding shortages. Therefore, stimulating the development of green finance in the central and western regions has become an urgent practical problem that needs to be solved, and it will also be an important lever to promote the new journey of sustainable development in China.

2.2. Measurement and Analysis of Ecological Efficiency in China

2.2.1. Indicator Construction

Table 3. Ecological Efficiency Index System

Indicator type	Indicator content	Indicator Name	Company
Investment indicators	energy resources Labor resources Capital resources	Total energy consumption	10000 tons of standard coal
		Year-end employed population	ten thousand people
		Fixed capital stock	RMB100mn
Expected output	environmental benefit	Green coverage area	hectare
	Economic output	Regional Gross Domestic Product	RMB100mn
Unexpected output	environmental pollution	Industrial sulfur dioxide emissions	Ten thousand tons
		Industrial wastewater discharge volume	Ten thousand tons
		Industrial solid waste generation	Ten thousand tons

Ecological efficiency is the maximum benefit of resource utilization achieved while protecting the natural ecological environment as much as possible. This chapter establishes an ecological efficiency index system from three perspectives: input, expected output, and unexpected output^[3] to analyze the level of ecological efficiency in China.

2.2.2. Measurement Methods

This article uses the super efficient SBM model. There are three elements in the model: total input, expected output, and unexpected output. The observation period is T, the total input types are m, the expected output types are n, and the unexpected output types are p. Expected output is y_t^e represented by, and unexpected output is represented by. Let DMU_i be the i-th decision unit within the observation period t, t=1,2,3,T, i = 1,2,3,...,N.

$$\rho = \frac{1 - \frac{1}{m} \sum_{k=1}^m \frac{s_k^x}{x_k^i} - \frac{1}{p} \sum_{r=1}^p \frac{s_r^u}{y_r^i}}{1 + \sum_{r=1}^n \frac{s_r^e}{y_r^i}}$$

Among them, represents the ecological efficiency value, x_k^i represents the input of the k-th decision unit, y_r^i represents the output of the r-th decision unit, s_k^x represents the total input, s_r^e represents the expected output, s_r^u and represents the slack variable corresponding to the expected output.

2.2.3. Horizontal Measurement

Table 4. Measurement of Ecological Efficiency Level

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
east	0.676	0.676	0.593	0.567	0.533	0.546	0.550	0.566	0.562	0.611
central section	0.329	0.326	0.324	0.322	0.319	0.313	0.321	0.327	0.333	0.349
west	0.314	0.313	0.306	0.299	0.286	0.286	0.292	0.286	0.323	0.331
whole country	0.469	0.460	0.416	0.403	0.390	0.385	0.400	0.407	0.408	0.437

The development of national ecological efficiency has gone through a fluctuating process of "rise decline rise again", and presents a spatial distribution characteristic of gradually decreasing from east to west. Among all regions, the average ecological efficiency in the eastern region is the highest, reaching 0.588, significantly higher than the national average level; The average values for the central and western regions are 0.326 and 0.303, respectively, with little difference and significantly lower than the national average.

3. The Coupling Study of Green Finance on Ecological Efficiency

3.1. Coupling Degree Model

Coupling was originally a concept in physics, referring to a mutual influence relationship formed by the interactions between multiple systems. Nowadays, this concept has expanded to the economic field and is increasingly used to analyze the interactions and coordinated development levels between different systems. This article refers to the research of Deng Rongrong et al. (2021)^[4] to construct a coupled coordination model between ecological efficiency and green finance. The specific formula is as follows:

$$C = (X_1 \times X_2)^{1/2} / (X_1 + X_2)$$

In the formula, X_1 represents the comprehensive index of green finance, and X_2 represents the comprehensive index of ecological efficiency development; C reflects the coupling degree between the development of green finance and ecological efficiency.

3.2. Classification of Coupling Degree Levels

This article mainly refers to the research results of Xie Tingting and Pan Yu (2017)^[5], and divides the coupling degree and coordination degree into the following four levels.

Table 5. Classification of Coupling Degree Levels

Value range	Current stage
$0 < C \leq 0.2$	Imbalance and decline
$0.2 < C \leq 0.4$	Low coupling
$0.4 < C \leq 0.6$	Jieyu Stage
$0.6 < C \leq 0.8$	Running in stage
$0.8 < C \leq 1$	High level coupling

3.3. Evaluation and Analysis of Coupling Results

To evaluate the coupling relationship between green finance and ecological efficiency in different regions of China, this article uses the standardized measurement results of green finance and ecological efficiency in the previous chapters, and adopts the coupling degree calculation formula introduced earlier to analyze the coupling degree between the two from 2014 to 2023, in order to measure their mutual influence.

The coupling degree between green finance and ecological efficiency in the three major regions of China can be obtained from the previous analysis, as shown in the table below.

Table 6. Coupling Degree of Green Finance and Ecological Efficiency in Various Regions of China from 2014 to 2023 (C)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
east	0.426	0.431	0.446	0.454	0.460	0.460	0.464	0.462	0.468	0.459
central section	0.491	0.494	0.494	0.491	0.494	0.497	0.495	0.493	0.494	0.490
west	0.491	0.492	0.493	0.494	0.497	0.495	0.494	0.489	0.482	0.483
whole country	0.459	0.463	0.474	0.476	0.481	0.483	0.481	0.478	0.481	0.477

According to national data analysis, the coupling degree between green finance and ecological efficiency in China has remained relatively stable from 2014 to 2023, showing a slow upward trend. The average coupling degree has increased from 0.459 to 0.477, with an average coupling degree of 0.475 across 30 regions in China over the past 10 years, indicating a highly interdependent relationship between the two and being in a competitive stage.

At the regional level, the coupling degree between green finance and ecological efficiency is relatively good in the central region. It is worth noting that the coupling degree in the eastern region is not significantly better than that in the central and western regions. This is mainly due to the significant lag in the development of green finance in some eastern regions compared to the central and western regions^[6].

Especially from 2012 to 2022, the coupling degree among the three major regions has been continuously increasing, and the gap between regions has been narrowing year by year. This phenomenon can be seen as a manifestation of China's unremitting efforts to promote the coordinated progress of green finance and ecological development. However, it is worth noting that there was a brief decline in the coupling degree between green finance and ecological efficiency during the two time points of 2019 and 2021. The main reason behind this phenomenon is the slight decline in the level of green finance and the improvement of ecological

efficiency. However, in almost all years covered by the study, the coupling degree was higher than 0.4, and all three regions were in the antagonistic stage.

4. Conclusion and Suggestions

4.1. Conclusion

(1) From 2014 to 2023, China's green finance overall shows a stable growth trend. Before 2021, there was not much difference in the development of green finance among the three major regions of eastern, central, and western China. However, the level of green finance in the eastern region has rapidly improved, while some areas in the central and western regions have clearly declined. This change is not directly related to the economic situation of each region, and the impact of local economic development level on green finance is relatively limited. In this context, the overall decline of green finance in the central and western regions has had a significant impact on the slow development of green finance nationwide, especially in areas such as green credit, green securities, and green insurance.

(2) Overall, the coupling and coordination between green finance and ecological efficiency are still in the development stage, with a particularly evident trend of 'high in the east and low in the west'. This is not accidental, but due to differences in regional economic development, industrial structure, and policy orientation. Therefore, this article suggests that each region should develop differentiated development strategies based on its own actual situation and characteristics. For example, the eastern region can further innovate financial products and introduce more green investments to enhance its ecological efficiency; The western region should concentrate resources on improving infrastructure construction, promoting the rapid development of green finance, and enhancing ecological protection awareness to achieve a win-win situation of sustainable development and ecological efficiency.

4.2. Suggestions

(1) In order to promote the development of green finance, it is necessary to accelerate the formulation of unified standards. Introduce relevant laws and regulations to build a scientific and reasonable green financial system. At the same time, strengthen policy support and incentive mechanisms for green finance, formulate preferential policies such as tax reductions and financial subsidies to encourage enterprises and individuals to participate in green investment and consumption. Improve laws and regulations, establish a sound legal system related to green finance, clarify standards and certifications for green projects, and protect the rights and interests of investors and consumers.

(2) Establish a supervision and evaluation system to enhance ecological efficiency and establish an environmental information disclosure mechanism. Require enterprises to regularly disclose their environmental protection measures and effectiveness, improve transparency and public environmental awareness. This will enhance the operational efficiency of green finance, thereby accelerating the improvement of green ecological benefits.

(3) Applying advanced technology to improve ecological efficiency. Encourage the use of technologies such as the Internet of Things, big data, and artificial intelligence to monitor and optimize production processes, reduce resource waste, and environmental pollution. Furthermore, it will have a positive impact on China's economic transformation and significantly enhance the country's economic strength. This comprehensive approach will help promote the sustainable development of green finance.

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