HAS GREEN FINANCE FACILITATED THE REALIZATION OF ECOLOGICAL PRODUCT VALUE? EVIDENCE FROM COUPLED COORDINATION MECHANISMS IN CHINESE PROVINCIAL PANEL DATA

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Abstract. Green finance and ecological product value realization coupling are crucial for promoting economic green transformation and achieving the Global Carbon Neutrality and Net-Zero Emissions Targets. Based on data from 30 Chinese provinces (2010–2021), we use the Coupling Coordination Model, Kernel Density Estimation, Obstacle Degree Model, and Tobit Model to explore the coordination mechanisms. Our research shows that (1) the coupling coordination exhibits a dynamic upward trend and is multipolar. (2) The spatial distribution gradually expands inward from the east and west, presenting four phases: the northwest-east region axis with linear (I-shaped) development, the southeast coastal region with intersecting (T-shaped) development, the east-central-west region axis with linear (I-shaped) development, and the north and south poles with a central zone (T-shaped) development. (3) The obstacle severity hierarchy in the green finance system is structural development, scale development, and efficiency development. For the ecological product value realization system, we find that the degree of barriers is operational capability, investment capability, and organizational capability. We confirm that government intervention, farmers' income level, technology market development level, industrial structure development level, and transportation infrastructure level have a positive impact on coordination. Therefore, we recommend enhancing government intervention precision and optimizing ecological industrial structures.
Keywords: *spatial expansion path, multipolar distribution, regional synergy, differentiated governance, sustainable development*

Introduction

A healthy ecological environment possesses economic and social value, while economic prosperity is intrinsically linked to environmental sustainability. Consequently, many countries are increasingly focusing on the development of green finance (Lee and Lee, 2022). Driven by the carbon peak and neutrality goals, transforming "green mountains" into "golden mountains" centers on the value realization of ecological products (Wu et al., 2024a). Countries like India (Nenavath and Mishra, 2023) and members of the Organization for Economic Co-operation and Development (OECD) (Huang et al., 2023) have been actively exploring the role of ecological products in economic growth. Despite the potential for ecological products to contribute to economic and environmental symbiosis (Li et al., 2021), several challenges hinder the realization of their full value. The value realization of ecological products continues to encounter multiple systemic constraints, including underdeveloped value transformation channels (Van Hemel and Cramer, 2002), a restricted supply pool with marked product homogeneity (Xu et al., 2018), and the absence of an integrated value conversion framework (Xing et al., 2018). Green finance offers a crucial instrument to overcome these obstacles and facilitate the realization of the value inherent in ecological products,

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as it is recognized as an effective mechanism for simultaneously advancing economic and environmental goals (Kong et al., 2022).

In the context of global climate governance and low-carbon transformation of the economy, China's green financial market is not only an important pillar of domestic ecological civilization construction (Khalid et al., 2025) but also has a far-reaching impact on the flow of global green capital as well as the improvement of the global green financial system (Min et al., 2018). In terms of scale, at the end of the fourth quarter of 2024, China's foreign-currency green loan balance was 36.6 trillion yuan, up 21.7% year over year (https://www.gov.cn/lianbo/bumen/202502/content_7004167.ht), the first in the world in terms of volume. The development of green finance in China is improving steadily, which can provide an effective engine and sustained impetus for the realization of the value of ecological products (Wu, 2023). Integrating green finance and realizing the value of ecological products is increasingly recognized, in theory and practice, as a way to achieve both ecological and economic benefits (Hu et al., 2023). This consensus is driven by the increasing emphasis on ecological civilization construction and the ongoing refinement of China's green financial system (Fang et al., 2024). However, the development of green finance and the effective realization of ecological product value face several challenges (Akomea-Frimpong et al., 2022). These include a lack of financial innovation, low efficiency in value transformation, and, critically, limited market acceptance of current methods for accounting ecological product value (Cui et al., 2020). Addressing these challenges is crucial to guide the synergistic development of these two domains and to foster a positive feedback loop between green finance and the realization of ecological product value (Ma et al., 2023).

Our study creatively combines green finance, ecological economics, and sustainable development ideas to build a four-step research plan that includes creating theories, developing new methods, analyzing data, and applying policies. First, we carefully look at existing research to create a theoretical model that explains how green finance and ecological product value interact with each other. We construct a dual-system quantitative assessment indicator system to ensure the scientific validity and operational feasibility of the indicators. In our research methods, we have improved on old analysis techniques by using a new approach that combines the Coupling Coordination Model and Kernel Density Estimation. The Coupling Coordination Model measures how strongly the green finance system and the ecological product value system interact and work together, which is better than just looking at one indicator. The Kernel Density Estimation shows how things change over space and time, which is much more useful than older methods like Moran's I Index that only look at static data (Imran et al., 2023). Second, we systematically examine the pilot phase of China's green finance reform policies and the deepening stage of ecological compensation mechanisms. Using reliable data from 30 provinces in China from 2010 to 2021, we carefully study how the two systems have changed over time and space, making sure our findings are relevant and applicable. Third, after measuring how well the provinces work together, we observe internal challenges using an Obstacle Degree Model and confirm the importance of outside factors using the Tobit Model. Finally, we propose specific policy recommendations and countermeasures based on the empirical results. The result helps decision-makers understand, predict, and manage how green finance and ecological product value work together, along with the factors that influence this relationship, so they can set future goals, contribute to the sustainable growth of green finance, and provide a model for others around the world.

For the first time, we have included the realization of ecological product value in our analysis of how green finance works together, which helps address the lack of research on how green finance and ecological product value influence each other and offers a new way to study these topics in the future. Our detailed research approach for the whole process of green finance and ecological product value not only guarantees that our findings are scientifically sound but also offers a way for others to analyze and work together on global sustainable development goals. In terms of practical application, our innovative research findings not only provide important references for improving China's green finance policy framework but also serve as a global model for green development, contributing to the sustainable development of green finance worldwide.

Literature review

Conceptualization and logic construction of green finance and ecological products

The primary goal of green finance is to promote financial institutions to provide financial flows to environmentally friendly economic entities (Zhang et al., 2024a), internalize negative environmental externalities through market mechanisms (Wang et al., 2022), and reconfigure the behavioral logic and behavioral choices of financial market entities (Qian and Yu, 2024). Its essence is to use financial means to change the flow of production factors (Jiakui et al., 2023), promote the transfer of traditional high-pollution modes to green and sustainable industries or green production methods (Wang and Ma, 2024), and realize the purpose of sustainable development (Song and Du, 2024).

Unlike green finance, the concept of ecological products can be traced back to the main functional area planning (Xia et al., 2020), which refers to the natural elements that maintain ecological security, safeguard ecological regulatory functions, and provide a healthy human habitat (Zhu et al., 2024), with the aim of lowering the costs of the environment, ecology, and human consumption (Schultz et al., 2024). Ecological products value realization emphasizes the rational development and utilization of natural ecological environment resources (Marcon et al., 2022), transforming them into social or economic attributes (Rizzo et al., 2024), and promoting sustainable development (Yurui et al., 2021).

Environmental economics emphasizes the interdependence between the economy and the environment (Gendron, 2014). Under this theoretical framework, green finance, as a tool that combines financial instruments and environmental objectives (Xu et al., 2023a), explores how it supports the accounting of ecological product values, property rights clarification, commercialization, and financialization of the ecological product market under the logical framework constituted by ecological product value realization (Herath et al., 2019).

Policies driving green finance and ecological value realization

At the international level, how to make advantageous use of green finance to realize the value of ecological products has become the core issue of international policy (Bhattacharyya et al., 2021). In 2008, the UK formally passed the Climate Change Act, which specifies a net-zero emissions target for 2050. A key project under this act, the CIF Clean Energy Green Bonds, plans to raise $7.5 billion to invest in renewable energy projects in developing countries (Lockwood, 2013), including investment in Philippine geothermal power generation projects, using green financial means to activate ecological value (Cuevas, 2018).

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Focusing on China's domestic policies, in 2017, the Chinese government issued the Opinions on Establishing and Improving the Mechanism for Realizing the Value of Ecological Products (https://www.gov.cn/gongbao/content/2021/content_5609079.htm), which called for increased green financial support and in-depth development of the pilot mechanism for realizing the value of ecological products. In 2024, the Chinese government issued the Guiding Opinions on Further Strengthening Financial Support for Green and Low-Carbon Development (https://www.gov.cn/gongbao/content/2021/content_5609079.htm), which called for strengthening green financial support for Eco-environment-oriented Development (EOD) models. In this regard, Wuhan, China (Yang et al., 2023a), and Changzhou, China (Zhang et al., 2024b), have actively explored the practice of rationally allocating green financial resources to help realize ecological value.

Mechanism innovation and regional pathway practice for ecological value realization

In the process of ecological industry development, the shortage of funds has been the key bottleneck restricting its sustainable development (Hailiang et al., 2023). To effectively solve this problem, a new mechanism for realizing the value of ecological products with multiple synergies has been gradually constructed in the practical exploration (Xu et al., 2023b). The mechanism takes the government as the leading force, giving full play to its key role in policy formulation, resource integration, and macro-control (Shen et al., 2024), while actively guiding enterprises, social organizations, the public, and other social sectors to participate in the formation of synergy (Wei et al., 2018). On this basis, the depth of the combination of green financial instruments and innovative financial models (Ahmed et al., 2024) to explore a series of ecological industry characteristics of the transaction mode and market-oriented operation mechanism (Jin and Zhao, 2021). Through the operation of this mechanism, it can provide a stable and sufficient source of funds for ecological projects, thus effectively alleviating the financial pressure on the development of ecological industry (Farrell and Löw Beer, 2019).

In addition, the relevant research is still expanding the application field of green financial tools, actively exploring its ecological products in watershed ecological management (Cai and Zhang, 2018) and the ecological protection of border areas (De et al., 2015) and other specific regional ecological products in the realization of the value of the innovative path, with a view to the development of ecological industries for the different regions to provide more targeted financial support and solutions (Vezzoli et al., 2015) and to further promote the realization of the ecological products value of the mechanism of the improvement and development (Yang et al., 2023b).

Our rationale

The interaction between green finance and ecological products value realization remains an under-explored frontier in sustainable development research. While existing research has extensively documented the actual pathways of green finance implementation and ecological value realization, respectively, the coupling coordination mechanisms between these two systems remain poorly understood theoretically. The field has been dominated by qualitative analyses, and researchers have conducted very limited empirical validation using quantitative frameworks, a critical gap given the complexity and spatial heterogeneity of these interacting systems.

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Developing a synergistic assessment system for green finance and the realization of ecological product value has become essential for managing regional low-carbon transitions. Assessing the level of coupled and coordinated development of the two requires a better economic theory to construct the indicator system. Under the sustainable development perspective of our current study, the core elements such as the market-oriented operation mechanism of green finance, the value transformation path of ecological products, the guiding role of policies and regulations, and the incentive mechanism for multi-principal participation are comprehensively considered. To achieve the Global Carbon Neutrality and Net-Zero Emissions Targets under the Paris Agreement, we promote the synergistic development of green finance and value realization of ecological products through financial innovation tools, integrate the demands of various stakeholders, and take into full consideration the differences in regional ecological carrying capacity and economic development levels in our empirical research. Furthermore, our methodology assists decision makers in pinpointing and enhancing the weak points within the interconnected system, thereby enhancing the synergistic impact of green finance and ecological protection. We hope that future scholars in the field of environmental finance will learn from our methodology, incorporate regional characteristics, and replicate our quantitative assessment model of the synergistic development of green finance and ecological values in different regions of the world.

Existing research has explored the supporting role of green finance in ecological product value realization and systematically analyzed cases of coordinated development in typical regions. To accurately assess the degree of coupling between green finance and ecological product value realization at the provincial level, we select data from 30 provinces in China covering the years 2010 to 2021 to ensure that it includes key periods of green finance and ecological protection policies and is representative. Based on the Coupling Coordination Model and Kernel Density Estimation, we establish an assessment system for the coordinated development of green finance and ecological product value realization. We employ the Obstacle Degree Model and the Tobit Model to diagnose internal obstacle factors and external influence factors within different regional systems. Our study not only helps decision-makers precisely identify and enhance weak links within the coupling system but also provides a quantitative framework that can be applied to different regions globally, offering methodological references for future research in the field of environmental finance. Our research not only fills the theoretical gap in the coupling coordination and bidirectional interaction mechanisms between green finance and ecological product value but also provides a scientific basis and practical guidance for the coordinated development of these two systems.

The coupling and coordination mechanism and the construction of comprehensive evaluation index system

Coupling and coordination mechanism

The coupling and coordinated development of green finance with the realization of ecological product value is a crucial measure for implementing the “Two Mountains” Theory (Lucid Waters and Lush Mountains Are Invaluable Assets), achieving carbon peak and neutrality goals, and facilitating the green transformation of the economy. The “Two Mountains” Theory was first put forward by President Xi Jinping on August 15, 2005, in Yucun, Anji County, Zhejiang Province. It emphasizes the dialectical relationship between ecological environmental protection and economic development and serves as an important

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guiding principle for China's ecological civilization (Huang et al., 2024). Among them, green finance has the dual functions of traditional finance and environmental regulation (Tariq and Hassan, 2023) and promotes the realization of the value of ecological products with the development of its scale, efficiency, and structure as a driving force. The value realization of ecological products promotes the diversified development of green finance with its input, operation, and organizational capacity, and promotes the trading of ecological resource rights and interests (Xiao and Tabish, 2025). Green finance and ecological product value realization have the consistency of the goal of promoting sustainable development and the interactive coupling of mutual promotion, risk sharing, and policy synergy, forming a dynamic synergistic effect. The coupling and coordination mechanism of green finance and ecological products value realization is shown in *Figure 1*.

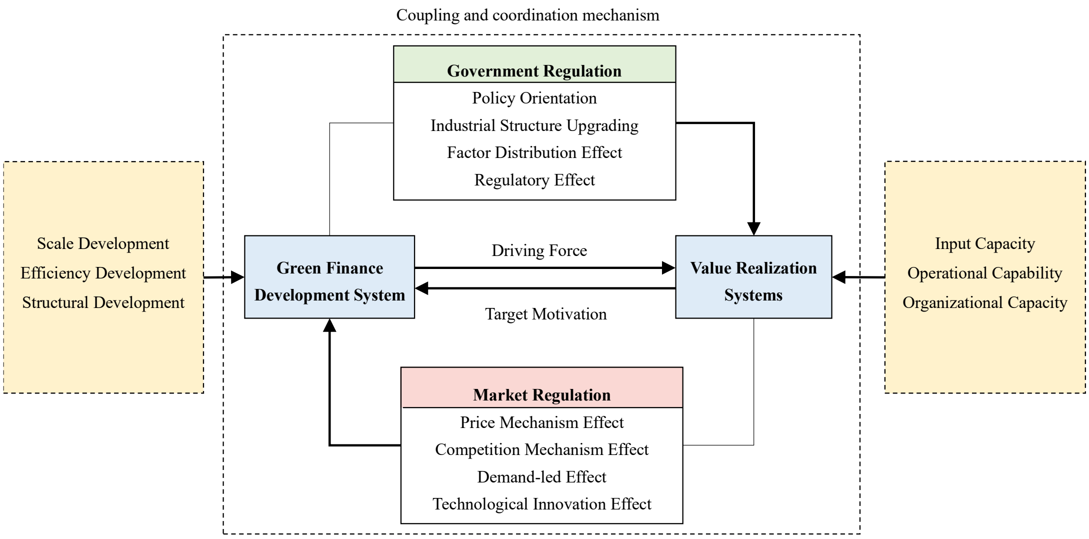

Figure 1. *Coupling and coordination mechanism of green finance and ecological products value realization*

On the one hand, green finance drives the realization of the value of ecological products. Green finance uses financial instruments such as green credit, green securities, and green insurance to serve the marketization of ecological products and drive the realization of their value through policy orientation, industrial structure upgrading, factor distribution, and regulatory effects (Yang et al., 2023c). First, as an important means to promote sustainable development, the core concept of green finance is closely linked to national policy orientation, which guides green financial institutions to provide financing and guarantee services for the operation of ecological products and the development of green industries and points out the direction for the development of green finance. Second, green finance promotes the upgrading of industrial structure in the direction of green, low-carbon, and environmental protection through financial guidance and accelerates the commercialization of ecological products. Once again, green finance improves the distribution effect of ecological resource factors by optimizing the allocation of resources to environmental protection, clean energy, and other environmentally friendly industrial projects (Zhang and Xu, 2024). Finally, green finance protects the property rights and commercial interests of ecological products and maintains market order and fair competition by establishing a sound legal framework and regulatory mechanism.

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On the other hand, ecological product value realization is the target motivation for green finance. Ecological products value realization affects green finance through price mechanism, competition mechanism, demand-led effect, and technological innovation effect, and ecological financial products are constantly explored and tried (Ben et al., 2024). First, the value realization of ecological products affects the investment decision and capital flow of green finance through the price mechanism, and green financial institutions will consider the market price of ecological products and the potential value-added space to decide the direction of investment when evaluating investment projects. Second, the competition mechanism in the ecological products market promotes the innovation and optimization of green financial products, and there is competition and cooperation between various ecological products, which prompts financial institutions to continuously innovate green financial products to serve various ecological projects. In addition, as the ecological products market continues to expand and consumers' environmental awareness increases, the market demand for green financial products continues to increase, leading financial institutions to increase the research and development and promotion of green financial products. Finally, green finance influences the realization of ecological products' value through green technological innovation (Sun et al., 2017). To accurately assess the value of ecological products, monitor their status, and manage associated risks, green finance has been prompted to introduce digital technology, artificial intelligence, and other technological means to develop smarter and more efficient green financial products.

Therefore, in the process of interaction and synergy, the two mechanisms of government regulation and market regulation as external driving forces drive the coupling and coordinated relationship between green finance and ecological products value realization to evolve in a spiral and ultimately realize the benign synergistic development of the economy, society, and ecological resources.

Construction of comprehensive evaluation index system

We construct the evaluation index system on the basis of the coupling and coordination mechanism of the green financial development system and the ecological products value realization system. Green finance involves using financial institutions or financial markets as the vehicles to optimize the allocation of financial resources, regulate the flow of funds towards green low-carbon initiatives, promote efficient resource use, and enhance the quality of the ecological environment (Khan et al., 2022). Drawing on scholarly research, we decompose the level of green finance development into scale, efficiency, and structural development (Lv et al., 2021). Green finance is an important branch of the financial industry. As financial institutions strengthen their ability to absorb reserves, the scale of financial employment increases, allowing for better investments in environmental protection, clean energy, and other environmentally friendly industrial projects (Kong et al., 2022). It can promote the scale development of green finance and increase the employment opportunities in the field of green finance, and the scale development is measured by the ability of the green financial institutions to absorb reserves and the scale of employment.

Furthermore, within the realm of green finance, several factors contribute to its advancement. First, a higher per capita output value signifies enhanced labor productivity in green financial activities, indicating that each unit of labor generates greater value. Second, elevated financial deposit and loan ratios suggest a stronger capacity to channel

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savings into green investment projects. Finally, effective financial regulation enhances both the transparency and standardization of green finance operations, fostering a more reliable and efficient market. Therefore, we use the level of financial efficiency to evaluate the difference in the ability of provinces to utilize green financial funds (Yan et al., 2022) and measure the efficiency development by the output value per capita of the green financial industry, the financial deposit-to-lending ratio, and financial regulation. The green financial structure reflects the composition and distribution of different green financial instruments, including green credit, green securities, green investment, green insurance, green funds, and green equity.

Evaluation indicators of ecological products value realization are mainly constructed based on the three major elements of input, operational, and organizational capacity (Liu et al., 2024). Input capacity is the basis of ecological products value realization, focusing on the effect of inputs for ecological environmental protection and pollution control (Lou et al., 2024), which is measured by indicators of ecological protection and pollution control. Operational capacity evaluates the economic benefits of ecological products, focusing on how to realize their value through industrial operation and market activities. The assessment includes industrial ecologization and ecological industrialization, in which industrial ecologization enables traditional industries to reduce environmental loads and improve resource efficiency in the production process. Ecological industrialization transforms ecological resources into economic value and promotes the development of ecological economy through market mechanisms. Organizational capacity assesses the government's overall capacity in organizing and managing the realization of ecological products, covering both ecological regulation and ecological demonstration. We finally selected two subsystems, six primary indicators, 17 secondary indicators, and 42 specific indicators that include green finance and ecological products value realization, the indicators and data sources at various levels are shown in *Table 1*.

Data sources

We select 30 provinces, autonomous regions, and municipalities in China as the study sample. But since there is too little data in Tibet, it is not in the regression sample, and because the data for some variables of green finance and ecological products value realization after 2022 have not been reported, it is challenging to interpolate. We select the span of 2010 to 2021 to ensure data completeness, resulting in a total of 360 observations. Among them, the data for green finance indicators come from the 2010-2021 China Statistical Yearbook, China Statistical Yearbook on Science and Technology, China Energy Statistical Yearbook, Almanac of China's Finance and Banking, China Agricultural Statistical Yearbook, China Industrial Statistical Yearbook, and China County-Level Statistical Yearbook. The data for indicators measuring the value realization of ecological products come from the 2010-2021 China Statistical Yearbook and China Statistical Yearbook on Environment.

Methods

We use the Coupling Coordination Model, the Kernel Density Estimation, the Obstacle Degree Model, and the Tobit Model to explore the spatio-temporal distribution and drivers of the coupled and coordinated development of green finance and ecological products value realization.

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Table 1. *Comprehensive evaluation index system for green finance and ecological product value realization*

<table>
<tr><th>Subsystem</th><th>Primary indicator</th><th>Secondary indicator</th><th>Specific indicator</th><th>Weight</th><th>Attribute</th><th>Data source</th></tr>
<tr><td rowspan="16">Level of green finance development</td><td rowspan="3">Scale development</td><td rowspan="2">Deposit mobilization capacity of green financial institutions</td><td>X_1: Balance of deposits in financial institutions</td><td>0.1075</td><td>+</td><td rowspan="6">China Statistical Yearbook</td></tr>
<tr><td>X_2: Balance of loans to financial institutions</td><td>0.0983</td><td>+</td></tr>
<tr><td>Employment in green finance</td><td>X_3: Employment in urban financial institutions/Urban employment</td><td>0.0697</td><td>+</td></tr>
<tr><td rowspan="3">Efficiency development</td><td>Labor productivity in green finance</td><td>X_4: Value added of the financial sector/Employment in Urban financial institutions</td><td>0.0400</td><td>+</td></tr>
<tr><td>Green finance loan-to-deposit ratio</td><td>X_5: Outstanding loans of financial institutions/Outstanding deposits of financial institutions</td><td>0.0261</td><td>+</td></tr>
<tr><td>Supervisory mechanisms in green finance</td><td>X_6: Expenditure on financial regulation and related affairs</td><td>0.1740</td><td>+</td></tr>
<tr><td rowspan="10">Structural development</td><td rowspan="2">Green credit</td><td>X_7: Interest payments of six high energy-consuming industries/Industrial interest payments</td><td>0.0265</td><td>-</td><td rowspan="10">China Statistical Yearbook on Science and Technology, China Energy Statistical Yearbook, Almanac of China's Finance and Banking, China Agricultural Statistical Yearbook, China Industrial Statistical Yearbook, and China County-Level Statistical Yearbook</td></tr>
<tr><td>X_8: Credit for environmental projects/Banking credit</td><td>0.0291</td><td>+</td></tr>
<tr><td rowspan="2">Green securities</td><td>X_9: Gross output of environmental protection enterprises/Market capitalization of a-share market</td><td>0.0792</td><td>+</td></tr>
<tr><td>X_{10}: Total issuance volume of green bonds/Bond issuance volume</td><td>0.0339</td><td>+</td></tr>
<tr><td rowspan="2">Green investment</td><td>X_{11}: Investment in environmental pollution control/GDP</td><td>0.0536</td><td>+</td></tr>
<tr><td>X_{12}: Government spending on eco-industries/Government expenditure</td><td>0.0359</td><td>+</td></tr>
<tr><td rowspan="2">Green insurance</td><td>X_{13}: Premium income from environmental pollution liability insurance/Insurance premium income</td><td>0.0321</td><td>+</td></tr>
<tr><td>X_{14}: Agricultural insurance premium income/Gross agricultural output value</td><td>0.1251</td><td>+</td></tr>
<tr><td>Green fund</td><td>X_{15}: Market value of green funds/Market capitalization of all funds</td><td>0.0327</td><td>+</td></tr>
<tr><td>Green equity</td><td>X_{16}: Aggregate value of carbon, energy rights, and pollution rights trading／Total equity market transactions</td><td>0.0363</td><td>+</td></tr>
<tr><td rowspan="6">Level of value realization of ecological products</td><td rowspan="6">Input capacity</td><td rowspan="6">Ecological protection</td><td>Y_1: Investment in ecological construction and protection completed this year</td><td>0.0155</td><td>+</td><td rowspan="6">China Statistical Yearbook, and China Statistical Yearbook on Environment</td></tr>
<tr><td>Y_2: New soil erosion control area</td><td>0.0213</td><td>+</td></tr>
<tr><td>Y_3: New grass planting area in the current year</td><td>0.0564</td><td>+</td></tr>
<tr><td>Y_4: Number of national nature reserves</td><td>0.0366</td><td>+</td></tr>
<tr><td>Y_5: Area of forest pest control</td><td>0.0393</td><td>+</td></tr>
<tr><td>Y_6: Expenditures on environmental protection of local finance</td><td>0.0170</td><td>+</td></tr>
</table>

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Subsystem	Primary indicator	Secondary indicator	Specific indicator	Weight	Attribute	Data source
		Pollution control	Y_7: Completed investment in waste gas treatment projects	0.0341	+	
			Y_8: Completed investment in industrial pollution treatment	0.0272	+	
			Y_9: Daily treatment capacity of urban sewage	0.0231	+	
			Y_{10}: Harmless treatment capacity of domestic garbage	0.0250	+	
			Y_{11}: Sewage treatment rate	0.0038	+	
			Y_{12}: Number of harmless treatment plants	0.0145	+	
	Operational capability	Ecological industrialization	Y_{13}: Gross output value of agriculture, forestry, animal husbandry and fishery/GDP	0.0116	+	
			Y_{14}: Investment in pollution control projects completed this year/GDP	0.0282	+	
			Y_{15}: Forestry industry development investment completed this year/GDP	0.1227	+	
			Y_{16}: Total ecological water consumption/GDP	0.0431	+	
			Y_{17}: Tourism income of A-class scenic spots/GDP	0.2524	+	
			Y_{18}: Tourism passenger transportation turnover/GDP	0.0156	+	
		Industrial ecologization	Y_{19}: Comprehensive utilization of general industrial solid waste/industrial output value	0.0372	+	
			Y_{20}: Emission of sulfur dioxide, the main pollutant in waste gas/Industrial output value	0.0044	-	
			Y_{21}: Emission of Chemical Oxygen Demand (COD), a major pollutant in wastewater/Industrial output value	0.0017	-	
			Y_{22}: Effective irrigated area/Total sown area of crops	0.0142	+	
			Y_{23}: Energy consumption per unit of GDP	0.0049	-	
			Y_{24}: Fertilizer use per unit of arable land area	0.0035	-	
	Organizational capacity	Ecological regulation	Y_{25}: Number of key enterprises that should carry out monitoring of heavy metal pollution prevention and control	0.0465	-	
			Y_{26}: Number of environmental protection acceptance projects completed in that year	0.0213	+	
			Y_{27}: Number of social environmental publicity and education activities carried out in the year	0.0286	+	
		Ecological demonstration	Y_{28}: General ecological and environmental events	0.0005	-	
			Y_{29}: Number of beautiful leisure villages in China	0.0399	+	
			Y_{30}: Leisure agriculture and rural tourism demonstration counties	0.0100	+	

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Step 1: Determination of indicator weights

We determine the weights of the indicators using the entropy value method after dimensionless processing of the data, and the results are shown in *Table 1*. The specific steps are as follows.

(1) The proportion of the jth indicator for the ith geoprovince is calculated using *Equation 1*.

$$P_{ij} = \frac{z_{ij}}{\sum_{i=1}^{m} x_{ij}}, \quad i = 1, .., m; j = 1, \ldots, n \tag{Eq.1}$$

(2) The entropy value and coefficient of variation of the jth indicator are determined using P_{ij} as specified in *Equation 2*.

$$E_j = -\frac{1}{lnm}\sum_{i=1}^{m}\left(P_{ij} \times lnP_{ij}\right) \text{ and } G_j = 1 - E_j \tag{Eq.2}$$

(3) The share of indicator j in all indicators as defined by *Equation 3*.

$$W_j = \frac{G_j}{\sum_{j=1}^{m} G_j} \tag{Eq.3}$$

(4) A composite evaluation index for each province utilizing *Equation 4*.

$$U = \sum_{j=1}^{n}\left(X_{ij} \times W_j\right) \tag{Eq.4}$$

(5) The indicator weights for the subsystems by *Equation 5*.

$$U_1 = \sum_{j=1}^{n}\left(X_{ij} \times W_j\right); \;\; U_2 = \sum_{j=1}^{n}\left(X_{ij} \times W_j\right) \tag{Eq.5}$$

where U_1 and U_2 are the integrated levels of the subsystems, respectively, X_{ij} is the value of each indicator after standardization, and W_j is the weight of each indicator in the two subsystems.

Step 2: Coupling coordination model

We construct the Coupling Coordination Model using *Equation 6*.

$$C = \sqrt{\frac{U_1U_2}{(U_1+U_2)^2}}; \;\; D = \sqrt{C \times T}; \;\; T = \beta_1 \times U_1 + \beta_2 \times U_2 \tag{Eq.6}$$

where C is the degree of coupling, D is the degree of coupling coordination, T is the comprehensive coordination index, and β is the coefficient to be determined. We consider that green finance and ecological product value realization are equally important, and we set both β_1 and β_2 to 0.5. Drawing on scholarly practice, we categorize the coupling coordination degree into 10 levels (Li et al., 2012), as shown in *Table 2*.

Step 3: Kernel density estimation

We use *Equation 7* to estimate kernel density.

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$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{X_i - x}{h}\right), \text{while } K(x) = \frac{1}{\sqrt{2\pi}} exp\left(-\frac{x^2}{2}\right) \quad \text{(Eq.7)}$$

where $f(x)$ is the kernel function, X_i is the sample observations, x is the mean, n is the number of observations, h is the bandwidth, and $K(x)$ is the basic form of the Gaussian kernel function.

Table 2. *Classification criteria for coupling coordination level*

Harmonization range	Harmonization level	Harmonization range	Harmonization level
0.00 < D ≤ 0.10	Extreme disordination	0.50 < D ≤ 0.60	Reluctant coordination
0.10 < D ≤ 0.20	Severe disordination	0.60 < D ≤ 0.70	Primary coordination
0.20 < D ≤ 0.30	Moderate disordination	0.70 < D ≤ 0.80	Intermediate coordination
0.30 < D ≤ 0.40	Mild disordination	0.80 < D ≤ 0.90	Good coordination
0.40 < D ≤ 0.50	Marginal disordination	0.90 < D ≤ 1.00	High-quality coordination

Step 4: Obstacle degree model

We calculate the obstacle degree using *Equation 8*.

$$Q_{ij} = \frac{(1-E_{ij})w_j}{\sum_{j=1}^{n}(1-E_{ij})w_j} \quad \text{(Eq.8)}$$

where Q_{ij} is the obstacle degree of the jth indicator in year i, E_{ij} is the indicator deviation degree of the jth indicator in year i, w_j is the weight of the jth indicator in the total indicator, in other words, factor contribution, and n is the number of indicators.

Step5: Panel Tobit model

The coupling and coordinated development of green finance and ecological products value realization are affected by various factors. We draw on the scholarly research (Wu et al., 2024b), based on the panel data of 30 provinces, autonomous regions, and municipalities directly under the central government in China from 2010 to 2021. The coupling and coordinated degree of green finance and ecological products value realization (COD) is selected as an explanatory variable, and the degree of government intervention (GID), the level of farmers' income (FIL), the level of technology market development (TML), the level of industrial structure development (ISD), and the level of transportation basic facilities (TBF) are selected as the explanatory variables. We consider that the coupling coordination degree of the two varies from 0 to 1. The Tobit Model (*Eq. 9*) is constructed to analyze it due to the limitations of the dependent variable and to avoid the bias caused by OLS estimation.

$$COD_{it} = Con + \alpha_1 GID_{it} + \alpha_2 FIL_{it} + \alpha_3 TML_{it} + \alpha_4 ISD_{it} + \alpha_5 TBF_{it} + \varepsilon_{it} \quad \text{(Eq.9)}$$

where Con is a constant term, i denotes the city, and t denotes the year, and the specific variables are explained in *Table 3*.

Table 3. *Tobit model variables*

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Variable type	Variable name	Notation	Definition	Unit	Mean	Std.Err	Min	Max
Dependent variable	Degree of coupling coordination	COD	Coupling coordination model calculation results	-	0.3894	0.0553	0.2593	0.5626
Independent variable	Degree of government intervention	GID	Local government fiscal expenditure/GDP	100 million yuan	0.2590	0.1126	0.1050	0.7583
	Level of farmers' income	FIL	Per capita disposable income of rural residents	Yuan	9.3538	0.4482	8.2287	10.559
	Level of technology market development	TML	Technology market turnover/GDP	100 million yuan	0.0160	0.0274	0.0002	0.1757
	Level of industrial structure development	ISD	(Added value of primary industry and tertiary industry)/GDP	%	0.2612	0.1540	0.0336	0.7601
	Level of transportation basic facilities	TBF	Highway mileage	Kilometer	11.6790	0.8515	9.3905	12.8965
Test variable	Level of urbanization	UBL	Urban population/Total population	%	0.5896	0.1245	0.3400	0.9000
	Level of opening to the outside world	OUW	Total import and export of goods/GDP	%	0.2772	0.2947	0.0076	1.4638

The data for the above explanatory variables come from the China Statistical Yearbook 2010-2021 for each province, and to reduce data heteroskedasticity and multicollinearity, we take the logarithmic treatment for the level of farmers' income and the level of transportation basic facilities. In addition, the urbanization level (UBL) and the level of opening to the outside world (OUW) are also selected as subsequent robustness test variables.

Empirical analysis

Analysis of the coupling and coordination degree between green finance and ecological products value realization subsystems

Characteristics of temporal evolution

We plot the three-dimensional kernel density estimation surface of the coupling coordination degree between green finance and ecological products value realization in 30 provinces and regions in China from 2010 to 2021 with the help of Matlab R2021b software, as shown in *Figure 2*. We characterize the time-series evolution of the coupling coordination degree of green finance and ecological products value realization from the territorial scale (30 provinces) and local scale (East, Central, West, Northeast, and Southwest).

(1) Territorial scale

In terms of distribution and shape, the main peak of the coupling coordination curve experienced a "rising-declining-rising" evolution during the study period. Its coverage broadened, and the peak shape shifted from "sharp and narrow" to "flat and flat," indicating an expanding absolute difference in coupling levels across Chinese provinces. The center of the kernel density curve exhibited a "left shift-right shift" pattern, with the largest leftward shift in 2019, likely due to the pandemic, before gradually returning rightward. From the perspective of distribution extensibility, the kernel density curve initially showed

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a left-trailing phenomenon, which extended to the right over time, reflecting that some regions initially had lower coordination levels but improved later. Regarding the polarization trend, the curve evolved from a “double-peak” to a “single-peak” distribution, indicating a more uniform distribution and reduced polarization in coupling coordination.

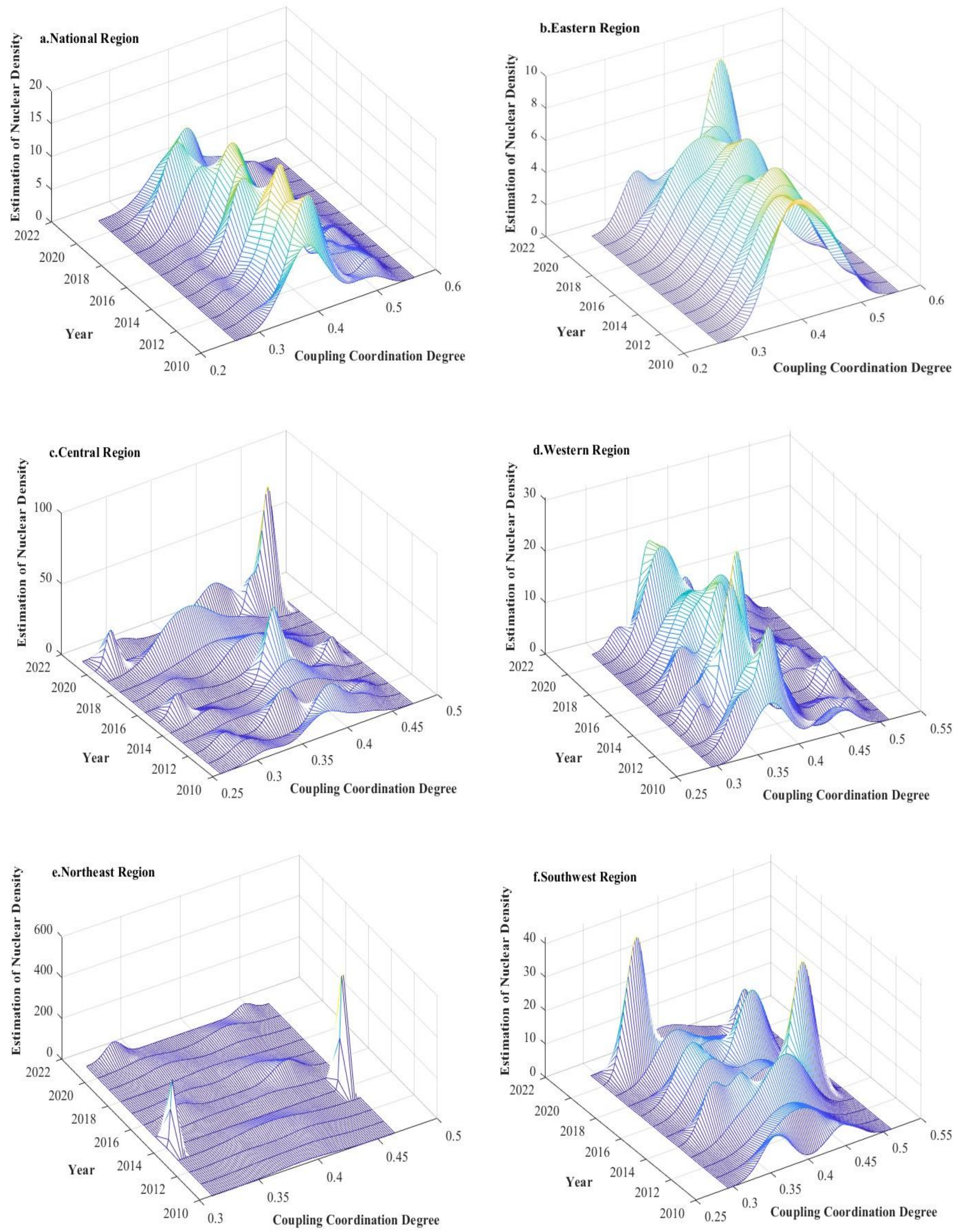

Figure 2. *Kernel density curve of the coupling coordination degree between green finance and ecological product value realization*

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(2) Local scale

In terms of distribution and shape, the nuclear density curves in the five major regions were highly irregular. The eastern region's curve center shifted rightward, with a rapid increase in coupling coordination, a rising main peak, and a left sub-peak appearing later, indicating widening differences and emerging polarization. The central, northeastern, and southwestern curves showed irregular jumps with significant fluctuations, while the western curve center shifted leftward and peaks flattened. From the perspective of distribution extensibility, the eastern region evolved from a left-right trailing tail to a left trailing tail, the western region remained left-biased, and other regions fluctuated without a clear trend. Regarding the polarization trend, the eastern and northeastern regions transitioned from a "one main once" to a "one main twice" pattern, while the central, western, and southwestern regions shifted from "one main twice" to "one main many times." This variation indicates a gradient effect and multipolar differentiation in internal coupling coordination levels.

Characteristics of spatial evolution

Figure 3 shows that from 2010 to 2021, the degree of coupling coordination in green finance and ecological product value realization has been rising, with the number of provinces and regions experiencing mild dislocation significantly decreasing. Meanwhile, those on the verge of dislocation have successively increased, and the provinces and regions with barely coordinated efforts have gradually risen. Additionally, the spatial distribution is expanding inwardly from both the east and west, with an overall pattern indicating high levels along the southeastern coast and low levels in the northwestern and inland areas.

From an intra-regional perspective, the level of coordination between green finance and ecological products value realization coupling was generally low in 2010, presenting the northwest-east region axis with linear (I-shaped) development. First, the overall distribution pattern of "Northwest East" is "Northwest High, Southeast Low," and the proportion of provinces in moderate and light disorder reaches 86.67%, widely distributed in the east and south, of which Hainan (0.2709) is in the stage of moderate disorder. Secondly, the provinces with high coupling coordination form an "I-shaped" spatial pattern, with Inner Mongolia (0.4018), Sichuan (0.4337), and Chongqing (0.4124) having the highest coupling coordination and being on the verge of becoming dysfunctional, and Ningxia (0.4326) being on the verge of becoming dysfunctional, together with Gansu (0.3343), which is mildly dysfunctional. Ningxia (0.4326) is on the verge of dislocation, together with Gansu (0.3343), which is mildly dislocated, constituting a highly coupled "I-shaped" inland longitudinal belt.

In 2014, the spatial distribution of the degree of coupling coordination developed into the southeast coastal region with intersecting (T-shaped) development, expanding from inland to the coast. The "I," led by Inner Mongolia (0.4547), moves toward the southeast coast, and Shandong (0.4436), Jiangsu (0.4059), Zhejiang (0.4058), and Guangdong (0.4501) are upgraded to the verge of being out of coordination, forming a highly coupled "T-shaped" coastal longitudinal belt together. "T-shaped" coastal longitudinal belt. In 2018, the degree of coupling coordination has been significantly improved, with the spatial distribution from the southeast coast of the "T-shaped" inward expansion showing the east-central-west region axis with linear (I-shaped) development. The western coupling coordination is low in areas such as Xinjiang (0.3926), Qinghai (0.3911),

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Yunnan (0.3841), Guizhou (0.3655), and Chongqing (0.3899), together forming a low coupling coordination "I-shaped" western vertical axis belt. In 2021, the spatial distribution of the coupling coordination degree presents the north and south poles with a central zone (T-shaped) development. Compared to 2018, the coupling coordination degree of Ningxia and Tianjin at the northern end, as well as Hunan and Guizhou at the southern end, is on the verge of dislocation, indicating that these regions still maintain a low coupling coordination level. Meanwhile, central areas such as Shanxi, Jiangxi, and Hubei are also on the verge of dislocation, which forms the intermediate zone. The central region of Shanxi, Jiangxi, Hubei, and other areas is still on the verge of dislocation, forming an intermediate zone, and the high coupling coordination "T-shaped" coastal vertical axis formed in 2014 in Shandong (0.5318), Jiangsu (0.5168), Zhejiang (0.5367), and Guangdong (0.5483) continues to strengthen, entering the stage of barely coordinated, and with Sichuan, Hubei, Anhui, and other areas, the coupling coordination of the high coupling coordination "T-shaped" coastal vertical axis formed together.

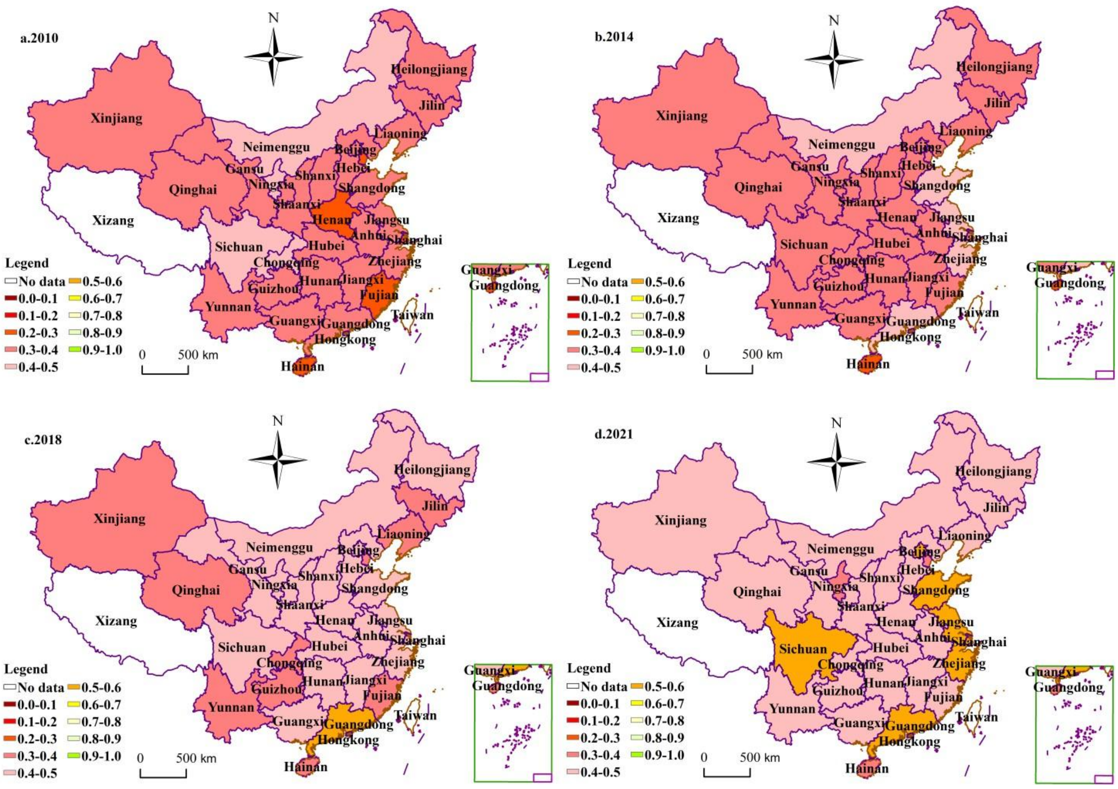

Figure 3. Spatial distribution evolution of coupling coordination degree between green finance and ecological product value realization. (Produced based on the standard map GS [2023] 2767 downloaded from the Ministry of Natural Resources Standard Map Service website, with no modifications to the base map)

In terms of sub-regions, the coordination level in the east is relatively high, rising from 0.3239 in 2010 to 0.4808 in 2021, and transitioning from mildly dysfunctional to on the verge of dysfunctional stage, as shown in *Table 4*. The East has better economic development, a relatively perfect financial system, and the policies related to green finance and ecological product value realization are steadily advancing and in the lead, and the state of coordinated development of the two is steadily improving. The

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coordinated level of the Northeast develops relatively slowly, from 0.3468 in 2010 to 0.4236 in 2021, and also enters the stage of endangered dislocation, but relative to other regions, there is still room to rise, and there is a need to increase support for the coordinated development of green finance and ecological product value realization in the Northeast. The coordinated development level in the central, western, and southwestern regions of the country has improved more steadily, evolving from a mildly dislocated stage during 2010 to 2017 to gradually transition into an endangered dislocation stage after 2018. Overall, the degree of coordination of green finance and ecological product value realization coupling in China is gradually becoming more coordinated, but there is still a gap with high-quality coordination.

Table 4. *Coupling and co scheduling of green finance and ecological product value realization by region*

Year	East		Central		West		Northeast		Southwest	
	D	Level of coordination	D	Level of coordination	D	Level of coordination	D	Level of coordination	D	Level of coordination
2010	0.3239	Mild	0.3190	Mild	0.3533	Mild	0.3468	Mild	0.3616	Mild
2011	0.3361	Mild	0.3148	Mild	0.3247	Mild	0.3299	Mild	0.3230	Mild
2012	0.3440	Mild	0.3323	Mild	0.3394	Mild	0.3396	Mild	0.3391	Mild
2013	0.3656	Mild	0.3423	Mild	0.3508	Mild	0.3609	Mild	0.3457	Mild
2014	0.3810	Mild	0.3464	Mild	0.3660	Mild	0.3681	Mild	0.3610	Mild
2015	0.3972	Mild	0.3565	Mild	0.3741	Mild	0.3754	Mild	0.3772	Mild
2016	0.4115	Marginal	0.3760	Mild	0.3849	Mild	0.3887	Mild	0.3778	Mild
2017	0.4188	Marginal	0.3879	Mild	0.3929	Mild	0.3929	Mild	0.3929	Mild
2018	0.4435	Marginal	0.4159	Marginal	0.3996	Mild	0.3940	Mild	0.3961	Mild
2019	0.4666	Marginal	0.4174	Marginal	0.4008	Marginal	0.4110	Marginal	0.3973	Mild
2020	0.4618	Marginal	0.4161	Marginal	0.4148	Marginal	0.4059	Marginal	0.4204	Marginal
2021	0.4808	Marginal	0.4383	Marginal	0.4261	Marginal	0.4235	Marginal	0.4457	Marginal
Mean	0.4026	Marginal	0.3719	Mild	0.3773	Mild	0.3781	Mild	0.3782	Mild

Diagnosis of obstacle factors within the system of green finance and ecological products value realization

We calculate the top three obstacle factors in the two systems of green finance and ecological product value realization in 2010-2021, according to *Equation 8*, and the results are shown in *Table 5*.

We analyze the obstacle factors of the secondary indicators, and we can know that in the green financial development system, the first obstacle factor in most of the provinces and regions is the expenditure on financial regulation and other affairs (X_6), except for the first obstacle factor in Guangdong and Shandong, which is the depth of agricultural insurance (X_{14}). In most regions, the second obstacle is the depth of agricultural insurance (X_{14}). However, in some regions, such as Shandong and Guangdong, the second obstacle factor shifts to the expenditure on financial supervision and other related affairs (X_6). For Beijing, the second obstacle factor is the market capitalization share of environmental protection enterprises (X_9), while Inner Mongolia and Qinghai have the balance of deposits of financial institutions in local and foreign currencies (X_1) as their second obstacle factor. When examining the third obstacle factor, most provinces face the balance of deposits in local and foreign currencies at financial institutions (X_1). While Beijing has the balance of loans in local and foreign currencies in financial institutions (X_2) as its third obstacle factor. Meanwhile, Inner Mongolia and Qinghai encounter the depth of agricultural insurance

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(X_{14}) as their third obstacle factor, and Guangdong deals with the share of market capitalization of environmental protection enterprises (X_9) as its third obstacle factor.

***Table 5.** The main obstacles and degree of obstacles in realizing the value of green finance and ecological products*

Region	Green finance			Value realization of ecological products		
	First obstacle factor (handicap (%))	Second obstacle factor (handicap (%))	Third obstacle factor (handicap (%))	First obstacle factor (handicap (%))	Second obstacle factor (handicap (%))	Third obstacle factor (handicap (%))
Beijing	X_6(24.12)	X_9(11.00)	X_2(10.55)	Y_{17}(27.84)	Y_{15}(13.52)	Y_3(5.49)
Tianjin	X_6(21.48)	X_{14}(13.62)	X_1(12.42)	Y_{17}(26.91)	Y_{15} (13.09)	Y_3(5.90)
Hebei	X_6(21.41)	X_{14}(14.75)	X_1(11.18)	Y_{17}(28.64)	Y_{15} (13.89)	Y_3(5.92)
Shanxi	X_6(19.52)	X_{14}(14.73)	X_1(12.33)	Y_{17}(28.19)	Y_{15} (13.71)	Y_3(5.12)
Inner Mongolia	X_6(20.58)	X_1(13.19)	X_{14}(12.96)	Y_{17}(30.45)	Y_{15} (14.79)	Y_{25}(5.34)
Liaoning	X_6(18.71)	X_{14}(14.79)	X_1(11.59)	Y_{17}(28.01)	Y_{15} (13.80)	Y_3(5.70)
Jilin	X_6(19.81)	X_{14}(13.52)	X_1(12.68)	Y_{17}(27.47)	Y_{15} (13.37)	Y_3(5.54)
Heilongjiang	X_6(21.16)	X_{14}(14.08)	X_1(12.50)	Y_{17}(28.30)	Y_{15}(13.66)	Y_3(5.54)
Shanghai	X_6(21.42)	X_2(10.28)	X_{14}(10.27)	Y_{17}(27.51)	Y_{15}(13.38)	Y_3(5.28)
Jiangsu	X_6(21.93)	X_{14}(17.04)	X_3(9.79)	Y_{17}(29.05)	Y_{15}(14.07)	Y_3(6.25)
Zhejiang	X_6(20.52)	X_{14}(16.66)	X_1(9.75)	Y_{17}(29.18)	Y_{15}(14.17)	Y_3(6.19)
Anhui	X_6(20.62)	X_{14}(14.20)	X_1(11.76)	Y_{17}(28.07)	Y_{15}(13.63)	Y_3(5.99)
Fujian	X_6(20.86)	X_{14}(15.13)	X_1(11.66)	Y_{17}(28.03)	Y_{15}(13.26)	Y_3(6.12)
Jiangxi	X_6(20.53)	X_{14}(14.35)	X_1(12.10)	Y_{17}(28.28)	Y_{15}(13.77)	Y_3(5.16)
Shandong	X_{14}(17.34)	X_6(16.06)	X_1(11.08)	Y_{17}(29.96)	Y_{15}(14.42)	Y_3(6.23)
Henan	X_6(18.16)	X_{14}(15.33)	X_1(11.45)	Y_{17}(28.63)	Y_{15}(13.86)	Y_3(6.18)
Hubei	X_6(20.35)	X_{14}(15.29)	X_1(11.54)	Y_{17}(27.99)	Y_{15}(13.51)	Y_3(6.03)
Hunan	X_6(20.66)	X_{14}(14.80)	X_1(12.18)	Y_{17}(28.49)	Y_{15}(13.63)	Y_3(5.65)
Guangdong	X_{14}(18.20)	X_6(17.35)	X_9(10.90)	Y_{17}(30.27)	Y_{15}(14.71)	Y_3(6.57)
Guangxi	X_6(19.30)	X_{14}(14.71)	X_1(12.13)	Y_{17}(28.75)	Y_{15}(10.78)	Y_3(6.16)
Hainan	X_6(20.54)	X_{14}(13.87)	X_1(12.56)	Y_{17}(27.10)	Y_{15}(11.93)	Y_3(5.94)
Chongqing	X_6(21.49)	X_{14}(15.80)	X_1(12.65)	Y_{17}(26.54)	Y_{15}(13.43)	Y_3(5.64)
Sichuan	X_6(18.98)	X_{14}(14.95)	X_1(10.86)	Y_{17}(27.17)	Y_{15}(14.29)	Y_{16}(4.98)
Guizhou	X_6(20.54)	X_{14}(14.45)	X_1(12.02)	Y_{17}(27.83)	Y_{15}(13.29)	Y_3(5.76)
Yunnan	X_6(20.58)	X_{14}(14.50)	X_1(12.07)	Y_{17}(28.42)	Y_{15}(13.79)	Y_3(5.56)
Shaanxi	X_6(19.36)	X_{14}(15.22)	X_1(12.02)	Y_{17}(28.14)	Y_{15}(13.62)	Y_3(5.31)
Gansu	X_6(20.44)	X_{14}(14.33)	X_1(12.64)	Y_{17}(28.29)	Y_{15}(13.60)	Y_3(4.86)
Qinghai	X_6(21.21)	X_1(13.33)	X_{14}(12.31)	Y_{17}(27.91)	Y_{15}(13.38)	Y_{25}(5.02)
Ningxia	X_6(21.20)	X_{14}(13.82)	X_1(13.49)	Y_{17}(25.41)	Y_{15}(13.76)	Y_3(5.42)
Xinjiang	X_6(20.86)	X_{14}(13.00)	X_1(12.60)	Y_{17}(28.18)	Y_{15}(13.78)	Y_3(5.32)

Meanwhile, in the ecological products value realization system, the first obstacle factor of each province and region is the development of tourism income of A-class scenic spots (Y_{17}), and the development of the forestry industry (Y_{15}) is the second obstacle factor of each province and region. Except for Sichuan, Inner Mongolia, and Qinghai, where the third obstacle factor is the total amount of ecological water use (Y_{16}) and the number of key enterprises for heavy metal pollution prevention and control that should be monitored (Y_2), the third obstacle factor for other regions is the new grass planting area in the year (Y_3).

Based on China's regional development strategy and natural geographical characteristics, we adopt the standard regional division method of the National Bureau of Statistics of China to scientifically divide the 30 provinces within the scope of our study into five major regions. These regions are the East, the Central, the West, the Northeast, and the Southwest. The specific division results are shown in *Table 6*.

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***Table 6.** Research on regional distribution and provincial composition*

Region	Provinces
East	Hebei, Beijing, Tianjin, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Hainan
Central	Shanxi, Henan, Anhui, Hubei, Jiangxi, Hunan
West	Chongqing, Sichuan, Yunnan, Guizhou, Guangxi, Shaanxi, Gansu, Ningxia, Qinghai, Xinjiang, Inner Mongolia
Northeast	Liaoning, Jilin, Heilongjiang
Southwest	Guangxi, Chongqing, Sichuan, Guizhou, Yunnan

To further explore the degree of barriers to green finance and ecological products value realization subsystems in each region, we analyze the degree of barriers of first-level indicators by region and year, and the results are shown in *Table 7*.

***Table 7.** Barrier levels for regional green finance and ecological product value realization criteria in China*

Region of China	Year	Green finance			Value realization of ecological products		
		Scale development	Efficiency development	Structural development	Input capacity	Operational capability	Organizational capacity
East	2010	0.2850	0.2535	0.4616	0.3039	0.5503	0.1458
	2014	0.2908	0.2594	0.4498	0.2875	0.5714	0.1411
	2018	0.2859	0.2771	0.4370	0.2929	0.5861	0.1210
	2021	0.2700	0.2833	0.4467	0.2850	0.6033	0.1117
Central	2010	0.2967	0.2529	0.4504	0.3042	0.5457	0.1501
	2014	0.3067	0.2590	0.4343	0.2942	0.5652	0.1406
	2018	0.3117	0.2683	0.4200	0.2813	0.5879	0.1308
	2021	0.3350	0.2318	0.4332	0.2978	0.5882	0.1139
West	2010	0.2999	0.2512	0.4489	0.3230	0.5115	0.1656
	2014	0.3169	0.2565	0.4266	0.2921	0.5586	0.1493
	2018	0.3252	0.2630	0.4118	0.2953	0.5653	0.1394
	2021	0.3334	0.2550	0.4116	0.2988	0.5767	0.1246
Northeast	2010	0.3004	0.2546	0.4450	0.2969	0.5470	0.1561
	2014	0.3093	0.2603	0.4304	0.2856	0.5654	0.1491
	2018	0.3175	0.2787	0.4038	0.2979	0.5688	0.1333
	2021	0.3442	0.2532	0.4026	0.3067	0.5700	0.1233
Southwest	2010	0.2973	0.2489	0.4538	0.3205	0.5522	0.1144
	2014	0.3076	0.2548	0.4376	0.2944	0.5959	0.0984
	2018	0.3121	0.2627	0.4252	0.2930	0.6110	0.0869
	2021	0.3262	0.2402	0.4336	0.2851	0.6382	0.0665
Nationwide	2010	0.2978	0.2495	0.4526	0.3103	0.5348	0.1549
	2014	0.3082	0.2537	0.4380	0.2904	0.5648	0.1448
	2018	0.3137	0.2629	0.4234	0.2919	0.5771	0.1309
	2021	0.3273	0.2455	0.4272	0.2948	0.5872	0.1180

(1) In the green finance system, the obstacle degree order from 2010 to 2021 is structural development > scale development > efficiency development across the country and regions. This situation is likely caused by a single supply structure and an unreasonable market structure in the green finance sector. Despite the dominance of green

credit, other financial products such as green bonds, funds, and insurance are lagging behind and failing to meet the diverse financing needs. Green credit is mainly led by large banks, with low participation from smaller banks, focusing supply on large enterprises and projects while neglecting localized green projects. Policy implementation strength and effects vary regionally, affecting green finance scale growth. Green projects are complex, and risk assessment is difficult, hindering investment efficiency. Inefficiencies in policy implementation further constrain efficiency.

(2) In the value realization system of ecological products, we determine that the obstacle degree ranking from 2010 to 2021 is operational capacity > input capacity > organizational capacity. Operational capacity is the primary obstacle. Ecological products are complex and require specialized knowledge and skills for production and management. Insufficient operational capacity leads to inefficient production and unmet market demand. Information asymmetry and high transaction costs in the market further limit operational capacity. However, increased policy support and financial investment, along with technological advancements and growing public awareness, have improved input and organizational capacity, reducing their obstacle strength.

Analysis of external influences on green finance and ecological products value realization system

Analysis of the results of external influences

We use the Tobit Model to regressively analyze the external influences of the coupling coordination system of green finance and ecological products value realization, and the results obtained are shown in *Table 8*.

We can learn from the regression results of the Tobit Model that all five independent variables passed the significance test, and the degree of government intervention (GID), the level of farmers' income (FIL), the level of technology market development (TML), the level of industrial structure development (ISD), and the level of transportation basic facilities (TBF) are significant at the 5% level. Ranked by the magnitude of their coefficients from smallest to largest impact: TML(0.1956), GID(0.1511), ISD(0.1266), FIL(0.0901), and TBF(0.0237). The evidence shows that the level of technology market development, the degree of government intervention, and the level of industrial structure development in China's provinces have a greater impact on the degree of coordination of the coupling of green finance and eco-products value realization in 2010-2021, while the level of farmers' income and the level of transportation basic facilities have a relatively small impact.

Table 8. *Regression results of external influences on the coupling coordination system*

Y	Coef.	Std.Err	Z-value	P-value
Degree of government intervention (GID)	0.1511***	0.1869	8.0843	0.0000
Level of farmers' income (FIL)	0.0901***	0.0044	20.4334	0.0000
Level of technology market development (TML)	0.1956***	0.0670	2.9222	0.0035
Level of industrial structure development (ISD)	0.1266***	0.0174	7.2725	0.0000
Level of transportation basic facilities (TBF)	0.0237***	0.0029	8.2613	0.0000
Adjust-R^2	0.7020			
D.W	1.6968			
F	170.1514			

*, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively

First, provinces with a higher level of technology market development have a sound mechanism for technology research and development and transformation, making it easier for green financial institutions to enlarge the "eco-cake," transform the "eco-cake," and distribute the "economic cake" (Chen et al., 2022), providing technical support and market opportunities for realizing the value of ecological products. Second, government intervention influences the coordinated development of the two couplings with policy support and financial input, stimulates the enthusiasm for green financial investment with the establishment of a special fund for green finance, the implementation of ecological environmental protection policies, and other measures to enhance the market demand for ecological products and improve the overall market environment. In addition, the level of industrial structure development influences both the proportion and structural characteristics of green industries. As high-pollution and high-energy-consumption industries shrink while green industries expand, market demand for ecological products increases. In response to these industrial structure changes, green financial institutions allocate funds to ecological projects and energy-saving industries while providing financial support for agricultural ecologization, decarbonization, and greening initiatives (Van Veelen, 2021). This coordinated approach significantly enhances the synergistic effect between industrial transformation and green finance. However, the level of farmers' income and the level of transportation basic facilities have relatively small impacts on the synergistic development, probably because the decision-making related to the realization of green finance and ecological products pays more attention to the macroeconomic environment, technological innovation, and policy support, and the improvement of farmers' income can indirectly increase the demand for ecological products but has a limited impact on green finance. Green finance investment decisions are mainly focused on environmental technology and large-scale green projects, and transportation infrastructure improvement mainly affects logistics and supply chain efficiency, which has no direct impact on the core concerns of green finance and does not reflect sufficient power to promote synergistic development of the two.

Analysis of robustness tests

To test the reliability of the above estimates, we perform the following robustness tests: (1) Shortening the sample years. Shortening the time from 2010-2020 to 2010-2016 is re-regressed, and the results are shown in the first column of *Table 8*. (2) Re-measurement of explanatory variables. The second column of *Table 8* shows the results from re-estimating the level of fiscal intervention using local fiscal expenditures and revenues, as well as the level of technology market development using internal expenditures on R&D funding relative to GDP. (3) Adding explanatory variables. Adding the level of urbanization (UBL) and the level of opening to the outside world (OUW) enriches the study dimensions, and the results are shown in the third column of *Table 8*. As can be seen from *Table 9,* the sign of the estimated coefficients of all explanatory variables on the degree of coordination of the coupling of green finance and ecological products value realization does not change, and only the estimated coefficient magnitude and significance level change, but do not result in substantial changes. Therefore, the above estimation results pass the robustness test.

Analysis of regional heterogeneity

Building on previous research (Xing et al., 2021) and the National Sustainable Development Plan for Resource-Based Cities, we classify the 30 provinces in China into

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two categories based on their mineral resource endowment and economic contribution: resource-based (16 provinces) and non-resource-based (14 provinces). The specific classification is shown in *Table 10*.

Table 9. *Results of robustness test*

Variables	Shortening the sample years	Re-measurement of explanatory variables	Adding explanatory variables
GID	0.1386***	0.0123***	0.1520***
FIL	0.0704***	0.0889***	0.0604***
TML	0.0975	0.3009***	0.1375***
ISD	0.1097***	0.1050***	0.1663***
TBF	0.0251***	0.0186***	0.0223***
UBL			-0.0417***
OUW			0.1820***
Adjust-R^2	0.5292	0.6811	0.7175
D.W	1.6982	1.6717	1.7310
F	47.9800	151.1852	131.2436

*, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively

Table 10. *Classification of resource-based and non-resource-based provinces in China*

Classification	Provinces
Resource-based regions	Qinghai, Shanxi, Inner Mongolia, Heilongjiang, Liaoning, Hebei, Shaanxi, Xinjiang, Gansu, Ningxia, Shandong, Henan, Guizhou, Anhui, Jiangxi, Jilin
Non-resource-based regions	Beijing, Tianjin, Shanghai, Chongqing, Jiangsu, Zhejiang, Guangdong, Hubei, Hunan, Sichuan, Yunnan, Guangxi, Hainan, Fujian

We analyze the heterogeneity of the factors influencing the synergistic development of green finance and ecological products value realization by dividing the 30 provinces in China into resource-based and non-resource-based regions (Xing et al., 2021), and the results are shown in *Table 11*.

Table 11. *Regional heterogeneity analysis*

Variables	Resource-based regions				Non-resource-based regions			
	Coef.	Std. Err	Z-value	P-value	Coef.	Std. Err	Z-value	P-value
GID	0.0621***	0.0235	2.6439	0.0082	0.1349***	0.0384	3.5101	0.0004
FIL	0.0908***	0.0061	14.8754	0.0000	0.0964***	0.0058	16.6235	0.0000
TML	0.1574	0.1601	0.9831	0.3256	0.2080***	0.0668	3.1136	0.0018
ISD	0.0561***	0.0251	2.2380	0.0252	0.2018***	0.0213	9.4821	0.0000
TBF	0.0098*	0.0059	1.6782	0.0933	0.0929***	0.0035	5.5075	0.0000
R^2	0.6378				0.8228			
Adjust-R^2	0.6280				0.8174			
D.W	1.7878				1.7055			
F	65.4941				150.4927			

*, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively

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The results show that the degree of government intervention in resource-based and non-resource-based regions has a significantly positive effect on the coupled and coordinated development of the two from 2010 to 2021, but the effect is greater in non-resource-based regions. Resource endowment and policy support are crucial for promoting the development of green finance (Shao and Huang, 2023). In non-resource-based regions, the government places greater emphasis on implementing policies effectively and enhancing efficiency. It ensures smooth policy execution by strengthening supervision, improving laws and regulations, and increasing the transparency of information disclosure, which in turn promotes the rapid development of green finance and the realization of ecological product value. In addition, the level of technology market development has a significantly positive effect on the synergistic development of the two, but not in resource-based regions, possibly because the focus of economic activities in resource-based regions tends to be on resource extraction and processing, while green finance and technological innovation may be considered secondary or auxiliary means of development. With regard to the level of farmers' income, the impact on both resource-type and non-resource-type areas is significantly positive, and the increase in farmers' income has a greater effect on the demand for environmentally friendly products. The impact of the level of industrial structure development is significantly positive in both types of areas, but the impact on non-resource areas is greater, probably because non-resource areas have relative advantages in industrial structure diversification, technological innovation and industrial upgrading, and policy support. In contrast, the industrial structure of resource-based regions tends to be relatively homogeneous, with a high degree of dependence on the extraction and processing of one or several types of resources, making resource-based regions more vulnerable in the face of challenges such as resource depletion and changes in market demand and making it difficult for them to quickly adjust their industrial structure to the new economic environment. In addition, the level of transportation basic facilities has a significant positive impact on both types of areas, with a slightly larger effect on non-resource-based areas, highlighting that it also plays an integral role in the synergistic development of the two.

Conclusions and recommendations

Conclusions

Based on the research sample of 30 provinces, autonomous regions, and municipalities in China from 2010 to 2021, we use the Coupling Coordination Model, Kernel Density Estimation, Obstacle Degree Model, and Tobit Model to study the spatio-temporal characteristics and driving factors of the coupling coordination of green finance and the realization of the value of ecological products, and the main conclusions we got are as follows.

(1) From the results of the Coupling Coordination Model, we can see that the degree of coupling coordination between green finance and ecological products value realization are both on the rise, consistent with the national conclusions of Dong et al. (2023). However, our research further confirms the imbalance in regional development (Xu and Wang, 2023). The number of provinces and regions with mild dysfunctions has shrunk significantly, the number of provinces and regions on the verge of dysfunctions is expanding, the number of provinces and regions that are barely coordinated is gradually increasing, and the number of provinces and regions with mild dysfunctions is increasing. This finding provides an important supplement to the empirical research proposed by

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Zhang et al. (2022). The spatial layout expands from the inland to the coastal area (Cao et al., 2022), transitioning from the northwest-east region axis with linear (I-shaped) development in 2010 to the southeast coastal region with intersecting (T-shaped) development in 2014, expanding from the inland to the coastal area. In 2018, it will expand inward from the "T-shape" of the southeastern coast, showing the development of the east-central-west region axis with linear (I-shaped), and in 2021, it will develop into a spatial development of the north and south poles with a central zone (T-shaped). This spatial evolution pathway provides new empirical support for the coastal priority diffusion trend proposed by Wang et al. (2024).

(2) Our Kernel Density Estimation analysis revealed that the global-scale curve's main peaks followed a "rising-declining-rising" evolutionary pattern during the study period, which partially aligns with the findings of Liu et al. (2023). The pattern of wave peaks has changed from "sharp and narrow" to "flat and level," indicating that the absolute difference in the level of coordination of the coupling of green finance and ecological products value realization has shown a tendency to widen, and the overall level has shown a fluctuating upward trend (Song and Du, 2024). On a local scale, the distribution of nuclear density curves in the five regions is extremely irregular, with a clear gradient effect in the level of internal coupling coordination and a tendency toward multipolarization. This verifies the gradient effect hypothesis proposed by Huang et al. (2022) and also reveals a clear trend toward multipolarization (Wang et al., 2022).

(3) Our analysis of the Tobit Model results indicates that government intervention, farmers' income, technology market development, industrial structure development, and transportation basic facilities positively influence the coordinated development of the two systems and provide an important supplement to research on regional heterogeneity. Additionally, the key positive factors in each region are government intervention and industrial structure development (Yue et al., 2024), which show significant positive effects in both resource and non-resource regions, with a more pronounced impact in non-resource regions (Li et al., 2024).

Recommendations

Based on these findings, we make the following policy recommendations:

(1) *Improve the top-level design of green finance and ecological products value realization, and strengthen the precision and effectiveness of government intervention.* The degree of government intervention has a positive impact on the coordinated development of green finance and the realization of ecological product value (Shao and Huang, 2023), and a unified standard system of green finance and transition finance should be established (Wang et al., 2022) to realize the multiplier amplification effect of "four two pounds to a thousand catties" through the organic complementarity of policy-based carbon finance and commercial carbon finance (Wang and Gao, 2024). Guiding green finance to support integrated ecological and environmental services such as regional and watershed environmental governance, overall solutions, and supporting collaborative innovation pilots for pollution reduction and carbon reduction in resource-oriented cities and industrial parks (Hu et al., 2023). Improve the system for confirming and registering the rights to sewage, water, and other ecological resources and trading, as well as establishing a cross-regional compensation mechanism for environmental protection. Thoroughly advance the prevention and management of pollution in resource-dependent regions and implement pilot demonstrations of integrated pollution control and ecological restoration. Promote market-oriented strategies to rejuvenate natural

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resources, enhance the precision and efficacy of governmental interventions, and facilitate the recognition of ecological product value within green financial services.

(2) *Actively build a spatially linked synergistic development pattern that couples and coordinates the realization of the value of green finance and ecological products.* Encourage Jiangsu, Zhejiang, Guangdong, and other regions with high levels of coupling and coordination in the "T-shaped" coastal vertical axis to play a good role in demonstrating and leading (Bhattacharyya et al., 2021) and to radiate and drive the development of neighboring regions through policy synergism, information sharing, resource integration, and technology transfer. In this way, a favorable situation of complementary advantages and synergistic development will be formed. For regions with a low degree of coupled coordination, it is necessary to expand the new mode of realizing the value of ecological products of green financial services, take the initiative to strengthen the synergistic linkage with neighboring regions in the financial support of ecological environment-oriented development (EOD) projects, take cities with a high level of coordination as a benchmark for development, strengthen the sustainability of ecological support of green financial support, narrow the regional disparities and multi-polarization (Chen et al., 2022), and then achieve the spatial linkage of the degree of coupled coordination of the two and coordinated development.

(3) *To formulate strategies for coordinated regional development of green finance and value realization of ecological products according to local conditions.* As a pioneer zone for green financial development, the East should support green financial institutions in exploring the use of resource and environmental elements as qualified collateral (Chen et al., 2025), developing new products such as green asset-backed securities related to resource and environmental elements, and developing ecological natural resource financing products and services in a steady manner. The western region should increase policy support, guide financial capital investment in green industries and environmental protection projects (Zhang and Xu, 2024), explore regional financial support models for ecological and environmental protection projects (Fang et al., 2024), and support the construction of major projects in the field of ecology and environment. The central region should rely on its own industrial foundation to promote the deep integration of green finance and industrial upgrading, increase the construction of green transportation infrastructure (Yurui et al., 2021), and strengthen the application of scientific and technological innovation in the realization of the value of green finance and ecological products (Jiakui et al., 2023). The northeastern region must expedite the transformation and enhancement of its industrial structure while examining and refining the technological standards for access, trading, and services related to the carbon market. This initiative encompasses advocating for carbon emission reductions within pivotal industries and urging green financial institutions to improve their financial goods and services by utilizing carbon footprint data (Bedendo et al., 2023). The southwest region should rely on its own resources and environmental advantages, guide green financial institutions to support the integrated development of industrial digitalization and greening, broaden the sales channels of ecological products through branding of agricultural products, e-commerce, and other means, raise the level of farmers' income, and promote green consumption.

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