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# The Coupling Relationship between Green Finance and Ecosystem Service Demand in China Based on an Improved Coupling Coordination Degree Model

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**Abstract:** With the rapid development of society and economy, people's demand for ecosystem services is constantly increasing. All countries support this demand by vigorously developing green finance. The coordinated development of green finance and ecosystem service demand is of great significance for sustainable development. Most of the existing studies separately study green finance or ecosystem service demand, separating the relationship between the two. At present, there is still a lack of clear understanding of the coupling relationship between green finance and ecosystem service demand. In addition, in the existing coupling relationship calculation models, the setting of relevant parameters is subjective. Therefore, based on the green finance and ecosystem service demand database of 30 provinces in China from 2010 to 2017, this paper firstly evaluates the green finance and ecosystem service demand quantitatively, and then analyzes the coupling coordination relationship between them by using an improved coupling coordination degree model. The results show that: (1) compared with the traditional coupling coordination degree model, the contribution coefficient of each subsystem in the improved coupling coordination degree model has a more sufficient basis, and more objective evaluation results; (2) from 2010 to 2017, the level of green finance in China's provinces increased significantly, showing a spatial pattern of "high in the east and low in the west"; the ecosystem services demand increased first and then decreased, with an increase in nearly two-thirds of provinces; (3) the coupling coordination relationship between green finance and ecosystem service demand in China's provinces was optimized continuously from 2010 to 2017, showing the spatial differentiation of "eastern China > central China > northeast China > western China"; (4) in 2017, the coupling coordination degree of green finance and ecosystem service demand in Guangdong Province was the highest, reaching a high level of coordination, while Qinghai Province was the lowest, as a result of a serious level of incoordination. It is worth noting that the comprehensive development level of green finance in China is still low and seriously lags behind the development level of ecosystem services demand. In the future, green and low-carbon transformation should be accelerated to promote the sustainable development of financial ecology.

**Keywords:** green finance; ecosystem service demand; coupling coordination relationship



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## 1. Introduction

The natural ecological environment provides essential ecosystem services for human beings [1], is the space for human survival, and is also the basis of sustainable economic and social development [2]. China's economy has maintained a fast growth rate in the past 40 years, with an average annual GDP growth rate of 10%. However, due to the long-term use of a factor input-driven economic growth mode characterized by sacrificing the ecological environment and consuming large amounts of resources, economic growth has gradually slowed down in recent years: GDP growth dropped to 6.7% in 2018, 6.0% in

2019, and 2.2% in 2020. At the same time, problems, such as resource shortage, environmental pollution, and ecological deterioration, have become increasingly prominent [3]. In response to the above problems, the Chinese government pointed out in the Boao Forum for Asia in 2010 that "green economy is the trend of the times in today's world" [4]. The adoption of the United Nations 2030 Agenda for Sustainable Development and the New Urban Agenda also show that the "green economy", as a new development model, has attracted global attention [5]. As the core of the modern economy, finance is an effective means to promote the coordinated development of the natural environment, economy, and society [6]. The transformation of the economic development mode from a high-carbon model to a low-carbon model is inseparable from the reform and innovation of finance. Based on the actual situation of economic development and ecological environment, China has proposed to develop green finance [7]. Green finance can not only promote high-quality economic development but also be the core driving factor for improving ecological environment [8]. It is an inevitable trend in China's economy to promote the coordinated development of ecological environment and economy and society through green finance.

As a bridge connecting natural environmental systems and economic and social systems, ecosystem service research includes two aspects: it not only pays attention to the supply of ecosystem services generated by the natural environment, but also pays attention to the ecosystem service demand for the benefit of economic and social activities [9]. In recent years, the research on ecosystem services has developed rapidly. Quantitative measurement of the correlation and collaborative evolution trend between ecosystem services and natural environment [10,11], economic, and social systems [12,13], as well as the supply and demand of ecosystem services [14,15], has become a research hotspot in this field. The eco-environmental protection principle adopted by green finance is very consistent with the concept of coordinated development [16]. However, at present, there are few studies on the coordinated development of green finance and ecosystem services in the world. Most of the existing studies study the relationship between green finance and the economic and social system from the external perspective of "economy explains economy". For example, Wang et al. studied the different stages of the integrated development degree of green finance and related industries, and believed that the initial stage should be resource-driven, and the later stage should strengthen the input of technical elements [17]. Yin et al. analyzed the close relationship between green finance and economy and pointed out that the two have an obvious synergistic effect and are in a highly coordinated and coupled development state [18]. Dong et al. studied the coordination with green finance from the perspective of urbanization, believing that the two have strong spatial agglomeration effects and spatial spillover effects, and urbanization generally lags behind green finance [19]. To sum up, existing research focuses on the single field of ecosystem services or green finance, ignored the organic connection between green development and financial innovation, and still lacks a clear understanding of the coupling relationship between ecosystem services and green finance.

Scale dependence and temporal-spatial heterogeneity are key characteristics of both natural environmental systems and economic and social systems [20], so they have significant time and space coupling characteristics. The quantitative measurement of the coupling relationship between the two is the focus of the cross-research of natural and social sciences. The coupled coordination degree model is widely used in the fields of ecology [21,22], environment [23,24], economy [25,26], society [27,28], and some scholars have also applied it to the study of green finance because of its advantages in a quantitative study of the interaction and interactive coupling relationship between two or more systems [29]. Yu et al. calculated the coupling degree and coordination degree between green finance and social development level and pointed out the positive promoting effect and threshold effect of green finance [30]. Wang et al. established a coupling coordination degree model between green finance and industrial technology innovation, and the results showed that there was strong regional heterogeneity between them [31]. Zhu et al. studied the coupling coordinated development degree of green finance and circular economy and believed that green

finance would fall into a "low development trap" if its development lagged [15]. However, the traditional coupling coordination degree model used in the above study regards the contributions of both subsystems as equally important. Some scholars have questioned this, pointing out that this assignment method is inconsistent with reality, and its distorted results may mislead policymakers to make wrong decisions [32]. Reasonable sub-system contribution coefficient assignments will directly affect the coupling coordination degree, and then affect the accurate evaluation of the coupling coordination relationship between ecosystem service demand and green finance. Therefore, the reasonable improvement of the coupling coordination degree model is still worth further discussion.

To sum up, most current studies focused on green finance or ecosystem service demand individually, and lacked a clear understanding of the coupling relationship between green finance and ecosystem service demand. Therefore, based on the panel data of 30 provinces in China from 2010 to 2017, this paper calculates the demand levels of green finance and ecosystem services by using the global principal component analysis and entropy method. Then, based on the improved coupling coordination degree model, the coupling coordination relationship between the two is quantitatively analyzed to provide scientific reference for the coordinated promotion of green finance and ecological environment construction.

## 2. Study Area and Data Sources

### *2.1. Study Area*

In this paper, 30 provinces in mainland China, excluding Hong Kong, Macao, Taiwan, and Tibet Autonomous Region, are selected as research areas. According to economic regionalization of China, they can be divided into four regions: eastern China, central China, western China, and northeast China (Figure 1).

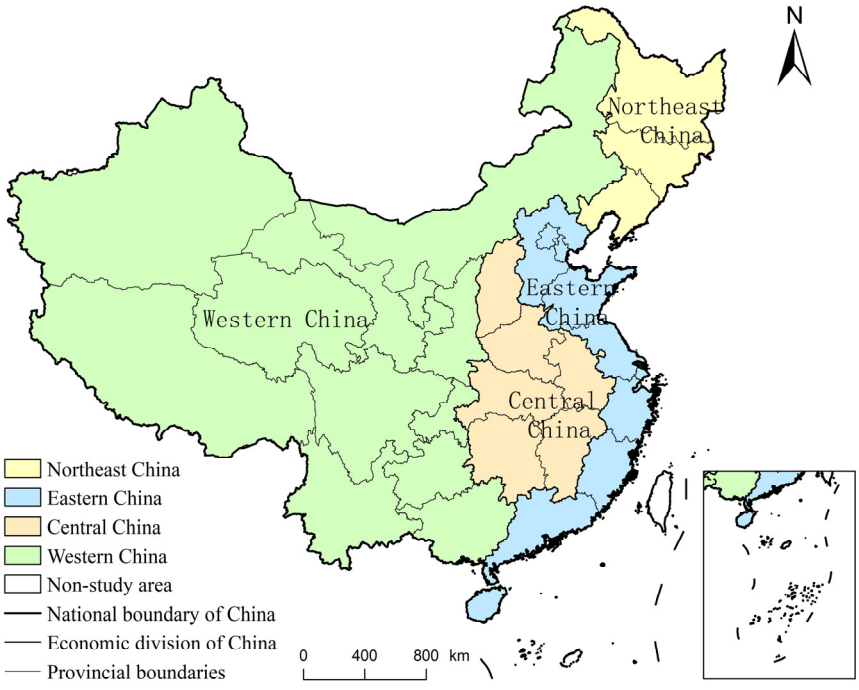


**Figure 1.** The four economic divisions of China.

In 2006, the International Finance Corporation (IFC) partnered with Industrial Bank to launch the first green credit product on the Chinese market. At its 18th National Congress in 2012, the CPC Central Committee included the construction of ecological civilization into the Five-sphere Integrated Plan which refers to China's overall plan for building socialism with Chinese characteristics. The China Banking Regulatory Commission issued

the Green Credit Guidelines, which became the programmed document of China's green credit system. China's green credit policy system began to be established, developed, and gradually improved. More banks are providing green credit, and green financial products are increasingly abundant. In August 2016, seven state ministries jointly issued the Guiding Opinions on Building a Green Finance System, which clarified the definition of green finance in China and established the top-level framework system of green finance. According to China Green Finance Development Report (2018), China issued more than 280 billion yuan of green bonds in 2018, with a stock of nearly 600 billion yuan, making it the country with the largest issuance of such bonds in the world [19]. At the same time, the ecosystem services demand in China also has strong spatial heterogeneity. The ecosystem services demand in most of the western and northern regions is at a low level, indicating that ecosystem services demand is relatively low. In contrast, the regions with high ecosystem services demand are mainly concentrated in the Yangtze River Delta, Pearl River Delta, Beijing-Tianjin-Hebei region, and some densely populated urban areas, as well as the Huang-Huai-Hai Plain [33].

### *2.2. Data Sources*

The data used in this study mainly includes green finance and ecosystem service demand. Green finance data are mainly from the Wind database (www.wind.com.cn/, accessed from 5 September 2022 to 17 October 2022) and the China Environmental Statistical Yearbook (2011–2018). Data on ecosystem service demand are mainly derived from the China Statistical Yearbook (2011–2018), provincial statistical yearbooks of corresponding years, and the China Carbon Accounting Database (https://www.ceads.net.cn/, accessed on 12 November 2022).

## 3. Methods

### *3.1. Evaluation of Green Finance*

Green financial instruments include a variety of products and mechanisms, including green credit, green securities, green insurance, green investment, carbon finance, etc. [34–36]. However, green finance in China is still in its development stage and relevant statistics are lacking. Therefore, referring to relevant studies [37] and following the principles of reflecting the basic connotation of green finance, covering the scope of green finance services, index representativeness and data accessibility, six indicators from four aspects of green credit, green securities, green investment, and carbon finance are selected to construct an evaluation index system of green finance (Table 1).

**Table 1.** China's provincial green finance evaluation index system.

| Criterion | Index | Index Meaning | Unit | Efficiency |
|---|---|---|---|---|
| Green-credit policy | Green finance evaluation Total liabilities of listed companies in environmental protection industry | The total debt generates from *i*th province (city) registers environmental protection listed company in *t*th year | Yuan | – |
| Green securities | Total market value of listed companies in environmental protection industry | The total market value generates from *i*th province (city) registers the environmental protection listed company in *t*th year | Yuan | + |
| Green investment | Expenditure on energy conservation and environmental protection | The total expenditure on energy and environmental protection of the *i*th province (municipality) in *t*th year | Yuan | + |
| | Total investment in environmental pollution control | The total investment in pollution control of *i*th province (city) in *t*th year | | |
| | Total equity investment of listed companies in environmental protection industry | The total equity investment of environmental protection listed companies register in the *i*th province (city) in the *t*th year | Yuan | + |
| Carbon finance | Carbon financial trading volume | Carbon financial trading volume in the *i*th province (city) in the *t*th year | Yuan | + |

The global principal component analysis was used to calculate the comprehensive score of green finance, which is an improvement on traditional principal component analysis. It combines traditional principal component analysis and time series analysis [38]. Therefore, it can be used to process panel data, such as the green finance data of Chinese provinces from 2010 to 2017 in this paper.

### *3.2. Evaluation of Ecosystem Service Demand*

Ecosystem service demand refers to the quantity and quality of services that humans expect to obtain from natural systems, namely the potential demand [39,40]. Typically, latent demand includes not only the actual demand that humans have consumed but also the unfulfilled demand that humans would like to consume within ecosystem services. Accounting for ecosystem service demand is required in terms of both consumption of ecosystem services and the amount expected to be obtained.

Ecosystem services can be divided into nine subtypes [41]. Among them, climate regulation and biodiversity maintenance services belong to the category of "global non-proximity" services [42], while the generation and acquisition of cultural services are subjective, and the consumption process is non-expendable, making it difficult to quantify their demands. Therefore, the supply and demand of these three services—climate regulation, biodiversity maintenance services and cultural services—are not carried out in this paper. Finally, six types of ecosystem services, including food demand, water conservation, carbon sequestration, raw material production, gas regulation, and waste treatment, are selected to analyze ecosystem service demand (Table 2).

**Table 2.** Index system of provincial ecosystem service demand evaluation in China.

| Criterion | Index Meaning | Index Efficiency | Weights | Index Calculation Method |
|---|---|---|---|---|
| Food supply services | Total food demand in *i*th province (city) in *t*th year | + | 0.156 | Food demand = per capita food demand ∗population. Food demand is replaced by consumption (including consumption of grain, oil, vegetables, meat, aquatic products, eggs, milk, melons, and fruits) [43] |
| Water conservation services | Total water demand of *i*th province (city) in *t*th year | + | 0.175 | Water demand = per capitawater consumption ∗ population density. Per capita water consumption, including per capita agricultural, industrial, domestic and ecological water consumption [44] |
| Carbon sequestration services | Total carbon emissions of the *i*th province (city) in *t*th year | + | 0.172 | Carbon sequestration service = per capita carbon emission ∗ population [45] |
| Raw material production | Forestry output value of *i*th province (city) in *t*th year | + | 0.171 | The use of forestry output value represents provinces' demand for ecosystem raw material production services [14,46] |
| Gas regulation | Industrial airpollutants (including smoke dust, $SO_2$, NOx) discharges into the ecosystem in the *i*th province (city) in the *t*th year | + | 0.150 | The total emission of smoke dust, $SO_2$ and NOx is taken as the demand of ecosystem gas regulation service |
| Waste disposal | Wastes include solid wastes and wastewater discharges into the ecosystem in the *i*th province (city) in *t*th year | + | 0.177 | Since statistics show very little solid waste is discarded by industry in each province, only total wastewater discharges are calculated in the actual calculation [14] |

The entropy method was used to determine the weight of the ecosystem service demand evaluation index. Based on the standardized values and weights of evaluation

indicators, the weighted sum model is adopted to calculate the comprehensive score of ecosystem service demand. The calculation formula is as follows:

$$V_i = \sum_{j=1}^{n} \left( W_{ij} \times x'_{ij} \right) \tag{1}$$

where $V_i$ represents the comprehensive score of ecosystem service demand; $n$ is the number of indicators; $W_{ij}$ is the weight of indicators; and $x'_{ij}$ represents the standardized value of evaluation indicators.

### *3.3. Coupling Coordination Degree Model*

In this paper, the coupling coordination degree model is used to measure the coupling relationship between green finance and ecosystem service demand. The coupling coordination degree model is an effective method to analyze the interaction between two systems. Among them, the coupling degree reflects the degree of mutual restriction or dependence between two systems, and the coupling coordination degree reflects the degree of benign coupling interaction between systems [19,47].

#### 3.3.1. Traditional Coupling Coordination Degree Model

The formula of traditional coupling coordination degree model is as follows:

$$C = 2 \left\{ \frac{U \times A}{(U + A)^2} \right\}^{1/2} \tag{2}$$

$$T = \alpha U + \beta A \tag{3}$$

$$D = \sqrt{C \times T} \tag{4}$$

where $C$ is the coupling degree; $T$ is the comprehensive level of green finance and ecosystem service demand; $D$ is the coupling coordination degree between green finance and ecosystem service demand; $U$ and $A$ are green finance comprehensive scores and ecosystem service demand comprehensive score respectively; $\alpha$ and $\beta$ are contribution coefficients of green finance and ecosystem service demand, respectively. It is generally assumed that the green finance subsystem and ecosystem service demand subsystem are equally important, i.e., $\alpha = \beta = 0.5$.

#### 3.3.2. Improved Coupling Coordination Degree Model

To objectively and accurately reflect the coupling relationship between green finance and ecosystem service demand, the corresponding contribution coefficient should be determined comprehensively according to the performance of green finance and ecosystem service demand. When a subsystem is relatively backward, it should be given a relatively large contribution coefficient, to attract more attention from the government and society, and then government and society take effective measures to promote the development of the system, narrow the gap between the systems, and realize the coordinated development of the systems [32,48]. Accordingly, the formula of the improved coupling coordination degree model is as follows:

$$T' = \alpha' U + \beta' A \tag{5}$$

$$\alpha' = \frac{A}{U + A} \tag{6}$$

$$\beta' = \frac{U}{U + A} \tag{7}$$

$$D' = \sqrt{C \times T} \tag{8}$$

where $\alpha'$ and $\beta'$ are the improved contribution coefficients of green finance and ecosystem service demand, respectively. If the comprehensive score U of green finance is low, $\alpha'$ is relatively large, which reminds decision-makers to pay more attention to the development of green finance. If the comprehensive score of A of ecosystem services demand is low, $\beta'$ is relatively large, which reminds policymakers to pay more attention to the improvement of the ecosystem services demand. Referring to relevant studies [24,49], the coupling coordination relationship between the green finance subsystem and the ecosystem service demand subsystem is divided into 3 categories, 8 subtypes, and 24 development modes according to the coupling coordination degree score and the role of the relationship between the two subsystems (Table 3).

**Table 3.** Green finance and coupling coordination degree types of ecosystem service demand.

| Categories | D | Subgroup | Development Modes | |
|---|---|---|---|---|
| Balanced development | $0.8 < D \leq 1$ | High-level coordination | U > A | High coordination—lagging ecosystem services demand |
| | | | U < A | High coordination—lagging green finance |
| | | | U = A | Advanced coordinated development of green finance and ecosystem service demand |
| | $0.7 < D \leq 0.8$ | Favorably coordinated development | U > A | Good coordination—lagging ecosystem services demand |
| | | | U < A | Good coordination—lagging green finance |
| | | | U = A | Well coordinated development of green finance and ecosystem service demand |
| Transitional development | $0.6 < D \leq 0.7$ | Moderate coordination | U > A | Moderate coordination—lagging ecosystem services demand |
| | | | U < A | Moderate coordination—lagging green finance |
| | | | U = A | The green finance and ecosystem services demand will be appropriately coordinated |
| | $0.5 < D \leq 0.6$ | Basic coordination | U > A | Basic coordination—lagging ecosystem services demand |
| | | | U < A | Basic coordination—lagging green finance |
| | | | U = A | The green finance and ecosystem services demand is basically coordinated |
| | $0.4 < D \leq 0.5$ | Low-level coordination | U > A | Low level of coordination—lagging ecosystem services demand |
| | | | U < A | Low level of coordination—lagging green finance |
| | | | U = A | Green finance and coordinated development of low ecosystem services demand |

**Table 3.** *Cont.*

| Categories | D | Subgroup | Development Modes | |
|---|---|---|---|---|
| Unbalanced development | $0.2 < D \leq 0.4$ | Slightly uncoordinated | U > A | Mild incoordination—lagging ecosystem services demand |
| | | | U < A | Mild incoordination—lagging green finance |
| | | | U = A | Green finance and the ecosystem services demand developed slightly incongruously |
| | $0 < D \leq 0.2$ | Seriously uncoordinated development | U > A | Serious incoordination—lagging ecosystem services demand |
| | | | U < A | Serious incoordination—lagging green finance |
| | | | U = A | There is serious incoordination between green finance and the development of the ecosystem services demand |

## 4. Results

### *4.1. Temporal and Spatial Characteristics of Green Finance*

From the time dimension, the development level of green finance in China's provinces improved significantly, showing a spatial distribution pattern of "high in the east and low in the west" (Figure 2). Among them, Guangdong had the best green finance development level, followed by Beijing, Shanghai, Jiangsu, Shandong, Zhejiang, and Hubei provinces. After 2015, the comprehensive scores of green finance in Guangdong Province, Beijing, and Shanghai all exceeded 0.6 and gradually approached 1. Jiangsu Province exceeded 0.5 in 2015. The comprehensive scores of green finance in other provinces were concentrated between 0 and 0.4.

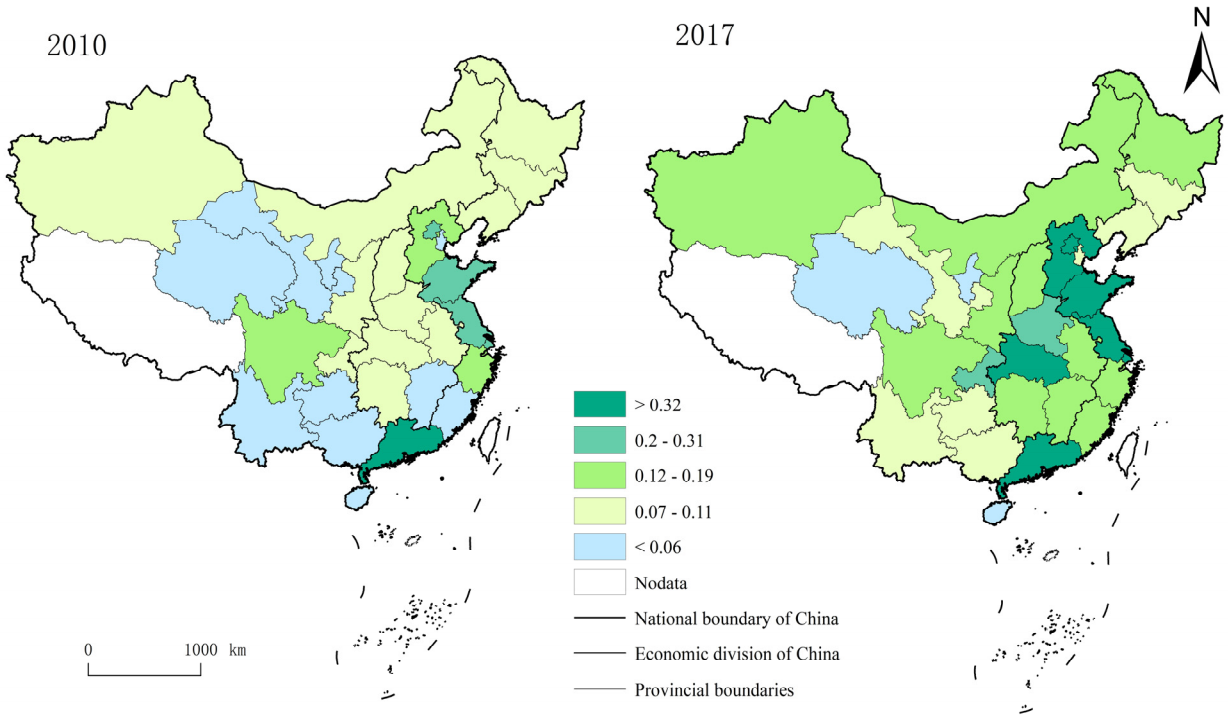


**Figure 2.** Spatial distribution of green finance in China from 2010 to 2017.

In 2010, the level of green finance in China was relatively low, with most provinces (21 provinces account for 70% of the studied provinces) scoring below 0.11. Only Guangdong Province had a high level of green finance development. The remaining eight

provinces (Shandong, Jiangsu, Beijing, Hebei, Fujian, Zhejiang, Henan, and Sichuan), which are all located in eastern China (except for Sichuan and Henan), had values between 0.12 and 0.31.

However, with the development of the national green economy, the development level of green finance in various places had improved significantly. In 2017, most provinces (20 provinces account for 66.7% of the studied provinces) scored above 0.12. Except for Fujian and Hainan, the scores in eastern China were all higher than 0.32. The spatial distribution of provinces with scores between 0.20 and 0.31 tended to move westward. Provinces with scores below 0.11 (Qinghai, Ningxia, Hainan, Gansu, Yunnan, Guizhou, Guangxi, Jilin, and Liaoning) were mainly located in western China.

### *4.2. Temporal and Spatial Characteristics of Ecosystem Service Demand*

From 2010 to 2017, the comprehensive score that represented the ecosystem services demand in China rose and then slightly decreased. There was an upward trend from 0.27 in 2010 to 0.31 in 2015 and then to 0.29 in 2017. There were significant regional differences in China's ecosystem service demand, with the overall characteristics of "central > eastern > northeast > western"(Figure 3). The comprehensive score of ecosystem service demand in China in the central region was the highest, with a range of 0.36–0.41. The comprehensive level of demand for ecosystem services in Shanxi Province, Jiangxi Province, and Hubei Province was very similar, and the evolution trend was basically overlapping. The demand for ecosystem services in the eastern region was clearly polarized, with Guangdong Province having the highest level, reaching 0.7 in 2017. Jiangsu Province and Shandong Province followed, with an overall score between 0.53 and 0.56. However, the overall level of Hainan, Tianjin, and Beijing Provinces was low, remaining below 0.1. Between 2014 and 2015, demand for ecosystem services increased significantly in most provinces and then tended to decline. The overall demand for ecosystem services in China has developed slowly, and the changes in the demand for ecosystem services in the eastern, western, central, and northeastern regions are 33%, 38%, 67%, and 28%, respectively. Overall, demand for ecosystem services increased in most of China's provinces during the study period, with 19 provinces accounting for 63 percent.

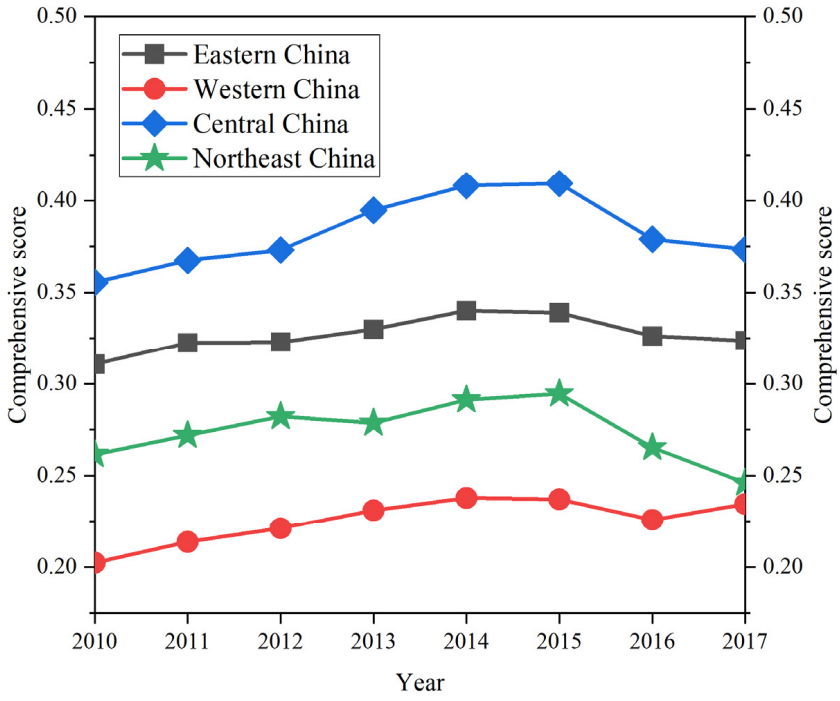


**Figure 3.** Temporal variation of ecosystem service demand in China from 2010 to 2017.

As can be seen from Figure 4, Guangdong has always been the province with the highest level of demand for ecosystem services. The biggest change in ecosystem services demand was in Guizhou, which saw a 44.19 % increase, followed by Sichuan, which saw a 30.98 % increase. Ningxia and Gansu saw a decrease of 15.3 % and 15.26%, respectively. In 2010, only three provinces—Fujian, Anhui, and Sichuan—had ecosystem service demand levels between 0.32 and 0.38. But in 2017, six more provinces—Zhejiang in the east, Guangxi and Yunnan in the west, and Shanxi, Jiangxi, and Hubei in the central region—were added. The spatial distribution shifted from east to east and central.

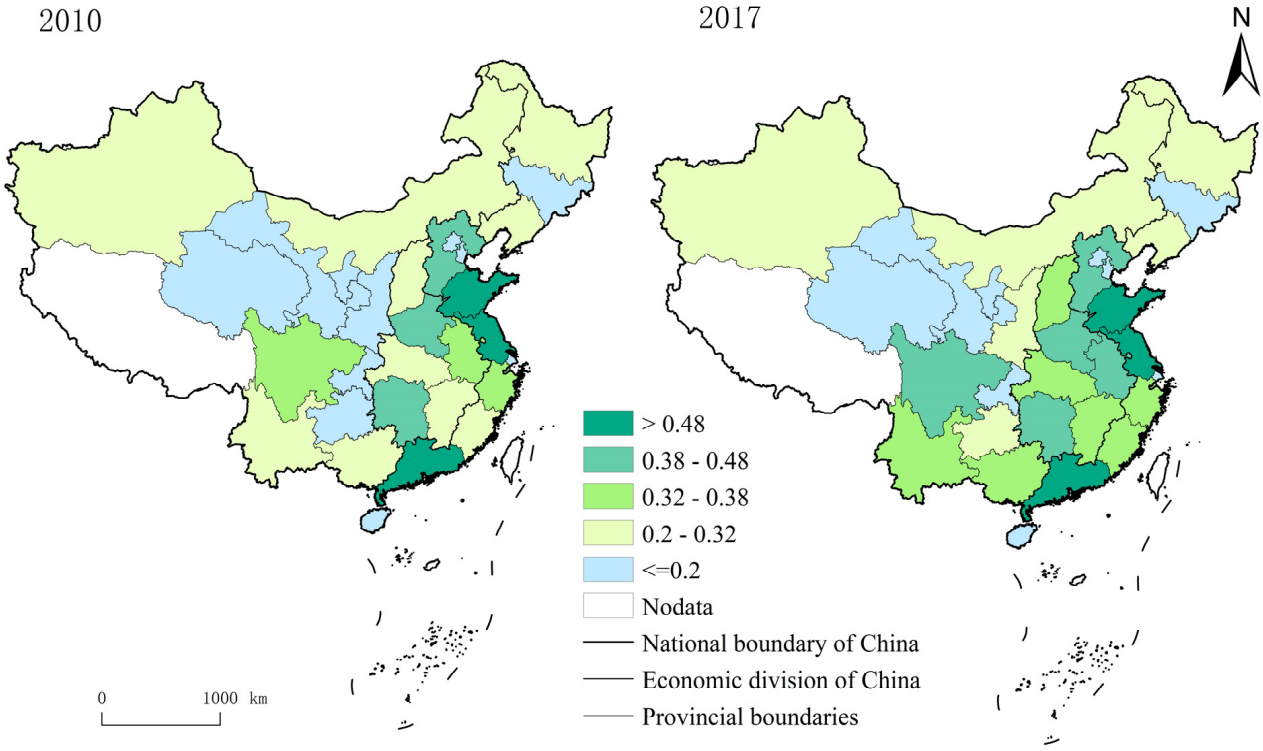


**Figure 4.** Spatial distribution of ecosystem service demand in China from 2010 to 2017.

### *4.3. The Coupling Coordination Relationship between Green Finance and Ecosystem Service Demand*

#### 4.3.1. Traditional Coupling Coordination Model

To verify whether the values of α and β have significant effects on the evaluation results of coupling coordination degree, five different combination scenarios were set (α = 0.2, β = 0.8; α = 0.4, β = 0.6; α = 0.5, β = 0.5; α = 0.6, β = 0.4; α = 0.8, β = 0.2), and the corresponding evaluation results of the coupling coordination degree were compared and analyzed. According to Formulas (2)–(8), the above values of α and β can be substituted to calculate the coupling coordination degree of green finance and ecosystem service demand and its type. Due to space limitation, only Jiangsu Province was selected here as an example to illustrate the results, as shown in Figure 5. The different values of α and β can lead to some differences in the size of coupling coordination degree, and the types of coupling coordination degree. Specifically, from the effects of different α and β values on the coupling coordination degree, when α = 0.2 and β = 0.8, the maximum value of the coupling coordination degree in Jiangsu Province was 0.77, and the minimum value was 0.69. When α = 0.8 and β = 0.2, the maximum and minimum of the coupling coordination degree in Jiangsu Province were 0.75 and 0.55. From the effects of different α and β values combinations on the coupling coordination types, when α = 0.2 and β = 0.8, the coupling coordination type of green finance and ecosystem service demand in 2010–2011 had moderate coordination and good coordination in 2012–2017. When α = 0.8 and β = 0.2, the coupling coordination type of green finance and ecosystem service demand was basic

coordination in 2010–2012, moderate coordination in 2013–2014, and had improved to good coordination in 2015–2017.

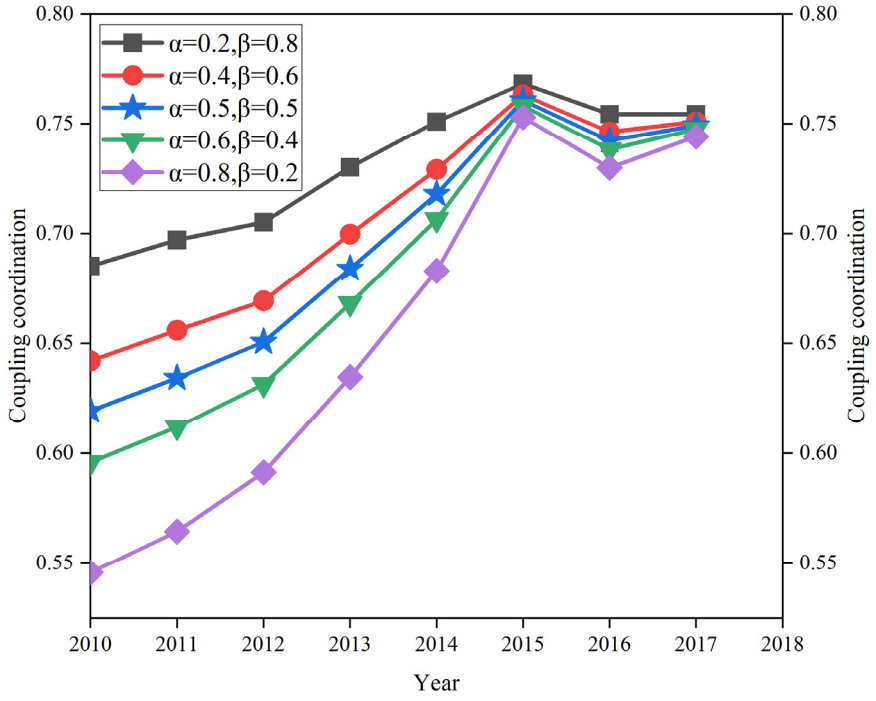


**Figure 5.** Change of coupling coordination degree of green finance and ecosystem service demand in Jiangsu Province based on traditional coupling coordination degree model.

#### 4.3.2. Improved Coupling Coordination Degree Model

(1) Improved contribution coefficient ($\alpha'$, $\beta'$)

Compared with the traditional coupling coordination degree model, which sets $\alpha = \beta = 0.5$, the improved coupling coordination model comprehensively determines the values of $\alpha'$ and $\beta'$ according to the performance of green finance and ecosystem service demand. Based on the comprehensive evaluation results of green finance and ecosystem service demand, the contribution coefficients $\alpha'$ and $\beta'$ of green finance and ecosystem service demand were calculated according to Formulas (7) and (8).

The result is shown in Figure 6. There was sustainable growth in both green finance and ecosystem service demand levels in Jiangsu Province, with the green finance evaluation index rising from 0.259 to 0.549, and the ecosystem service demand index rising from 0.568 to 0.574. The development level of green finance continues to increase, but $\alpha'$ was constantly decreasing, while $\beta'$ was consistent with the changing trend of the demand level of ecosystem services. However, the green finance index was still smaller than the comprehensive index of ecosystem service demand, thus it was always a relatively large $\alpha'$ and a relatively small $\beta'$.

(2) Results of the improved coupling coordination degree model

The coupling coordination degree of ecosystem service demand and green finance saw a continuously optimal trend (Figure 7), but the regional differences of the coupling coordination degree were obvious. The coupling coordination degree of the eastern region was significantly higher than that of central, western, and northeast China. The coupling coordination degree of China's four major economic divisions was in the order of east–central–northeast–west from high to low, with an average of 0.45, 0.40, 0.34, and 0.32, respectively. Specifically, coordination levels in eastern and central regions experienced a process of "mild discoordination—low-level coordination—basic coordination". The northeast and western regions had been in a state of mild disharmony. In addition, the

coupling coordination degree of green finance and ecosystem service demand has been increased in China, but the coupling coordination degree is not high, indicating that the coupling coordination relationship between green finance and ecosystem service demand needs to be further optimized.

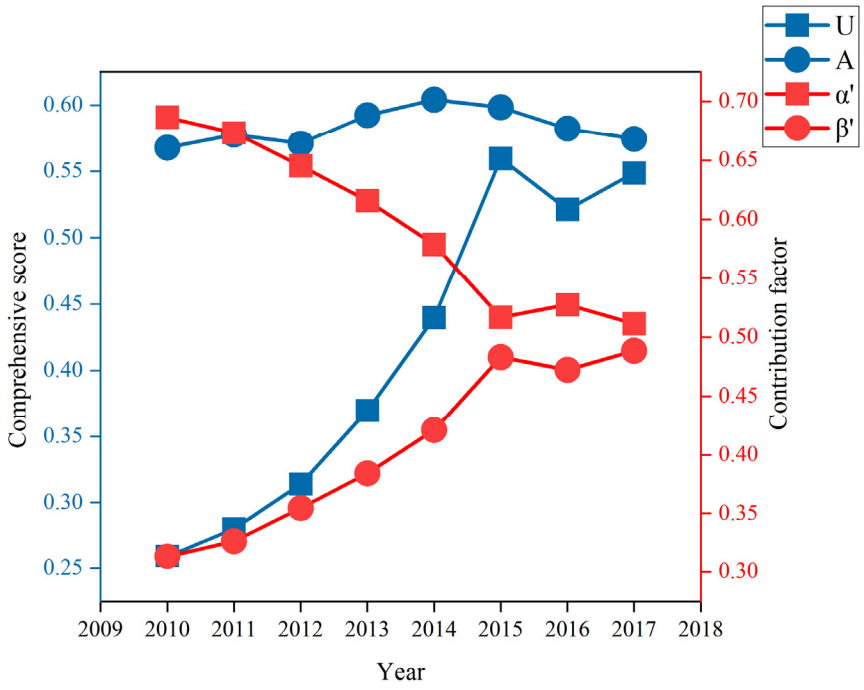


**Figure 6.** Changes of the improved contribution coefficient.

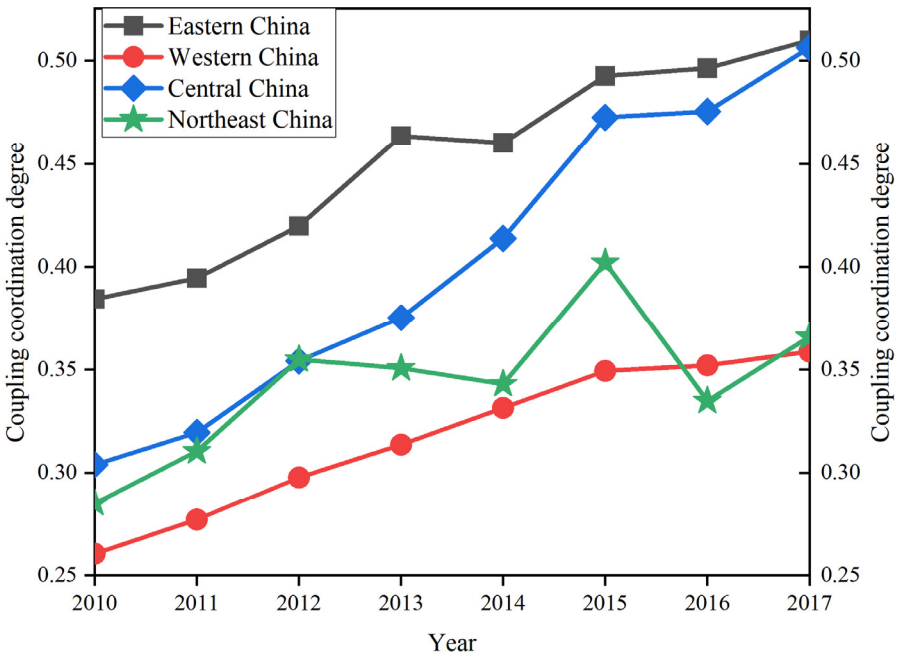


**Figure 7.** Temporal and spatial characteristics of the coupling coordination degree between green finance and ecosystem service demand in China from 2010 to 2017.

During the study period, the coupling coordination degree between green finance and ecosystem service demand increased significantly in the provinces, but there was an expanding trend in the inter-provincial differences.

In 2010, the coupling coordination relationship between green finance and ecosystem service demand in various provinces included six types: high coordination, moderate coordination, basic coordination, low level coordination, mild incoordination, and serious incoordination. Among them, serious incoordination and mild incoordination were the main types, with 11 and 13 provinces, respectively, accounting for 80% of the studied provinces. The 6 other provinces had moderate coordination (Guangdong), basic coordination (Shandong, Jiangsu), and low coordination (Hebei, Henan, Hunan), and were mainly distributed in the eastern region.

In 2017, only Qinghai was still in the stage of serious incoordination, the other provinces improved. The number of mild incoordination provinces decreased by 2, the number of provinces with low level coordination and basic coordination increased to 4, the number of provinces with moderate coordination increased to 3, and Guangdong Province was in the stage of moderate coordination to high coordination stage.

## 5. Discussion

### *5.1. Analysis of Reasons for Temporal and Spatial Differences between Green Finance and Ecosystem Service Demand*

As is shown in Figure 8, the coupling coordination degree between green finance and ecosystem service demand was concentrated between 0.3 and 0.6, with a low level. From the provincial level, only Guangdong Province's coupling coordination degree had been in a state of medium–high coordinated development, while the coupling coordination degree of green finance level and ecosystem service demand of other provinces was still at a low level of development. The overall coupling coordination degree was lowered. At the national level, the coupling and coordination degree between green finance and ecosystem service demand in China was not high, but the overall level and the comprehensive development level of subsystems saw an increasing trend. Therefore, we believe that green finance, the ecosystem services demand, and the coordinated development of the two have bright prospects in the future.

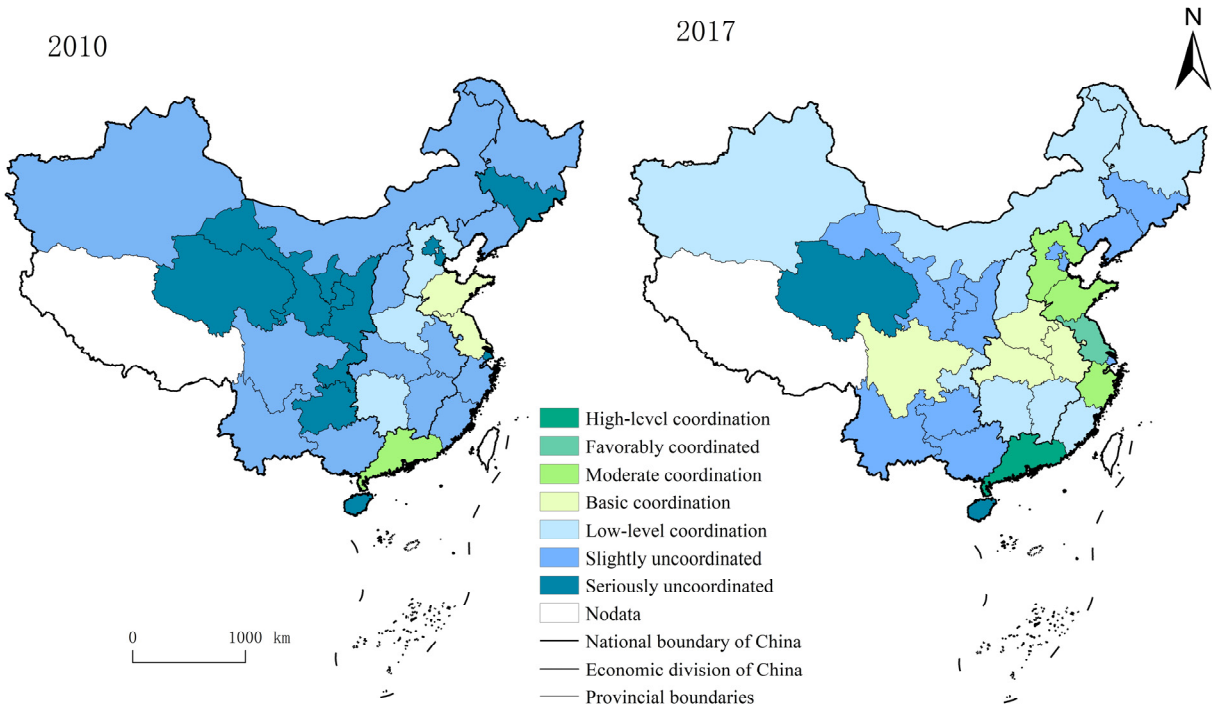


**Figure 8.** Spatial distribution of the coupling coordination degree of green finance and ecosystem service demand in China from 2010 to 2017.

In 2010, the coupling degree of green finance and ecosystem service demand was the lowest. The data analysis suggests that the reason was that the development level of green finance in various provinces lagged behind ecosystem services demand in 2010. From the perspective of policy, the reason was that the development of green finance in China started late, and the concept of green finance was not improved until 2016. Therefore, 2010 was just the beginning stage of green finance development, and all indicators were at a low level. In 2010, the coupling between green finance and ecosystem service demand was coordinated in only six provinces, distributed in the eastern coastal regions (Guangdong, Jiangsu, Shandong, Hebei, etc.), while the remaining severe uncoordinated areas were clustered in the western region (Chongqing, Guizhou, Shaanxi, Gansu, Qinghai, Ningxia, etc.). This was because the eastern region had a developed and stable financial system as well as a sound ecological environment foundation, and it attached more importance to the development of green finance under the guidance of national policies. The western region of China was not economically developed, the financial system was not active enough, and there was not a strong demand for green funds. Moreover, the westward migration of industries brought by China's western development strategy would also affect the development of green finance in the western region to a certain extent.

In 2017, the coupling coordination degree of green finance and ecosystem service demand was the highest. For the country as a whole, China introduced many policies in 2016 to encourage the development of green finance. For example, seven state ministries and commissions, including the People's Bank of China and the Ministry of Finance, issued the "Guidelines on Building a Green Finance System", which was the first time that the country systematically proposed the definition, incentive mechanism, development plan of green financial products, and risk monitoring measures of green finance. Therefore, the development level of green finance has been continuously improved under the incentive of relevant policies. At the provincial level, because the green finance development level of 1/5 provinces was ahead of the ecosystem service demand level, the coupling coordination degree of most provinces had been significantly improved. The coordination level of the two systems was more balanced. At that time, the provinces with high coupling coordination degrees were concentrated in East China (Jiangsu, Shandong, Zhejiang, Anhui, etc.) and central China (Henan, Hubei, etc.), which indicated the spatial diffusion from east to central China, which was also the achievement of China's coordinated development strategy.

### *5.2. Advantages of Improved Coupling Coordination Degree Model*

Through comparative analysis, it found that the contribution coefficients $\alpha$ and $\beta$ affect not only the coupling coordination degree, but also the coupling coordination type. However, the theoretical basis for the traditional coupling coordination degree model to set the same contribution coefficient of the two systems is not sufficient, and the calculation results struggle to reflect the coupling relationship between green finance and ecosystem service demand accurately and objectively [31]. Decision-makers are prone to make unreasonable or even wrong decisions that have a bad impact on the coordinated development of green finance and ecosystem services demand when facing such evaluation results.

To fill the subjective judgment of the contribution coefficients $\alpha$ and $\beta$ in the traditional coupled coordination degree model, an improved coupled coordination degree model is introduced to determine the contribution coefficients according to the comprehensive performance of green finance and ecosystem service demand, which means that, with the continuous cooperation and competition between green finance and ecosystem service demand, the contribution coefficients of the two systems continue to develop and change. At the beginning of the study, the contribution coefficient of green finance ($\alpha'$) was much larger than the contribution coefficient of ecosystem services demand ($\beta'$). As time passed, China's ecological environment continued to improve, so the proportion of the contribution coefficient of this system rose constantly. At the end of the study, $\alpha'$ was almost equal to $\beta'$. Therefore, policymakers should focus on promoting ecological environment construction and achieving coordinated improvement of green finance and ecosystem service demand

on the premise of maintaining appropriate economic growth. In conclusion, the improved coupling coordination degree model can reflect the coordinated development of green finance and ecosystem service demands accurately, and help decision-makers to further develop more scientific and reasonable measures.

### *5.3. Limitations*

Using data from 30 provinces in China, this paper evaluated the coupling relationship between green finance and ecosystem services demand in four major regions of China's economy, which made up for the shortcomings of the traditional coupling coordination model, but the research still has certain limitations. Firstly, considering the availability of data from 2018 to 2021, only the eight years from 2010 to 2017 were selected as the study period, and data from recent years should be supplemented for inclusion in the study in the future. Secondly, when constructing the indicator system for ecosystem service demand assessment, this paper used the actual human food consumption to measure food demand services, and replaced the demand with food consumption in the calculation process. Food consumption data (including grain, oil, vegetables, meat, aquatic products, eggs, milk, melons, and fruits) were all from the China and provincial statistical yearbooks. However, since some provinces (such as Heilongjiang Province, Sichuan Province, etc.) did not calculate the specific consumption of eggs, milk, melons, and fruits in 2013 and 2014, the missing data were replaced with data from adjacent years. The proportion of missing data is very small, so it has little impact on the calculation results. In the later stage, the method can be improved to make the empirical results more accurate by extrapolating the missing data.

## 6. Conclusions

This paper constructed a multi-index evaluation system for green finance and ecosystem service demand. Based on the panel data of 30 provinces in China from 2010 to 2017, the comprehensive development level of green finance and ecosystem service demand was evaluated by using the global principle component analysis and entropy method. Then, the improved coupling coordination degree model was used to explore the temporal and spatial evolution characteristics of the coupling coordination degree between green finance and ecosystem service demand in each province of China during the study period. The results show that:

(1) During the study period, the level of green finance in China's provinces improved significantly, showing a spatial pattern of "high in the east and low in the west". The ecosystem services demand in all provinces in China saw an initial increasing trend that eventually began decreasing. Nearly two-thirds of provinces had gradually increased the demand level for ecosystem services, showing a spatial pattern of "high demand for ecosystem services in East and South China and low ecosystem services demand in northwest and northeast China".

(2) The results of the improved coupling coordination degree model showed that the static coupling coordination relationship between green finance and ecosystem service demand in Chinese provinces continued to improve from 2010 to 2017, and the spatial distribution showed a spatial pattern of "high in eastern coastal and central China, low in western and northeast China".

(3) Contribution coefficients $\alpha$ and $\beta$ not only affect the coupling coordination degree, but also affect the type of coupling coordination degree. Compared with the traditional coupling coordination degree model, the improved coupling coordination degree model can provide more effective information for decision-makers and help them to formulate more reasonable control measures.

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