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Coupling Coordination Relationship and Influencing Factors between Green Finance and the Digital Economy

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Abstract: Against the backdrop of the "Dual Carbon" goals and high-quality development, Green Finance and the Digital Economy are of great significance to China's high-quality development. Taking Sichuan Province as the research object, this paper employs panel data on green finance and the digital economy from 2011 to 2024. The Entropy Weight Method is applied to construct the indicator systems of the two subsystems and calculate their development indices. Furthermore, the Coupling Coordination Degree Model is adopted to analyze their interactive relationship. The findings indicate that: (1) both subsystem indices exhibited a steady upward trend, with the digital economy index increasing from 0.025 to 0.693 and the green finance index rising from 0.219 to 0.654; (2) the coupling coordination degree advanced from severe imbalance (D = 0.10 in 2011) to high-quality coordination (D > 0.90 since 2020), undergoing a three-stage evolution of "imbalance–transition–coordination." Based on these findings, this study proposes policy recommendations, including strengthening the synergy mechanism between digitalization and greening and optimizing the structure of green finance, with the aim of contributing to the green, low-carbon, and high-quality development of Sichuan Province.

Keywords: Green finance; Digital economy; Entropy weight method; Coupling coordination degree model; Sichuan Province; High-quality development

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1. Introduction

Under the macro background of the strategic goal of "dual carbon" and the acceleration of the cultivation of new quality productivity, green finance and digital economy, as the two key engines driving high-quality development, their coordinated evolution has become the core path of regional sustainable development. Green finance guides capital to flow to environmentally friendly industries through credit, bonds, insurance, funds, and other tools, and eases the financing constraints of green projects; The digital economy relies on digital infrastructure, data elements, and platform technology to improve the production organization mode

and resource allocation efficiency. There is no one-way empowerment relationship between the two. Digital technology can reduce the information asymmetry of green finance and improve the accuracy of environmental risk identification and post-investment management ability; Green finance can also accelerate the application of digital technology in energy saving and emission reduction, smart energy, green supply chain, and other scenarios through policy incentives and capital leverage [1,2]. It is of theoretical value and practical significance to clarify the dynamic evolution characteristics and driving mechanism of the coupling and coordination of the two.

The real dilemma is still prominent: From the national level, there is a structural imbalance in the development of green finance: "heavy scale, light efficiency" and " stronger development in eastern regions than in central and western regions"; The digital economy presents a spatial difference pattern of "the east is strong and the west is weak, the city is strong and the countryside is weak" [3,4]. Especially in ecological functional areas and underdeveloped areas, such as Sichuan Province. As an important ecological barrier in the upper reaches of the Yangtze River, one of the national digital economy innovation and development pilot provinces, and one of the pilot provinces for green financial reform, Sichuan Province has problems such as insufficient supply of green finance, uneven coverage of digital infrastructure, and weak industrial green transformation momentum. As a result, the two major systems have not yet formed an efficient interaction mechanism. Against this background, exploring the coupling and coordination level of green finance and the digital economy in Sichuan Province and its influencing factors is the key to solving the problem of unbalanced and insufficient regional development and realizing the implementation of the strategy of "ecological priority and green development." Scientifically measure the development level of the two systems. Evaluate its coupling and coordination status and identify the influencing factors. It is conducive to revealing the law of coordinated evolution of typical provinces in the central and western regions, and can provide empirical basis and decision-making support for optimizing the regional policy combination and building a new development pattern of "digital and green integration."

2. Literature review

2.1. Research on green finance

The academic community's measurement of green finance has formed a relatively mature methodology system. Yang constructed an indicator system covering five dimensions, namely green credit, green bonds, green insurance, green investment, and carbon finance. Using the Entropy Weight Method to measure data from 30 provinces in China from 2010 to 2022, the study found that the development of green finance exhibited a gradient distribution characterized by "high in the east and low in the west" and was significantly positively correlated with the upgrading of industrial structure [5]. Gao *et al.*, focusing on the Xinjiang region, adopted the entropy weight-TOPSIS method to evaluate the level of green finance. Their study pointed out that the coupling between green finance and low-carbon agriculture demonstrated the characteristics of "financial advancement and agricultural lagging," with rural residents' income and the proportion of the secondary industry serving as key moderating variables. They further proposed establishing a combined "green credit + insurance" instrument to bridge this gap [6]. In research on the coupling relationship with new energy development, Feng *et al.* refined green finance into seven secondary indicators, such as the proportion of environmental protection project loans and the proportion of green bond issuance, and verified its significant promoting effect on new energy development [3]. Yu and Ao, in their study of the ecological economy in Tibet, emphasized that fiscal

environmental protection expenditure and green funds constitute the core support for green finance in plateau regions, while the low degree of marketization constrains the effectiveness of such financial mechanisms [7].

2.2. Research on the digital economy

Research on the measurement of the Digital Economy has deepened rapidly in recent years. Liang *et al.* constructed a four-level indicator system consisting of "digital infrastructure–digital industrialization–industrial digitalization–innovation output," including 14 tertiary indicators such as broadband penetration rate, e-commerce transaction volume, R&D personnel input, and green patents. Based on data from 41 cities in the Yangtze River Delta from 2013 to 2022, the study found that the digital economy generally showed an upward trend, although significant inter-city disparities and a pronounced "core–periphery" structure remained [4]. In research on total factor carbon productivity, He *et al.* refined the digital economy into 23 indicators across five criterion layers and, for the first time, introduced "digital finance level" as an independent dimension, confirming its mediating and enhancing effect on green transformation [1]. Liu *et al.* further pointed out that the level of digital economy development and the intensity of digital policies jointly regulate the carbon emission reduction effect of green finance, exhibiting a nonlinear U-shaped relationship [8].

2.3. Research on the coupling coordination relationship between the two systems

Current studies on the coupling coordination mechanism between the two systems mainly focus on three perspectives. The first is the causal relationship perspective. You *et al.* proposed a bidirectional circulation mechanism of "digital empowerment–green feedback," whereby digital technologies reduce the cost of green financing and enhance the rate of return on green projects, which in turn incentivizes financial institutions to expand the allocation of green assets [2]. Gao *et al.* further pointed out that agricultural greening drives the downward penetration of digital financial services, forming a path characterized by "industrial demand traction–financial supply response" [6]. The second perspective concerns dynamic evolution. Feng *et al.* found that the coupling coordination degree between green finance and new energy development experienced three stages: "initial imbalance–intermediate adjustment–later coordination," and was significantly affected by exogenous policy shocks [3]. Liang *et al.* revealed that the Yangtze River Delta exhibited a spatial evolution pattern of a "Z-shaped high-level corridor," relying on the spillover effects of core cities to drive coordinated development in surrounding areas [4]. The third perspective is the system structure perspective. He *et al.* emphasized that the three systems—digital economy, green finance, and carbon productivity—constitute a closed loop of "technology–capital–performance," in which the digital economy serves as the "catalyst" and green finance functions as the "transmission shaft" [1].

2.4. Review of existing studies

Over the past five years, substantial progress has been achieved in academic research on Green Finance and the Digital Economy. However, in light of the focus of this study, several critical gaps remain in the existing literature. Current coupling studies mainly concentrate on the national level, the Yangtze River Delta, or frontier provinces and autonomous regions, while there has been no specialized analysis of Sichuan Province, a representative province characterized by the integration of ecological and economic functions. Sichuan's dual positioning as both an "ecological barrier in the upper reaches of the Yangtze River" and a "digital economy hub in western China" makes it highly representative. Moreover, most existing studies focus on unidirectional

causal relationships, whereas relatively limited attention has been paid to the interactive relationship between the two systems.

Based on the above research gaps, this study utilizes panel data from Sichuan Province from 2011 to 2023, applies the Entropy Weight Method to measure the two systems, and employs the Coupling Coordination Degree Model to characterize their dynamic relationship. The aim is to fill the empirical research gap concerning coupling coordination at the provincial scale in central and western China, deepen the understanding of the bidirectional mechanism of "digital empowerment of green finance and green guidance of digital development," and provide a transferable analytical framework and policy implications for similar regions.

3. Research design and data sources

3.1. Construction of the indicator systems

Following the principles of scientific validity, systematicity, and data availability, and taking into account the practical situation of Sichuan Province, two indicator systems were constructed. **Table 1** presents the indicators for the digital economy, while **Table 2** presents those for green finance.

Table 1. Digital economy indicator system

Primary indicator	Secondary indicator	Tertiary indicator	Attribute
Digital Economy	A1 Digital Infrastructure	Number of broadband internet subscribers (10,000 households), mobile phone penetration rate (%), long-distance optical cable length (km)	+
	A2 Digital Industrialization	Operating revenue of information transmission/software and information technology services (100 million CNY), number of electronic information manufacturing enterprises	+
	A3 Industrial Digitalization	E-commerce transaction volume (100 million CNY), express delivery volume (10,000 items), Digital Inclusive Finance Index	+
	A4 Innovation Capacity	R&D expenditure (100 million CNY), number of patents granted (units)	+
	A5 Application Breadth	Proportion of enterprises engaged in e-commerce, total number of web pages	+

Table 2. Green finance indicator system

Primary indicator	Secondary indicator	Tertiary indicator	Attribute
Green Finance	B1 Green Credit	Scale of green bond issuance (100 million CNY), loans to A-share environmental protection listed companies (100 million CNY)	+
	B2 Green Investment	Investment in environmental pollution control (100 million CNY), proportion of fiscal expenditure on energy saving and environmental protection (%)	+
	B3 Green Insurance	Agricultural insurance compensation rate (%), proportion of revenue from environmental liability insurance (%)	+
	B4 Capital Market Support	Total market capitalization of A-shares (100 million CNY), proportion of market capitalization of environmental protection enterprises (%)	+
	B5 Green Transformation Pressure	Interest expenditure proportion of six high-energy-consumption industries (%), carbon emission intensity (tons/10,000 CNY GDP)	-

3.2. Entropy weight method

The entropy weight method was used to assign objective weights to indicators. For positive indicators,

standardization was performed as follows:

$$Y_{ij}=\frac{x_{ij}-\min(x_j)}{\max(x_j)-\min(x_j)} \tag{1}$$

(Negative indicators are treated using reciprocal transformation.) The information entropy, redundancy, and weight for each indicator are calculated as:

$$e_j=-\frac{1}{\ln n}\sum_{i=1}^{n}p_{ij}\ln p_{ij} \tag{2}$$

$$d_j=1-e_j \tag{3}$$

$$w_j=\frac{d_j}{\sum_{k=1}^{m}d_k} \tag{4}$$

Where $p_{ij}=Y_{ij}/\sum_{i}Y_{ij}$.

3.3. Coupling coordination degree model

The coupling degree model is shown in Equation (5):

$$C=\sqrt{U_1U_2}/\frac{U_1+U_2}{2} \tag{5}$$

The coordination index is calculated as:

$$T=0.5U_1+0.5U_2 \tag{6}$$

Accordingly, the coupling coordination degree is expressed as:

$$D=\sqrt{C\cdot T} \tag{7}$$

3.4. Data sources

The data used in this study were obtained from the *China Statistical Yearbook*, *Sichuan Statistical Yearbook*, *China Financial Yearbook*, reports issued by the Sichuan Branch of the People's Bank of China, the CEInet Statistics Database, the China Green Bond Information Service Platform, the Sichuan Communications Administration, and the Sichuan Provincial Department of Commerce, and were processed using the SPSSPRO platform. The sample period covers 2011–2024. All indicators were subjected to range standardization and outlier treatment.

4. Empirical results

4.1. Analysis of the digital economy and green finance indices

Based on relevant data from Sichuan Province from 2011 to 2024, this study applies the Entropy Weight Method to calculate the comprehensive development indices of the digital economy system and the green finance system, respectively. Combined with indicator weights and annual variation trends, the coordinated development level of the two systems is further analyzed.

4.1.1. Analysis of indicator weights in the two systems

According to the entropy weight results of the digital economy system, significant differences exist among the indicator weights, indicating that different indicators contribute differently to the comprehensive digital economy index of Sichuan Province, as shown in **Figure 1**. Overall, indicators related to digital infrastructure, the development of information service industries, and digital circulation capacity account for relatively high weights. Specifically, the indicators with the highest weights include total telecommunications services per capita (13.154%), long-distance optical cable length (10.163%), the number of legal entities in information transmission, software, and information technology services (8.179%), express delivery volume (6.817%), and e-commerce sales volume (5.717%). This shows that in the process of digital economic development in Sichuan Province, the construction of communication networks, the expansion of the scale of the information service industry, and the activity of digital trading are the key factors affecting the improvement of the comprehensive level. But the weight of indicators such as the scale of mobile phone facilities, digital inclusive finance, and the proportion of employees in the information software industry is relatively low. It shows that during the sample period, although these indicators can reflect some of the characteristics of digital economic development, their annual fluctuations are relatively small, and the distinguishing effect on the comprehensive index is relatively limited. The digital economic development of Sichuan Province mainly depends on the improvement of infrastructure, the expansion of industrial entities, and the expansion of application scenarios.

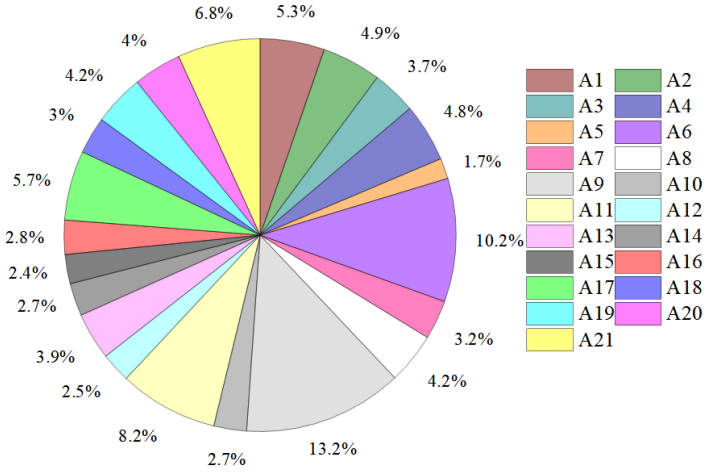

Figure 1. Weight proportions of indicators in the digital economy system

From the perspective of the green finance system, indicators with relatively high weights are mainly concentrated in green financing, capital market support, and green industry development, as shown in **Figure 2**. Specifically, the scale of green bond issuance carries the highest weight (9.732%), indicating that bond financing channels play a highly important role in Sichuan's green finance system. This is followed by the total market capitalization of A-shares (7.476%), loans to A-share environmental protection listed companies (7.114%), the proportion of market capitalization of environmental protection enterprises (6.198%), and the loan scale of environmental protection enterprises (4.931%). These findings suggest that the level of capital market development and the financing capacity of green enterprises are important dimensions affecting the comprehensive level of green finance in Sichuan Province. At the same time, indicators such as the agricultural insurance compensation rate, the proportion of energy conservation and environmental protection expenditure,

and loan balances also carry certain weights, indicating that fiscal support, insurance protection, and the overall scale of financial resources also play important roles in the development of green finance. Relatively speaking, indicators such as the total market capitalization of the six high-energy-consuming industries (1.815%), the proportion of interest expenditure of the six high-energy-consuming industries (1.861%), industrial interest expenditure (2.216%), and investment in environmental pollution control (2.362%) have relatively low weights. It shows that these indicators fluctuate little during the sample period, or their effect on the comprehensive level of green finance is relatively limited. In the green financial system of Sichuan Province, the construction of green financing channels and the capital allocation capacity of green industries are the focus of the changes in the comprehensive index.

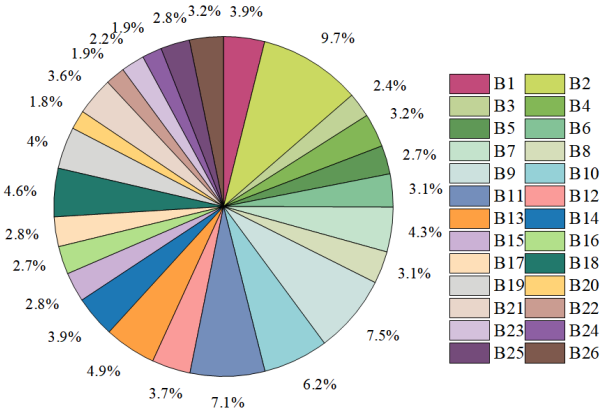

Figure 2. Weight proportions of indicators in the green finance system

The digital economic development of Sichuan Province relies more on the expansion of communication networks, digital service subjects and digital transaction activities. The development of green finance depends more on green bonds, green credit, capital market support, and green industry financing capacity. Although both systems have obvious "finance-technology-industry" linkage characteristics, the digital economy is more biased towards "infrastructure and application scenarios," while green finance is more biased towards "financing channels and capital allocation." This also provides a basis for the subsequent analysis of the coupling and coordination relationship between the two.

4.1.2. Analysis of the two system indices

Judging from the comprehensive index of digital economy, the overall development of digital economy in Sichuan Province shows an obvious upward trend. From 0.0253 in 2011 to 0.6925 in 2024, with a large increase. It shows that the digital economic development of Sichuan Province has made obvious stage progress during the sample period, as shown in **Figure 3**. Among them, the index rose from 0.0253 to 0.1683 in 2011–2014, and the overall index is still at a low level. During this period, the digital economy of Sichuan Province is still in its infancy, and the level of digital infrastructure construction and industrial digitalization is still insufficient. From 2015 to 2018, the index rose from 0.2594 to 0.4837, the growth rate accelerated, and the development of digital infrastructure construction and digital industry achieved results. From 2019 to 2020, the digital economy index rose to 0.6546 and 0.7503, entering the stage of accelerated development. The index fell slightly from 2021 to 2022, 0.6677, and 0.6618 respectively, with slight fluctuations, but still maintained at

a high level; From 2023 to 2024, it will rebound to 0.6705 and 0.6925, indicating that the digital economy of Sichuan Province has entered the stage of adjustment and optimization after rapid growth, and the overall trend is still maintaining a steady upward trend.

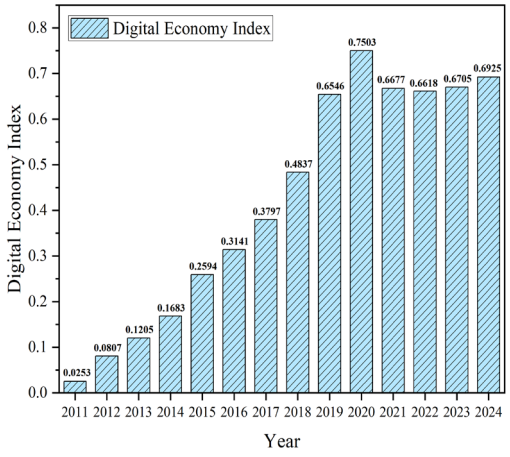

Figure 3. Digital economy index of Sichuan Province

Judging from the changes in the comprehensive index of green finance (**Figure 4**), green finance in Sichuan Province also showed a continuous upward trend, from 0.2191 in 2011 to 0.6539 in 2024. From 2011 to 2014, the green finance index rose from 0.2191 to 0.2755, and the overall growth was relatively flat; From 2015 to 2018, the index rose from 0.3199 to 0.4160, showing a steady growth trend; From 2019 to 2022, the index increased from 0.5390 to 0.7112, the growth rate increased significantly, and reached the highest value of the sample period in 2022. This shows that the green financial system in Sichuan Province continues to improve, driven by factors such as the expansion of green credit, the development of green bonds, and the strengthening of green industry support. The index fell to 0.6130 in 2023 and rose to 0.6539 in 2024, indicating that there are some fluctuations in the process of high-level development of green finance, but the overall trend is good.

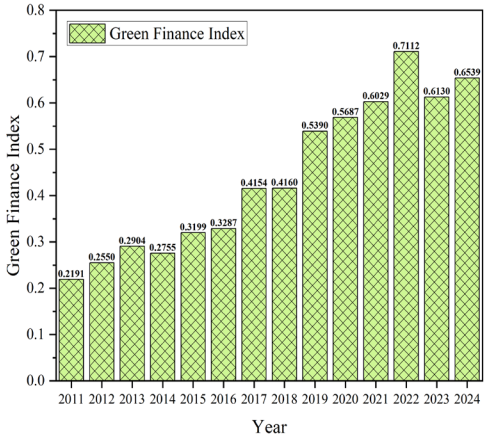

Figure 4. Green finance index of Sichuan Province

Further comparison of the two system indexes can be found that the green financial index from 2011 to 2018 has always been higher than the digital economy index. It shows that in the early stage of the sample, the development foundation of green finance in Sichuan Province is relatively good. The level of digital economic development is relatively low. After entering 2019, the growth of the digital economy index has accelerated significantly, the gap with green finance has been narrowing, and in some years, it has surpassed.

During the research period, both the digital economy and green finance in Sichuan Province have achieved great improvement, but the pace of development of the two is not exactly the same. The digital economy is growing faster, and the fluctuations are more obvious; the starting point of green finance is higher, and the rise is more stable. The joint improvement of the development level of the two systems has laid the foundation for the formation and evolution of the subsequent coupling and coordination relationship.

4.2. Coupling coordination analysis of the digital economy and green finance

In order to further investigate the interaction between the digital economy and green finance in Sichuan Province. On the basis of measuring the comprehensive index of digital economy and green finance, this paper further adopts the coupling coordination model. It measures the coupling degree (C), coordination index (T), and coupling coordination degree (D) of the two systems in Sichuan Province from 2011 to 2024, and analyzes their evolution characteristics in combination with the coupling coordination grade division criteria. As shown in **Table 3**.

Table 3. Evolution of coupling coordination types in Sichuan Province

Year	Coordination level	Coupling coordination degree	Year	Coordination level	Coupling coordination degree
2011	2	Severe imbalance	2018	8	Intermediate coordination
2012	3	Moderate imbalance	2019	9	Good coordination
2013	4	Mild imbalance	2020	10	High-quality coordination
2014	4	Mild imbalance	2021	10	High-quality coordination
2015	6	Barely coordinated	2022	10	High-quality coordination
2016	6	Barely coordinated	2023	10	High-quality coordination
2017	7	Primary coordination	2024	10	High-quality coordination

Judging from the coupling degree C value (see **Figure 5**). Except for individual years, the whole has always been at a high level, close to 1, which shows that there is a strong correlation and interaction between the digital economy and green finance. But high coupling does not mean high coordination. Although there was a connection between the two systems in Sichuan Province in the early days, due to the low level of digital economic development and the weak overall coordination efficiency of the system, effective interaction has not been formed.

Judging from the T value of the coordination index. The overall comprehensive development level of the two systems in Sichuan Province has been continuously improved, from 0.0100 in 2011 to 0.8938 in 2024. This shows that with the simultaneous improvement of the digital economy and the green finance index, the foundation for the coordinated development of the two systems continues to be strengthened. Especially after 2017, the T value has increased significantly, reflecting that the two systems have entered a stage of rapid development at the same time, and the overall coordination foundation has been significantly enhanced.

Judging from the D value of coupling coordination. The overall coordination level of digital economy and

green finance in Sichuan Province continues to improve. In 2011, the D value was only 0.1000, which was in a state of serious imbalance; In 2012, it rose to 0.2886, which was a moderate disorder; from 2013 to 2014, it was 0.3811 and 0.3973 respectively, which was a mild disorder. This shows that although there is a certain connection between the two systems in the early stage of the sample, the overall coordination level is low.

From 2015 to 2016, the D value rose to 0.5121 and 0.5499 respectively, entering the barely coordinated stage. Sichuan Province's digital economy and green finance began to gradually shift from an imbalance to preliminary coordination. In 2017, the D value reached 0.6654 and entered the primary coordination stage; in 2018, it was further increased to 0.7094 and entered the intermediate coordination stage. With the continuous improvement of digital infrastructure and the continuous enrichment of green financial instruments, the mutual promotion between the two systems has been significantly enhanced, and the coordinated development has entered the stage of substantial promotion.

After 2019, the coupling and coordination level of the two systems in Sichuan Province will be further improved. In 2019, the D value was 0.8639, which reached a good coordination level; in 2020, it rose to 0.9144, entering the high-quality coordination stage for the first time. From 2021 to 2024, the D values are 0.9081, 0.9635, 0.9149, and 0.9453 respectively, all of which are in the high-quality coordination range. The digital economy and green finance in Sichuan Province have formed a relatively stable high-level synergy relationship, and the system coordination has become relatively resilient.

From 2011 to 2024, the coupling and coordination relationship between digital economy and green finance in Sichuan Province has roughly gone through three stages:

The first stage was the imbalance stage (2011–2014), during which the development foundations of the two systems were relatively weak. The coupling coordination degree gradually improved from severe imbalance to mild imbalance, indicating that although a synergistic relationship had begun to emerge, it remained unstable.

The second stage was the transitional improvement stage (2015–2018), during which the development levels of the two systems continuously improved. The coupling coordination degree gradually advanced from barely coordinated to intermediate coordination, and the foundation for coordinated development was progressively strengthened.

The third stage was the high-level coordination stage (2019–2024), during which the two systems entered the states of good coordination and high-quality coordination, with synergistic development characteristics becoming increasingly evident.

In general, the coupling coordination degree between the digital economy and green finance in Sichuan Province continued to rise throughout the study period. This indicates that with the improvement of digital infrastructure, the acceleration of digital industry development, and the continuous enhancement of the green finance system, the relationship between the two systems has gradually evolved from low-level synergy in the early stage to high-level coordinated development. It also demonstrates that the interactive mechanism of "digital empowerment of green finance and green guidance of digital transformation" in Sichuan Province is continuously strengthening, thereby providing a practical foundation for the subsequent analysis of influencing factors.

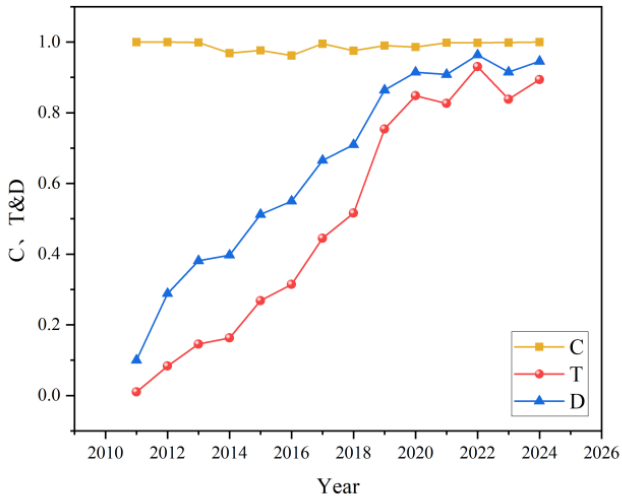

Figure 5. Changes in the coupling coordination parameters C, T, and D

5. Conclusion

5.1. Conclusions

Based on data from Sichuan Province from 2011 to 2024, this study measured the development levels of the Digital Economy and Green Finance, as well as their coupling coordination relationship, and reached the following conclusions:

(1) The indices of both systems exhibited an upward trend. The digital economy index increased from 0.025 to 0.693, while the green finance index rose from 0.219 to 0.654, with growth rates gradually stabilizing in the later stage.

(2) The entropy weight results indicate that digital infrastructure and green bonds are the core driving factors influencing the development of the two systems.

(3) The coupling coordination degree improved from severe imbalance (D = 0.10 in 2011) to high-quality coordination (remaining above 0.90 since 2020), demonstrating an evolutionary path characterized by "low initial level–rapid catch-up–high-level coordination."

5.2. Recommendations

It is necessary to strengthen the synergy mechanism between digital infrastructure and green finance by promoting platform-based digital financing for green projects. The structure of green finance should be optimized by increasing the proportion of direct financing instruments such as green bonds and carbon finance. The policy coordination system should be further improved by incorporating digital governance capabilities into the regulatory evaluation framework of green finance, thereby promoting the deep integration of digitalization and greening and supporting the high-quality development of Sichuan Province.

Disclosure statement

The author declares no conflict of interest.

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