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Coupling coordination analysis of green finance and industrial technology innovation: A case study in Zhejiang Province, China

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Both green finance and industrial technology innovation play irreplaceable roles in the framework of sustainable development. Research on the coupling and coordination between these systems will deepen the realization of sustainable development models. This study applied the TOPSIS entropy weight method to measure the development of green finance and industrial technology innovation in Zhejiang Province between 2012 and 2019 and used the coupling coordination degree model to determine the strength and effect of the interaction between these systems in Zhejiang Province. The results showed strong regional heterogeneity in the development of green finance and industrial technology innovation in the nine cities in Zhejiang Province within the study period. Moreover, mutual assistance and correlation between green finance and industrial technology innovation in the nine cities of Zhejiang Province increased over time. Finally, the effect of green finance and industrial technology innovation in the nine cities of Zhejiang Province was complex. The results of this study may inform policy suggestions regarding the roles potential roles of the government, commercial banks, and enterprises.

1 Introduction

In the previous period of relatively low productivity, the limited scope and frequency of human activities did not significantly impact resource status and environmental quality (Bugnot et al., 2019). However, during industrialization and urbanization, the active pursuit of productivity has expanded the scope and frequency of human activities, with obvious increases in the intensity of resource exploitation and environmental utilization (Whiting, 2022). While appropriate exploitation and utilization have positive effects on improving productivity (Liu et al., 2023), human activities are full of disorder and inefficiency when blindly pursuing productivity, which amplifies the negative effects on resources and the environment; namely, destroying stable human development of the environment (Erum and Shazia, 2022). The importance of the positive development of

resources and the environment has gradually attracted worldwide attention. The book, "Limits of Growth" put forward the concept of "sustainable development", which triggered discussion and reflection on the rationality of the development mode among academic circles (Koutaissoff, 1980). Since then, sustainable development has been cited by many scholars and has become the most advanced concept and representative theoretical perspective in academic research. Moreover, many institutions have adopted sustainable development, which has become the most valued core value in practical application as a progress orientation (Sun et al., 2022a).

Among practical cases that embody the concept of sustainable development, green finance and industrial technology innovation have shown remarkable achievement. As a service method for the comprehensive development of projects in the fields of environmental protection and energy conservation, green finance provides the advantages of supporting environmental improvement, addressing climate change, and promoting the efficient use of resources (Mamun et al., 2022). From a broader perspective, the effects of green finance are recognized worldwide, including the optimization of the supply structure of regional production factors (Wang and Wang, 2021), significantly weakening the excess capacity of regional traditional industries (Xiao and Peng, 2021), improving the development speed of regional green industries (Wu, 2022), and improving the regional green production engine (Rasoulinezhad and Taghizadeh-Hesary, 2022). Green finance has injected vitality into sustainable development. As the sum of all material means and methods developed by using natural laws to promote the transformation and upgrading of traditional industries, industrial technology innovation can also stimulate interest in relevant subjects (Desmet et al., 2020), effectively reducing the unit cost of industrial products (Chen et al., 2021), and enhance the market competitiveness of industrial products (Nawaz, 2021). From a broader perspective, the effects of industrial technology innovation are recognized worldwide, including clarifying the strategic focus of regional development (Li et al., 2022), effectively reducing the process loss of regional industrial development (Zhang and Fu, 2022), enhancing the driving effects of regional industrial development (Su and Fan, 2022), and organically adjusting the regional industrial production system (Wu et al., 2022). Thus, industrial technology innovation can improve the resilience of sustainable development.

As an institutional innovation to achieve energy conservation and environmental protection, green finance is an implementation path to promote sustainable development. As a method of ensuring industrial development, industrial technology innovation is another implementation path to promote sustainable development. Cautious evaluation of the relationship between green finance and industrial technology innovation shows that both attach adequate importance to ecological quality, environmental conditions, and pollution

status (Sun et al., 2022b). Therefore, green finance and industrial technology innovation can be regarded as a group of concepts that extend the logic of sustainable development and show a strong correlation. Based on this correlation, it is of practical significance to explore the mechanism of interactions between green finance and industrial technology innovation.

Current research seldom discusses green finance and industrial technology innovation, instead focusing on the identification of the causal relationship between financial development and technology innovation. For example, finance development can provide an inexhaustible source of funds, ensure the continuity, and reduce the external risk impact of technology innovation (Irwan et al., 2021; Stefano et al., 2022; Wang W. J. et al., 2022). Technology innovation can significantly improve, accelerate, and stabilize the quality of finance development (Chi et al., 2021; Ge et al., 2022; Sun and Razzaq, 2022). Strictly speaking, there are three main points. First, with increasing sample size, the internal differences between finance development and technology innovation will be obscured by the average effect; thus, the conclusions will be distorted. Second, organic components, each with strong heterogeneity, exist between finance development and technology innovation. Therefore, discussions of the relationship between finance development and technology innovation cannot highlight the pertinence of the research in a general sense. Third, whether at the theoretical or social application levels, the relationship between finance development and technology innovation is more likely to be mutually causal. In other words, from the perspective of causal mechanism, discussion of this issue will affect the degrees of practical or theoretical connections.

The present study aimed to correct for shortcomings of previous research. First, this study explored the relationship between green finance and industrial technology innovation in a setting with a reasonably controlled sample size and representative cases. The rationale for this study location is that Zhejiang Province in China was an early adopter of green finance reform; thus, its development achievements and experience make it a demonstration and experimental area for green finance; therefore, it is a vivid link for green finance development cases. Moreover, industrial technology innovation in Zhejiang Province is occurring within a relatively complex industrial process; that is, the steady growth of industrial added value but the decline of industrial proportion. This characteristic fully demonstrates the uniqueness of industrial technology innovation in Zhejiang Province; its existence is an indispensable part of the process of regional industrialization. In Zhejiang Province, discussion on the relationship between green finance and industrial technology innovation is very relevant, which is helpful to clarify its real effect. Additionally, this study has developed an indicator system for green finance and industrial technology innovation, which increases the amount of information compared to previous

studies focusing on only a single variable from a single dimension. Moreover, the present study applied the TOPSIS entropy weight method to measure green finance and industrial technology innovation, to provide a more objective and accurate assessment. Finally, this study demonstrates the effect of the coupling of green finance and industrial technology innovation from the perspective of system theory and used the coupling coordination degree model, a more appropriate method to analyze the theoretical mechanism, as it can effectively avoid confusion at the causal level.

The following sections of the study are arranged as follows. Part 2 describes the literature review. Part 3 expounds on the materials and methods, while Part 4 demonstrates empirical results and discussion. Finally, Part 5 offers the conclusions and policy recommendations.

2 Literature review

2.1 Development and innovation

The pursuit of innovation is the vein of development. Strictly speaking, development and innovation promote and support each other. However, the role of innovation in promoting development has received more attention. Innovation can be categorized as progressive or radical. The former is more extensive than the latter, while the latter has a higher threshold than the former (Zhang et al., 2022). Regarding practical cases of innovation, industrial technology innovation can effectively respond to climate change and the energy crisis, thereby promoting the sustainable development of renewable energy (Bano et al., 2022). Innovations in production technology can reduce production costs and improve production efficiency and the return rates of industrial products (Wen et al., 2021). In the context of the innovation era value, the implementation of a low-carbon economy is key for the sustainable development of economies and societies; thus, low-carbon technology innovations related to new energy enterprises are driving forces and core to the promotion of low-carbon economies. Effectively achieving innovation for low-carbon economies is not only the key to the sustainable development of new energy enterprises but also a significant challenge and important task faced by new energy enterprises (Yang et al., 2022). The product of the development of another era, the digital economy, plays an increasingly important role in the national economic system. The development of digital technology innovation has provided an industry breakthrough in the limitations of the traditional budget and become a driving force for sustainable development (Ma and Zhu, 2022). Green innovation has a spatial spillover effect, which is an important method for accelerating the transformation and upgrading of China's urban economic structure and the realization of sustainable urban development (Peng et al., 2021). Regarding the conditions required for innovation,

innovation is closely related to the basis of development, from which further development based on innovation is achieved (Kong et al., 2021).

2.2 Finance development and technology innovation

Generally speaking, finance development and technology innovation are related and permeate each other. However, the discussion of the two is often based on the premise that technology innovation is an important engine of finance development in the new era. Therefore, previous literature focused more on the mechanisms of technology innovation in finance development. Some studies showed that, due to the high-risk and long-term externalities of technology innovation, long-term capital inflow is often required for technology innovation (Xiang et al., 2022). Research has also shown that finance development institutions promote the sustainable development of innovation activities by providing strong financial (especially long-term) support for technological innovation (Stefano et al., 2022). With the deepening of finance development, trade credit and bank finances are now the most common methods of finance in enterprise innovation activities. These activities have different effects due to different finance methods and the effectiveness of finance capital sources (Yano and Shiraishi, 2022). However, widespread financial constraints in the finance field are an important factor restricting enterprise innovation. When enterprises face higher finance constraints, the level of technological innovation decreases. Due to more stringent finance constraints, private enterprises are especially vulnerable in innovation activities compared to state-owned enterprises (Yu et al., 2021). To address the constraints and challenges that hinder innovation, emerging policy tools have been introduced to effectively promote the improvement of enterprise innovation ability (Liu and Xiong, 2022). For example, green finance specifically provides financial support for green projects, promotes technology progress and innovation activities, and is an important driving force for green economic growth and structural transformation (Wang and Wang, 2021). The development of green finance has a spatial spillover effect on technology innovation activities and is conducive to reducing the differences between regions (Huang et al., 2022). Climate finance specifically invests in activities related to climate change and strongly supports technology innovation and policy innovation (Warren, 2020). Therefore, much evidence supports the role of finance development in promoting technology innovation. However, disordered finance will hinder technology innovation. Thus, it is important to promote the appropriate development of finance to match steady technological innovation (Zhu et al., 2020).

2.3 Green finance and industrial technology innovation

The results of the literature review showed that the relationship between green finance and industrial technology innovation is not clear. The answer to this question is of great significance. First, clarifying the relationship between green finance and industrial technology innovation will provide empirical support for expanding the scope of application of finance development and technology innovation. Second, exploring the development level of green finance and industrial technology innovation will provide examples for the adjustment of regional development strategies. Third, demonstrating the strength of the force between the two systems of green finance and industrial technology innovation will provide a numerical reference for the further removal of obstacles to development and the design of stability mechanisms.

In this context, this study expounded on the coupling mechanism of green finance and industrial technology innovation as follows, As is shown in Figure 1. Starting from the bottom of green finance, first, as a development policy, the purpose of green finance is to promote green-biased technology innovation through the rational allocation of human resources. In the system of green technology innovation, industrial technology innovation has received the greatest attention; therefore, green finance promotes industrial technology innovation through the efficient flow of human resources. Second, as a development tool, green finance can directly provide substantial funds to relevant stakeholders. As a typical example of high pollution and high emissions, industry covers a large proportion of relevant stakeholders; that is, green finance provides sufficient capital elements for industrial technology innovation. Third, as a development orientation, green finance can help to create green development and provide green concept guidance for industrial technology innovation. In other words, green finance allows the development of industrial technology innovation that closely matches its own situation. Starting from the bottom of industrial technology innovation, first, as a means of value realization, industrial technology innovation aims to achieve green development goals such as energy conservation and emission reduction through the recreation of the core value of technology. To a certain extent, it can reduce industrial production costs and promote industry to a development path consistent with the value connotation of green finance to expand the development scale of green finance. Second, as a form of quality, industrial technology innovation can stimulate the demand for relevant subjects for finance services to promote the reform of green finance service modes and provide an impetus for the development of green finance. Third, as a development system, industrial technology innovation has clear positioning for its own development. With clear objectives, the radiation boundary of industrial technology innovation is also clear; that is, the relevant information for industrial technology innovation also tends to be

complete and clear to make the disclosure of the connected green finance information more transparent.

3 Materials and methods

3.1 Indicator system

Based on the design of the index systems of green finance and industrial technology innovation in previous literature (Jiang et al., 2020; Chen and Chen, 2021; Shao et al., 2021; Wang et al., 2021), the present study depicted the development level of green finance from the two levels (green credit and green investment) (Table 1) and reflected the level of industrial technology innovation from four dimensions (economic, innovation, social and environmental performances) (Table 2) based on the availability of these data in Zhejiang Province.

3.2 Data sources

The study period was from 2012 to 2019. Relevant data on green finance and industrial technology innovation were obtained from the CSMAR database and the statistical yearbooks of various regions in Zhejiang Province, respectively. Due to the certain incompleteness of information disclosure, annual data in some regions could not be obtained. This study used interpolation to supplement the relevant missing data.

3.3 Method selection

3.3.1 TOPSIS entropy weight method

The TOPSIS entropy weight method is an objective valuation method that determines the weight of each indicator according to its numerical change and the amount of information (Chaudhary et al., 2021). The weight of the indicator is directly proportional to the influencing factors; that is, the greater the weight of the indicator, the higher the influence degree. The principle of the TOPSIS entropy weight method lies in a unified matrix reference system that identified the best and worst scheme in the finite scheme, calculates and analyzes the distance between a scheme and the best and worst schemes to provide the degree of the scheme and the best scheme, and finally uses these result to determine the merits of the evaluation unit. The specific modeling process is as follows.

Step 1. Establish a matrix arrangement of evaluations. After the evaluation object is determined, a judgment matrix is established to obtain positive trends for non-positive indexes. There are a

TABLE 1 Indicator systems of green finance.

Indicator level 1	Indicator level 2	Indicator level 3	Measuring equation
Green finance	Green credit	Proportions of industrial loans for non-high energy consumption	Loan amounts for non-high energy consumption industries/loan amounts for industry
	Green investment	Proportion of green spending	Government expenditures for energy conservation and expenditures on environmental protection/government

TABLE 2 Indicator systems of industrial technology innovation.

Indicator level 1	Indicator level 2	Indicator level 3	Measuring equation
Industrial technology innovation	Economic performance	ROE	Industrial net profit/industrial net assets
		Ratio profit to cost	Total industrial profit/total industrial cost
		Sales-output ratio	The number of products sold this year/the number of products produced this year
	Innovation performance	R&D investment intensity	Internal Expenditure of Industrial R&D Funds/Industrial Operating Income
		Proportion of inventing patent	Numbers of invention patents granted/numbers of patent applications granted
		Capability of technology innovation	Industrial R&D personnel/number of industrial employees
	Social performance	Contribution rate of gross output	Industrial added value/total output value
		Tax contribution rate	Total industrial tax/fiscal revenue
		Industrial employment rate	Industrial employment/employees at the end of the year
	Environmental performance	Electricity rates	Industrial electricity consumption/electricity consumption for the whole industry
		Comprehensive energy consumption	Total annual industrial energy consumption-total industrial energy consumption of last year/total all industrial energy consumption of last year
		Comprehensive utilization rate of industrial solid waste	Comprehensive amount of industrial solid waste/amount of industrial solid waste generated

treatments, each of which has β evaluations. The original data matrix of the indicators is as follows.

$$X = \left(x_{ij}\right)_{\alpha \times \beta} = \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1\beta} \\ x_{21} & x_{22} & \cdots & x_{2\beta} \\ \vdots & \vdots & \vdots & \vdots \\ x_{\alpha 1} & x_{\alpha 2} & \cdots & x_{\alpha \beta} \end{pmatrix}_{\alpha \times \beta}$$
$$\left(i = 1, 2, \cdots, \alpha; j = 1, 2, \cdots, \beta\right) \tag{1}$$

Step 2. Normalize the original data matrix.

$$x'_{ij} = \frac{x_{ij}}{x_{\max}} \tag{2}$$

Step 3. Calculate the information entropy.

$$K_j = -k \sum_{i=1}^{\alpha} p_{ij} \ln p_{ij} \tag{3}$$

$$p_{ij} = \frac{x'_{ij}}{\sum_{i=1}^{\alpha} x'_{ij}}; k = \frac{1}{\ln \alpha}$$

Step 4. Determine the weight of the index j.

$$\gamma_j = \frac{1 - K_j}{\sum_{j=1}^{\beta} \left(1 - K_j\right)} \tag{4}$$

$$\gamma \in [0, 1], \sum_{j=1}^{\beta} \gamma_j = 1$$

Step 5. Construct a weighted norm matrix Z.

$$Z = \left(z_{ij}\right)_{\alpha \times \beta} = \begin{pmatrix} z_{11} & z_{12} & \cdots & z_{1\beta} \\ z_{21} & z_{22} & \cdots & z_{2\beta} \\ \vdots & \vdots & \vdots & \vdots \\ z_{\alpha 1} & z_{\alpha 2} & \cdots & z_{\alpha \beta} \end{pmatrix}_{\alpha \times \beta} \tag{5}$$

$$z_{ij} = \gamma_j \times x'_{ij} \left(i = 1, 2, \cdots, \alpha; j = 1, 2, \cdots, \beta\right)$$

Step 6. Determine the optimal value vector Z_j^+ and the worst value vector Z_j^-.

$$Z_j^+ = \max\left(z_{1j}, z_{2j}, \cdots, z_{\beta j}\right) \tag{6}$$

$$Z_j^- = \min\left(z_{1j}, z_{2j}, \cdots, z_{\beta j}\right) \qquad (7)$$

Step 7. Calculate each evaluation unit and the Euclidean distance between the optimal and worst solutions. As the chi-square distance has processed the information repeatability, the chi-square distance is used instead of the Euclidean distance to measure each evaluation unit close to the ideal solution.

$$D_i^+ = \sum_{j=1}^{\beta}\left(\frac{\left[z_{ij} - e_{ij}^+\right]^2}{e_{ij}^+} + \frac{\left[z_{\max j} - e_{\max j}^2\right]}{e_{\max j}}\right) \qquad (8)$$

$$D_i^- = \sum_{j=1}^{\beta}\left(\frac{\left[z_{ij} - e_{ij}^-\right]^2}{e_{ij}^-} + \frac{\left[z_{\min j} - e_{\min j}^2\right]}{e_{\min j}}\right) \qquad (9)$$

Among them, $z_{\max j}$ and $z_{\min j}$ are the maximum and minimum values of the J index.

$$e_{ij}^+ = \frac{z_{ij} \times \sum_{i=1}^{\alpha} z_{ij}}{\sum_{j=1}^{\beta} z_{ij} + \sum_{j=1}^{\beta} z_{\max j}}$$

$$e_{ij}^- = \frac{z_{ij} \times \sum_{i=1}^{\alpha} z_{ij}}{\sum_{j=1}^{\beta} z_{ij} + \sum_{j=1}^{\beta} z_{\min j}}$$

$$e_{\max j} = \frac{z_{\max j} \times \sum_{i=1}^{\alpha} z_{ij}}{\sum_{j=1}^{\beta} z_{ij} + \sum_{j=1}^{\beta} z_{\max j}}$$

$$e_{\min j} = \frac{z_{\min j} \times \sum_{i=1}^{\alpha} z_{ij}}{\sum_{j=1}^{\beta} z_{ij} + \sum_{j=1}^{\beta} z_{\min j}}$$

Step 8. Calculate the comprehensive evaluation index.

$$H_i = \frac{D_i^-}{D_i^+ + D_i^-} \qquad (10)$$

Step 9. Compare the results to the reference frame and rank them. The larger the solution, the closer the result is to the optimal solution.

3.3.2 Coupling degree model

According to the concept and physical principle of electromagnetic field coupling, a coupling degree model covering M systems can be established.

$$C_m = m\left[\frac{U_1 U_2 \cdots U_m}{(U_1 + U_2 + \cdots U_m)^m}\right]^{\frac{1}{m}} \qquad (11)$$

Next, the coupling degree model of the green finance development and industrial technology innovation systems is established.

$$C = 2\sqrt{\frac{U_1 \times U_2}{(U_1 + U_2)^2}} \qquad (12)$$

In this case, $U_i \geq 0$ represents the evaluation value of system S_i and C represents the coupling degree, where $0 \leq C \leq 1$. When any evaluation value is 0, the coupling degree is 0; when all evaluation values are 0, the coupling degree is meaningless. The coupling degree C measures the strength of the correlation between two different systems. The closer the value of C to 1, the higher the degree of coordinated development of green finance and industrial technology innovation. Moreover, the two systems tend to have a new orderly structure. Otherwise, it tends to be disordered (Zhu et al., 2022). However, this calculation ignores the advantages and disadvantages of the interaction between the systems, and it is difficult to explain the overall efficacy and synergistic amplification between green finance and industrial technology innovation. To overcome this limitation, the present study introduces a coupling coordination degree model to measure the degree of coordination between the green finance and industrial technology innovation systems.

3.3.3 Coupling coordination degree model

$$D = \sqrt{CT} \qquad (13)$$
$$0 \leq D \leq 1$$
$$T = \alpha U_1 + \beta U_2 \qquad (14)$$
$$\alpha + \beta = 1$$

The degree of system coupling and coordination is reflected by D, while T represents the comprehensive harmony index of the green finance development and industrial technology innovation systems, where $0 \leq T \leq 1$. a and β are the weights of the green finance and industrial technology innovation systems, respectively. This present study used $a = \beta = 0.5$; that is, the two subsystems are equally important.

4 Results and discussion

As shown in Figure 2, analysis of spatial–temporal evolution demonstrated upward trends in the development of green finance in nine cities in Zhejiang Province, while green finance in parts of cities showed the complex spatial–temporal evolution. Concerning the differences, the range of green finance in nine cities in Zhejiang Province was obvious; all were >0.6 and showed no volatility. The development of green finance in some cities changed greatly in specific years. For example, the development
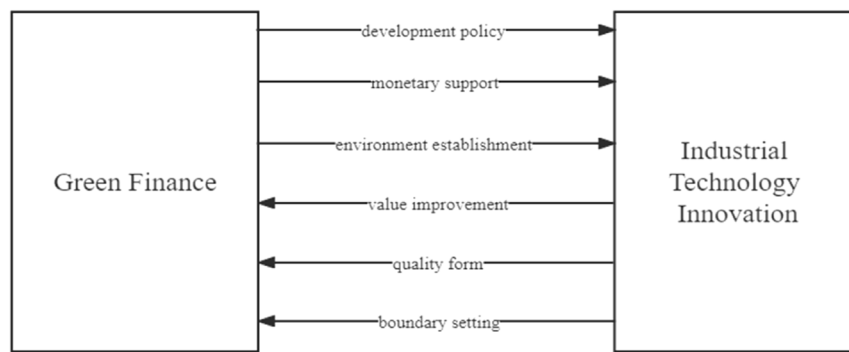
FIGURE 1
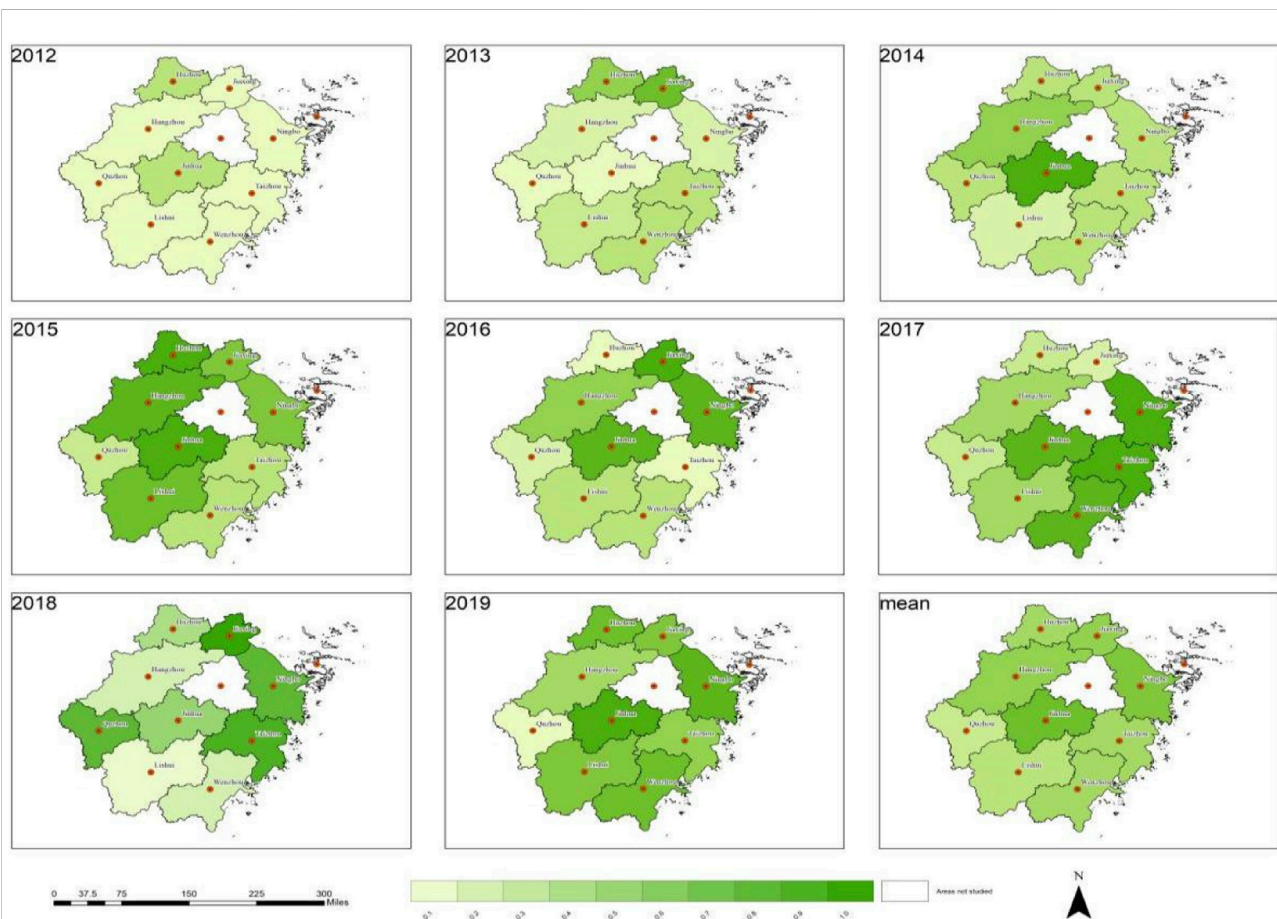Coupling coordination mechanism of green finance and industrial technology innovation.

FIGURE 2
Spatial–temporal evolution of green finance in nine cities in Zhejiang Province (2012–2019).

of green finance in Taizhou increased by 0.856 from 2016 to 2017, while the development of green finance in Wenzhou increased by 0.541 from 2016 to 2017, indicating that the

development of green finance in Zhejiang province lacked stability. Regarding the ideal values, in 2019, the development of green finance in Taizhou (1.000) and Quzhou (1.000) reached

FIGURE 3
Spatial–temporal evolution of industrial technology innovation in nine cities in Zhejiang Province (2012–2019).
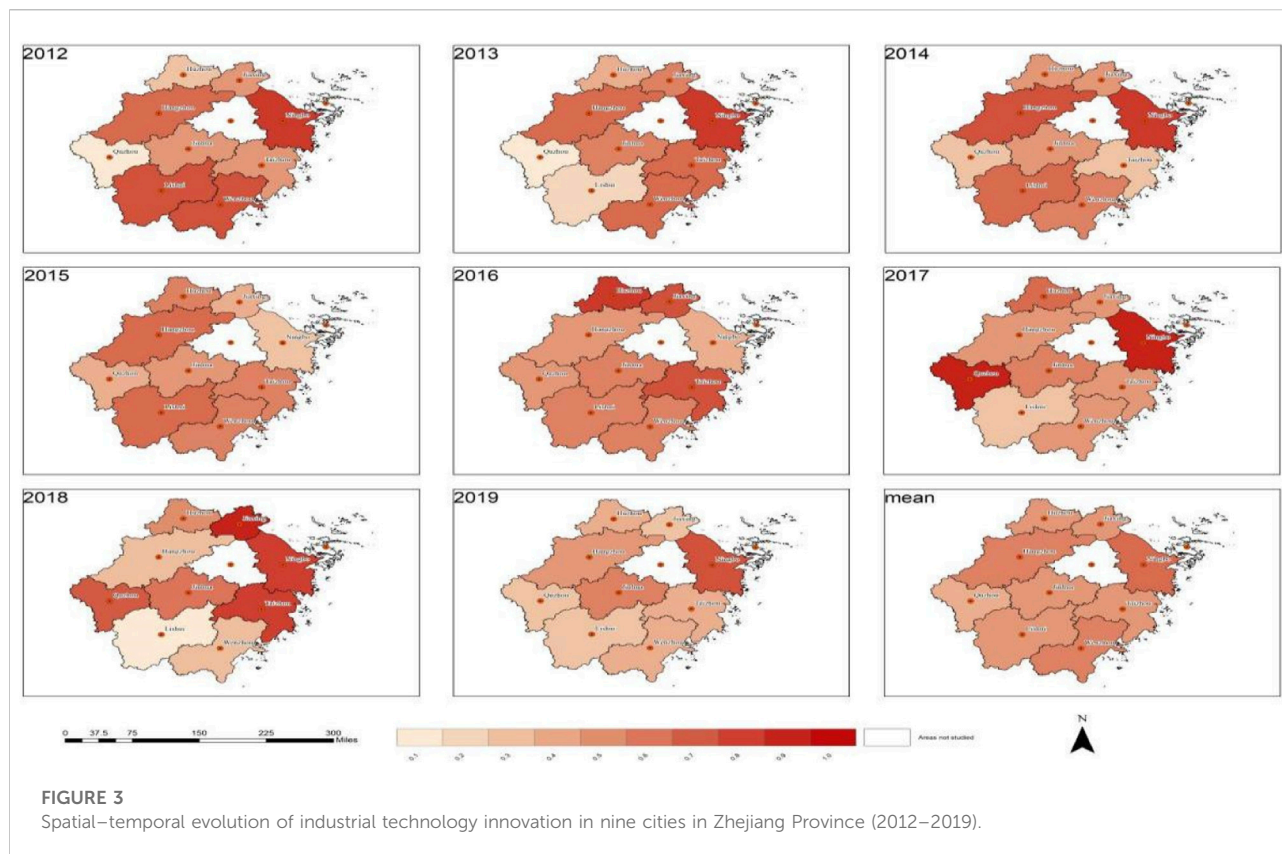
the ideal scheme, while the development of green finance in Jinhua (0.993) was close to the ideal scheme. The average values of the development of green finance in Jinhua (0.733) and Ningbo (0.597) were relatively ideal, while that of Lishui (0.385) was relatively unsatisfactory, indicating the presence of regional differences in the development of green finance in Zhejiang Province. Regarding prominent time periods, the data from 2017 to 2019 showed a general increase in the development of green finance in nine cities in Zhejiang Province, which was related to the fact that Zhejiang Province became a pilot zone for green finance reform in 2017. The success of the pilot zone has provided a replicable and promotable development mechanism and improved the development of green finance in nine cities in Zhejiang Province. Overall, the average development of green finance in nine cities in Zhejiang Province was 0.482, indicating a moderate gap between the development of green finance in Zhejiang Province and the ideal status; however, the overall situation remains at a stable and good level. This is closely related to the economic foundation of Zhejiang Province.

As shown in Figure 3, concerning spatial–temporal evolution, the development trends of industrial technology innovation in Huzhou, Jinhua, and Quzhou showed slight increases in shock, while the industrial technology innovation in the other six cities showed the evolution

characteristics of decline. The range of industrial technology innovation development in more than half of the cities was >0.6, reflecting obvious volatility. The range of industrial technology innovation in Quzhou reached 0.983, demonstrating a lack of stability in the development of industrial technology innovation in Zhejiang Province. Regarding the ideal value, the development of industrial technology innovation in Ningbo (0.933) and Quzhou (0.998) in 2017 was the closest to the ideal scheme. In 2013, the development of industrial technology innovation in Quzhou (0.015) was far from the ideal scheme. The average values of the development of industrial technology innovation in Ningbo (0.692), Hangzhou (0.570), and Wenzhou (0.509) were ideal and higher than the average values of nine cities in Zhejiang Province. The scores of the other six cities are lower than the average value of nine cities in Zhejiang Province. These findings demonstrated the regional differences in the development of industrial technology innovation in Zhejiang Province. The tense development of industrial technology innovation is the result of the joint action of multi-dimensional factors, among which deindustrialization cannot be ignored. The direct impact of this phenomenon is to reduce the proportion of industry. The indirect impact is to destroy the stability of the real economy and cause a lack of

FIGURE 4
Coupling degree between green finance and industrial technology innovation in nine cities in Zhejiang Province (2012–2019).
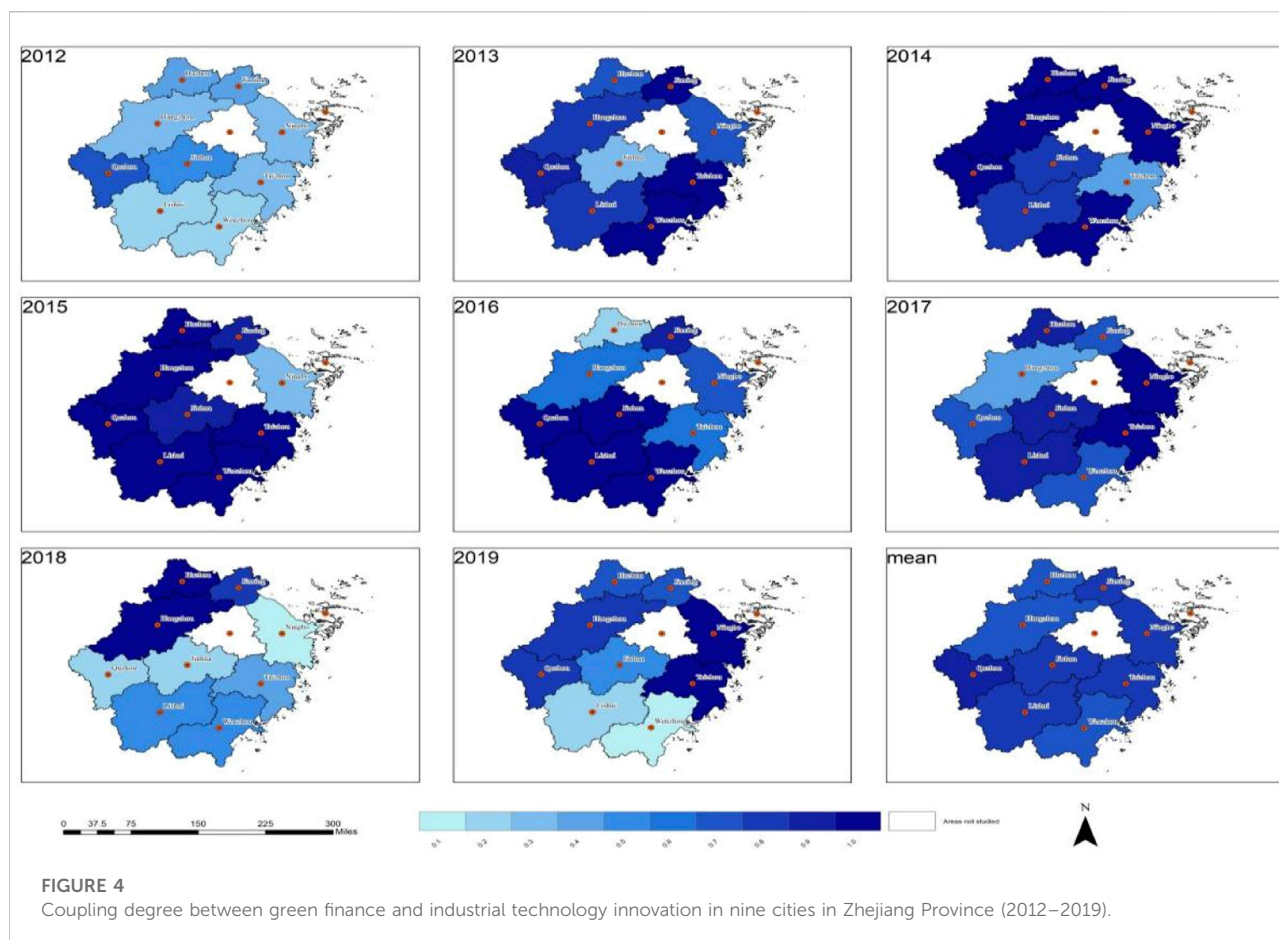
motivation for industrial technology innovation. Overall, the average development of industrial technology innovation in nine cities in Zhejiang Province was 0.5, indicating a moderate gap between the development of industrial technology innovation in Zhejiang Province and the ideal status, and the overall situation remains at a peaceful and optimized level. This is closely related to the development strategy of Zhejiang Province.

As shown in Figure 4, from the perspective of spatial–temporal evolution, the development trend of coupling degree of other cities except for Jiaxing from 2012 to 2019 shows that it rises in shock. The coupling degrees in Hangzhou City, Ningbo, and Jinhua has improved significantly from 2012 to 2019. The coupling degrees in Wenzhou and Quzhou have not increased significantly, while the coupling degree in Jiaxing has decreased, demonstrating regional differences in the intensity of the two systems in cities in Zhejiang Province. The average coupling degree of green finance and industrial technology innovation in nine cities of Zhejiang Province was 0.726, which indicated that the interaction intensity between the two systems in Zhejiang Province was high and tended to be orderly.

As is shown in Figure 5, assessment of the spatial–temporal evolution showed that the coupling coordination degree of nine cities in Zhejiang Province was in a state of shock and upward. Except for Jiaxing and Wenzhou, the average values in the other cities reached the barely coordinated level or above in 2019, demonstrating that the coupling and coordination relationship between green finance and industrial technology innovation systems among regions in Zhejiang Province was relatively balanced. The results of the analysis of coupling coordination degrees in cities showed that the changes in these degree were closely related to the development of green finance and industrial technology innovation. That is, the development and regression of green finance and industrial technology innovation in nine cities in Zhejiang Province will affect the rise and fall of the coupling coordination degree in the corresponding cities. Except for Taizhou and Wenzhou, the range of coupling coordination degrees of other cities was >0.6, reflecting high volatility. Regarding the degree of coupling coordination, Hangzhou, Jiaxing, Ningbo, Lishui, and Jinhua have achieved high-quality coordination, among which Jinhua maintained high-quality coordination in 2019.

FIGURE 5
Coupling coordination degree between green finance and industrial technology innovation in nine cities in Zhejiang Province (2012–2019).
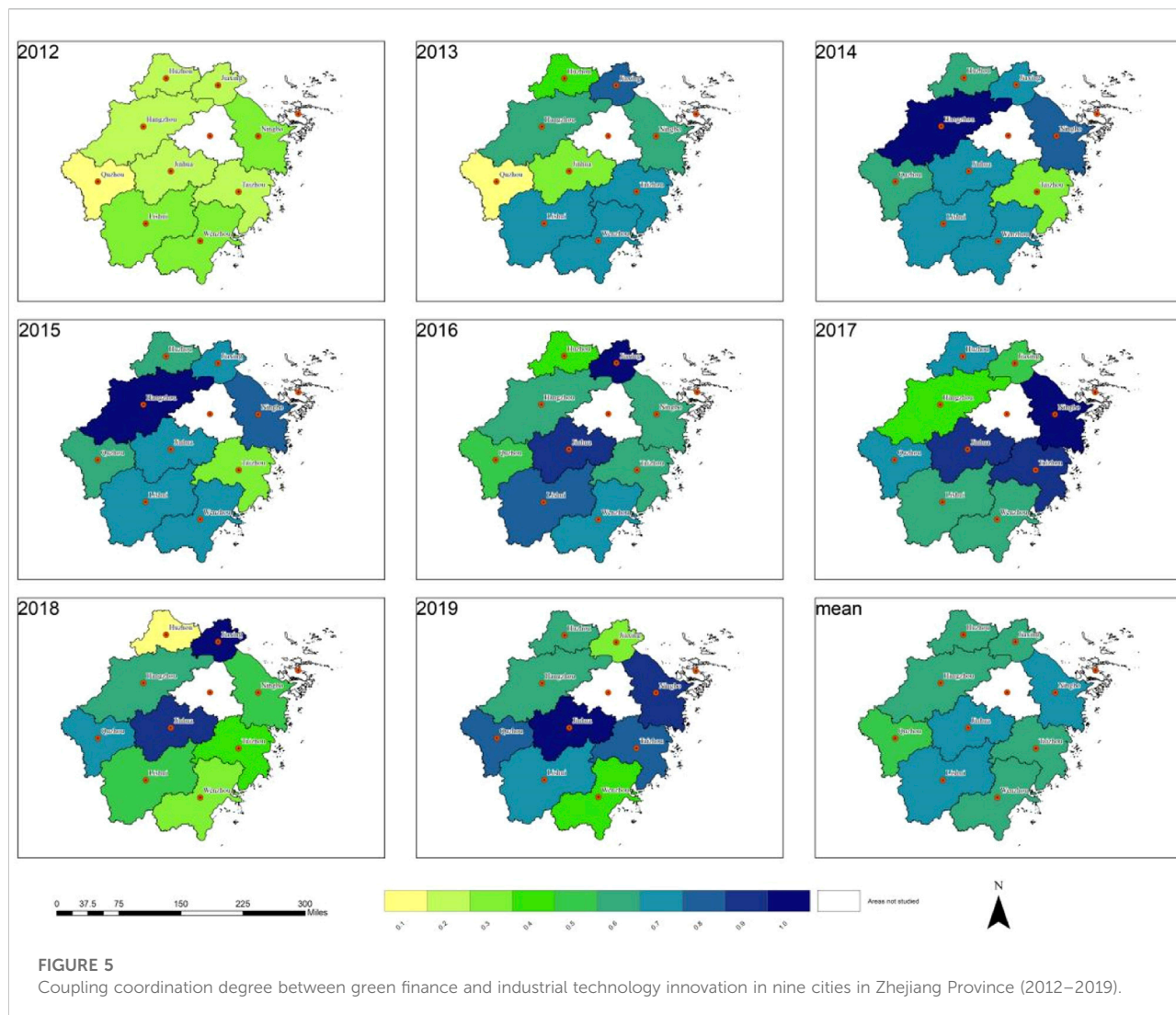
The average degree of the coupling coordination between the green finance and industrial technology innovation systems in nine cities of Zhejiang Province was 0.575, reaching the level of barely coordinated, suggesting that the two systems tend to have a benign correlation and are moving towards coordinated development. This is closely related to the vigorous development of green finance and industrial technology innovation in Zhejiang Province.

5 Conclusion and policy recommendations

5.1 Conclusion

1) The development of green finance and industrial technology innovation in nine cities in Zhejiang Province showed strong regional heterogeneity within the study period. While the development momentum of green finance was better than that of industrial technology innovation, its stability was worse.

2) The relationship between green finance and industrial technology innovation in nine cities in Zhejiang Province has become closer over time. The communication and coordination mechanism between green finance and industrial technology innovation is more complete with improvement in relevant policies.

3) The effects of green finance and industrial technology innovation in nine cities in Zhejiang Province are complex. Subject to the volatility of the development of green finance and industrial technology innovation, the coupling and coordination between the two systems was characterized by the superposition of mutual constraints at a low level and related promotion at a high level.

5.2 Policy recommendations

1) The government should play an active role in macro-control, integrate the industrial resources of different regions in Zhejiang Province, and establish industrial cluster areas, to fully release the spillover and radiation effects of industrial innovation technology, effectively break the spatial barriers of industrial technology innovation, promote the sustainable development of industrial innovation technology, and realize the optimization of regional industrial development patterns (Wang X. Y. et al., 2022). During resource integration, we should pay increased attention to areas with low industrial innovation technology. In these instances, green finance should be used as a means for development to give full play to the supporting effect of green finance policies, formulate the development plan for regional industrial technology innovation and green finance from the perspective of coordination, actively explore interactive mechanisms, and steadily promote the green diffusion and industrial technology transfer between regions. These actions will ensure the linkage of green finance and industrial technology innovation on the premise of considering both speed and quality (You et al., 2022).

2) As the main body of green finance, commercial banks should provide different financial measures for different regions. While banks should increase the credit threshold of polluting enterprises or reduce the loan repayment period, we also need to guide the flow of funds to enterprises engaged in green production. Furthermore, we should also classify and implement policies according to the finance development and resource utilization efficiency of different cities, end the use of rigid pricing mechanisms to restrict the development of enterprises in different regions, and reduce the asymmetric effects of policies on enterprises.

3) Enterprises should fully grasp the dividends of green financial policies and strive for long-term financial support by improving production technology, strengthening investment in innovation, and accelerating their information disclosure. Moreover, we should increase the awareness of learning, actively learn industrial technology suitable for our own development from enterprises in adjacent areas with better development and realize full

exchange and stable cooperation between industrial and supply chains. These steps are necessary to achieve not only the end goals but also green production.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding authors.

Author contributions

WW conceived of the study, JL wrote the manuscript, TH polished the manuscript, HZ developed the figures, XZ edited the manuscript, and TH just performed the final check of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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