Analysis of Spatio-Temporal Coupling Evolution Characteristics and Differences between Digital Economy and Green Logistics from the Perspective of Big Data

Jingyi Ji[a], Longfei Shen[b*], Jiong Zhang[c], Hongyi Le[d], Qirui He[e]

Northeastern Forestry University, Haerbin, China

[a]13230506725@163.com, [b*]shenlongfeislf@outlook.com, [c]2365627577@qq.com, [d]warpten_2023@foxmail.com, [e]heqipan88@qq.com

Abstract. In the context of rapid big data development, this paper evaluates the development levels of the digital economy and green logistics in the Harbin-Changchun and Central-Southern Liaoning urban agglomerations using the Technique for Order Preference by Similarity to an Ideal Solution entropy weight method. Then, by constructing a coupling coordination indicator system, it studies the spatio-temporal characteristics of the coupling between green logistics and the digital economy in these two urban agglomerations. The results indicate significant differences within the two urban agglomerations. Large cities such as Harbin and Shenyang perform prominently in the coupling and coordination of the digital economy and green logistics, while some smaller cities lag behind. Over time, although the overall level of coupling and coordination has improved, there are still issues of uneven spatial distribution and low coupling degrees in some regions. Therefore, measures such as accelerating the deep integration of the digital economy and green logistics, strengthening inter-regional collaboration and cooperation, and adapting to local conditions are proposed, aiming to promote the overall green development and enhance the digital economy levels of the Harbin-Changchun and Central-Southern Liaoning urban agglomerations, and contribute to the goal of achieving integration in Northeast China.

Keywords: big data; digital economy; green logistics; urban agglomerations; coupling coordination indicator system.

1 Introduction

In recent years, new technologies such as the Internet of Things, 5G, and AI have propelled the digital economy into playing a pivotal role in China's economic and social landscape. Data, as a crucial resource for new-type productivity, is vital to the development of the digital economy[1]. In the context of big data, deepening the integration of the digital economy and green logistics can help build international digital industrial clusters and achieve high-quality green development in logistics[2]. The Harbin-Chang

K. Zhang et al. (eds.), *Proceedings of the 5th International Conference on Economic Management and Big Data Application (ICEMBDA 2024)*, Advances in Economics, Business and Management Research 313,
https://doi.org/10.2991/978-94-6463-638-3_45

chun and Central-Southern Liaoning urban agglomerations are significant in the Northeast China economy. As new drivers, the digital economy and green logistics are crucial for enhancing the economic efficiency and sustainable development of urban agglomerations[3]. Studying the spatio-temporal coupling relationship between them can reveal new driving forces and trends. Currently, understanding the degree of coupling coordination and the level of synergy between the digital economy and green logistics in these two urban agglomerations, as well as the regional differences that exist, has practical significance for optimizing the development of the digital economy and the high-quality development of logistics in Northeast China[4-6].

2 Literature Review

Many scholars have previously conducted research on the digital economy and green logistics. Methods for measuring the digital economy vary among countries, international organizations, and scholars, and can be broadly classified into four types: value-added accounting, indicator system construction, satellite account compilation, and policy text word frequency analysis. Gu[7] et al. conducted statistical surveys from the perspectives of digital product input and output, and then calculated the value-added of the digital economy from an industry perspective. Fu[8] et al. attempted to construct a comprehensive and internationally comparable basic framework for China's digital economy satellite account, designing core tables and related aggregate indicators. Secondly, research on green logistics mainly involves multi-angle analysis of its conceptual essence, quantitative measurement, and implementation pathways. He defined green logistics as minimizing the ecological impact of logistics resources, optimizing resource utilization, and promoting sustainable development in socio-economic production and consumption. Thirdly, research on the relationship between the digital economy and green logistics. Luo[9] et al. constructed a coupling coordination degree model for the digital economy and green logistics to study the development status of both at the provincial level and the spatio-temporal evolution of their coupling coordination degree.

In summary, current research on the digital economy, green logistics, and their interrelationships has achieved certain results, but there are still two major areas for further exploration.

The innovations of this paper are as follows: firstly, from a coupling perspective, it innovatively integrates the digital economy and green logistics, deeply analyzes their coupling and coordination mechanisms, reveals their bidirectional promotion relationship, and provides new perspectives and content for related theories. Secondly, this study adopts a revised coupling coordination degree model, which can more accurately measure the coordinated development level of the digital economy and green logistics, enabling detailed classification of different coupling coordination degrees. Thirdly, this study focuses on the Harbin-Changchun and Central-Southern Liaoning urban agglomerations, which are economic growth poles and collaborative development demonstration areas in Northeast China. Not only reveals new drivers of regional economic development but also provides important references for coordinated development nationwide.

3 Research Area and Data Sources

3.1 Research Area

The Harbin-Changchun urban agglomeration (including Harbin, Changchun, etc.) and the Liaoning Central and Southern urban agglomeration (with Shenyang and Dalian as its cores) are both located in Northeast China and serve as significant economic growth poles, shown in Fig. 1. The location of the study area. Despite high urbanization rates, they still face challenges such as uneven development[10]. Discussing the spatio-temporal coupling changes can reveal new drivers of regional economic development and provide valuable experiences and insights for coordinated development nationwide.

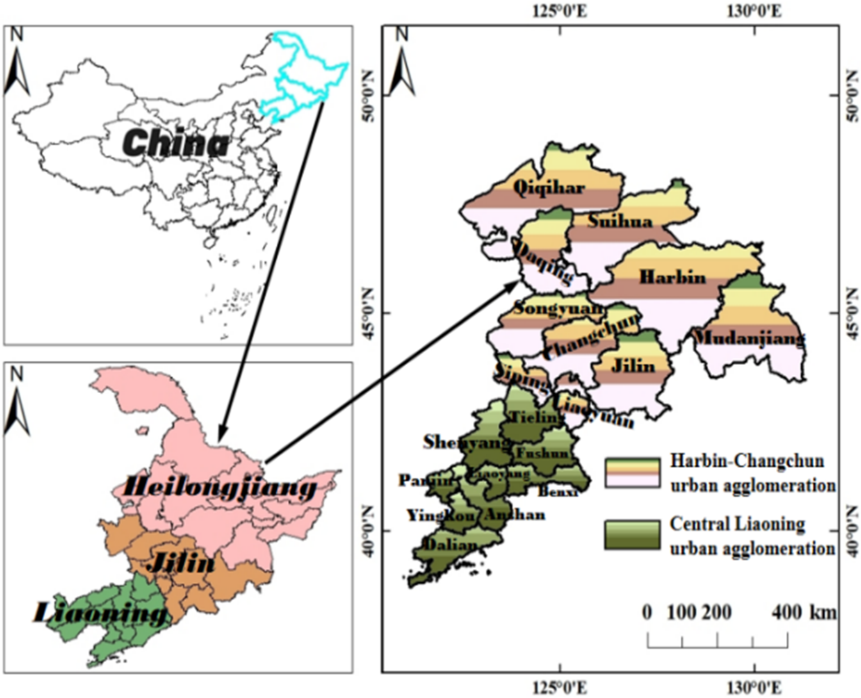


Fig. 1. The location of the study area

3.2 Data Sources

Based on data availability, scientific rigor, and the timeliness of the article, the data sources include the "China City Statistical Yearbook," "Heilongjiang Statistical Yearbook," "Jilin Statistical Yearbook," and "Liaoning Statistical Yearbook" from 2006 to 2022, as well as public data from municipal statistical yearbooks, statistical bulletins, and other sources. Interpolation methods were used to fill in some missing data.

4 Analysis of Coupling and Coordination Mechanism

The theory of coupling and coordination explores the dynamic connections and positive interactions between systems. The digital economy and green logistics are tightly coupled in structure and coordinated in function. The digital economy relies on new technologies to drive economic growth, while green logistics supports economic activities and facilitates digital transformation. The integration of these two systems forms a comprehensive and hierarchical structural system. As shown in Fig. 2.

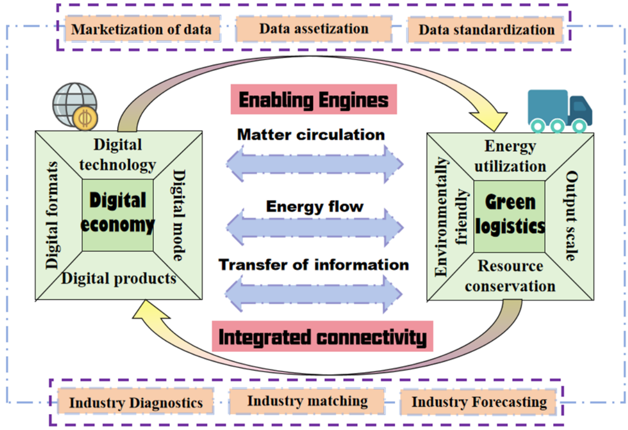


Fig. 2. Analysis of Coupling and Coordination Mechanism

5 Research Design

5.1 Establishment of Evaluation Indicator System

Currently, there is no standardized method for assessing the degree of digital economy development. The results obtained through the indicator system method are more concise and clear, facilitating comparison and analysis. Therefore, this paper constructs an evaluation indicator system for digital economy development that includes five dimensions: digital infrastructure, digital industry development, industrial digitalization, and digital innovation. For green logistics, this paper establishes an evaluation system from four dimensions: output scale, energy utilization, environmental friendliness, and resource intensification.

5.2 TOPSIS Entropy Weight Method

Determining the weights of indicators scientifically and reasonably is crucial for accurately measuring the digital economy and green logistics. This paper selects the Topsis entropy weight method as a comprehensive evaluation tool and can reduce the subjective influence of human judgment.

5.2.1 Handling Missing Values.

For minor data gaps in certain years, three imputation methods—nearest neighbor substitution, mean imputation, and linear interpolation—are employed to maintain data completeness.

5.2.2 Data Standardization.

With m indicators and n objects, x_{ij} denotes original data. Due to differences between positive (larger values preferred) and negative indicators (smaller values preferred), distinct standardization formulas based on range transformation are applied, avoiding zero values in results. As shown in Equations Positive indicators: $y_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)}$ and Negative indicators: $y_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)}$.

Positive indicators:

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

Negative indicators:

$$y_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)} \tag{2}$$

y_{ij} represents the standardized value of the j evaluation indicator for the i evaluation object.

5.2.3 Calculation of Indicator Weights.

Convert indicators into random variables. Let q be the probability value corresponding to the indicator value. Calculate the information entropy H(x) for each indicator. Compute the weight w_k for each indicator. The evaluation index function can be expressed as M. As shown in Equations Positive indicators: $y_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)}$ — Negative indicators: $y_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)}$.

$$q_{ij} = \frac{y_{ij}}{\sum_{i=1}^{l} \sum_{j=1}^{m} y_{ij}} \tag{3}$$

$$H(x) = \begin{cases} x \ln \frac{1}{x}, & x > 0 \\ 0, & x = 0 \end{cases} \tag{4}$$

$$E_k = \frac{1}{\ln(lm)} \sum_{i=1}^{l} \sum_{j=1}^{m} H(q_{ij}) \tag{5}$$

$$w_k = \frac{1 - E_k}{\sum_{k=1}^{n} (1 - E_k)} \tag{6}$$

$$M = \sum_{j=1}^{n} w_k y_{ij} \tag{7}$$

5.3 Coupling Coordination Model

There has been a shift to comprehensively evaluating its overall balanced development state. The coupling coordination degree model has emerged as a powerful evaluation tool for this purpose. This paper intends to adopt the improved coupling coordination degree model framework proposed by Wang Shujia (2021) to conduct an in-depth analysis of the synergistic effects.Assuming there are two subsystems, U1 and U2. As shown in Equations Positive indicators: $y_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)}$ — Negative indicators: $y_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)}$.

$$C = \sqrt{\left[1 - \sqrt{(U_2 - U_1)^2}\right] \times \frac{U_1}{U_2}} = \sqrt{[1 - (U_2 - U_1)] \times \frac{U_1}{U_2}} \tag{8}$$

$$T = \alpha U_1 + \beta U_2 \tag{9}$$

$$D = \sqrt{C \times T} \tag{10}$$

C represents the coupling degree; T represents the evaluation index; D represents the coupling coordination degree; and α and β represent the weights of the subsystems. Both the digital economy and green logistics are equally important, and green logistics cannot be overlooked. In this paper, we assume equal weights for both.

Based on the actual coupling and coordination situation of the Harbin-Changchun urban agglomeration and the central and southern Liaoning urban agglomeration, their coupling coordination degree is divided into six levels, as shown in Table 1.

Table 1. The division of coupling coordination degree

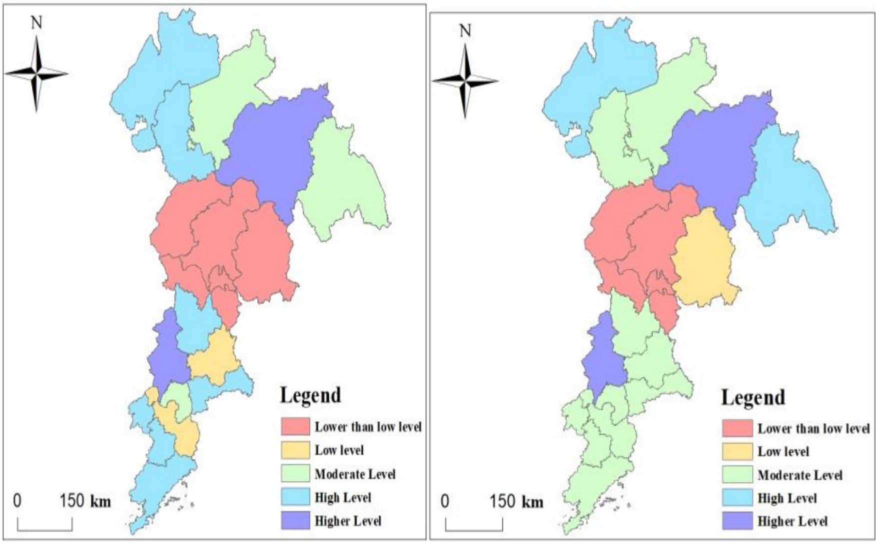
The range of coupling coordination degree.	level	The range of coupling coordination degree.	level
0—0.40	Out of Balance	0.61—0.70	Basic Coordination
0.41—0.50	Near Out of Balance	0.71—0.80	Intermediate Coordination
0.51—0.60	Forced Coordination	0.81—1.00	Excellent Coordination

6 Results and Analysis

6.1 Spatial-Temporal Characteristics of Digital Economy and Green Logistics Development Levels

6.1.1 Spatial-Temporal Characteristics of Digital Economy Development Level. This paper employs the Natural Breaks Classification to categorize the digital economy into five levels. It selects data from four key time points in 2006, 2012, 2018, and 2022. As shown in Fig.3. The results indicate that China's digital economy has grown significantly overall, but significant disparities remain among cities. Harbin and Shenyang have maintained highly active digital markets, leading the way. In contrast, central cities such as Siping, Songyuan, and Liaoyuan, lag behind due to issues like underdeveloped digital infrastructure, insufficient technological innovation.

Since the 18th National Congress of the Communist Party of China, China has actively responded to the call for building a network digital China. In terms of spatial distribution, in 2006, there were seven cities at the low and lower-middle levels; by 2016, the overall digital economy had improved, with one city each dropping out of the low and lower-middle levels; and in 2022, the number of cities at the high and upper-middle levels reached seven. This also reveals potential volatility in digital economy development, suggesting that its stability and sustainability need further enhancement.



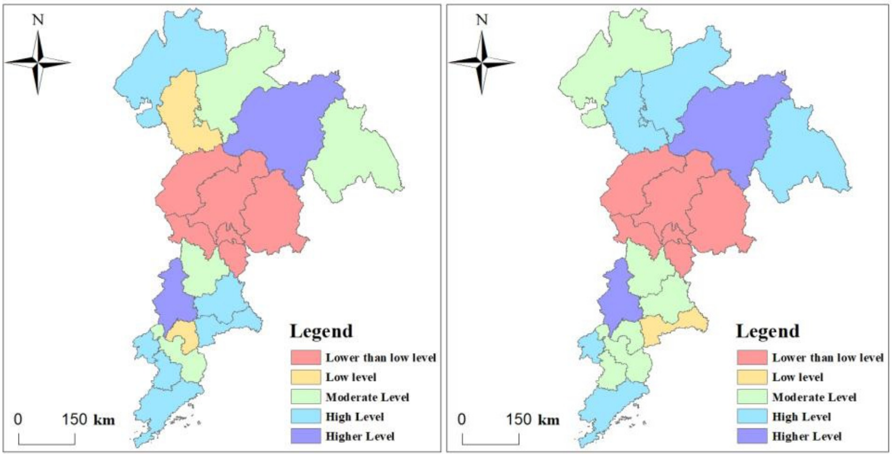
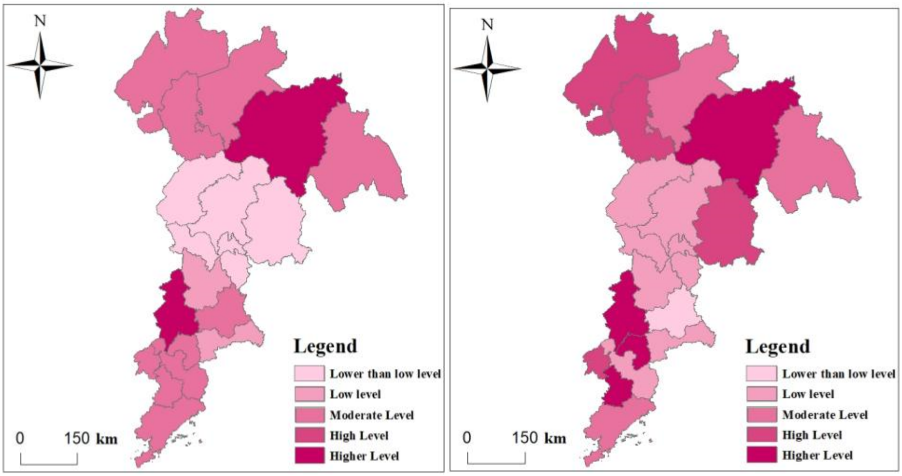


Fig. 3. The spatiotemporal evolution of the digital economy

6.1.2 Spatial-Temporal Characteristics of Green Logistics Development Level. The development level of green logistics is subdivided into five tiers. As shown in Fig. 4 Harbin and Shenyang rank among the top in urban agglomerations in green logistics, backed by robust economic support, advantageous geographical locations, leading logistics technology, and comprehensive infrastructure. In contrast, cities like Changchun and Fushun lag in green logistics development due to a shortage of logistics professionals, insufficient technological innovation drive, and their logistics industry's still-coarse growth model.

In 2006, eight cities were at the low or lower tier of green logistics development; by 2022, the spatial distribution pattern of green logistics had significantly changed, with high and upper regions contracting towards the southwest.



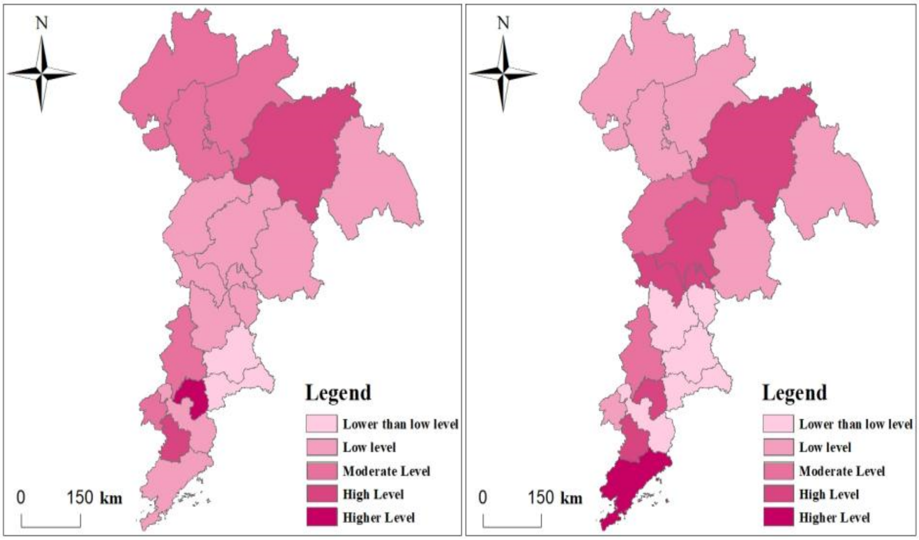


Fig. 4. The spatiotemporal evolution of green logistics

6.2 Spatial-Temporal Characteristics of Coupled and Coordinated Development between Digital Economy and Green Logistics

This paper uses a modified coupling coordination degree model to assess the coupling and coordination between digital economy and green logistics in China's two major urban agglomerations, Harbin-Changchun and Central-Southern Liaoning. As shown in Fig. 5. The results show that large cities in China performed better in the coupling and coordination of digital economy and green logistics, while small cities lagged behind. Most cities failed to achieve a positive interaction between digital economy and green logistics due to inadequate digital and transportation infrastructure, lack of digital innovation capability, and high energy consumption, forming a regional pattern with Harbin and Shenyang leading and other cities following.

Specifically, in 2006, 68.42% of provinces were in a state of imbalance in the coupling and coordination of digital economy and green logistics; by 2012, the number of cities near imbalance increased, including Qiqihar, Suihua, and Daqing. Due to a lack of vitality in the digital economy, Mudanjiang and Anshan failed to effectively promote the development of green logistics, becoming weak links in coordinated development. By 2022, cities such as Harbin, Shenyang, Liaoyang, Tieling, and Dalian demonstrated high coupling coordination degrees, mainly benefiting from the high-level development of their digital economy in recent years, which provided effective solutions to the pressures faced by green logistics and enhanced its capabilities.

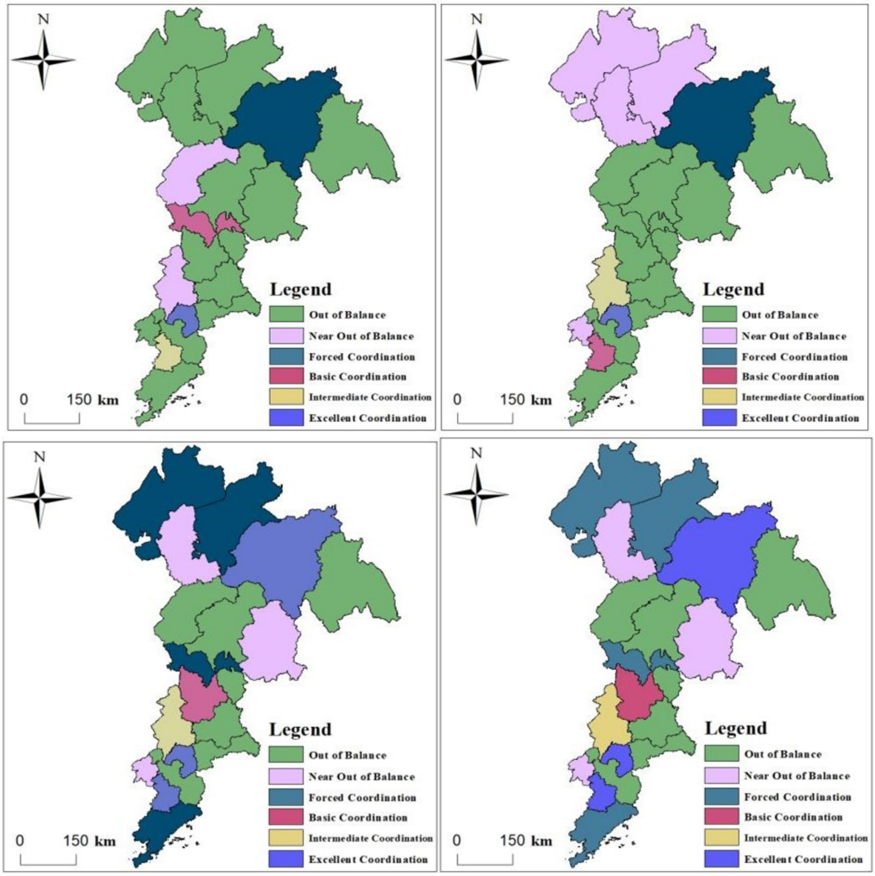


Fig. 5. Spatial distribution of coupling and coordination types

7 Conclusion

From 2006 to 2022, significant disparities in digital economy development persisted among cities. Representative cities such as Harbin and Shenyang maintained highly active digital markets at the forefront. Siping, Songyuan, and Liaoyuan, lagged due to various constraints. Spatially, China's digital economy hierarchy gradually improved, with fewer low and lower level cities and more high and upper level cities. However, this also revealed potential volatility in digital economy development.

Harbin and Shenyang led in green logistics, benefiting from economic advantages, geographical location, logistics technology, and infrastructure. In contrast, cities like Changchun and Fushun lagged in green logistics due to talent shortages and insufficient technological innovation. The number of low-level green logistics cities decreased between 2006 and 2022, but high-level areas contracted towards the southwest, while cities like Dalian and Yingkou experienced rapid green logistics growth.

Using a revised coupling coordination degree model, this study found that large cities outperformed small cities in coupling coordination. Most cities failed to achieve positive interactions due to inadequate infrastructure, lack of innovation, and high energy consumption, forming a pattern led by Harbin and Shenyang with other cities following. In 2006, 68.42% of provinces were in imbalance; by 2012, more cities were near imbalance, with Mudanjiang and Anshan as weak links. By 2022, cities like Harbin, Shenyang, Liaoyang, Tieling, and Dalian had high coupling coordination degrees, mainly benefiting from advanced digital economy development, providing effective solutions for green logistics.

8 Suggestions

Accelerate Deep Integration of Digital Economy and Green Logistics. The Harbin-Changchun and Central-Southern Liaoning urban agglomerations should leverage their economic, geographical, and technological advantages to accelerate digital economy development and promote its deep integration with green logistics. Governments should invest in digital technology and green logistics, encouraging enterprises to adopt advanced technology to improve resource efficiency.

Leverage Leading Role of High-Coupling Cities. Cities like Harbin and Shenyang in the Harbin-Changchun and Central-Southern Liaoning urban agglomerations excel in coupling coordination between the digital economy and green logistics. These cities should further lead by driving surrounding cities' development through industrial transfers and technology spillovers. Governments should strengthen cross-regional cooperation, break administrative barriers, and facilitate the flow and sharing of capital, knowledge, and technology.

Explore Locally Distinctive Paths Based on Conditions. The Harbin-Changchun and Central-Southern Liaoning urban agglomerations differ in resource endowments, economic bases, and human capital. Therefore, in promoting high coupling coordination between the digital economy and green logistics, locally distinctive paths should be explored based on each city's reality.

Reference

1. Su Yi, Zhi Pengfei, Guo Xiufang. Measurement of the scale of regional digital economy and its impact on regional innovation[J]. Science Research Management, 2023, 44(9): 29-38.
2. Dan Ma, Qing Zhu,Innovation in emerging economies: Research on the digital economy driving high-quality green development,Journal of Business Research,Volume 145,2022,Pages 801-813,ISSN 0148-2963, https://doi.org/10.1016/j.jbusres.2022.03.041.
3. Wang, Q.-J. et al. (2024) 'The Coupling and Coordination Between Digital Economy and Green Economy: Evidence from China', Emerging Markets Finance and Trade, pp. 1–17. doi: 10.1080/1540496X.2024.2399555.
4. Khuong Vu, Trung Nguyen,Exploring the contributors to the digital economy: Insights from Vietnam with comparisons to Thailand,Telecommunications Policy,Volume 48, Issue 1,2024,102664,ISSN 0308-5961,https://doi.org/10.1016/j.telpol.2023.102664.

5. Xu Lan, Wang Kaifeng. A Review of Research on the Connotation and Measurement Indicator System of the Digital Economy [J]. Statistics & Decision, 2024, 40(12): 5-11. DOI: 10.13546/j.cnki.tjyjc.2024.12.001.
6. Sun Xuefu. A Quantitative Study on Policy Texts of Digital Government Construction in Heilongjiang Province [D]. Harbin University of Commerce, 2024. DOI: 10.27787/d.cnki.ghrbs.2024.000553.
7. Gu Yali, Li Jiayi. Research on the Calculation of Digital Economy Value Added from the Perspective of Government Statistics [J]. China Statistics, 2024, (03): 58-60.
8. Fu Zhengjiang, Zheng Zhiqi, Qu Xiaoe. Construction of an Indicator System and Empirical Analysis for High-Quality Development of the Digital Economy: Evidence from Shaanxi Province [J]. Statistics & Decision, 2023, 39(13): 28-32. DOI: 10.13546/j.cnki.tjyjc.2023.13.005.
9. Luo Liangqing, Ping Weiying, Zhang Yulu. Research on the Compilation of China's Digital Economy Satellite Account Based on an Integration Perspective [J]. Statistical Research, 2021, 38(01): 27-37. DOI: 10.19343/j.cnki.11-1302/c.2021.01.003.
10. Wang Shujia, Kong Wei, Ren Liang, et al. Misunderstandings and Corrections of the Domestic Coupling Coordination Degree Model [J]. Journal of Natural Resources, 2021, 36(03): 793-810.