

Coupling and Coordination Analysis of Digital Economy and Regional Green Development

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Received: 28 February 2026; Accepted: 25 March 2026; Published: 13 April 2026

Abstract:

This study aims to explore the coupling and coordination relationship between the digital economy and regional green development. Employing a combination of theoretical and empirical methods, the study first constructs a theoretical framework for the mutual influence between the two systems. The entropy method is used to evaluate the levels of digital economy and green development across 30 Chinese provinces from 2014 to 2022, followed by an empirical analysis using a coupling coordination degree model. The findings reveal that: (1) since 2014, both digital economy and green development levels have steadily increased, with digital economy growth being more pronounced; (2) the coupling coordination between the two has gradually improved, though spatial differences persist across regions; and (3) significant regional disparities exist, showing a development trend of east > central > west > northeast. Based on these conclusions, relevant policy recommendations are proposed.

Keywords:

Digital Economy, Regional Green Development, Entropy Method, Coupling Coordination Degree

1. Introduction

1.1. Research Background and Significance

In recent years, the digital economy, centered on information technology, has developed rapidly worldwide and has become a key driver of economic growth. Meanwhile, as environmental issues such as global climate change and resource scarcity become increasingly severe, green development has emerged as a central concern of global significance. Against this backdrop, exploring the harmonious relationship between the digital economy and regional green development is particularly critical. As an innovative economic model characterized by efficiency, intelligence, and sustainability, the digital economy interacts with green development in multiple ways. First, the application of digital technologies helps improve resource utilization efficiency, reduce environmental pollution, and promote the transformation

of industries toward greener and more intelligent directions. Second, green development also expands market space and provides demand-side support for the digital economy. It is important to note that despite the rapid growth of the digital economy worldwide, significant disparities exist in development levels across regions, and green development similarly faces the challenge of regional imbalance. Therefore, investigating the coupling and coordination between the digital economy and regional green development can facilitate a deeper understanding of interregional development differences and key challenges, thereby providing a scientific basis for formulating more targeted policies.

The significance of this study is reflected in both theoretical and practical dimensions. Theoretically, grounded in the context of digitalization, this paper explores the connotations of the digital economy and regional green development, elucidating the necessity of information technology innovation for green development and the important role of the digital economy in driving it. By analyzing the coupling and coordination mechanism between the two, this study constructs a more comprehensive theoretical framework and further examines the key factors influencing coupling and coordination, as well as the direction and intensity of their effects, thereby offering theoretical support for policy formulation. Practically, this paper takes the digital economy as a point of departure, revealing its significant advantages in promoting regional green development. It provides valuable references for regions in formulating green development strategies, while also injecting new momentum into China's high-quality economic development, facilitating the green transformation of regional economies, and accelerating the process of socialist modernization.

1.2. Literature Review

Against the backdrop of global digitalization, the relationship between the digital economy and regional green development has attracted widespread attention. The digital economy is becoming a key driver of economic growth and industrial transformation, while green development is a critical pathway for addressing climate change and achieving sustainability.

For digital economy indicator systems, the OECD (2014) proposed an early evaluation framework with 38 indicators, providing a reference for international comparison, though it remained theoretical without determining weights [1]. Singh's Digital Economy offers theoretical support for indicator selection [2]. Li Yan (2021) analyzed digital economy output efficiency across eight economic regions, finding that efficiency increased but regional disparities widened [3]. Li Zhiguo et al. (2021) argued that innovation and entrepreneurship are key transmission pathways for digital economy-driven industrial transformation, with most studies showing a steady upward trend in China's digital economy [4].

For regional green indicator systems, Zhang Xu et al. (2020) constructed a high-quality green development evaluation system and confirmed an upward trend in China's green development level [5]. Gai Mei et al. (2021) reached similar conclusions [6]. Shi Minjun and Xu Ying (2018) categorized provinces into four types—low-development, green preservation, coordinated development, and economic pilot zones—facilitating regional analysis [7]. Gao Honggui and Zhao Lu (2019) revealed significant spatial agglomeration in industrial green development across 11 provinces in the Yangtze River Economic Belt [8]. Wang (2020) found a U-

shaped relationship between green economic efficiency and environmental regulation, more pronounced in developed regions [9].

For the relationship between the digital economy and green development, Cheng et al. (2023) constructed a coupling coordination degree model to explore China's innovation network and ecological efficiency [10]. Zhang Lingyu quantitatively assessed the coupling coordination level and its influencing factors [11]. Qian Zhengming and Liu Xiaochen (2013) proposed an inverted U-shaped relationship between green development efficiency and economic development level [12]. Xue Wei (2016) argued that IoT reduces resource consumption and avoids waste through intelligent management, promoting low-carbon development [13]. Hong et al. (2018) analyzed the interaction mechanisms between economic and environmental systems [14]. Fan Yixia and Xu Hao (2021) found a quadratic curve relationship between the digital economy and energy intensity [15]. Wang Qingxi et al. (2022) emphasized that the digital economy promotes green development by reducing energy consumption, lowering emissions, and improving efficiency [16]. Fu Duanxiang and Xie Kaikai (2024) explored the coupling coordination between the digital economy and logistics industry in Henan Province [17]. Luo Xing et al. (2024) studied the coupling coordination between county-level digital inclusive finance and new urbanization, offering a new perspective [18].

Overall, current research is relatively abundant. Most studies indicate a steady upward trend in both areas and suggest they reinforce each other, though with regional heterogeneity. However, limitations remain. First, as new infrastructure and IT evolve, existing indicator systems lack comprehensiveness and fail to reflect the digital economy environment. Second, most research focuses on single domains, with few examining the relationship between the two, and most are theoretical. Research on their coordination is largely limited to digital economy with green technology or green industries, lacking comprehensive evaluation. Third, most studies use pre-2020 data, with a lack of updated panel data. Therefore, this paper uses 2014–2022 data, employs entropy and coupling coordination analysis, refines the indicator system, measures digital economy and green development levels, and analyzes their coordination to better promote their integrated development.

1.3. Research Framework and Content

This study follows the logical path of “theoretical exploration—status analysis—empirical research—countermeasure analysis.” Chapter 1 serves as an introduction, covering the research background, significance, literature review, framework, content, and innovations. Chapter 2 defines key concepts, elaborates on the theoretical foundation, and analyzes the interaction mechanism between the digital economy and regional green development. Chapter 3 quantitatively evaluates the levels of both using the entropy method, conducts descriptive analysis, and applies the coupling coordination model to examine the coupling and coordination status across regions. Chapter 4 summarizes the research findings and proposes countermeasures and recommendations from four dimensions to promote the deep integration of the two. Two main research methods are employed: first, the CRITIC comprehensive evaluation method, which determines weights based on the correlation and variability of indicator data to objectively reflect the levels of the digital economy and green development; second, the coupling coordination degree model, which treats the digital economy and green development as two independent systems to analyze the

interaction and coordination between them across various provinces and cities in China.

1.4. Innovations

A review of existing literature reveals abundant research findings on the digital economy and green development. Building upon previous studies, this paper presents innovations in research content, indicator selection, and research methodology, as detailed below:

In terms of research content, this study integrates the digital economy with green development, analyzing the development trends and characteristics of the digital economy, green development, and their coupling coordination relationship across 30 provinces and municipalities in China from 2014 to 2022 from both temporal and spatial dimensions. By comparing spatial differences, it provides a more comprehensive understanding of the development status of each province and city.

In terms of indicator selection, this study incorporates elements of the digital economy environment into the digital economy indicator system and adds multiple indicators related to new information and communication technologies. For green development indicators, in addition to ecological environment and pollution control, this study includes indicators related to green living, integrating aspects of people's convenience and comfort, thereby more closely aligning with high-quality development and green transformation and upgrading.

In terms of research methodology, this study employs the coupling coordination degree model to analyze the coordination level between the digital economy and regional green development, as well as the differences across regions, enabling a more accurate reflection of the dynamic changes and regional disparities in the relationship between the two.

2. Conceptual Definition and Relevant Theoretical Analysis

2.1. Conceptual Definition

2.1.1. Digital Economy

The digital economy, as an emerging economic model, is characterized by digital knowledge and information as key production factors, digital technology as the core driving force, and modern information networks as important carriers. It is committed to deeply integrating digital technology with the real economy, continuously enhancing the degree of digitalization, networking, and intelligence, thereby reshaping the direction of economic growth and forming new management strategies at an accelerated pace. The digital economy primarily consists of the following key components: Digital industrialization, which mainly involves the information and communication industry, including electronic information manufacturing, telecommunications services, software and information technology services, and the internet industry. Industrial digitalization refers to the integration of digital technologies into traditional industries and the promotion of industrial progress and transformation through technological integration. This encompasses multiple emerging industries such as the industrial internet, intelligent manufacturing, the Internet of Vehicles, and platform economy, empowering traditional industries to increase production and efficiency through digital technologies, while creating new

industrial forms, models, and business formats. Digital governance emphasizes a multi-governance model supported by digital technologies, combining technology with management, with “digital technology + governance” as its distinctive feature. Data valorization covers multiple aspects including data collection, organization, analysis, utilization, and protection, aiming to maximize data value through effective data utilization and management. This includes the formulation of data standards, confirmation of data rights, improvement of data annotation, rationalization of data pricing, standardization of data transactions, optimization of data flows, and strengthening of data protection. These four core components collectively constitute a complete system for the digital economy, promoting its sustainable growth.

2.1.1. Digital Economy

Green development is committed to economic and social growth centered on efficiency, harmony, and sustainability, emphasizing the harmonious progress of economy, society, and environment, and regarding environmental resources as the foundation of economic development. In the process of development, it is essential to deeply recognize the finiteness and fragility of environmental resources and to actively take measures to protect and restore the ecological environment. The goal of green development is to achieve comprehensive and sustainable development, ensuring that economic activities do not cause irreversible damage to the ecological environment, and realizing the harmonious unity of economic development and environmental protection. The main pathways to achieving green development lie in promoting the “greening” and “ecologization” of economic activities, including the widespread adoption of clean energy, deepening the practice of circular economy, improving resource utilization efficiency, and strengthening ecological protection and restoration efforts. Through these measures, a virtuous cycle between economic development and environmental protection can be effectively promoted, achieving true green development.

2.2. Analysis of Mutual Influence Mechanisms

2.2.1. The Impact of the Digital Economy on Regional Green Development

The impact of the digital economy on regional green development is multifaceted. First, the digital economy facilitates the innovation and widespread application of green technologies. With the help of digital technologies, enterprises can conduct green technology research and development and product innovation more efficiently, improve resource utilization efficiency, reduce carbon emissions, and promote the establishment of green production and consumption models. Second, the digital economy provides impetus for the optimization and upgrading of industrial structures, promoting the digital transformation of traditional industries and the rise of new green industries, reducing the proportion of high-energy-consumption and high-pollution industries, and increasing the proportion of green industries, thereby driving the green transformation of regional economies. Furthermore, the digital economy strengthens inter-regional connections and cooperation. The application of digital technologies facilitates information exchange and enhances knowledge spillover effects, contributing to resource sharing and complementary advantages. It should be noted that the impact of digital economy development on regional green development exhibits differences and complexities. Different regions have varying levels of digital economy and green development. Therefore, development strategies should be tailored to local conditions, fully considering regional differences and adopting

appropriate policies and measures to better achieve the goals of sustainable development.

2.2.2. The Impact of Regional Green Development on the Digital Economy

At the same time, regional green development also exerts significant influence on the digital economy. First, the concept of green development emphasizes the harmonious integration of economic growth with resources and the environment, setting sustainable development standards for the digital economy. This drives the digital economy to place greater emphasis on environmental protection and resource conservation, promotes the development of digital technologies in a green direction, and achieves harmonious coexistence with the ecological environment. Second, green development faces resource and environmental constraints, creating demand for innovative technologies and providing broad opportunities for innovation and advancement in the digital economy. For example, by promoting green cloud computing, big data, and other information technologies, the digital economy is driven to evolve in a greener, smarter, and more efficient direction. Third, green development emphasizes the integration of economic efficiency with social equity, helping to enhance the industrial value of the digital economy. By promoting the green transformation of the digital economy, optimizing industrial layout, and improving overall quality, a win-win situation can be achieved between economic growth and ecological protection. Finally, driven by green development, regions place greater emphasis on the green development of the digital economy, which helps enhance the regional competitiveness of the digital economy, attract more green investment, and promote the green, low-carbon, and sustainable development of regional economies.

3. Measurement and Coupling Coordination Analysis of Economic Development and Regional Green Development

3.1. Indicator System Construction

3.1.1. Digital Economy Indicator System

Guided by the Statistical Classification of the Digital Economy and Its Core Industries, this paper constructs a digital economy indicator system consisting of three subsystems, seven primary indicators, and thirteen secondary indicators, as detailed in Table 1. The framework encompasses digital industrialization—covering computer communications, electronic equipment manufacturing, telecommunications, broadcasting and television, satellite transmission services, internet services, and software and information technology services—which forms the foundation of the digital economy; industrial digitalization, which leverages digital technologies and data resources to enhance efficiency in traditional industries, reflecting the deep integration of the digital economy with the real economy and serving as its core pillar; and the digital economy environment, a comprehensive system that provides foundational support for sustainable development, with a focus on future talent cultivation, technological R&D trends, and the evolving landscape of information dissemination, software development, and information technology services.

Table 1. Indicator System for Digital Economy Development Level.

Subsystem	Primary Indicator	Secondary Indicator	Unit	Variable	Direction
Digital Industrialization	Industrial Scale	Urban Employed Persons in Information Transmission, Software, and Information Technology Services	10,000 persons	X1	+
		Urban Employed Persons in Scientific Research and Technology Services	10,000 persons	X2	+
	Industrial Efficiency	Revenue from Software Business	CNY 10,000	X3	+
		Total Telecom Business	CNY 100 million	X4	+
	Foundational Technology	Number of Domain Names	10,000 units	X5	+
		Internet Broadband Access Subscribers	10,000 subscribers	X6	+
Industrial Digitalization	Industry Integration	Proportion of Enterprises with E-commerce Transaction Activities	%	X7	+
	Innovation and R&D	Number of R&D Projects of Industrial Enterprises Above Designated Size	Projects	X8	+
		Domestic Patent Applications Received	Applications	X9	+
	Scale Efficiency	E-commerce Sales	CNY 100 million	X10	+
Digital Economy Environment	Talent Environment	Number of Legal Entities in Information Transmission, Software, and Information Technology Services	Entities	X11	+
		Full-time Equivalent of R&D Personnel in Industrial Enterprises Above Designated Size	Man-year	X12	+
		Expected Number of Undergraduate Graduates in Regular Higher Education Institutions	CNY 10,000	X13	+

Note: Source: National Bureau of Statistics of China; China Statistical Yearbook.

3.1.2. Construction of the Green Development Indicator System

Green development represents a pathway to social progress that pursues efficiency, harmony, and sustained economic growth, deepening and extending the concept of sustainable development with its core objective being the coordinated enhancement of economic, ecological, and social benefits. This paper constructs a green development evaluation indicator system encompassing three dimensions—green ecology, green living, and environmental governance—comprising five primary indicators and fourteen secondary indicators, as detailed in Table 2. For green ecology, indicators are selected to reflect the actual conditions of ecological protection and resource utilization across regions, including green coverage rate of built-up areas, per capita park green space, forest coverage rate, per capita water resources, electricity

consumption, and per capita daily domestic water consumption. For green living, key indicators capture the convenience of residents' daily lives as well as the state of social security and social equity, including per capita urban road area, number of urban sanitation vehicles, number of public transportation vehicles per 10,000 persons, and number of public restrooms per 10,000 persons. For environmental governance, the focus is on the intensity of environmental management and the control of pollutant emissions, measured by urban wastewater treatment capacity, harmless treatment rate of municipal solid waste, sulfur dioxide emissions, and nitrogen oxide emissions. Among these indicators, electricity consumption, per capita daily domestic water consumption, sulfur dioxide emissions, and nitrogen oxide emissions are treated as negative indicators, implying that green development entails reducing resource consumption and pollutant emissions.

Table 2. Indicator System for Green Development Level.

Subsystem	Primary Indicator	Secondary Indicator	Unit	Variable	Direction
Green Ecology	Ecological Environment	Green Coverage Rate of Built-up Areas	%	Y1	+
		Per Capita Park Green Space	m ² /person	Y2	+
		Forest Coverage Rate	%	Y3	+
		Per Capita Water Resources	m ³ /person	Y4	+
	Resource Conservation	Electricity Consumption	100 million kWh	Y5	–
		Per Capita Daily Domestic Water Consumption	Liter	Y6	–
Green Living	Convenience of Living	Per Capita Urban Road Area	m ²	Y7	+
		Number of Specialized Urban Sanitation Vehicles	Unit	Y8	+
		Number of Public Transportation Vehicles per 10,000 Persons	Standard Unit	Y9	+
		Number of Public Restrooms per 10,000 Persons	Unit	Y10	+
Environmental Governance	Treatment Intensity	Urban Wastewater Treatment Capacity	10,000 m ³	Y11	+
		Harmless Treatment Rate of Municipal Solid Waste	%	Y12	+
	Emission Intensity	Sulfur Dioxide (SO ₂) Emissions	10,000 tons	Y13	–
		Nitrogen Oxide (NO _x) Emissions	10,000 tons	Y14	–

Note: Source: National Bureau of Statistics of China; China Statistical Yearbook.

3.1.3. Data Sources and Processing

(1) Data Sources

Due to the lack of relevant data for Hong Kong, Macau, Taiwan, and Tibet, this study focuses on 30 provinces, autonomous regions, and municipalities directly under the central government, covering the period from 2014 to 2022. To facilitate a comparative analysis of the digital economy and green development levels across different regions, this study adopts the classification standards of China's economic regions, dividing the country into four major geographical regions: Eastern, Central, Western, and Northeast China. The detailed classification is presented in Table 3. The primary indicator data are sourced from the statistical yearbooks of each province, the China Statistical Yearbook, the China Regional Economic Statistical Yearbook, the National Bureau of Statistics of China, the National Data portal, and the EPS database, among other sources.

Table 3. Classification of the Four Major Economic Regions.

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

(2) Data Preprocessing

During the process of collecting data for the digital economy and green development indicators, the corresponding indicator data for the study period were downloaded from the National Bureau of Statistics of China and the statistical yearbooks of each province. For missing data, this study employs the trend value method and the mean value method to supplement the gaps. Subsequently, the max-min normalization method is applied to standardize the data in order to mitigate the adverse effects arising from dimensional differences among the indicators. Here, X_{ij} represents the collected raw data, while $\max(X_{ij})$ and $\min(X_{ij})$ denote the maximum and minimum values of the j -th indicator for the i -th city, respectively. The normalization formulas for positive and negative indicators are shown in Equations (3-1) and (3-2), respectively.

$$x'_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \quad (3-1)$$

$$x'_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \quad (3-2)$$

3.2. Comprehensive Evaluation Method

This paper considers digital industrialization, industrial digitalization, and the digital economy environment to be equally important for the development of the digital economy. Following the approaches adopted by numerous scholars regarding system weighting, equal weights are assigned to these three dimensions. Similarly, equal weights are assigned to green ecology, green living, and environmental governance [14–17]. For determining the weights of the secondary indicators, this study adopts an objective weighting method, specifically the CRITIC (Criteria Importance Through Intercriteria Correlation) weighting method. This approach not only accounts for the variability within each indicator but also analyzes the correlations among indicators, thereby providing a more comprehensive reflection of the importance of each indicator within the digital economy and green development

indicator systems. Accordingly, the CRITIC method is ultimately selected as the effective approach for determining the weights of the secondary indicators in the digital economy and green development indicator systems.

3.2.1. Comprehensive Evaluation Method Based on the CRITIC Method

The CRITIC weighting method, an objective weighting approach originally proposed by Diakoulaki, is specifically designed to quantify the importance of various indicators in evaluation. The core idea of this method is based on the contrast intensity and the conflict among evaluation indicators. When applying the CRITIC weighting method for comprehensive evaluation, the calculation steps are typically determined by the number of indicators in the system and the actual conditions of the evaluated objects. The steps are outlined as follows:

Step 1: For each fixed year, the data are standardized using the max-min normalization method.

Step 2: The proportion of the j -th indicator for the i -th province is calculated as:

$$y_{ij} = \frac{x_{ij}}{\sum_{i=1}^m x_{ij}} \quad (3-3)$$

where m represents the number of provinces.

Step 3: The entropy value of the j -th indicator is calculated as:

$$e_j = -k \sum_{j=1}^m y_{ij} \ln y_{ij} \quad (3-4)$$

where $k = \frac{1}{\ln m}$.

Step 4: The degree of diversity d_j is calculated based on the entropy value e_j :

$$d_j = 1 - e_j \quad (3-5)$$

Step 5: The weight is calculated as:

$$w_j = \frac{d_j}{\sum_{i=1}^m d_j} \quad (3-6)$$

Step 6: By multiplying the indicator weights derived from the CRITIC method with the weights of the corresponding subsystems, the final weights of the secondary indicators, denoted as W'_j , are obtained. This method yields the weights of the m indicators for each year.

Step 7: The comprehensive evaluation indices for the digital economy and green development are calculated as:

$$U_1 = \sum_{i=1}^m w_j y_{ij} \quad (3-7)$$

$$U_2 = \sum_{i=1}^m w_j y_{ij} \quad (3-8)$$

where U_1 represents the ecological and environmental protection index, and U_2 represents the digital economy development index; w_j denotes the weight of each indicator within the system.

3.3. Coupling Coordination Analysis of Digital Economy and Green Development

3.3.1. Coupling Coordination Degree Model

The coupling coordination degree model is widely applied in assessing the degree of coordination among multiple systems, demonstrating particular efficacy in analyzing the interactions and mutual influences between two or more systems or elements. This model consists of two core components: the coupling degree model and the coordination degree model. The coupling degree model serves to explore the interactions and influences between two or more systems, depicting the dynamic and complex interrelationships among them. Through this model, the degree of interdependence and mutual constraint between systems can be understood more intuitively. In software development, the coupling degree model can represent the interactive dependencies within system software, describing the connections between system components and their assigned tasks—a key performance indicator that can be used to diagnose systems, analyze their stability and reliability, and thereby enhance system scalability and extensibility. The coordination degree model focuses on whether the system or its elements have achieved a state of harmony and consistency during the development process. It provides a quantitative expression of the degree of synergy among subsystems within a system, revealing the trend of the system gradually shifting from a disordered to an ordered state. Assessing the coordination degree is crucial for understanding the coordination between ecological environment and economic and social development, serving as an important foundation for the implementation of regional sustainable development strategies and a key factor in achieving the coordinated development of economic, social, and ecological benefits.

To thoroughly investigate whether the two subsystems—the digital economy and the ecological environment—meet the needs and current state of coordinated development, this study constructs a coupling degree model and a coordination degree model tailored to this purpose.

First, the coupling degree model for the digital economy and ecological environment is constructed. The model is specified as follows:

$$C = n \left(\frac{U_1 U_2 \dots U_n}{(\prod U_i + U_j)^n} \right)^{\frac{1}{n}} \quad (3-9)$$

In the formula, U_i , U_j , U_n represent the growth indicators of the i -th, j -th, and n -th subsystems, respectively, and nn denotes the number of subsystems. CC represents the degree of interdependence among subsystems, with $0 \leq C \leq 1$. When C approaches 1, it indicates a stronger interaction between the systems.

As this study focuses on two systems—the digital economy and green development $n=2$. Accordingly, the coupling degree model is derived as follows:

$$C = 2 \times \sqrt{\frac{U_1 U_2}{(U_1 + U_2)^2}} \quad (3-10)$$

Next, the coordination degree model for the digital economy and green development is constructed. The model is specified as follows:

$$T = aU_1 + bU_2 \quad (3-11)$$

$$D = \sqrt{C \times T} \quad (3-12)$$

The coupling coordination degree D is used to measure the level of coordinated development between the digital economy and green development. A larger D value indicates a higher degree of coordination between the two systems, suggesting more harmonious interactions and associations; conversely, a smaller D value implies a

lower level of coordination, reflecting relatively less harmonious cooperative relationships.

To analyze the coupling coordination development between the digital economy and green development, the parameters a and b are set as coefficients to be determined, satisfying the condition $a+b=1$. This assigns equal weights to the digital economy and green development, reflecting the assumption that they hold equivalent importance in economic development.

Additionally, by comparing the relative levels of the digital economy and green development, a relative development model is employed to reveal their development pattern:

$$\beta = U_1/U_2 \quad (3-13)$$

where β represents the relative development degree between the digital economy and green development. When $0 \leq \beta < 0.6$, the digital economy is classified as extremely lagging; when $0.6 \leq \beta < 0.8$, it is classified as severely lagging; and when $0.8 \leq \beta$, it is classified as moderately lagging.

The criteria for evaluating the coupling coordination degree are presented in Table 4:

Table 4. Criteria for Evaluating the Coupling Coordination Degree.

Coupling Coordination Degree	Coupling Stage	Coordination Level	Category
[0.0000,0.1000)	Minimal Coupling	Extremely Uncoordinated	Dysfunctional Decline Type
[0.1000,0.2000)	Low-Level Coupling	Severely Uncoordinated	
[0.2000,0.3000)	Low-Level Coupling	Moderately Uncoordinated	
[0.3000,0.4000)	Antagonistic Coupling	Mildly Uncoordinated	
[0.4000,0.5000)	Antagonistic Coupling	On the Verge of Uncoordinated	Intermediate Transition Type
[0.5000,0.6000)	Running-in Coupling	Barely Coordinated	
[0.6000,0.7000)	Running-in Coupling	Primarily Coordinated	Coordinated Enhancement Type
[0.7000,0.8000)	Running-in Coupling	Moderately Coordinated	
[0.8000,0.9000)	High-Level Coupling	Well Coordinated	
[0.9000,1.0000)	Maximal Coupling	Excellent Coordinated	

3.3.2. Coupling Coordination Degree Analysis

Based on the previously calculated digital economy and green development indices, the coupling degree between the two systems can be determined using Equation (3-10), and the coordination degree can be further calculated by assigning corresponding weights, as presented in Table 5. From a macro perspective, provinces in China have gradually demonstrated higher levels of coupling and coordination between the digital economy and green development, with overall coordination effects showing continuous improvement. Ranked by the average annual growth rate of the coupling coordination degree, regions that have achieved improvements in coordination levels include Guangdong, Beijing, Henan, Hunan, Guizhou, and Qinghai. Notably, Beijing and Guangdong had already entered the preliminary coordination stage in 2014, and by 2022, their coordination capacity had further improved, consistently maintaining the top positions nationwide. In contrast, Heilongjiang, Jilin, and Liaoning exhibited relatively low levels of coupling coordination, with no significant growth in coordination levels over the past nine years, indicating relatively slow development

progress. The coupling coordination levels in most regions have shown improvement. The three northeastern provinces performed well in green development, yet their digital economy development remained relatively slow, resulting in low coordination levels between the two systems. This may be attributed to relatively weak digital infrastructure and a low degree of digitalization in the region, which has deprived digital economy development of the necessary technological support and material foundation. Meanwhile, the three northeastern provinces possess abundant natural resources and a unique ecological environment, granting them certain advantages in green development. However, the slow development of the digital economy and its insufficient integration with green development have led to low coordination levels between the two.

Table 5. *Coupling Coordination Degree of Digital Economy and Green Development in Chinese Provinces and Municipalities, 2014–2022.*

Region	2014	2015	2016	2017	2018	2019	2020	2021	2022	Coordination Level
Beijing	0.7299	0.7353	0.7364	0.7376	0.7393	0.7577	0.7609	0.7637	0.7674	Moderately Coordinated
Tianjin	0.4678	0.4767	0.4718	0.4471	0.4218	0.4128	0.4233	0.4308	0.4130	On the Verge of Uncoordinated
Hebei	0.4822	0.4949	0.5021	0.4772	0.4792	0.4902	0.4962	0.4891	0.4939	On the Verge of Uncoordinated
Shanxi	0.3817	0.3909	0.3989	0.3730	0.3876	0.3916	0.3985	0.3993	0.3996	Mildly Uncoordinated
Inner Mongolia	0.3699	0.3878	0.3935	0.3780	0.3667	0.3745	0.3749	0.3782	0.3814	Mildly Uncoordinated
Liaoning	0.4740	0.4753	0.4770	0.4743	0.4645	0.4704	0.4699	0.4632	0.4591	On the Verge of Uncoordinated
Jilin	0.4026	0.4072	0.4027	0.3809	0.3815	0.3746	0.3738	0.3679	0.3733	Mildly Uncoordinated
Heilongjiang	0.4721	0.4655	0.4377	0.4100	0.3931	0.4052	0.3977	0.3945	0.3936	Mildly Uncoordinated
Shanghai	0.6003	0.6057	0.6020	0.5800	0.5563	0.5567	0.5449	0.5629	0.5457	Barely Coordinated
Jiangsu	0.7501	0.7624	0.7516	0.7142	0.6938	0.7118	0.7135	0.7178	0.6951	Primarily Coordinated
Zhejiang	0.6857	0.7150	0.7204	0.6754	0.6665	0.6850	0.6680	0.6747	0.6578	Primarily Coordinated
Anhui	0.5012	0.5216	0.5236	0.5042	0.5125	0.5244	0.5271	0.5310	0.5314	Barely Coordinated
Fujian	0.5644	0.5904	0.6225	0.6147	0.6034	0.6023	0.5680	0.5885	0.5863	Barely Coordinated
Jiangxi	0.4303	0.4667	0.4601	0.4538	0.4532	0.4832	0.4883	0.4842	0.4996	On the Verge of Uncoordinated
Shandong	0.6521	0.6472	0.6544	0.6249	0.6182	0.6255	0.6307	0.6524	0.6406	Primarily Coordinated
Henan	0.4974	0.5183	0.5391	0.5396	0.5533	0.5594	0.5587	0.5515	0.5450	Barely Coordinated
Hubei	0.5314	0.5702	0.5633	0.5374	0.5243	0.5380	0.5475	0.5474	0.5432	Barely Coordinated
Hunan	0.4919	0.5080	0.5229	0.4940	0.5013	0.5304	0.5348	0.5221	0.5206	Barely Coordinated
Guangdong	0.7942	0.8134	0.8244	0.7961	0.8118	0.8236	0.8065	0.8118	0.8021	Well Coordinated
Guangxi	0.44	0.45	0.45	0.44	0.44	0.46	0.45	0.45	0.46	On the Verge of

	18	99	64	19	21	08	82	45	39	Uncoordinated
Hainan	0.36 91	0.36 74	0.37 73	0.36 45	0.36 38	0.35 83	0.35 42	0.36 70	0.35 74	Mildly Uncoordinated
Chongqing	0.48 09	0.49 35	0.49 53	0.48 12	0.47 78	0.47 25	0.48 00	0.47 92	0.48 36	On the Verge of Uncoordinated
Sichuan	0.54 68	0.56 68	0.57 17	0.56 07	0.56 93	0.57 37	0.57 68	0.56 72	0.57 90	Barely Coordinated
Guizhou	0.37 77	0.39 56	0.40 70	0.39 63	0.39 53	0.41 41	0.42 45	0.44 27	0.44 89	On the Verge of Uncoordinated
Yunnan	0.44 76	0.46 54	0.46 31	0.45 91	0.45 15	0.44 91	0.46 11	0.44 71	0.44 51	On the Verge of Uncoordinated
Shaanxi	0.49 89	0.51 87	0.51 26	0.49 76	0.49 49	0.50 23	0.50 02	0.49 67	0.48 54	On the Verge of Uncoordinated
Gansu	0.32 33	0.33 32	0.34 01	0.33 69	0.34 95	0.35 38	0.35 79	0.35 25	0.35 24	Mildly Uncoordinated
Qinghai	0.24 11	0.29 27	0.29 49	0.27 96	0.27 98	0.27 19	0.28 12	0.30 51	0.29 51	Moderately Uncoordinated
Ningxia	0.28 31	0.28 62	0.28 03	0.26 39	0.26 81	0.26 40	0.26 12	0.26 57	0.26 00	Moderately Uncoordinated
Xinjiang	0.35 18	0.36 56	0.35 23	0.32 96	0.32 45	0.34 02	0.34 31	0.34 50	0.35 54	Mildly Uncoordinated
Eastern	0.59 42	0.60 53	0.59 27	0.60 32	0.59 45	0.60 05	0.61 29	0.62 41	0.62 88	Primarily Coordinated
Central	0.47 23	0.49 60	0.50 13	0.48 37	0.48 87	0.50 54	0.50 92	0.50 59	0.50 65	Barely Coordinated
Western	0.39 66	0.41 50	0.41 52	0.40 22	0.40 18	0.40 70	0.41 08	0.41 20	0.41 37	On the Verge of Uncoordinated
Northeast	0.46 96	0.46 92	0.44 91	0.42 17	0.41 30	0.41 67	0.41 38	0.40 85	0.40 87	On the Verge of Uncoordinated

Based on the calculation results presented in Table 5, the development trends of the coupling coordination degree between the digital economy and green development across China's four major regions are illustrated in Figure 1. As shown in Figure 1, the coupling coordination degree between the digital economy and green development in various regions of China exhibits a sustained and stable growth trend. The coupling coordination level of the Central Region has consistently remained close to the national average, and since 2015, it has surpassed the national average, demonstrating a slow but steadily increasing trajectory. Meanwhile, the Eastern Region has shown outstanding performance, not only significantly ahead of the other three regions but also entering a new stage of coordinated enhancement as early as 2017. During the period from 2014 to 2019, the coupling coordination degree of the Northeast Region was slightly higher than that of the Western Region; however, by 2020, the gap between the two had become negligible. In recent years, the Western Region has demonstrated strong development momentum across multiple domains, and its coordination level between the digital economy and green development has caught up from behind, surpassing the Northeast Region since 2020 and exhibiting an increasingly optimized coupling coordination status. By 2022, the coupling coordination degree of the Eastern Region had reached the level of primary coordination, while the Central Region, although barely coordinated, maintained a relatively coordinated state. However, the Western and Northeast Regions remained on the verge of being uncoordinated, requiring further strengthening of the coordination and integration between the digital economy and green development.

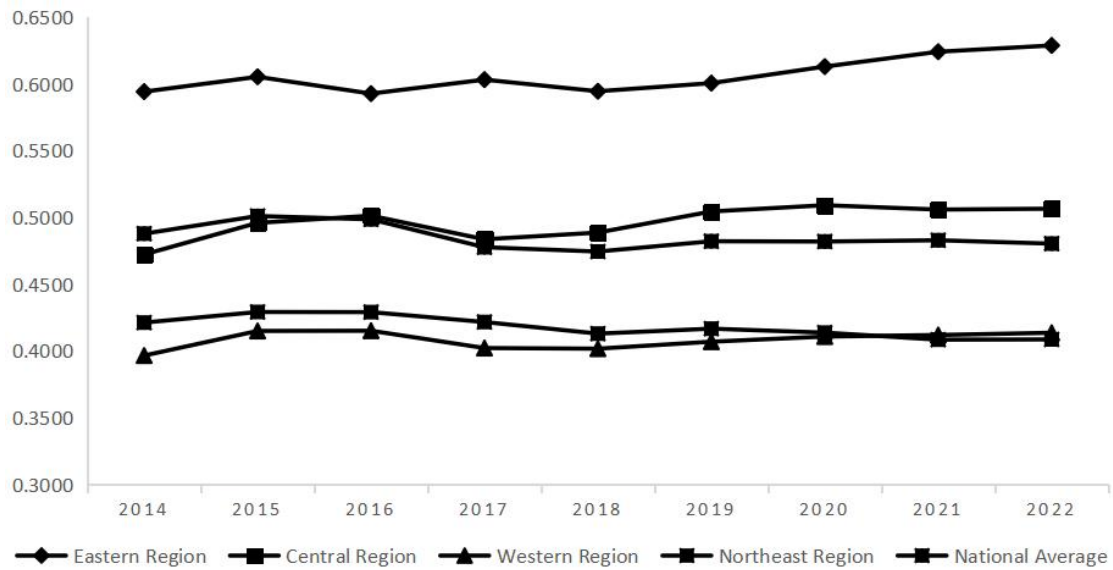


Figure 1. Development Trends of Digital Economy and Green Development in China's Four Major Regions.

4. Research Conclusions and Policy Recommendations

4.1. Research Conclusions

This study employs the CRITIC comprehensive evaluation method to quantitatively assess the digital economy and green development levels of 30 Chinese provinces and municipalities from 2014 to 2022, and uses the coupling coordination degree model to calculate the coordination between the two systems. The findings reveal a significant coordination relationship, though some instances of poor coordination persist—in some cases, digital economy growth is accompanied by lagging green development, while in others, green development is relatively advanced but digital economy development remains insufficient. China's digital economy exhibits a stable and rapid growth trend, with significant regional disparities. The Eastern Region outperforms the Central, Western, and Northeast Regions, exceeding the national average. Beijing, Guangdong, Shanghai, Jiangsu, Zhejiang, and Shandong demonstrate relatively high digital economy levels, benefiting from high-quality talent, geographical advantages, a strong innovation environment, and a favorable business climate. By leveraging their unique strengths, these regions have continuously enhanced their digital economy development, positively influencing surrounding areas.

Overall, the coupling coordination level between the digital economy and green development across Chinese provinces has gradually improved. Ranked by the average annual growth rate of the coupling coordination degree, regions that have achieved improvements include Guangdong, Beijing, Henan, Hunan, Guizhou, and Qinghai. Among these, Beijing and Guangdong had already reached the primary coordination stage in 2014, and by 2022 had advanced to the well-coordinated stage, consistently ranking among the top nationwide. In contrast, Heilongjiang, Jilin, and Liaoning exhibited relatively low coupling coordination degrees with no significant improvement over the nine-year period, indicating relatively slow development.

4.2. Policy Recommendations

To promote the integration of the digital economy and green development, the government should introduce policies encouraging deep integration across regions

based on their specific conditions. In the Northeast Region, where green development is relatively strong but digital economy growth is sluggish, efforts should leverage existing green advantages to drive coordinated development. In regions where the digital economy outpaces green development, such as Guangdong, Beijing, and Shanghai, green digital technologies should be advanced to foster innovation in clean energy, energy conservation, emission reduction, and the circular economy, while enhancing the application of digital tools in green product and service design. Cultivating innovative talent is essential to enhancing regional innovation capacity, as the increase in R&D personnel full-time equivalent indicates greater enterprise investment in innovation, which in turn sustains digital economy growth. Regions with lagging development should optimize research environments, increase funding for research institutions and innovative enterprises, establish mechanisms for commercializing research outcomes, and implement talent incentive programs to attract and retain outstanding domestic and international talent. Leveraging the diffusion effect of developed regions is also critical, as the coupling coordination between the digital economy and green development exhibits significant positive spatial correlation. The Eastern Region should take the lead in driving development in the Central, Western, and Northeast Regions, with neighboring areas establishing cooperative mechanisms and environmental protection agreements to promote coordinated regional development. Finally, improving the regulatory system for green development in the digital economy is necessary, including the establishment of strict environmental and energy standards, enhanced supervision, and incentive policies encouraging digital economy enterprises to adopt green production methods. Strengthening enforcement and imposing penalties on violators will create an effective constraint mechanism, while public environmental awareness and participation should be enhanced through education and promotion efforts.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

Funding

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

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