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A study on the current development of digital economy and industrial green economy in Northeast Sichuan: a case study of Dazhou City

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Abstract. The digital economy, following agricultural and industrial economies, represents a primary economic form characterized by modern information networks as the carrier, integrated application of information and communication technologies, and extensive integration with various industries to enhance efficiency. Amid the vigorous development of the modern digital economy, equal attention should be paid to the advancement of industrial green economy. The synergistic integration of digital economy (centered on information technology) and industrial green economy forms a new model that boosts efficiency and elevates socio-economic value. This study analyzes the index values of digital economy and industrial green economy, calculates the weight of each index within these systems, and examines data from 2018 to 2023 for five prefecture-level cities in Northeast Sichuan (Dazhou, Guang'an, Bazhong, Nanchong, and Guangyuan). Focusing on Dazhou, it evaluates its ranking in digital and industrial green economy development within the region and proposes constructive suggestions for Dazhou's future progress.

Keywords: Digital Economy, Industrial Green Economy

1. Introduction

The Evolution of Digital Economy: From Technological Inception to Comprehensive Penetration

The origins of the digital economy can be traced back to the birth of computer technology in the mid-20th century, when information technology primarily served military and scientific research fields, with limited applications in the economic sector. In the 1990s, the standardization of Internet protocols and widespread adoption of fiber-optic communication technology gave rise to the concept of the "information superhighway." Emerging formats such as e-commerce and portal websites began to take shape, marking the initial entry of the digital economy into commercial domains in a "connective" form. While information transmission speed and scope improved significantly, the scale and influence of the digital economy remained relatively limited at this stage.

Entering the 21st century, the popularization of broadband technology and the continuous miniaturization and intelligentization of mobile terminals propelled the digital economy into the "platform economy" phase. Innovations like search engines, social media, mobile payments, and ride-sharing emerged rapidly. Data gradually transformed from ancillary information into a critical production factor, and various Internet platforms became new intermediaries connecting supply and demand, integrating resources, and optimizing allocation. During this period, the digital economy expanded rapidly, exerting a profound impact on traditional business models and social lifestyles, though its applications remained primarily concentrated in the consumer sector.

Over the past decade, the cross-integration and rapid development of cutting-edge technologies such as cloud computing, the Internet of Things, artificial intelligence, and blockchain have injected new impetus into the digital economy. The institutionalization of data elements has accelerated, driving the digital economy's deep expansion from consumer Internet to industrial Internet, characterized by "interconnection of all things, real-time online presence, and intelligent decision-making." Today, digital technologies are increasingly embedded in production processes—machinery, factories, mines, and industrial parks—reshaping production functions, organizational boundaries, and value networks, thus ushering the digital economy into the "ecosystem" stage. In this phase, multiple stakeholders (governments, enterprises, research institutions, financial entities, and the public) collaborate on a shared data infrastructure, forming a new growth paradigm centered on trusted data circulation and multi-stakeholder value co-creation. The digital economy has become a pivotal force driving economic and social development.

The Internal Logic of Digital Economy Promoting Industrial Green Economy

The core goal of industrial green economy is to minimize environmental impact while maximizing economic output, ensuring sustainable social welfare. Traditional industrial development models often rely on end-of-pipe governance and administrative mandates, which are costly and lack flexibility and incentives for innovation. The emergence of the digital economy offers new ideas and solutions for industrial green transformation, with its internal logic manifested in the following aspects:

First, the integration of ubiquitous sensing technology and digital twin technology enables real-time, precise mapping of high-energy-consumption, high-emission industrial processes into virtual digital objects. This is analogous to equipping industrial production with "clairvoyance" and "clairaudience," transforming resource consumption and pollutant emission from post-hoc statistics into process-visible data, thereby providing a solid cognitive foundation for precise green governance. Enterprises can identify energy waste points and pollution sources, allowing targeted optimization and improvement.

Second, algorithmic optimization and simulation technologies provide unprecedented optimization capabilities for industrial production. Traditional industrial decision-making in process improvement, energy allocation, and logistics scheduling relied on experience and trial-and-error, which were inefficient and prone to resource waste. In contrast, algorithmic optimization and simulation in the digital economy enable rapid iterative optimization in the digital space. By simulating and evaluating various production schemes, optimal process paths, energy allocation plans, and logistics schedules can be identified, reducing material/energy consumption and carbon emissions while improving production efficiency and product quality.

Third, the rise of platform-based organizational structures has broken down boundaries between traditional industrial enterprises. In the digital economy era, design, manufacturing, logistics, finance, and recycling are integrated into a collaborative ecosystem rather than existing in isolation. Within this system, enterprises can share production capacity, energy, and logistics, significantly reducing the specificity risks of green technologies. For example, small and medium-sized enterprises can access idle production equipment, surplus energy, and optimized logistics services through shared platforms, achieving green production and operations without increasing their own investments.

Finally, trusted data and smart contract technologies provide robust market incentives for industrial green economy. In the digital economy, enterprises’ emission reduction efforts can be verified, measured via trusted data, and automated transactions/rewards can be implemented through smart contracts. This means green performance is no longer merely a manifestation of social responsibility but can be directly converted into market returns, forming an endogenous incentive mechanism where "emission reduction equals profit." This mechanism greatly stimulates enterprises’ enthusiasm for green innovation and energy conservation, promoting the scaling of green technologies from demonstration to widespread adoption.

Through these multifaceted effects, the digital economy not only enhances resource allocation efficiency in industrial production but, more importantly, restructures the driving force of industrial green transformation—shifting from traditional external constraint-driven to endogenous growth-driven models, thus injecting strong momentum into the sustainable development of industrial green economy.

2. Literature review

2.1. Research on the integration of digital economy and green economy

The synergistic development of digital economy and green economy remains a critical topic. The digital economy serves as a path for high-quality, rapid economic development, while green development is essential for ecological protection and harmonious coexistence between humans and nature, ensuring sustainability without sacrificing growth. Jiang Jinhe [1] proposed that to achieve high-quality integration, attention should be paid to institutional framework design, sustainable paradigm shifts in green economic transformation, strengthening digital technology leadership, and improving data governance capabilities. Lin Keliang [2] noted that green economy guides the direction of digital economy development, while digital economy facilitates the sustainability of green economy. In planning digital green economy, comprehensive consideration of economic, resource, and environmental factors is necessary to formulate digital economy value chains systematically. Yang Xi, Gao Jiaqi, Geng Ruixuan, and Peng Yuanchao [3] argued that governments and organizations should play their roles in promoting high-quality integration, leveraging national institutional frameworks, emphasizing sustainable paradigm shifts in green transformation, and strengthening digital technology leadership. With the rapid development of the digital economy, its integration with traditional industries cannot be ignored. Wei Yuan [4] suggested that big data platforms could build new models for green economy development, enabling multi-departmental environmental monitoring and supervision. By collecting and analyzing data from polluting enterprises, pollution can be integrated, precisely monitored, and adjusted in real-time to protect the environment.

2.2. Research on the integration of digital economy and real economy

The integration of digital economy and real economy has a broad impact on enterprises' green innovation. Under traditional operational models, Ou Wenzhi [5] pointed out that enterprises face constraints in information and knowledge utilization, with internal silos and information asymmetry issues that can be addressed through this integration. Additionally, Zhang Ziran and Hai Meihong [6] used data from 281 cities nationwide (2012–2022) to construct a mathematical model of how digital-real integration affects green development, systematically evaluating its impact on green total factor productivity and underlying mechanisms.

2.3. Regional research on digital economy and green real economy

Differentiated studies on regional integration of digital economy and green real economy have been conducted. Chen Ying [7] noted that northern Guangdong, an important ecological barrier in Guangdong Province, should promote integration through green low-carbon technologies, energy-saving transformation of data centers, renewable energy utilization, industrial structure optimization, and green digital talent cultivation. Zhao Chunyan and Lü Xing [8] studied the high-quality integration of digital economy and industrial green transformation in Anhui Province, evaluating development levels in cities from 2012 to 2021 and proposing suggestions such as prioritizing strategic development, exploring differentiated coordinated growth, and emphasizing education.

3. Theoretical analysis

Digital economy and industrial green economy synergistically promote each other's development. Widespread application of digital technologies—such as big data, artificial intelligence, blockchain, and the Internet of Things—provides strong technical support for industrial green economy, reducing operational costs, improving efficiency, facilitating diversified development, and expanding production types. Meanwhile, green economy, characterized by low consumption and low pollution, is pursued by modern industrial enterprises, with technological innovation and renewable energy reuse as its core. This study analyzes the relationship between the two, emphasizing the importance of digital economy for industrial green economy. Drawing on indicator selection by Wang Lei [9] and Guo Chuan [10], it selects digital industry development, digital integration application, and digital innovation level as primary indicators for the digital economy system, with corresponding secondary indicators. Referencing Sun Haibo's [11] analysis of industrial green economy, it selects quality growth, technological innovation, and resource consumption as primary indicators for the industrial green economy system, with corresponding secondary indicators.

4. Research methods and index system construction

4.1. Entropy method

This study uses the entropy method to assign weights to secondary indicators of digital industry development and digital innovation level in the digital economy system, as well as to secondary indicators of quality growth, technological innovation, and resource consumption in the industrial system.

The steps are as follows:

Step 1: Standardize indicators. Assume there are r years, m regions, and n indicators, where x_{ijk} represents data for the k-th indicator in region j in year i. To enable effective comparison after standardization, positive and negative indicators are processed separately using the following formulas:

Positive indicators:

$$x_{ijk}^{'} = {}^{x_{ijk}}/_{x_{max}} \quad \text{(Formula 1)}$$

Negative indicators:

$$x_{ijk}^{'} = {}^{x_{min}}/_{x_{ijk}} \quad \text{(Formula 2)}$$

Where x_{max} and x_{min} are the maximum and minimum values of the indicator in the sample, respectively.

Step 2: Calculate the proportion of each indicator value to the total for the k-th indicator:

$$y_{ijk} = {}^{x_{ijk}^{'}}\Big/_{\sum_i \sum_j x_{ijk}^{'}} \quad \text{(Formula 3)}$$

Step 3: Calculate the entropy value of the k-th indicator:
$e_k = -p. \sum_i \sum_j y_{ijk} ln(y_{ijk})$, where $\mathrm{p} = 1/_{\ln(\mathrm{rm})}$ (Formula 4)

Step 4: Calculate the difference coefficient g_k for the k-th indicator. A larger difference indicates a greater role in the indicator system and a smaller entropy value:

$$g_k = 1 - e_k \quad \text{(Formula 5)}$$

Step 5: Calculate the weight of the k-th indicator:

$$w_k = {}^{g_k}/_{\sum_{i=1}^{n} g_k} \quad \text{(Formula 6)}$$

4.2. Data sources

To ensure data reliability, this study uses data from the Sichuan Statistical Yearbook (2018–2023) and statistical yearbooks of six cities in eastern Sichuan. Refer to Formulas 1–6 for calculations, as shown in Table 1.

Table 1. Index System for Digital Economy and Industrial Green Economy

System Name	Primary Indicator	Secondary Indicator	Indicator Direction	Weight
Digital Economy	Digital Industry Development	Proportion of IT practitioners (%)	Positive	0.0871
		Internet users per 100 people (persons/100 people)	Positive	0.2733
		Per capita telecommunications business volume (yuan/person)	Positive	0.1073
		Mobile phone users per 100 people (persons/100 people)	Positive	0.1006
	Digital Innovation Level	Per capita number of invention patent applications (items/10,000 people)	Positive	0.1003
		Full-time equivalent of R&D personnel per 10,000 people (person-years/10,000 people)	Positive	0.1021
		R&D expenditure intensity (%)	Positive	0.0995
		Proportion of higher education graduates (%)	Positive	0.1298
Green Economy	Quality Growth	Profit rate of main business income of industrial enterprises (%)	Positive	0.0383
		Industrial enterprise assets/average employment (10,000 yuan/person)	Positive	0.1266
		Growth rate of industrial added value of industrial enterprises (%)	Positive	0.1143
	Technological Innovation	Number of valid invention patents/main business income of industrial enterprises (items/100 million yuan)	Positive	0.1224
		Proportion of internal R&D expenditure in industrial enterprises (%)	Positive	0.1864
		Proportion of innovative personnel in industrial enterprises (%)	Positive	0.2226
	Resource Consumption	Industrial energy consumption per 10,000 yuan output (m^3/10,000 yuan)	Negative	0.1894

4.3. Comprehensive development model index evaluation

The formula for constructing the evaluation model of digital economy and industrial economy is:

$$U_s = \sum_{k=1}^{n} u_{sk} w_{sk} \quad \text{(Formula 7)}$$

where U_s represents the comprehensive development level of model s; u_{sk} is the contribution coefficient of the k-th indicator to model s; and w_{sk} is the weight of the k-th indicator in model s. Results are shown in Table 2 (refer to Formula 7).

Table 2. Comprehensive Development Level of Digital Economy in Northeast Sichuan (2018–2023)

City	2018	2019	2020	2021	2022	2023	Average
Dazhou	0.5206	0.5656	0.6288	0.6536	0.5906	0.6582	0.6029
Guang’an	0.4463	0.5143	0.5902	0.6659	0.6173	0.6489	0.5805
Bazhong	0.3577	0.4051	0.4475	0.4704	0.5028	0.5214	0.4508
Nanchong	0.7583	0.7965	0.8783	0.8173	0.8328	0.8789	0.8270
Guangyuan	0.6195	0.6611	0.7006	0.7281	0.7268	0.7728	0.7015

Table 2 shows that from 2018 to 2023, due to the impact of the COVID-19 pandemic, the comprehensive digital economy development data of cities in Northeast Sichuan declined in 2022 but showed an overall upward trend with significant growth, indicating steady improvement in digital economy development. In terms of growth rate, Guang’an and Bazhong developed rapidly but remained at lower levels compared to other cities. Bazhong had the lowest average index (0.4508), while Nanchong had the highest (0.8270), reflecting uneven development—with the fastest-growing city being approximately twice as developed as the slowest. Excluding the highest and lowest, Dazhou ranked third with an average of 0.6029, with a small gap from fourth-place Guang’an, indicating generally low overall digital economy levels in the region.

Table 3 shows the comprehensive development level of industrial green economy in Northeast Sichuan from 2018 to 2023 (refer to Formula 7).

Table 3. Comprehensive Development Level of Industrial Green Economy in Northeast Sichuan (2018–2023)

City	2018	2019	2020	2021	2022	2023	Average
Dazhou	0.2907	0.2208	0.2640	0.3098	0.2367	0.3719	0.2823
Guang’an	0.1500	0.1568	0.1715	0.2197	0.1935	0.2025	0.1823
Bazhong	0.1236	0.0476	0.1488	0.1594	0.3476	0.5731	0.2333
Nanchong	0.1700	0.2059	0.2823	0.3582	0.3794	0.4704	0.3111
Guangyuan	0.1634	0.1463	0.1413	0.1552	0.1878	0.2106	0.1674

Table 3 indicates an overall upward trend in industrial green economy development from 2018 to 2023, with a significant decline in 2022 due to the pandemic. Nanchong had the highest average level (0.3111), followed by Dazhou (0.2823). The development gap between cities was smaller than in the digital economy, with more moderate growth. Industrial levels in the region remained low, highlighting the need for strengthened industrialization. Comprehensively, Nanchong had the highest economic level, followed by Dazhou, while Guang’an, Guangyuan, and Bazhong required accelerated industrial development.

4.4. Identification of urban development types

Using the calculated comprehensive development indices of digital economy U_1 and industrial green economy U_2 for the five cities, the coordination type of each region was determined by the ratio U_1 / U_2 . Drawing on relevant research:

If ${}^{U_1}/_{U_2} > 1.2$, the region is classified as "Digital Economy Advanced Type" (digital economy outpaces industrial green economy). If $0.8 < {}^{U_1}/_{U_2} < 1.2$, it is classified as "Synchronized Type" (balanced development). If ${}^{U_1}/_{U_2} < 0.8$, it is classified as "Industrial Green Economy Advanced Type" (industrial green economy outpaces digital economy). Table 4 shows the development types of cities in Northeast Sichuan.

Table 4. Development Types of Digital Economy and Industrial Green Economy in 5 Cities of Northeast Sichuan (2018–2023)

City	2018	2019	2020	2021	2022	2023
	u_1/u_2	Type	u_1/u_2	Type	u_1/u_2	Type
Dazhou	1.791	Digital Advanced	2.561	Digital Advanced	2.381	Digital Advanced
Guang'an	2.974	Digital Advanced	3.278	Digital Advanced	3.441	Digital Advanced
Bazhong	2.893	Digital Advanced	8.507	Digital Advanced	3.008	Digital Advanced
Nanchong	4.458	Digital Advanced	3.866	Digital Advanced	3.111	Digital Advanced
Guangyuan	3.790	Digital Advanced	4.516	Digital Advanced	4.958	Digital Advanced

Comprehensive analysis of the indices from 2018 to 2023 reveals that all cities except Bazhong (classified as Synchronized in 2023) were of the Digital Advanced type, indicating effective and stable implementation of digital economy development strategies in Northeast Sichuan. Bazhong showed the largest annual ratio difference (2019 vs. 2023), reflecting rapid industrial development in later years. For Dazhou, while digital economy grew annually, the declining U_1/U_2 ratio indicates increasingly balanced growth between digital and industrial economies, with promising synergistic development prospects.

5. Suggestions and conclusions

5.1. Constructive suggestions for leveraging digital economy in dazhou's industrial green economy

As a key industrial city in Northeast Sichuan, Dazhou boasts abundant natural resources and a solid industrial foundation but faces dual pressures from traditional industrial path dependence and ecological constraints. To fully harness the digital economy's role in promoting industrial green economy and achieve high-quality green transformation, the following suggestions are proposed:

5.1.1. Strengthen digital infrastructure construction to lay a solid foundation

Dazhou should increase investment in digital infrastructure, accelerating the deployment of new infrastructure such as 5G networks, data centers, and industrial Internet. By expanding network coverage and transmission speed, a high-speed, stable, and reliable information channel for deep integration of digital and industrial green economies can be established. Enterprises should be encouraged to participate in infrastructure development, promote digital transformation of traditional industrial facilities, and achieve interconnection and intelligent upgrading of production equipment, laying a solid foundation for green industrial transformation.

5.1.2. Promote enterprise digital transformation to enhance green competitiveness

Guide industrial enterprises in Dazhou to accelerate digital transformation, encouraging increased investment in digital technology R&D and application of big data, artificial intelligence, and the Internet of Things to optimize processes, improve efficiency, and reduce energy consumption and emissions. Support smart manufacturing pilot projects to explore digital workshops and intelligent factories, enhancing green manufacturing capabilities. The government can introduce preferential policies and special funds to reduce transformation costs and risks for small and medium-sized enterprises, helping them bridge the digital divide and enhance the overall green competitiveness of the industry。

5.1.3. Build green digital platforms to promote resource sharing and collaborative innovation

Establish a green digital platform in Dazhou to integrate resources from governments, enterprises, and research institutions, enabling data sharing and circulation. By aggregating energy consumption, emission, and production data, the platform can provide precise green diagnosis services, helping enterprises identify potential improvement areas. It can also serve as a bridge between enterprises, research institutions, and financial entities, promoting industry-academia-research integration and accelerating green technology R&D and application. For example, enterprises can publish green technology needs, research institutions can offer solutions, and financial institutions can provide funding based on technical feasibility and market prospects, forming a complete green innovation ecosystem.

5.1.4. Strengthen talent cultivation and introduction to provide intellectual support

The integration of digital and industrial green economies requires high-quality talent. Dazhou should collaborate with universities and vocational colleges to adjust majors and curricula according to local industrial needs, cultivating interdisciplinary talent proficient in both digital technology and industrial production. Encourage school-enterprise cooperation and order-based training to supply enterprises with practical talent. Additionally, introduce preferential policies to attract high-end talent in digital and green economies, providing intellectual support and innovation impetus.

5.1.5. Improve policy support systems to create a favorable environment

The government should refine policy support for integrated development, introducing industrial, fiscal, and tax policies. For example, offer tax incentives for green digital technology R&D, provide subsidies/rewards for digital-green transformation, and establish green digital industry investment funds to guide social capital into integration fields, diversifying financing channels. Strengthen market supervision, standardize order, and protect enterprises' legitimate rights to stimulate innovation and market vitality.

5.1.6. Enhance regional cooperation and exchanges to expand development space

Dazhou should actively cooperate with neighboring regions and the Chengdu-Chongqing Dual-City Economic Circle in digital and industrial green economies. Through industrial collaboration, resource sharing, and complementary advantages, a regional green digital industry cluster can be built. Connect with Chengdu-Chongqing's digital and green financial resources, undertake industrial transfers and technology spillovers, and develop an innovation model where "R&D is conducted in Chengdu-Chongqing, and transformation in Dazhou," expanding development space. Learn from advanced regions' experiences to improve overall integration capabilities.

5.2. Conclusion

As one of the most dynamic and innovative economic forms, the digital economy has evolved from technological inception to comprehensive penetration, profoundly reshaping global economic patterns and industrial development models. Its unique advantages and internal logic—via ubiquitous sensing, algorithmic optimization, platform-based organization, and trusted data—provide new solutions for industrial green transformation. As a key industrial city in Northeast Sichuan, Dazhou faces pressures from traditional industrial transformation and ecological protection. Harnessing the digital economy's role in industrial green economy is crucial for its high-quality development. Through strengthening digital infrastructure, promoting enterprise transformation, building green platforms, cultivating talent, improving policies, and enhancing regional cooperation, Dazhou is expected to achieve breakthroughs in integrating digital and industrial green economies.

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