

Research on Measuring the Development Level of Digital Economy in Five Provinces in Northwest China

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Abstract

The digital economy is a crucial factor in enhancing the quality of regional economic development. Conducting measurements and evaluations of the development level of the digital economy in the five northwestern provinces of China holds significant practical importance. Based on provincial panel data from 2012 to 2022 for these five provinces, this paper establishes a comprehensive evaluation index system encompassing digital infrastructure, digital innovation, digital application, and digital industry. An objective and comprehensive measurement method, namely the entropy value method, is employed for the assessment. The research team found that the digital economy in the five northwestern provinces is continually improving, yet there exists a significant development gap among them. Therefore, the five northwestern provinces should strengthen the formulation and implementation of supportive policy systems, ensure a favorable environment for digital economic development, enhance inter-provincial communication, promote integrated and complementary development of the digital economy, accelerate the exploitation of resource advantages, and address the shortcomings in digital economic development.

Keywords: entropy method; digital economy, Northwest China

1. Introduction

With the continuous advancement of technology, traditional economic growth models are increasingly facing the dilemma of insufficient driving force. Meanwhile, China is constantly confronted with new challenges and opportunities, necessitating the embrace of new economic forms to propel high-quality economic development. Integrating the digital economy and high-quality economic development into a single analytical framework and effectively combining them have emerged as significant drivers of economic progress (Jing Wenjun & Sun Baowen, 2019). Consequently, the digital economy has gradually come into research focus and received heightened attention. President Xi has emphasized the need to promote the deep integration of digital technology and the real economy, empowering the transformation and upgrading of traditional industries and fostering new industries, new business models, and new formats, thereby continuously strengthening and optimizing China's digital economy (Xi Jinping, 2022). The State Council has issued the "14th Five-Year Plan for Digital Economic Development," calling for the transition of digital economic development towards a new stage of deepened application, standardized development, and inclusive sharing. The digital economy has demonstrated its vitality and driving force for economic growth, becoming a new engine of growth. According to the "Research Report on the Development of China's Digital Economy (2023)" released by the China Academy of Information and Communications Technology, the scale of China's digital economy has reached RMB 50.2 trillion, with a nominal year-on-year growth rate of 10.3%. For 11 consecutive years, this growth rate has been significantly higher than the nominal growth rate of GDP over the same period, and the digital economy now accounts for 42.5% of GDP. Evidently, the digital economy has gradually become a core factor in high-quality economic development, and exploring the integrated development of the digital economy and manufacturing to achieve high-quality economic development will be a direction for national exploration.

The five northwestern provinces, located in the inland northwest of China, are important strategic depth areas with resource endowment advantages such as relatively inexpensive labor resources, green power resources, and land prices. However, their level of economic development lags significantly behind that of the eastern coastal regions, southwest, and even central China. Improving the economic development level of the five northwestern

provinces is an inevitable requirement for achieving high-quality economic development and common prosperity. The emergence of the digital economy provides options for this improvement. Seizing the opportunity and developing the digital economy against the backdrop of "transmitting computing power from the west to the east" has become the key to enhancing regional development. However, further research is needed to ascertain the current level of digital economy development in these five provinces, and it is crucial to conduct comprehensive and objective measurements and evaluations of the digital economy in the five northwestern provinces.

2. Literature Review

Research on the connotation of the digital economy. Internationally, Don Tapscott (Don Tapscott, David, et al, 2000) formally introduced the term "digital economy" in his book "The Digital Economy". Beomsoo Kim et al. (Kim B & Barua A, 2002) pointed out that the digital economy refers to transactions between demand and supply sides achieved through digital means, as opposed to traditional economic transaction methods. The CCID Group (2017) believes that the digital economy represents the sum of economic activities with digital technology as the key component, encompassing a series of new technologies, products, and business models spurred by digital elements. Domestically, research on the connotation of the digital economy can be broadly or narrowly defined. In a narrow sense, the digital economy is a new economic form emerging from the development of the information technology revolution. Wen Ting et al. (2022) define the digital economy as a new type of economic activity involving information and communication technology and digital technology. In a broader sense, the G20 Summit considers the digital economy as an economic form with digital knowledge and information as core production factors and communication technology as one of the means to improve production efficiency. Zhu Xiaoyan (2022) proposes that the digital economy is the process by which human society identifies, screens, filters, stores, and utilizes digital information, effectively accelerating the optimal allocation of resources and thereby accelerating high-quality socio-economic development. The China Academy of Information and Communications Technology (2022) define the digital economy as a new economic form with digital knowledge and information as core production factors and digital technology as the core driving force. In summary, the digital economy is both an emerging economic sector and a new production factor, primarily encompassing tools that enhance production and living standards, consisting of digital infrastructure, utilization of digital resources, digital innovation, and digital industries.

Research on measurement methods for the development level of the digital economy. Based on the evaluation methods currently used in academic circles, there are several approaches. One is the value-added measurement method. Xu Xianchun and Zhang Meihui (2020) defined the digital economy across four dimensions, categorized products into four scopes based on these dimensions, calculated the value added within these scopes, and introduced an industry value-added structure coefficient. Additionally, the China Academy of Information and Communications Technology (2017) and the Tencent Research Institute (2017) estimated the scale of digital economy growth through quantitative methods. Another approach is the digital economy satellite account method. The OECD (2017) proposed a basic framework for digital economy satellite accounts, while domestic scholars such as Yang Zhongshan et al. (2019) constructed digital economy indicators and systematically studied evaluation methods for satellite accounts. The final approach is to construct a digital economy indicator evaluation system. Bai Ru et al. (2024) built an evaluation indicator system from four dimensions: digital infrastructure, digital core industries, digital fusion industries, and digital development potential. Liu Jun et al. (2020) constructed an evaluation system from three dimensions: informatization development, internet development, and digital transaction development. Other scholars, such as Guan Huijuan et al. (2020), built digital economy evaluation indicators from three aspects: infrastructure, application, and innovation. The initial stage of constructing indicator systems focused on digital industrialization and industrial digitization, gradually expanding later to multiple dimensions and levels such as the development environment of the digital economy, digital industrialization, industrial digitization, digital governance, and digital talent.

There is also diversity in the calculation methods for indicator systems. For example, some scholars in the early stages utilized methods such as the Analytic Hierarchy Process (AHP), expert survey methods, entropy method (Gao Peipei, 2024), entropy weight TOPSIS method, factor analysis, and principal component analysis to calculate the comprehensive score of indicator systems. Other scholars have employed the index method, such as Zhang Xueling (2017), who used this approach to measure the development status of the digital economy in China. The study found that, overall, the development of the digital economy in China has grown steadily, but it also observed a decline in growth rates. Due to differences in methods, currently, more scholars use objective evaluation methods than subjective ones.

With the continuous updating and development of digital technology, various institutions and scholars have

emerged with different research on the connotation and evaluation methods of the digital economy. However, to date, there is no unified definition in the research on the connotation of the digital economy. Meanwhile, each scholar and institution has inconsistent measurement and evaluation methods for the development level of the digital economy. The indicator system method is gradually becoming the mainstream evaluation approach, but there is also no unified evaluation indicator system in selecting indicator systems. Furthermore, existing literature has different research perspectives and selects vastly different indicators. There is also a lack of specialized research on the northwestern region in existing studies, and relevant indicators for digital utilization are missing in the construction of indicator systems. This paper will select five northwestern provinces to construct an evaluation indicator system for digital economy development and analyze its development level.

3. Index System Construction and Data Processing

3.1 Construction of Index System for the Development Level of Digital Economy

The framework of the indicator system should adhere to the principles of scientificity, accessibility, and comprehensiveness. Based on literature research, this paper constructs a measurement indicator system for digital economy development from four dimensions, eight aspects, and a total of 22 tertiary indicators. The specific indicator system is shown in Table 1:

1. Digital Infrastructure. A high-quality development foundation determines the height of economic development, and the quality of digital economy infrastructure construction will determine the speed of digital economy development. Comprehensive and complete infrastructure will effectively promote the rapid development of the digital economy. This paper mainly considers mobile infrastructure and network infrastructure, involving multiple indicators to comprehensively reflect the provincial-level facilities.

2. Digital Utilization. The sound development of the digital economy is inseparable from the continuous expansion of user groups. Digital utilization reflects the degree of dependence of social groups on the digital economy. It mainly considers personal utilization and enterprise utilization at two levels, involving multiple tertiary indicators such as the proportion of digital TV and e-commerce transaction activities to comprehensively reflect the level of digital economy utilization.

3. Digital Innovation. Innovation is the core source of continuous development in the digital economy. The strength of innovation capability is equivalent to a catalyst for its high-level development. The measurement of innovation should consider both innovation input and innovation output, mainly analyzed through multiple tertiary indicators such as personnel, funding, and the number of patents in high-tech industries.

4. Digital Industry. The digital industry refers to the development of industries that highly utilize digital technology. It is mainly constructed and analyzed from multiple aspects such as research and development funding for new products, sales revenue, and e-commerce sales.

Table 1. Index system of digital economy development level

First-level indicators	Secondary indicators	Tertiary indicators	Units	Stats	Weights
Number base case	Moving Basics	Mobile phone penetration	Ministry / 100 people	Forward	0.0061
		Mobile phone switch capacity	Ten thousand households	Forward direction	0.0250
		Number of cell phone base stations	10,000	Positive	0.0233
		Internet broadband access port	Ten thousand	Positive	0.0251
	Network Basics	Web pages	10,000	Positive	0.0600
		Number of domain names IPV4	Thousands	Positive	0.0500
		Digital TV subscribers	Ten thousand households	Positive	0.0331
Numerical performance	Personal usage	Cable broadcast TV subscribers as a percentage of total households	%	Forward Direction	0.0123
	Enterprise	Number of websites per 100	a	Positive	0.0059

State of digital innovation	application	businesses				
		The proportion of enterprises in e-commerce transaction activities	%	Forward Direction	0.0342	
	Investment in innovation	Internal R&D expenditure in high-tech industries	Ten thousand yuan	Positive	0.0705	
		Number of R&D institutions in high-tech industries	a	Positive	0.0461	
		High technology R&D personnel	people	Positive	0.0739	
		Number of effective invention patents in high-tech industries	a	Positive	0.0752	
	Innovation output	Information technology services revenue as a share of GDP	%	Positive	0.0639	
		Technical market turnover	Billion yuan	Forward direction	0.0821	
	Digital industry situation	E-commerce situation	E-commerce sales	Billion yuan	Positive	0.0301
			E-commerce purchase volume	Billion yuan	Positive	0.0252
Software business revenue		Billion yuan	Positive	0.0937		
New product information		Sales revenue of new products in high-tech industries	Yuan Yuan	Positive	0.0561	
		Expenditures for new product development in high-tech industries	Yuan Yuan	Positive	0.0730	

3.2 Data Processing

This paper utilizes provincial panel data from 2012 to 2022, with data sources mainly compiled from the National Bureau of Statistics and the statistical yearbooks of Shaanxi Province, Gansu Province, Qinghai Province, Ningxia Hui Autonomous Region, and Xinjiang Uyghur Autonomous Region for the respective years. Missing values for some years have been filled using the linear interpolation method as referenced in Huang Ling (2023).

The measurement method selected in this paper is the entropy method. The entropy method is an objective evaluation method that eliminates human subjective factors. It determines the weight of indicators solely based on the actual information reflected by the data, relying only on the differences in the actual data to reduce errors and make the results more consistent with the actual situation. Furthermore, the entropy method is widely adopted in existing literature research and is considered mature and reliable. The specific steps are as follows:

(1) Data standardization processing

In order to eliminate the impact of different dimensions, orders of magnitude and positive and negative directions between indicators, it is first necessary to process data standardization, as follows:

Positive indicators:

$$X'_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} + 0.0001 \quad (1)$$

Negative indicators:

$$X'_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} + 0.0001 \quad (2)$$

Suppose there are n sample sizes and m index quantities, then the JTH evaluation index of the ith evaluation object is $X_{ij}(i=1,2,3,\dots,n; j=1,2,3,\dots,m)$. Where $\max(X_{ij})$ is the maximum value of the JTH indicator and $\min(X_{ij})$ is the minimum value of the JTH indicator.

(2) Calculate the proportion of the value of the i th scheme index under the JTH index. Find the P-value

$$P_{ij} = \frac{x'_{ij}}{\sum_{i=1}^m x'_{ij}} \quad (3)$$

Where, $i=1,2,3,\dots, n$; $j=1,2,3,\dots, m$

(3) Calculate the information entropy e of item j

$$e_j = -k \sum_{i=1}^n (P_{ij} * \ln P_{ij}) \quad (4)$$

Where, $k = \frac{1}{\ln(n)}$ k is greater than 0, $j=1,\dots,m$, satisfy that e_{ij} is greater than or equal to 0.

(4) Calculate the redundancy of information entropy (difference)

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

Where, $j=1,\dots, m$

(5) Indicator weight determination

$$\omega_j = \frac{d_j}{\sum_{j=1}^m d_j} \quad (6)$$

Where, $j=1,\dots, m$

(6) Calculate the score

$$\text{Score} = \sum_{i=1}^n (\omega_j * x'_{ij}) \quad (7)$$

4. Measurement Results and Analysis of the Development Level of Digital Economy

4.1 Comprehensive Measurement Results and Analysis of Digital Economy Development Level

Table 2 reports the measurement results of digital economy development levels for the five northwestern provinces from 2012 to 2022. There are significant differences in the degree of digital economy development among the five provinces. From the average of the measurement results, Shaanxi has an average of 0.6356, ranking first among the five provinces and demonstrating a leading position. Meanwhile, Gansu, Xinjiang, Ningxia, and Qinghai have averages of 0.1269, 0.1218, 0.0618, and 0.0394, respectively. The combined average of these four provinces is approximately 0.3499, still less than Shaanxi's. Notably, Shaanxi's average development level is 16.1320 times that of Qinghai. A comparative analysis reveals significant differences in digital economy development among the five provinces, with notable polarization.

Analysis of the reasons for these obvious development differences: Firstly, compared to the other four northwestern provinces, Shaanxi has better location conditions. Adjacent to Chengdu, Chongqing, and Hubei, Shaanxi had more opportunities for exposure and learning in digital economy development in the early stages, benefiting from spillover effects. Secondly, Shaanxi has multiple top-ranked universities nationwide, laying a foundation for a high-quality labor force and innovative talent pool for the development of its digital economy. It boasts a richer system for cultivating innovative talents, and research institutes and technology innovation enterprises are relatively more concentrated compared to the other four provinces. Finally, Shaanxi attaches great importance to the development of the digital economy policy-wise, formulating the "Implementation Plan for Accelerating the Development of the Digital Economy Industry in Shaanxi Province (2021-2025)" and the "Policy Measures for Promoting High-Quality Development of the Digital Economy" in 2021 and 2023, respectively. These contributions have significantly contributed to the take-off of Shaanxi's digital economy. Comparing the measurement results from 2012 and 2022, Shaanxi's development has increased from 0.3238 to 0.8963, demonstrating a remarkable growth rate.

Table 2 Measurement results of digital economy development level

	Shaanxi	Gansu	Qinghai	Ningxia	Xinjiang
2012	0.3238	0.0635	0.0132	0.0258	0.0603
2013	0.3635	0.0633	0.0160	0.0290	0.0681
2014	0.4442	0.0820	0.0209	0.0371	0.0915
2015	0.5100	0.1089	0.0363	0.0542	0.1277
2016	0.6060	0.1117	0.0474	0.0580	0.1130
2017	0.6319	0.1305	0.0299	0.0548	0.1125
2018	0.6721	0.1471	0.0452	0.0683	0.1432
2019	0.7900	0.1536	0.0452	0.0722	0.1456
2020	0.8420	0.1680	0.0516	0.0749	0.1495
2021	0.9118	0.1729	0.0594	0.0879	0.1562
2022	0.8963	0.1939	0.0684	0.1174	0.1719
Average	0.6356	0.1269	0.0394	0.0618	0.1218
Mean ranking	1	2	5	4	3

Note. Calculated by the author.

The degree of digital economy development in the five northwestern provinces has been relatively stable and continuously improving. From the analysis of Figure 1, the five provinces have gradually demonstrated upward development vitality, with their development levels being overall stable and gradually increasing. Compared to 2012, all five provinces achieved positive growth in 2022, with Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang increasing by 0.5725, 0.1304, 0.0522, 0.0915, and 0.1115, respectively. The level of the digital economy has been continuously improved. However, there have been declines in some provinces, such as Shaanxi in 2022. The reason for this decline may be due to significant impacts on the external economic environment, such as the sudden impact of public health crises like the COVID-19 pandemic, which led to a decline in the development of related digital economy indicators.

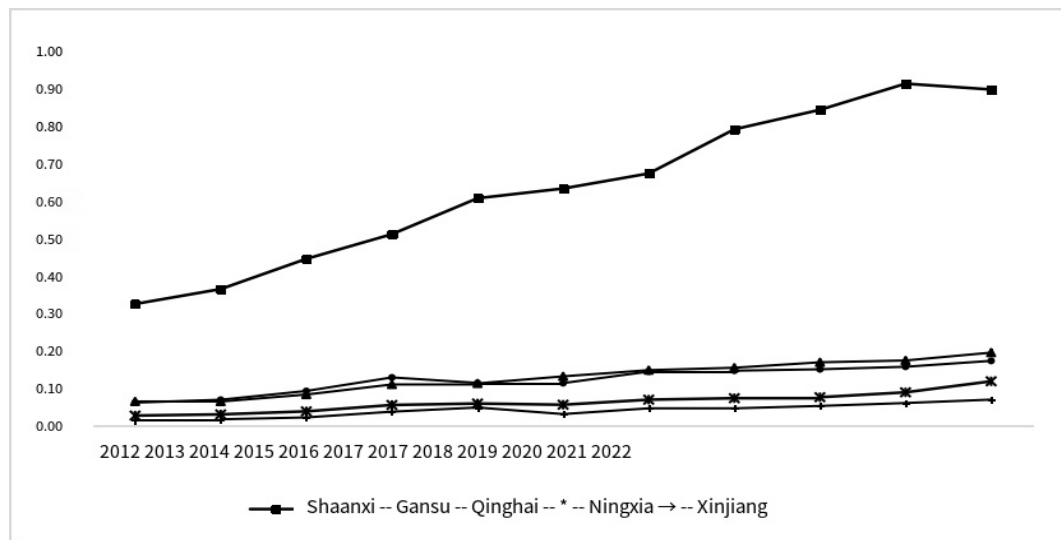


Figure 1. Digital economy development degree of the five provinces in Northwest China

Note. Calculated by the author.

4.2 Comprehensive Measurement Results and Analysis of Digital Economy Development Level

Table 3 reports the average levels of each first-level indicator within the digital economy indicator system for the five northwestern provinces.

There are deficiencies and shortcomings in the development of the digital economy in the five northwestern provinces. Analyzing the first-level indicators helps identify the deficiencies and shortcomings within the indicator system. Despite Shaanxi's relatively high overall development level, it still has deficiencies in the digital utilization indicator, with only 0.0660. This is a significant gap compared to the higher values of 0.1464, 0.2673, and 0.1559 for digital infrastructure, digital innovation, and digital industries, respectively. Meanwhile, among the five provinces, Gansu and Xinjiang also have shortcomings in digital utilization, with average values of 0.0186 and 0.0095, respectively. Qinghai lacks in digital innovation, with an average of only 0.0053, and Ningxia has deficiencies in digital industries, with an average value of only 0.0133 for this indicator.

Table 3. Average level of indicators of digital economy development

Provinces	Digital base situation	Use of numbers	Digital Innovation	Digital Industry Situation
Shaanxi	0.1464	0.0660	0.2673	0.1559
Gansu	0.0526	0.0186	0.0267	0.0577
Qinghai	0.0102	0.0137	0.0053	0.0102
Ningxia	0.0172	0.0163	0.0150	0.0133
Xinjiang	0.0652	0.0095	0.0095	0.0244

Note. Calculated by the author.

5. Conclusion and Development Suggestions

5.1 Conclusion

1. The level of digital economy development in the five northwestern provinces has improved overall, but with significant growth rates and disparities. The above research finds that during the period from 2012 to 2022, the digital economy in the five northwestern provinces exhibited an overall growth trend, especially in terms of digital infrastructure and industrialization. However, the phenomenon of uneven development among provinces is prominent. Shaanxi Province leads the way, while the development levels of Gansu, Xinjiang, Qinghai, and Ningxia lag behind relatively, and this disparity limits the potential for overall improvement in the digital economy of the northwest region.

2. There are shortcomings in the development of the internal structure of the digital economy. Through sub-indicator analysis, it is found that the provinces perform unevenly across different dimensions of the digital economy. For example, although Shaanxi leads in overall development, it scores low in digital utilization, reflecting that the widespread application of digital technology by individuals and enterprises still needs improvement. Qinghai and Ningxia perform weakly in digital innovation capabilities, especially facing obvious shortages in high-tech research and development funding and the cultivation of innovative talent.

3. Regional policy support and resource endowments play a decisive role in the development of the digital economy. Shaanxi Province has made significant progress in the field of the digital economy due to its superior policy environment and resource integration capabilities. This indicates that strong government policy support, technological innovation capabilities of higher education institutions, and collaborative cooperation with eastern regions are key drivers of rapid digital economy development.

5.2 Development Suggestions

1. Accelerate the formulation of digital economy development policies to consolidate existing achievements. The development of the digital economy in the five northwestern provinces is still in its infancy overall, and its sustained and stable growth requires a positive and favorable development environment as support. To this end, the government should expedite the formulation of supporting policies for digital economy development and provide targeted support through detailed planning in various aspects such as infrastructure construction, industrial transformation, and technological research and development, ensuring the coordination and implementation of policy execution. This will not only help consolidate existing achievements but also attract the clustering of more digital enterprises, external funds, and technological resources, further promoting regional economic development. A good development environment and effective policy support, like a magnet, can attract more resources to converge in the five northwestern provinces, thereby promoting the digital economy to move towards higher quality and more sustainable development, bringing new opportunities and growth points to regional economic and social development.

1. Strengthen inter-provincial communication to enhance the integrated and complementary development of the digital economy. Strengthening inter-provincial communication and cooperation is a key path to achieving coordinated development of the digital economy in the five northwestern provinces, especially given the large disparities in resource endowments and development levels among the provinces. The five provinces should establish cross-provincial cooperation mechanisms and form mutually beneficial and win-win situations through in-depth cooperation in multiple fields such as digital technology, industrial policies, and infrastructure construction. For example, they should rely on regional digital economy development forums and joint research platforms to regularly conduct experience exchanges and problem discussions, sharing the successful experiences of provinces with advantages such as Shaanxi, especially providing references for other provinces in the construction of digital talent training models under the higher education system. At the same time, each province should also increase R&D investment in high-tech industries, improve and accelerate the construction of digital facilities such as 5G networks and data centers, promote resource integration and technology sharing among provinces, further enhance the overall regional competitiveness, and drive the integrated development of the digital economy.

3. Accelerate the exploitation of resource advantages to fill the gaps in digital economy development. The five northwestern provinces possess unique advantages such as abundant green energy, land resources, and low-cost labor force, which are of great significance in promoting the development of the digital economy. Each province should tap into its resource potential based on its own characteristics and convert national strategies such as "West Computing, East Transmission" into specific local development opportunities. Shaanxi should further optimize its existing industrial layout, strengthen the development of digital economy application scenarios while consolidating its innovation and R&D advantages, and promote the popularization of related technologies in production and service fields. Gansu and Xinjiang should concentrate efforts on promoting the digital transformation of enterprises, enhance investments in e-commerce platforms and smart agriculture, and increase the degree of digitization of the economy. Qinghai needs to fill the gap in innovation capability building, focusing on increasing internal R&D expenditures for high-tech industries and cultivating high-tech R&D personnel to promote the improvement of technological innovation capabilities. Ningxia should take the development of e-commerce and digital industries as a breakthrough, accelerate the formation of industrial agglomeration effects, and improve market competitiveness and industrial maturity. By strengthening investments and resource integration in these areas of weakness, the five northwestern provinces will further narrow the digital economy gap with developed regions.

4. Promote inclusive digital economy development to narrow the urban-rural and regional gaps. The development of the digital economy must take inclusivity into account to ensure that more regions and groups benefit. The five northwestern provinces should accelerate the construction of rural internet infrastructure and promote the transformation and upgrading of the rural economy through smart agriculture, e-commerce in rural areas, and other means to improve the living standards of residents in remote areas. Local governments should also strongly support the digital transformation of small and medium-sized enterprises by providing technical training, policy support, and market guidance to help them integrate into the digital economy system faster. Through the implementation of inclusive policies, the digital skills and participation of urban and rural residents will be further enhanced, injecting new momentum into the comprehensive and coordinated development of the regional economy.

Informed consent

Obtained.

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Data sharing statement

No additional data are available.

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