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Big Data Perspectives on the Degree and Geographic Differences in the Synergistic Growth of the Digital as well as Green Economy

Abstract: - The interactive mechanism between the digital as well as green economy is examined, and an index system for evaluating their synergistic development is built, all based on the features of the big data era. Based on this, a mathematical model is created to examine the degree and geographic distribution of the synergistic growth of the digital as well as green economy in 30 China's provinces. The present state of China's synergistic development of the digital as well as green economies is explained, and a big data perspective is used to suggest a way forward for raising the level of synergistic development of the two economies. This approach offers an empirical foundation for policy formulation.

Keywords: Big data(BD), digital technology(DT), green digital economy (GDE), level of synergistic development (LSD),capacity coupling coefficient model(CCCM).

I. INTRODUCTION

A new economic paradigm known as the "digital economy" has been born as a result of information technology's current transition from an auxiliary tool to the main driver of social and economic development. Deep mining and integrated application of data are characteristics of this intelligent stage that the industry is currently entering. The degree of digitalization of the social economy has increased steadily with the advancement and extensive use of information technology; however, with the advent of the big data era, the meaning and connotation of the term "digital economy" have changed significantly[1,2]. As of right now, the phrase "digital economy" pertains to a broad category of economy endeavors that utilize digital technology as their principal driver, digital information as well as knowledge as critical components of production, and contemporary information networks as essential channels by completely integrating digital technology in the real economy in order to optimize economic structure and increase economic efficiency[3,4].

Big data is the central component and major engine of the digital economy, and the latter is an all-encompassing realization of the value of big data. Blockchain, Cloud computing, Big data, Internet of things, and other artificial intelligence technologies are the essential tools to help the digital economy grow[5-6]. In the big data period, digital economy has the potential to drastically accelerate the digital transformation of well-established industries, alter the economic structure, promote superior regional development, promote resource efficiency across a variety of sectors, and promote the growth of a green as well as low-carbon regional economy. Unfortunately, because of problems like excessive electricity use, electronic waste, and so on, the rise of the digital economy isn't completely low-carbon.

As seen in Figure 1, the integration of the principle of green development into the high-energy and high-emission regions of digital economic development is achieved by means of big data technology. This can successfully encourage green transformation of the digital economy's development mode as well as bring about the development of digital economy in a way that is low-carbon, sustainable, and healthful [5-9].

The extant literature indicates that a dearth of study with the synergistic development of the digital economy and the green economy by scholars both domestically and internationally [10-16]. Qualitative research primarily focuses on the interactive relationship between the two economies, whereas quantitative research primarily examines how the digital economy supports the growth of the green economy [17-19]. It is evident that, in the big data era, there is a dearth of quantitative study in the degree of synergistic development between the green economy as well as the digital economy. Thus, it is extremely important from a theoretical and practical standpoint to construct an index scheme for evaluating the degree of synergistic development of the digital economy as well as green economy from the big data perspective, create a model for data analysis, gauge the degree of development and synergistic development of these two economies in each Chinese province, and conduct quantitative research and analysis on the synergistic development of these two economies.

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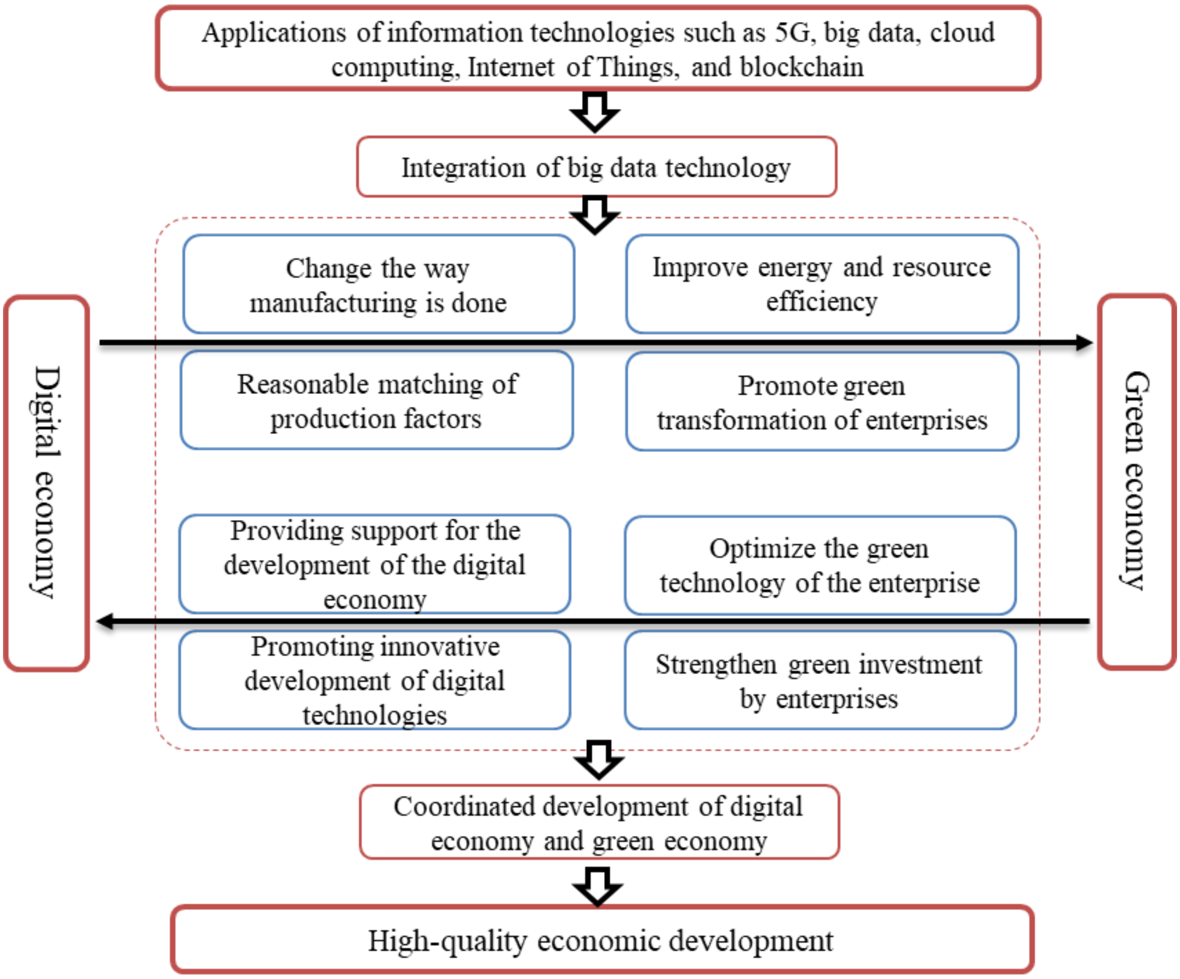


Figure 1: Interactive Mechanism of Digital As Well As Green Economy Based on Big Data Technology

II. RESEARCH DESIGN

A. *Index System for Evaluation*

Reference the "China Digital Economy Development Report 2022", it is evident from the three aspects of productivity, production relations, and production factors that digital economy is primarily composed of four parts: The first set of production factors is data value, which is primarily represented by data coverage capacity, transmission capacity, carrying capacity, and other elements. Productivity, or industrial digitalization and digital industrialization, is the second. The primary driver of digital industrialization is the application of technological innovation in the digital domain, which leads to particular industrial development. This is most evident in the growth of the software and information technology industries. Industrial digitalization, which essentially pertains to the use of digital technology with conventional industries, is necessary to construct a new framework for incorporating the digital economy into regional economic development. This is primarily reflected in enterprise informatization, trading platforms, digital finance, and other aspects. Third, the term "production relations", sometimes known as "digital governance", mostly relates to online public services. Consequently, the development level's assessment index scheme of digital economy is therefore established using the four elements of digital value, digital industrialization, industrial digitalization, as well as digital governance.

Right now, there isn't a consensus on what constitutes a "green economy" when it comes to building the subsystem's assessment index system. Nonetheless, academics agree that a green economy ought to be an efficient, low-carbon, sustainable, and green model of economic development [20–21].As a result, the assessment index value system is built using the following factors: the environment's carrying capacity, scientific, technical innovation, industrial structure, economic development level, and resource utilization efficiency.

In summary, based on the big data perspective, a digital economy as well as green economy level of development assessment index system was established. See Table 1 for details.

Table 1: An Index Scheme to Evaluate the Level of Advancement in The Digital As Well As Green Economy

Target layer	Criterion layer	Index layer
Digital economy development level	Digital value	Proportion of Internet broadband access users in total population(%)
		Proportion of mobile Internet users in total population(%)
		Number of Internet broadband access ports per capita (PCS/person)
		Mobile Internet Access traffic per capita (GB/ person)
		Number of Web pages per person (PCS/person)
	Digital industrialization	Software business revenue (ten thousand yuan)
		Software product revenue (ten thousand yuan)
		Information technology service revenue (ten thousand yuan)
		Employed persons in urban units of Information transmission, software and information technology services (ten thousand)
	Industrial digitization	Proportion of enterprises with e-commerce transactions (%)
		E-commerce sales (100 million yuan)
		E-commerce purchases (100 million yuan)
		Number of computers used by enterprises per 100 people (units)
		Number of websites per 100 companies (number)
		Number of websites owned by the enterprise (number)
		Digital Financial Inclusion Index
	Government digitization	Government digital governance work promotion index
		Government Digital Governance Social Impact Index
Green economy development level	Economic level	Per capita GDP (yuan)
		Total fiscal revenue (ten thousand yuan)
		Household consumption level (Yuan)
	Industrial structure	Proportion of tertiary Industry (%)
		Technology transactions as a percentage of GDP (%)
	Scientific and technological innovation	Proportion of Fiscal Expenditure on Science and Technology in GDP (Ten Thousand Yuan)
		R&D expenditure (ten thousand yuan)
		Sales revenue of new products of industrial enterprises above designated size (ten thousand yuan)
		Number of R&D projects (projects)
		Number of invention patents granted per 10,000 people (pieces)
	Green development	SO_2 discharge Environmental efficiency (ten thousand yuan /t)
		CDD discharge Environmental efficiency (ten thousand yuan /t)
		Comprehensive utilization rate of industrial solid waste
		Water consumption efficiency (Yuan/m^3)
		Electricity consumption efficiency (Yuan/KWH)
	Environmental bearing capacity	Forest coverage (%)
		Water resources per capita (m^3 / person)
		Investment in environmental protection as a percentage of GDP (%)
		Green coverage rate of built-up area(%)
		Industrial pollution control investment intensity (%)

B. Evaluation Methods and Criteria

1) Comprehensive evaluation model of development level: An approach to data analysis that gauges the assessment object's comprehensiveness is the efficacy function. For every evaluation index in the index system, there should be a satisfactory value and a disallowed value. These values should be taken as maximum and lower bounds of the index value, and the degree to which each index reaches the satisfactory value should be calculated for determining the efficacy score of each index. To obtain the comprehensive situation of the object researched, a weighted average is used to produce the comprehensive score. When the efficiency function is used to gauge the level of advancement in the green as well as digital economy, to reduce impact of subjective elements, the weighting of each index is determined using the entropy weight approach. The entropy weight-efficiency function comprehensive evaluation model is built as follows:

Assume the information of i assessment objects on j indexes is represented as b_{ij} . When it comes to the positive effect index, the highest value represents the satisfied value and the minimum value represents the banned value. The greatest value is considered to be the prohibited value for the negative effect index, while the least value is considered the satisfactory value.

a) *Calculate the efficacy score* b_{ij}^* *of each index:*

For the positive effect index: $b_{ij}^* = [(b_{ij} - \min_i b_{ij}) / (\max_i b_{ij} - \min_i b_{ij})] \cdot 0.99 + 0.01$ (1)

For the negative effect index: $b_{ij}^* = [(\max_i b_{ij} - b_{ij}) / (\max_i b_{ij} - \min_i b_{ij})] \cdot 0.99 + 0.01$. (2)

b) *Determine the j index's contribution:*

$$P_{ij} = b_{ij}^* / \sum_{i=1}^{m} b_{ij}^* \quad . \tag{3}$$

c) *Determine the* j *index's entropy value:*

$$E_j = -\frac{\sum_{i=1}^{m} P_{ij} \ln P_{ij}}{\ln m} \tag{4}$$

.If P_{ij} is 0, then let $E_j = 0$

d) *Determine the j index's entropy weight:*

$$\gamma_j = (1 - E_j) / \sum_{j=1}^{n} (1 - E_j) \quad . \tag{5}$$

e) *Determine the digital and the green economy's development level score:*

$$d_t = \sum b_{ij}^* \gamma_j \tag{6}$$

According to the principle of the model, $d_t \in [0,1]$. The closer it is to 1, the better the development level of the subsystem.

2) Modified capacity coupling coefficient model: The notion of capacity coupling in physics is congruent with the connection between the digital economy as well as green economy, which are two subsystems that are distinct, interacting, and connected. As a result, the integration level r *of the digital economy as well as green economy is determined using the capacity coupling coefficient model for assess the synergistic development level within them, as follows:*

$$r = \frac{2\sqrt{d_1 d_2}}{(d_1 + d_2)} \quad . \tag{7}$$

The calculation model has some flaws, according to the calculation principle. A "pseudo-high" phenomena of integration degree will arise when the growth levels of the digital as well as green economy are identical and minimal, this does not correspond to reality. To prevent this kind of issue, the cooperative development degree calculation model is built and the capacity coupling coefficient model is updated. The specifics are as follows:

a) *Ascertain each subsystem's degree of completion of development:* The following is the calculating formula:

$$F = \sum_i \alpha_i d_i \tag{8}$$

Where, α_i represents for each subsystem's weight. Given the same significance of the growth of the digital as well as green economy, each subsystem's weight in the particular computation is set at 0.5.

b) *Determine the synergistic development degree:* The following is the calculating formula:

$$R = \sqrt{rF} \quad . \tag{9}$$

The assessment concept states that the coordinated development degree's value should range from 0 to 1. The degree of synergistic development between subsystems advances with proximity to 1. In contrast, there is less synergistic development.

The relative level of development is computed so as to characterize the relative growth level of the digital economy as well as the green economy. The following is the calculating formula:

$$\varepsilon = \frac{d_1}{d_2} \tag{10}$$

With reference to existing research results, the developmental stages are defined as follows, see Table 2 for details.

Table 2: Relative Development Stage

Relative level of development	Developmental stages (d_1 denotes the digital economy, d_2 denotes the green economy)
$0 < \varepsilon \le 0.8$	d_1 lag d_2
$0.8 < \varepsilon \le 1.2$	d_1 equal d_2
$\varepsilon > 1.2$	d_1 better d_2

C. Data Sources and Evaluation Criteria

The existing statistics data and indicators of the digital economy are not perfect because it is a new economic form. Therefore, 30 Chinese states (excluding Tibet, Hong Kong, Macao, and Taiwan) have been selected as evaluation objects, with 2023 serving as the evaluation term, taking into account data integrity, accessibility, and continuity. The China Statistical Yearbook, the China Government Data Governance Development Report, the National Data Website ,The Peking University's Digital Financial Inclusion Index were used to obtain the values of each index in the assessment index system. Drawing on the results of current research[15-18], the synergistic growth levels of the digital as well as green economy is categorized into three areas and ten levels to provide a more accurate description, as displayed in Table 3.

Table 3: Standards to Gauge the Degree of Synergistic Development

Categories	synergistic development level score	synergistic development level
Synergistic development $0.6 < R \le 1$	(0.9,1]	High-quality synergistic development
	(0.8,0.9]	Advanced synergistic development
	(0.7,0.8]	Intermediate synergistic development
	(0.6,0.7]	Primary synergistic development
Transitional synergistic development $0.4 < R \le 0.6$	(0.5,0.6]	Forced synergistic development
	(0.4,0.5]	Proximity imbalances development
Imbalances development $0 < R \le 0.4$	(0.3,0.4]	Mildly imbalances development
	(0.2,0.3]	Moderate imbalances development
	(0.1,0.2]	Highly imbalances development
	(0,0.1]	Seriously imbalances development

III. Empirical Analysis

A. The State of Development and Geographical Arrangement of the Green As Well As Digital Economy in China's Provinces

Based on a comprehensive model of development level, the growth level and comparative development level of the digital as well as green economies of China's 30 provinces were determined. For more information, see Table 4. The results of the evaluation show that the green economy is currently growing at a level between 0.111 and 0.519, whereas the digital economy is currently developing at a level between 0.060 and 0.891. Twenty-two provinces, or 73.33% of the total, are not progressing as quickly as the country as a whole in building their green and digital economies. It is obvious that there is no apparent regional equilibrium in China's development of the digital as well as green economies. There is close association between the development of the digital economy as well as the green economy, as evidenced by their nearly similar rankings; Second, when considering the development stage, nine provinces (30%) are leading the way in the digital economy, while fourteen provinces (46.67%) are lagging behind the green economy. In addition, synergistic development levels of the digital as well as green economies in the top 10 provinces are higher than those of the green economy, while those in the bottom 10 provinces are not up to par in the growth levels of the green economy. It indicates that we are in the "leading green economic" stage of development, but not to a very high one. Development of the digital economy can successfully foster the high-quality economic growth of an area; however, the sluggish speed of this development hinders the expansion of the regional green economy, which further impacts the high-quality development of area.

Table 4: Chinese Province's Development of the Green and Digital Economies Within 2023

Province	Digital economy development level d_1	Green economy development level d_2	synergistic development level R	Ranking	Relative development level ε	Development stage
Beijing	0.891	0.519	0.825	1	1.72	d_1 better d_2
Guangdong	0.615	0.347	0.680	2	1.77	d_1 better d_2
Shanghai	0.472	0.344	0.635	3	1.37	d_1 better d_2
Zhejiang	0.405	0.305	0.593	4	1.33	d_1 better d_2
Jiangsu	0.439	0.277	0.591	5	1.58	d_1 better d_2
Shandong	0.304	0.251	0.526	6	1.21	d_1 better d_2
Hubei	0.189	0.168	0.422	7	1.12	d_1 equal d_2
Tianjin	0.198	0.160	0.422	8	1.24	d_1 better d_2
Fujian	0.183	0.169	0.420	9	1.08	d_1 equal d_2
Sichuan	0.235	0.124	0.413	10	1.90	d_1 better d_2
Anhui	0.132	0.195	0.400	11	0.68	d_1 lag d_2
Inner Mongolia	0.079	0.309	0.395	12	0.25	d_1 lag d_2
Ningxia	0.083	0.282	0.391	13	0.30	d_1 lag d_2
Shaanxi	0.163	0.135	0.385	14	1.20	d_1 equal d_2
Chongqing	0.171	0.127	0.384	15	1.35	d_1 better d_2
Liaoning	0.131	0.149	0.373	16	0.88	d_1 lag d_2
Hunan	0.112	0.158	0.365	17	0.71	d_1 lag d_2
Henan	0.126	0.120	0.350	18	1.05	d_1 equal d_2
Guizhou	0.098	0.152	0.349	19	0.64	d_1 lag d_2
Hainan	0.122	0.118	0.346	20	1.04	d_1 equal d_2
Jiangxi	0.091	0.153	0.344	21	0.60	d_1 lag d_2
Hebei	0.113	0.121	0.342	22	0.93	d_1 equal d_2
Guangxi	0.088	0.141	0.333	23	0.62	d_1 lag d_2
Qinghai	0.077	0.152	0.328	24	0.51	d_1 lag d_2
Heilongjiang	0.053	0.209	0.324	25	0.25	d_1 lag d_2
Gansu	0.075	0.124	0.310	26	0.60	d_1 lag d_2
Xinjiang	0.063	0.143	0.309	27	0.44	d_1 lag d_2
Shaanxi	0.073	0.117	0.303	28	0.62	d_1 lag d_2
Yunnan	0.067	0.106	0.291	29	0.63	d_1 lag d_2
Jilin	0.060	0.111	0.285	30	0.54	d_1 lag d_2
Mean value	0.197	0.193	0.442	-	-	-

Ward analysis of clusters was done in accordance with development scores of the digital as well as green economy in each of the provinces shown in Table 4. It can be separated spatially into four distinct development regions, as Table 5 illustrates.

Compared to other provinces, the first region's provinces have significantly higher levels of development in the digital as well as green economy. The second region's provinces have developed their digital economies to a high degree, which helps to further the development of the green economy. The third region's provinces digital as well as green economy growth levels are essentially the same, but they still require improvement. The fourth region's provinces have comparatively weaker digital economic development and insufficient green economic development, with the most provinces in this region.

Table 5: The Geographical Distribution of Growth Rates in China's Provinces for the Digital and the Green Economy

Development level category	Province
Double development strong region	Beijing
Digital economy strong region	Guangdong, Shanghai, Zhejiang, Jiangsu, Shandong
Double development primary region	Shaanxi, Chongqing, Hubei, Fujian, Tianjin, Sichuan
Digital economy development lag region	Henan, Hainan, Hebei, Liaoning, Hunan, Anhui, Gansu, Shaanxi, Yunnan, Guizhou, Jiangxi, Inner Mongolia, Ningxia, Guangxi, Qinghai, Xinjiang, Heilongjiang

B. Synergistic Development Level and Geographical Distribution of Digital As Well As Green Economy in China's Provinces

According to Table 4, current state of synergistic development of the digital as well as green economies in 30 Chinese provinces, as determined by the synergistic growth degree evaluation methodology. The geographic distribution of China's synergistic development of the digital as well as green economy is generated with combining Table 4 with Table 3 of the evaluation criteria. This is displayed in Table 6.

The overall synergistic development score for the digital and green economies is between 0.285 and 0.825, and 24 provinces (80%) have synergistic development levels that are below the national average. This suggests that there are notable variations and non-equilibrium differences with the synergistic growth levels of the digital economies as well as green economies across provinces, and a polarization phenomenon.

Particularly, Beijing, Guangdong, and Shanghai are the 3 provinces that have the most synergistic development of the digital as well as green economy, making up 10% of the total. The highest synergistic development level is the high-level synergistic development level. Seven provinces, or 23.33% of the total, fell into the category of transitional synergistic development; twenty provinces, or 66.67% of the total, fall into the category of imbalances development, with eighteen of them being at or near the mildly imbalances development level.

Table 6: Geographical Distribution of China's Synergistic Development Levels for the Digital and Green Economy Among Its Provinces

Category	Province	Synergistic development level
synergistic development category	Beijing	Advanced synergistic development
	Guangdong, Shanghai	Primary synergistic development
Transitional synergistic development category	Zhejiang, Jiangsu, Shandong	Forced synergistic development
	Hubei, Tianjin, Fujian, Sichuan	Proximity imbalances development
Uncoordinated development category	Anhui, Inner Mongolia, Ningxia, Shaanxi, Chongqing, Liaoning, Hunan, Henan, Guizhou, Hainan, Jiangxi, Hebei, Guangxi, Qinghai, Heilongjiang, Gansu, Xinjiang, Shaanxi	Mildly imbalances development
	Yunnan, Jilin	Moderate imbalances development

Present state of Chinese digital as well as green economy synergistic development is evidently low; most provinces are not yet in a synergistic development stage, but are on the verge of one, suggesting a positive trend in synergistic development; the most provinces fall into the dysfunctional development category, where the growth of the digital economy lags behind that of the green economy. So, the level of development of the digital economy has become a major barrier to the synergistic development of the digital as well as green economies in China.

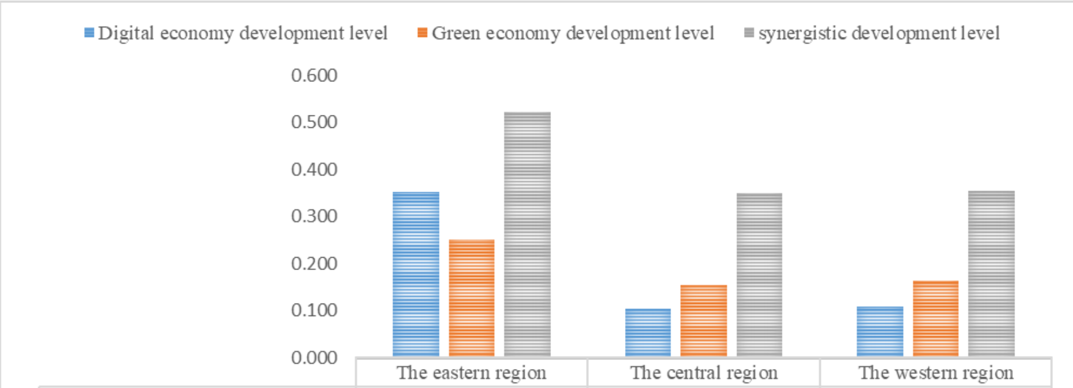
There exists a definite correlation between the development levels in each province and the degree of synergistic expansion of the digital as well as green economies. For example, the top five provinces in 2023—Beijing, Shanghai, Guangdong, Jiangsu, and Zhejiang—have relatively high levels of regional growth when it comes to the synergistic development of the green as well as digital economies. It is clear that the high-level synergistic expansion of the digital and green economies plays a major role with supporting the better development of low-carbon as well as green infrastructure in the region.

C. The Three Regions of China Exhibit Varying Levels of Synergistic Development and Geographical Distribution Between the Digital As Well As Green Economies.

Based on the development and synergistic development scores of the digital as well as green economies in each province, the average degree of development and synergistic development of these economies is determined for eastern, central, and western China. The characteristics of the digital as well as the green economy's cooperative development in different parts of China are obtained, as illustrated in Figure 2.

Figure 2 illustrates how China's digital as well as green economy are growing at quite different rates. In terms of the degree of expansion of the digital and green economies, as well as synergistic development, the eastern region performs better than the middle and western regions. With minimal overall development synergy, the green economy is growing more quickly than the digital economy. The digital as well as green the economy, with their mutual development, are at the same stage of development in central and west China. Nonetheless, there is a minor imbalance in overall development as the green economy has developed to a higher degree than the digital economy.

In summary, when considering regional areas, the synergistic development of Chinese digital as well as green economies illustrates the characteristics of "high in the east and low in the center and western regions" of geographical distribution.



	The eastern region	The central region	The western region
Digital economy development level	0.352	0.104	0.109
Green economy development level	0.251	0.154	0.163
synergistic development level	0.523	0.349	0.354

Figure 2: Distribution Characteristics of the Synergistic Development Levels of the Green As Well As Digital Economy Throughout China's Three Regions

IV. CONCLUSIONS AND ENLIGHTENMENTS

This study uses thirty Chinese provinces as its research subject and develops an indexing scheme to assess the degree of synergistic development of the digital and green economies. The assessment model of synergistic development degree and the comprehensive assessment model of development level are used to measure the degree of synergistic development of the digital economy as well as green economy. In conclusion, it evaluates and investigates the extent of synergistic growth of the green economy as well as digital economy in 30 Chinese provinces. It offers a crucial policy reference for the synergistic growth of China's green and digital economies.

The study's findings have significant application in raising the degree of synergistic growth of China's digital as well as green economy in the big data era and in advancing the efficient, sustainable, low-carbon, and green development of the region. Taking into account China's recent progress in both the digital and green economies, the following recommendations are made: First, Big data technology is being used to: create differentiated development goals for the digital economy according to local circumstances in different places; implement differentiated development modes; strengthen cooperation and exchanges between various regions; reduce development gaps between provinces; enhance the potential for the digital economy's develop; enhance the area economy's synergistic growth. The creation of "digital economy and green economy" spatial arrangement that is sustainable; Second, promote the application of big data in numerous industries, create a digital ecosystem based on digital supply chains, quicken the digital transformation of conventional industries by utilizing big data, 5G, blockchain, cloud computing, etc., and enhance the synergistic growth of the green as well as digital economies while highlighting the role that the former plays in the latter; Third, the areas in the west and center should make full use of big data technology to incorporate the digital economy into their distinctive sectors, fully utilize the benefits of their natural resources and ecological surroundings, and harness the power of the digital economy to further regional growth. Concurrently, there will be a push for the creation of massive data center platforms and increased investment in network infrastructure, including 5G, to offer a fundamental assurance for the development of the digital economy with the western as well as middle parts.

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