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Uncovering the Triple Synergy of New-Type Urbanization, Greening and Digitalization in China

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Abstract: The in-depth discussion and analysis of the synergistic effect of new-type urbanization, greening and digitalization (NUGD) is important for the achievement of sustainable social, ecological and economic development. Therefore, in this study, an evaluation index system composed of these three subsystems was constructed for Chinese cities from 2011 to 2021. The comprehensive and collaborative development levels of each subsystem were measured by means including the entropy weight method and the coupling coordination model, respectively. Then, methods such as ESDA and the Dagum Gini coefficient were applied to investigate the spatiotemporal evolution and spatial differences in the triple synergy effect of the NUGD system in Chinese cities. Finally, the constraining factors of the triple synergy effect were revealed using the obstacle degree model. The findings demonstrated the following: (1) Overall, the NUGD subsystems and their comprehensive levels were increasing, with moderate overall development levels. (2) The synergistic development of the NUGD system exhibited an upward trend. Spatially, the synergistic development level showed distinct differentiation, being higher in the east and lower in the west. The multidimensional dynamic variation characteristics obtained through kernel density estimation revealed that the triple synergy level exhibits high stability. (3) The differences within the east and between the eastern and western areas were the largest, with the intensity of transvariation as the main source. (4) The five criterion layers, including social and spatial urbanization variables, were the key constraints that affected the triple synergy of the NUGD in Chinese cities, and the restrictive role of factors such as the proportion of urban construction land and the per capita postal business volume should not be ignored. This study provides a valuable reference and decision-making guidance to promote China's acceleration toward a new urbanization path supported by both digitalization and green transformation.

Keywords: triple synergy of the NUGD system; spatiotemporal evolution; dynamic progression; obstacle factors

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1. Introduction

Currently, the most prominent features of global economic and social development are urbanization, greening and digitalization [1]. As early as the beginning of the 21st century, significant progress was achieved in the global urbanization process, with cities reaching high levels in terms of scale expansion, coverage and diversified development [2].Moreover, it is expected that, by 2070, global population will reach 9.7 billion, and two-thirds of the population will have flowed into urban areas [3]. It can be observed that, in a broad sense, urbanization is defined based on population changes. For example, in some Latin American countries, an area with a population of 2500 is considered urban; in other countries, the threshold is 5000. Meanwhile, in India, areas accommodating 100,000 residents are considered urban areas [4]. In fact, benefiting from the reform and opening up process, the urbanization process in China has shown unprecedented growth, with the urbanization

rate increasing from 17.92% in 1978 to 64.72% in 2021 [5]. However, rapid urbanization has a profound impact on climatic conditions, vegetation, lake ecosystems and global land resources [6–8]; furthermore, existing studies have shown that urbanization causes extensive and permanent damage to river systems [9]. In addition, the rapid expansion of cities and population growth have further reshaped the urban landscape and reduced urban biodiversity [10]. To address this challenge, which may be a common issue faced by most countries, this study takes China as an example and introduces the concepts of green development and digital transformation, emphasizing the importance of greening and digital empowerment and highlighting the urgency of sustainable urban development. Furthermore, from a sustainable development perspective, urbanization development should shift toward a new type—that is, new-type urbanization. Chinese new-type urbanization places a greater emphasis on promoting the citizenship of agricultural migrant workers in an orderly manner, ensuring that they have access to basic public services in towns and highlighting its human-oriented and pro-urban–rural equality characteristics [11,12]. In addition, it emphasizes optimizing the urban layout and spatial structure and places an emphasis on enhancing the sustainable development capacity and quality of urban development. It comprehensively considers various factors, such as the population, economic growth, social welfare and the spatial structure, aiming to guide cities toward inclusive, safe, resilient and sustainable development [13–15].

Promoting the in-depth integration of human-centered new-type urbanization construction and greening is essential to realize the goal of environmental sustainability and harmonious coexistence between humans and nature [16,17]. With the frequent occurrence of global natural disasters, rising sea levels and ecosystem destruction becoming the main obstacles constraining sustainable development, green development has been increasingly adopted in many countries to address challenges such as resource scarcity and the adverse effects of climate change [18,19]. For example, the UK has announced the Low-Carbon Transformation Plan and the Renewable Energy Strategy; in 2019, the European Union issued the "European Green Deal", proposing to become the world's first carbon-neutral country by 2050, expressing its pursuit of green and low-carbon development [20]. Moreover, in 2020, the dual-carbon goals were proposed by the Chinese government, and subsequently, a series of green and low-carbon transformation work plans were implemented to strengthen its ecological environmental protection and achieve its sustainable development goals, clearly demonstrating China's responsibility as a major country [21,22]. Greening is the path to realizing green development, and it includes the transformation of multi-dimensional development models such as economic–social–ecological models and achieving green production and industries at the economic level, green life at the social level and green protection and governance at the ecological level [23]. Its purpose is to reduce the pressure of economic and social development on the ecological environment, achieve efficient outputs and advocate for a green and environmentally friendly way of life. By implementing effective environmental governance measures, it promotes society's transition toward sustainable development and environmental friendliness, fostering harmony between humans and nature [24]. Thus, it plays a profound role in improving the quality of urban development and building a beautiful China [25].

In the green transformation process, the role of digital empowerment has become increasingly prominent [26,27]. Following the 2015 Paris Agreement, countries worldwide have been working together to promote environmental protection and have reached a consensus on green transformation [28]. Notably, with the advent of the digital age, global economic, social and environmental governance have achieved significant results against the backdrop of digital transformation. For example, digital transformation provides many new employment opportunities, significantly changing the prospects for global economic development [29]. In addition, by transforming operation mode, productivity and production relationships, optimizing resource allocation and improving innovation efficiency, digitalization has played an increasing role in facilitating urban development at a high level and driving the transformation of the development mode to a green and

low-carbon one [30,31]. Thus, in China, national policy documents and government work reports have repeatedly emphasized that digitalization is a significant engine for the improvement and growth of Chinese economic development. Through the dual role of technological change and policy support, it has been promoted as a key force for the long-term and sustainable development of the Chinese economy and society [32,33].

Importantly, the synergistic analysis in this study adopts a systems perspective, focusing on the dynamic changes in new-type urbanization, greening and digitalization while also revealing the complex interdependencies and interactions among the three major systems. New-type urbanization, greening and digitalization are important components of the complex social–ecological–economic system, and the promotion of the synergistic development of these three factors is a crucial step in addressing the common challenges faced by many countries around the world [34,35]. Unfortunately, there are currently few studies focusing on the dynamic interaction between these three systems. Therefore, referring to the relevant literature [36,37], this study places Chinese urban new-type urbanization, green development and digital transformation within the same research framework. Utilizing the coupling coordination model, ESDA and obstacle analysis, the following three objectives are determined: (1) to measure the levels of the three major subsystems and the NUGD system separately; (2) to describe the dynamic temporal and spatial distributions and regional differences in NUGD; and (3) to reveal the main obstacle factors affecting NUGD. In addition, the examination of this system combines different geographical, economic and social aspects. This study not only provides more targeted policy insights for sustainable development in China but also offers a template for sustainable development in other countries around the world that are facing similar challenges.

Therefore, in this study, 282 cities in China were adopted to explore the triple synergistic effect. The possible contributions herein may be as follows: (1) Regarding the research perspective, against the background of achieving long-term and sustainable socioeconomic development, this study focused on the inherent integration mechanisms and patterns of new-type urbanization, green transformation and digitalization. (2) Regarding the research content, the synergistic development of the NUGD system in Chinese cities was measured first, after which the spatial agglomeration and distribution characteristics were determined via the ESDA. Furthermore, regional differences and sources were analyzed. Finally, the factors affecting the improvement in the triple synergy level at the criterion and indicator levels were determined. (3) In terms of policy significance, the conclusions of this study enrich the related research on new-type urbanization, green transformation and digital development, providing a useful reference for the promotion of the steady progress of social sustainable development, ecological civilization construction and healthy economic growth in China and other countries.

2. Materials and Methods

2.1. Analysis of the Synergistic Development Mechanism of the NUGD System

Placing new-type urbanization, green transformation and digitalization within the same research framework and systematically analyzing the dynamic interactions among these three subsystems is of strategic importance in achieving new advancements in social civilization, improving the eco-quality and accelerating economic growth [38,39]. The three components of the NUGD system are highly interrelated and consistent, with its core being human-oriented, adhering to the unique path of digitalization and intelligence, promoting urban and rural development to a high level and steadily progressing toward the achievement of common prosperity [39,40]. Therefore, elucidating the internal mechanisms of the triple synergy of the NUGD system (Figure 1) is important in promoting the simultaneous enhancement of its social, ecological and economic benefits.

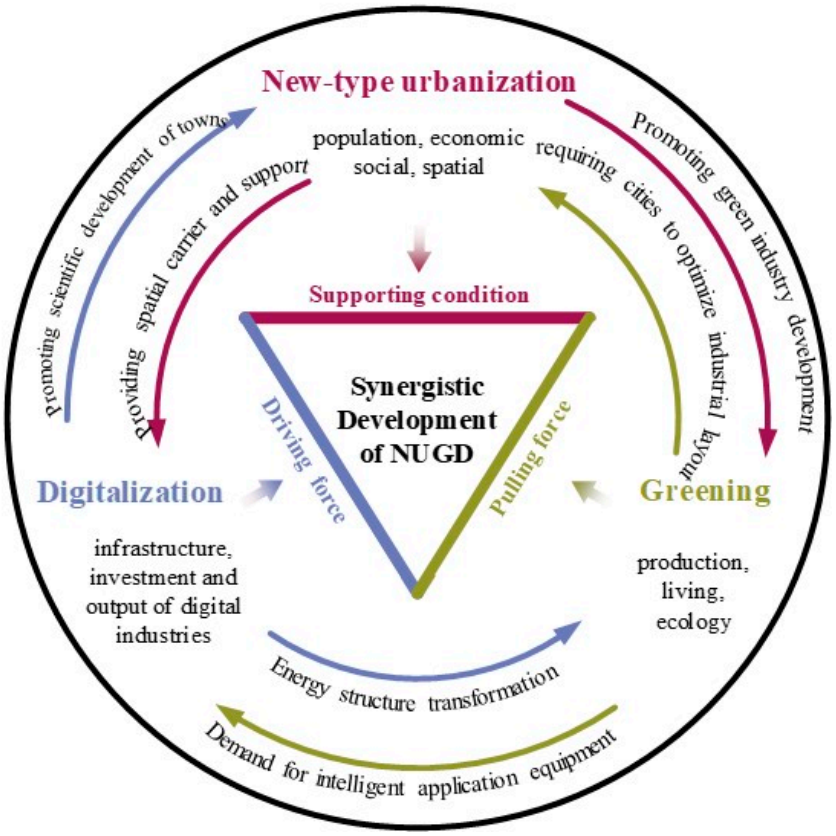


Figure 1. Synergistic development mechanism of the NUGD system.

Firstly, new-type urbanization serves as a supporting condition for the NUGD system. Chinese new-type urbanization is human-centered urbanization, comprehensively enhancing the quality of cities and optimizing the spatial layout [36]. Cities act as carriers and platforms for population aggregation, industrial transformation, information development and the provision of social services. Specifically, new-type urbanization provides a spatial carrier and application support for the digital economy. At the same time, new-type urbanization adheres to a development path characterized by intensity, intelligence, greenness and low carbon [41] and promotes environmentally friendly cities through the improvement of green infrastructure construction [42,43], the promotion of green industry development [40] and technological innovation [44].

Secondly, greening is the pulling force of the NUGD system. The Chinese government has stipulated that China should vigorously promote green development and foster a harmonious coexistence between humanity and nature. On one hand, although digitalization-assisted greening has great potential, the process of digital development itself is characterized by the notable issues of energy consumption and waste generation [45,46]. Greening imposes higher requirements and diverse demands on network transmission performance and intelligent application equipment. Thus, greening plays a leading role in driving digital transformation. On the other hand, as urbanization levels rise, negative issues such as environmental pollution and ecological damage are inevitable. Therefore, embedding the concept of green and low-carbon development into urban planning is particularly important. This is because green development can optimize the industrial layout and adjust the land use structure to continuously promote low-carbon development.

Thirdly, the development of digitalization is the driving force behind the NUGD system. Chinese national policy documents and government work reports emphasize the acceleration of digital development, seeking to exploit the full advantages of digital development, making it an important force for the continuous optimization and positive transformation of the Chinese economy and society [32,47]. On one hand, the digital

economy is a new economic concept in urbanization, becoming a new engine for promoting high-quality development, improving resource allocation efficiency and transforming development methods [48]. On the other hand, the White Paper on the Collaborative Development of Digitalization and Greening (2022) (http://www.caict.ac.cn/english/research/whitepapers/202303/P020230316598975246514.pdf (accessed on 20 June 2024)) points out that digitalization-empowered greening and greening-assisted digitalization are mutually supportive, and they are crucial for the long-term development of the economy. The development of digitalization is the primary means of promoting a green transition [27]. Specifically, digitalization provides full-chain support for green development, promoting new models of low-carbon production and leading new trends in green living.

In summary, new-type urbanization provides supporting conditions for greening and digitalization, with greening pulling digitalization and urban development toward agglomeration, greenness and high efficiency. Digitalization empowers greening and new-type urbanization. The organic integration of these three concepts can accelerate the realization of a more prosperous, democratic, harmonious and beautiful China.

2.2. Construction of an Indicator System

The NUGD system is a comprehensive system that consists of the triple synergy of new-type urbanization, greening and digitalization. Based on existing research findings, an evaluation index system consisting of these three subsystems was established to measure their synergistic effect (Table 1). Differing from the traditional type, new-type urbanization is a human-oriented one, which is a multidimensional process involving the population, economy, society and space [12,49]. Among these aspects, population urbanization is its core feature, reflecting the scale and density of the population; economic urbanization promotes the agglomeration of production factors toward cities, with economic prosperity and income growth as its key characteristics; social urbanization aims to promote the equalization of basic public services, enhancing people's happiness and satisfaction; and spatial urbanization reflects the urban spatial layout, land development and utilization and their impacts on population movement and economic growth. Green development focuses on improving resource utilization efficiency and alleviating environmental pressure during the production process, enhancing residents' awareness of green environmental protection in their daily lives, improving waste disposal efficiency and promoting the systematic coordination of society, ecology and economy by simultaneously focusing on regional ecological construction and environmental protection [23,50]. In the dimension of digitalization, considering existing findings [51,52], we focused on analyzing the following three aspects: digital infrastructure, investment in digital industries and the output of digital industries. The Internet and mobile phones have provided digital resources and modern information networks for the development of digitalization, which are basic conditions. Investment in digital industries is the key to digital development, and in this study, it was measured in terms of digital practitioners, scientific and technological expenditure and digital talent resources. The output of digital industries is a core aspect of digital development, and the per capita telecommunications output and per capita postal output were regarded as relevant indicators.

Table 1. Indicators for synergistic development of NUGD.

Subsystem	Dimension	Index	Property
The Development of New-type Urbanization	Population urbanization B_1	Ration of persons engaged in secondary and tertiary industries X_1	+
		Registered unemployment rate X_2	−
		Population density X_3	+
		Urbanization rate X_4	+

Table 1. *Cont.*

Subsystem	Dimension	Index	Property
The Development of New-type Urbanization	Economic urbanization B_2	Per capita disposable income of urban residents X_5	+
		Ration of output value of secondary and tertiary industries X_6	+
		Proportion of local budgetary revenue X_7	+
	Social urbanization B_3	Number of doctors per 10^3 persons X_8	+
		Amount of hospitals beds per 10^4 persons X_9	+
		Per capita expenditure on education X_{10}	+
		Number of books per 100 people in libraries X_{11}	+
		the proportion of college teachers X_{12}	+
	Spatial urbanization B_4	Per capita road area X_{13}	+
		Ration of urban construction land X_{14}	+
		Ration of built-up area X_{15}	+
The Development of Greening	Green Production B_5	Centralized treatment rate of wastewater X_{16}	+
		Industrial wastewater discharge per unit of GDP X_{17}	−
		Industrial SO2 emissions per unit of GDP X_{18}	−
	Green Living B_6	Harmless treatment rate of domestic garbage X_{19}	+
		Number of public transport vehicles per 10^4 population X_{20}	+
		Ratio of residential land area to green space area X_{21}	−
		Per capita daily domestic water consumption X_{22}	−
	Green Ecology B_7	Proportion of green space area X_{23}	+
		Per capita park green area X_{24}	+
		Green coverage rate in built-up area X_{25}	+
The Development of Digitalization	Digital Infrastructure B_8	Internet penetration rate X_{26}	+
		Mobile phone penetration rate X_{27}	+
		Fiber optic cable density X_{28}	+
		Per capita GDP X_{29}	+
		Digital Financial Inclusion Index X_{30}	+
	Investment in digital industries B_9	Proportion of employed personnel in computer services and software industry X_{31}	+
		Proportion of science and technology expenditure X_{32}	+
		Number of students in higher education X_{33}	+
	Output of digital industries B_{10}	Telecommunications services per capita X_{34}	+
		Per capita total post X_{35}	+

2.3. Methods

2.3.1. Entropy Weight Method

Due to its ability to effectively overcome the drawbacks of subjective weighting methods, the entropy weight method is commonly used to determine weights based on information entropy. Therefore, this method was applied to measure the development

levels of the three subsystems in this study. The detailed calculation process is shown below [2,16].

(1) Calculate the weight of indicator j:

$$W_j = \frac{d_j}{\sum_{j=1}^{n} d_j} = \frac{1 - e_j}{n - \sum_{j=1}^{n} e_j} \quad (1)$$

(2) Calculate the comprehensive index:

$$W_{ij} = \sum_{i=1}^{n} W_j \times y_{ij} \quad (2)$$

where y_{ij} is the standardized value of the indicator, d_j is the difference coefficient, W_j is the weight and W_{ij} is the comprehensive index.

2.3.2. Coupling Coordination Model

The extent of the interdependence and mutual restraint between multiple systems is reflected by the coupling level, while the degree of coordination indicates the beneficial coupling within the coupling relationships. The following process was applied to measure the NUGD system's synergistic development level [16,53]:

$$C = 3 \times \left[\frac{U_n U_g U_d}{(U_n + U_g + U_d)^3} \right]^{1/3} = 3 \times \frac{\sqrt[3]{U_n U_g U_d}}{U_n + U_g + U_d} \quad (3)$$

$$T = \alpha U_n + \beta U_g + \delta U_d \quad (4)$$

$$D = (C \times T)^{1/2} \quad (5)$$

where U_n, U_g and U_d denote the levels of new-type urbanization development, greening and digitalization, respectively, and α, β and δ denote the coefficients of the three subsystems. Considering the equal importance of the three subsystems to the overall system, we adopted $\alpha = \beta = \delta = 1/3$ [53,54]; moreover, C has a value ranging from 0 to 1, reflecting the degree of coupling among the NUGD subsystems. In addition, the higher the value is, the lower the degree of dispersion is, i.e., the higher the coupling degree indicates a more refined mechanism of interaction among the three subsystems. T is the comprehensive coordination level of the NUGD system, while D represents the degree of coupling coordination in the NUGD system's development. Moreover, a larger value denotes a greater degree of coordination in the NUGD system. In addition, referring to the studies of Zhang and Chen [55] and Zheng et al. [56], the following classifications were used (Table 2).

Table 2. Classification criteria for CCD.

CCD	Coordination Level	CCD	Coordination Level
[0, 0.1)	Extreme Disorder	[0.5, 0.6)	Barely Coordination
[0.1, 0.2)	Severe Disorder	[0.6, 0.7)	Primary Coordination
[0.2, 0.3)	Moderate Disorder	[0.7, 0.8)	Moderate Coordination
[0.3, 0.4)	Mild Disorder	[0.8, 0.9)	Good Coordination
[0.4, 0.5)	Near Disorder	[0.9, 1.0)	Excellent Coordination

2.3.3. Spatial Association Based on ESDA

To assess whether a region exhibits distinct spatial clustering, we employed the global Moran's I to evaluate the correlation of the collaborative development of the NUGD system

among Chinese cities across the entire geographical space. This can be expressed as follows [56]:

$$Moran's\ I = \frac{n}{\sum_i \sum_j W_{ij}} \cdot \frac{\sum_i \sum_j W_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_i (x_i - \overline{x})^2} \quad (6)$$

where the Moran's I range from -1 to 1, with positive (negative) values indicating positive (negative) spatial clustering characteristics. Moreover, its spatial distribution is random, with a value of 0.

The local Moran's I can be used to identify statistically significant spatial outliers. Therefore, the local Moran's I of Anselin (1995) [57] was applied herein to probe into the spatial clustering characteristics of the synergy effect of the NUGD system in Chinese cities. These were characterized using LISA and Moran scatter plots via the following equations:

$$I_i = \frac{x_i - \overline{X}}{S_i^2} \sum_{j=1, j*i}^{n} w_{ij}(x_j - \overline{X}) \quad (7)$$

$$S_i^2 = \frac{\sum_{j=1, j \neq i}^{n} (x_j - \overline{X})^2}{n - 1} \quad (8)$$

In the above equations, x_i is the observation value of indicator i, $\overline{X}$ denotes the average value of the corresponding observations and W_{ij} is the spatial weight between elements i and j.

2.3.4. Conditional Kernel Density Estimation

Being a nonparametric estimation method, kernel density estimation can be employed to fit the distribution function according to the characteristics of the data, thus avoiding any errors that may be caused by arbitrarily setting the form of the function. This can effectively address the issue of nonequilibrium. However, the traditional method can only describe the static characteristics of the synergistic effect of the NUGD system and cannot provide a systematic explanation for its dynamic characteristics. To address this issue, conditional kernel density estimation was introduced herein to depict and analyze the distribution features of the collaborative development of NUGD under spatial conditions. The calculation equations for kernel density estimation have been described by Li et al. [58] and Liu et al. [59].

$$f(x) = \frac{1}{Nh} \sum_{i=1}^{N} K\left(\frac{X_i - \overline{x}}{h}\right) \quad (9)$$

$$K(x) = \frac{1}{\sqrt{2\pi}} exp\left(-\frac{x^2}{2}\right) \quad (10)$$

where $f(x)$ represents the density function of the random variable x, $K(\cdot)$ is the Gaussian kernel function, N is the number of observations, X denotes the observed values, $\overline{x}$ denotes the mean of the observed values and h is the bandwidth, revealing the smoothness of the curve and the estimation accuracy. Moreover, a larger bandwidth results in a smoother curve but lower estimation accuracy, and vice versa.

2.3.5. Dagum Gini Coefficient and Its Decomposition

The dynamic variation in the absolute differences in the synergistic NUGD system among the Chinese cities can be described scientifically via kernel density estimation, but this method cannot reveal the trend in the changes in the relative difference. Therefore, it is necessary to rely on the Dagum Gini coefficient to achieve this objective.

In this study, this method was adopted to analyze the regional differences in the triple synergy of the NUGD system, and the differences were decomposed. Moreover, the research objects were divided into k groups, totaling n research objects, where a, b, ...

represent the different groups; n_a, n_b, ... indicate the number of research objects in each group; y_{ai}, y_{bj}, ... denote the variable data of any research object within the group that refers to the triple synergy of the NUGD system in the cities; μ is the average synergistic development level; and G denotes the overall Gini coefficient. In addition, the coefficient can be decomposed into the within-region difference contribution (G_w), the between-region contribution (G_{nb}) and the intensity of the transvariation (G_t), and the relationship between these three parts satisfies Equation (12). Generally, a smaller coefficient indicates that there is a closer coupling and coordination level among the cities, and the synergy is strong. The specific calculation process has been described in Dagum [60] and Ji et al. [61].

$$G = \frac{1}{2n^2\mu}\sum_{a=1}^{k}\sum_{b=1}^{k}\sum_{i=1}^{n_a}\sum_{j=1}^{n_b}\left|y_{ai} - y_{bj}\right| \tag{11}$$

$$G = G_w + G_{nb} + G_t \tag{12}$$

2.3.6. Obstacle Degree Model

The multidimensionality of the indicators measuring the collaborative development of the NUGD system determines the complexity of its state and future development. To clarify the obstacles to the synergy of the NUGD and to better understand the reasons for the differences in collaborative development among the different cities, the obstacle degree model was adopted to calculate and rank the target and various indicator layer factors. Then, we analyzed the impact of the various obstacles on the promotion of the collaborative development of the NUGD system in different prefecture-level cities. Finally, we provide helpful proposals to enhance the synergy of the NUGD system. The calculation equation has been introduced in Cheng et al. [62] and encompasses the following:

(1) Calculate the obstacle degree of indicator i in the indicator layer of coupling coordination:

$$O_i = \frac{I_i \times F_i}{\sum_{i=1}^{n} I_i \times F_i} \times 100\% \tag{13}$$

(2) Calculate the obstacle degree of coupling coordination for the criterion layer, denoted as U_j:

$$U_j = \sum o_{ij} \tag{14}$$

where F_i is the factor contribution degree and I_i is the indicator deviation degree.

2.4. Data Sources

Panel data for 282 Chinese cities from 2011 to 2021 were adopted in the study. To thoroughly analyze the internal mechanisms of the synergistic effect among new-type urbanization, greening and digitalization, methods such as the coupling coordination model and ESDA were employed to explore the spatiotemporal variations, agglomeration characteristics and regional differences in the NUGD system. Due to constraints in data integrity, the regions of Hong Kong, Macau and Taiwan, as well as cities with incomplete statistical data or adjusted administrative divisions, such as Bijie, Tongren, Sansha and Hami City, were excluded from this study. The data for the secondary indicators of new-type urbanization, greening and digitalization considered in the system mainly originated from the China City Statistical Yearbook, the China Urban-Rural Construction Statistical Yearbook and the statistical yearbooks of various provinces (cities), while the digital financial inclusion index was obtained from the Digital Finance Research Center of Peking University. In addition, the moving average method was applied to fill in any missing data.

3. Results

3.1. Comprehensive Development Level of NUGD in China

Figure 2 shows the average comprehensive index of the NUGD system and the three subsystems. Overall, the levels of these three subsystems and the corresponding comprehensive level showed relatively consistent upward trends, but the overall level was not high. The comprehensive index steadily increased from 0.109 in 2011 to 0.131 in 2021. Moreover, digital development significantly lagged behind the other two. As for each subsystem, there was a slight decline in digital development from 2011 to 2014; it rebounded in 2015 and then reached its lowest in 2016. Thereafter, it gradually increased until 2021, with the whole showing an upward characteristic. The reason behind this phenomenon may be that the policies and infrastructure related to digital development were not yet of a high standard in the early stages, so they were severely hindered. The new-type urbanization subsystem steadily improved during the sample period, with a particularly notable increase after 2015. The level of the green subsystem was significantly greater than that of the other two subsystems, indicating a gradual upward trend with an increase of 0.042. This occurred because, as ecological and environmental issues become increasingly prominent, green development has been one of China's leading strategies due to its ability to alleviate the conflicts that arise during the process of rapid economic growth and the construction of an ecological civilization.

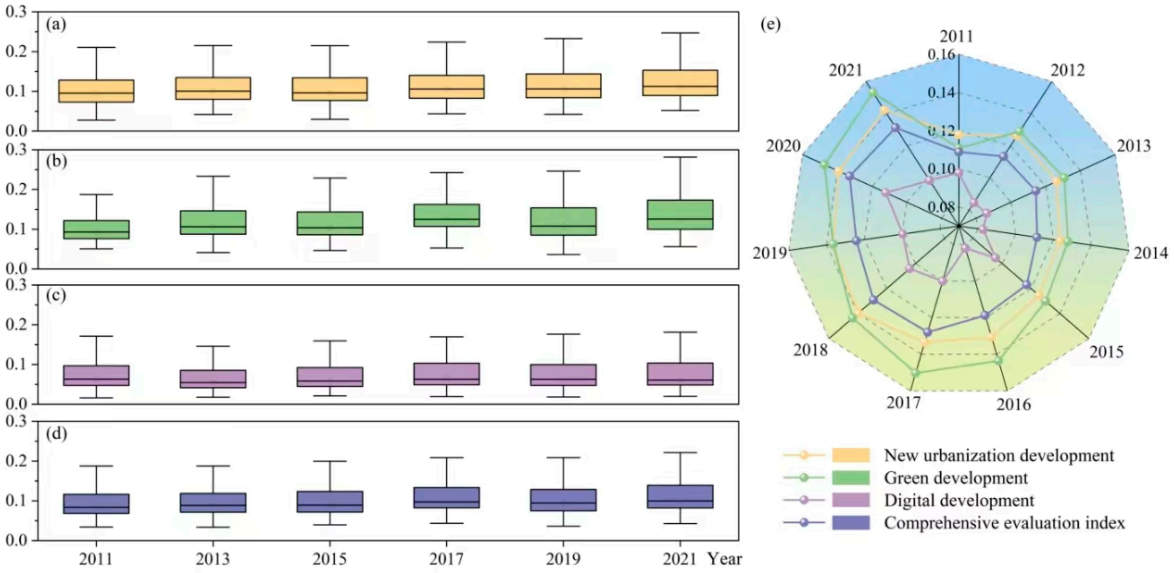


Figure 2. Development of the NUGD subsystems in Chinese cities from 2011 to 2021. (**a**) New urbanization development. (**b**) Green development. (**c**) Digital development. (**d**) Comprehensive evaluation index. (**e**) Development of the three subsystems and NUGD.

3.2. Synergistic Development of NUGD System and Its Spatial Autocorrelation

To accurately determine the temporal variation in the triple synergy of the NUGD system in Chinese cities, the cities under examination were divided into the eastern, central and western regions (Table 3). There was an increase from 0.312 to 0.340 in the average synergy of the NUGD system nationwide, indicating that the synergy of the NUGD system in Chinese cities was continuously strengthened and exhibited steady progress. The average synergistic level of the NUGD system in the three major regions followed the same growth trend as the national average, but there were obvious regional differences between the east and west. In addition, the average synergistic development of the NUGD system in the east was greater than that observed nationwide. The average synergy of the NUGD system in the central and western regions has significantly improved since 2011, with a continuous and steady ascent. Regarding its evolution, the differences between the western and central regions gradually decreased, but there was a gradual acceleration between the

eastern and western regions and between the eastern and central regions. This means that the current differences between these two could explain the imbalance at the national level of the NUGD system.

Table 3. Average synergistic level of NUGD nationwide and in three major areas from 2011 to 2021.

Year	Overall	East	Central	West
2011	0.312	0.349	0.295	0.288
2012	0.317	0.353	0.298	0.294
2013	0.318	0.355	0.300	0.294
2014	0.312	0.351	0.293	0.289
2015	0.321	0.363	0.300	0.296
2016	0.320	0.362	0.299	0.296
2017	0.337	0.378	0.316	0.312
2018	0.338	0.381	0.316	0.314
2019	0.331	0.373	0.308	0.307
2020	0.345	0.380	0.325	0.325
2021	0.340	0.380	0.317	0.320

The distribution of the synergistic level in space among the Chinese cities in 2011, 2016 and 2021 is exhibited in Figure 3. There was a stepped distribution pattern from east to west for the NUGD system as a whole. Primary coordination and above were mainly distributed in the east, while synergistic levels were mostly at the moderate and mild disorder levels in the other two regions. This finding indicates that the current synergistic effect of the NUGD system in China is still low, and progress toward a higher coordinated development level is constrained by various factors. Specifically, there were a few cities at the good and moderate coordination levels, and the primary coordination and above occurred mainly in eastern urban clusters and in regions such as the Yangtze River Delta and Pearl River Delta, showing significant spatial agglomeration characteristics. Moreover, the moderate and mild disorder levels were distributed in a continuous urban pattern in the central and western parts, while the borderline disorder and barely coordinated levels were scattered in cities such as Taiyuan, Dalian, Hefei, Zhengzhou and Chongqing. In terms of evolutionary trends, compared to 2011, the number of cities moving from moderate disorder to mild disorder increased in 2021, with a decrease in the fragmented distribution. Moreover, the changes were mainly concentrated in provinces such as Jiangxi, Shaanxi and Gansu, with particularly notable changes in Jiangxi, which may have been due to the radiation-driving effects of the surrounding urban clusters. Additionally, the coordinated development level in various urban clusters remained high, but the only city with good coordination was Shenzhen, showing that the improvement in the coordination level in the cities may have entered a bottleneck period and that local governments must seek a breakthrough and re-evaluate the coordinated development system and mechanism to meet the new requirements proposed and enable coordinated development to enter a new stage.

Moreover, the global Moran's *I* was obtained using Stata16, after which the local Moran's *I* was obtained to produce a LISA cluster map to reveal the agglomeration characteristics. As indicated by the results exhibited in Figure 4, the synergistic level of the NUGD system from 2011 to 2021 exhibited significant spatial autocorrelation, with values greater than 0. However, the correlation decreased from 2011 to 2013, gradually increased until 2015 and reached its highest in 2015. Then, from 2015 to 2021, the correlation again decreased. Overall, the global Moran's *I* of the synergistic level of the NUGD system in Chinese cities slightly decreased, from 0.196 in 2011 to 0.194 in 2021, with an inconspicuous decline, indicating a relatively stable overall spatial agglomeration level.

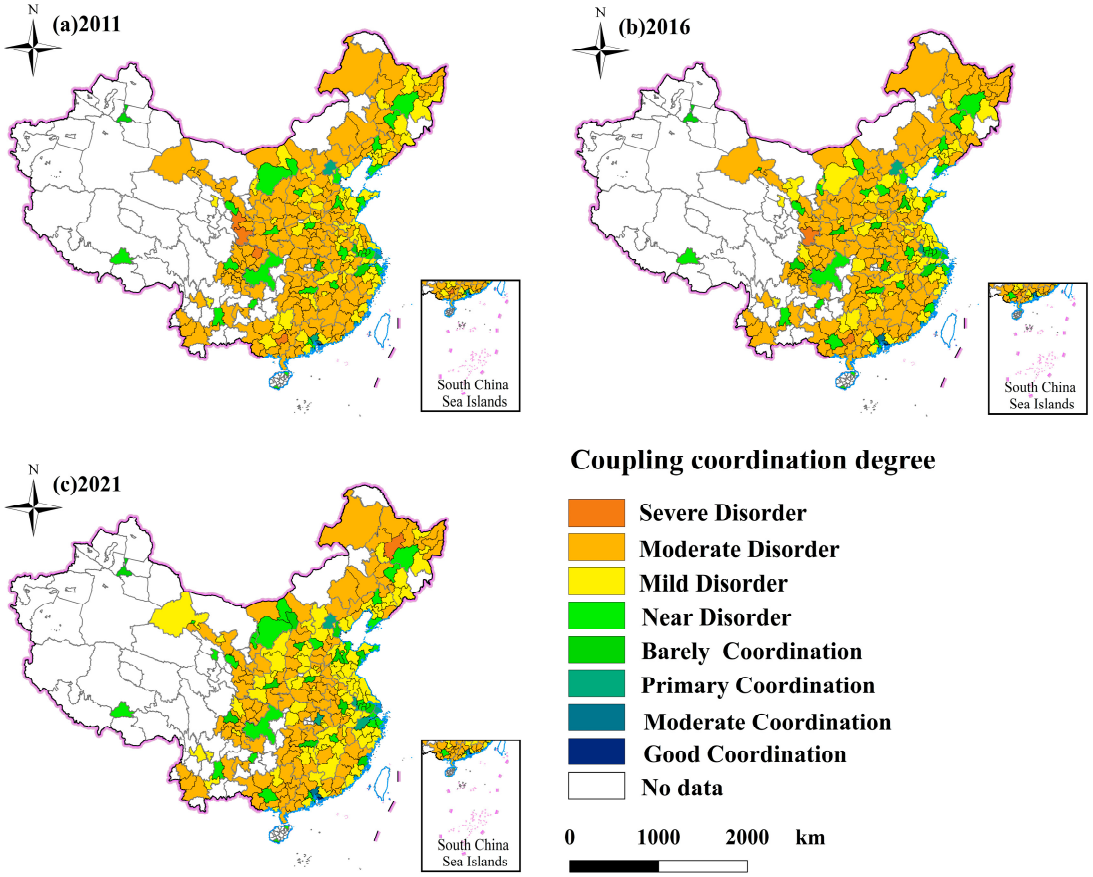


Figure 3. Spatial distribution of synergistic development in 2011, 2016 and 2021. (**a**) 2011. (**b**) 2016. (**c**) 2021.

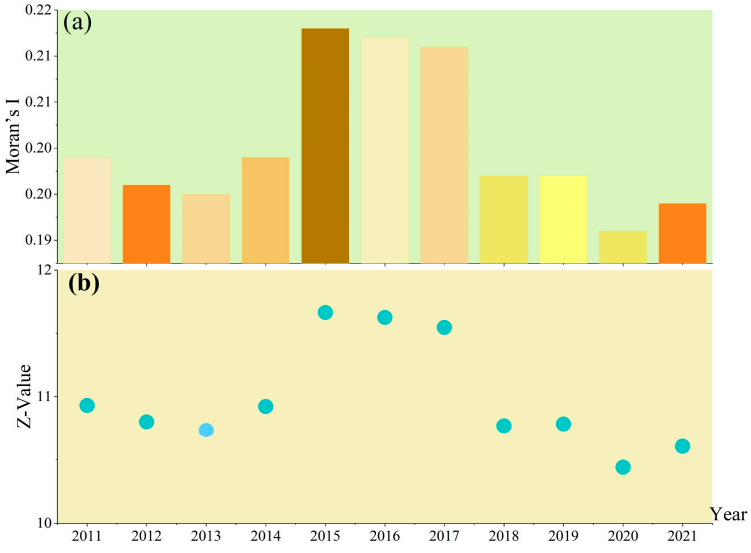


Figure 4. Global spatial distribution of the NUGD system from 2011 to 2021. (**a**) Moran's *I*. (**b**) Z-Value.

Subsequently, the local Moran's *I* was calculated, and ArcGIS 10.8 and Stata16 were applied to create LISA maps and Moran scatter plots, respectively. The agglomeration patterns of the NUGD system in Chinese cities in 2011, 2016 and 2021 are shown below (Figure 5). Overall, the spatial agglomeration pattern of the synergistic level of the NUGD system in Chinese cities from 2011 to 2021 remained relatively stable, with high–high and low–low as the main types. Specifically, the high–high-type cities were mainly located in

the eastern coastal regions, in Shanxi and Jiangxi in the central part and in Inner Mongolia in the western provinces. Furthermore, compared to 2011, there was a growing number of cities reaching a high–low state in 2021, and these cities were mainly located in the west, such as Yunnan, Gansu and Xinjiang. The number and distribution of low–high cities remained relatively stable, and these cities mainly occurred in eastern provinces such as Hebei, Fujian and Shanxi in the central region. The low–low cities were distributed in Yunnan in both 2011 and 2016, but, in 2021, they evolved into high–low areas, with the low–low areas primarily located in Guangxi.

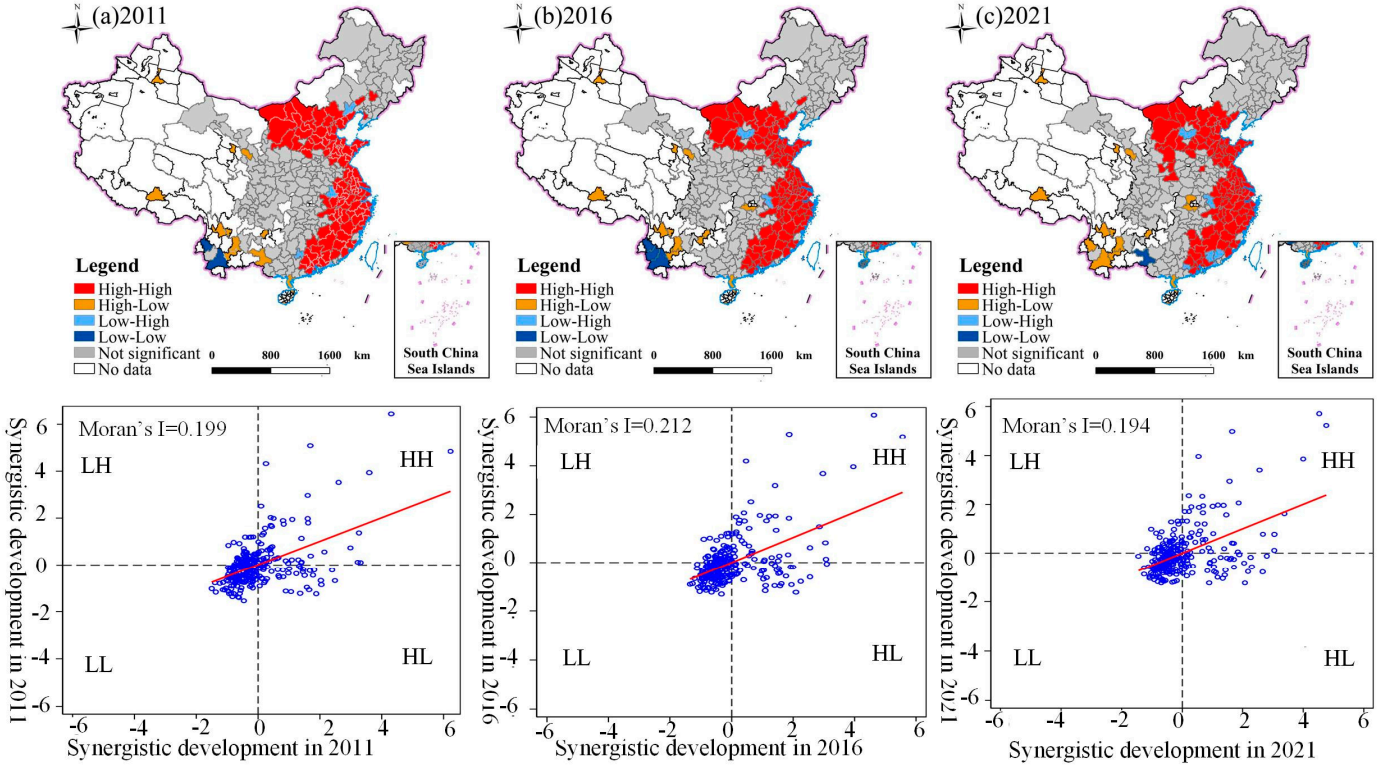


Figure 5. LISA maps and Moran scatter plots for 2011, 2016 and 2021. (**a**) 2011. (**b**) 2016. (**c**) 2021. ***Notes:*** The blue circles represent the individual cities, and the red line represents a linear fit to the scatter.

3.3. Regional Differences in the Synergistic Development of NUGD

3.3.1. Intraregional Differences in the NUGD System

Figure 6a shows that, at the overall level, the intraregional differences were relatively small, showing a W-shaped pattern between 2011 and 2019. Specifically, the national intraregional difference decreased from 2011 to 2012, rebounded and continued to increase until 2015, exhibited a downward trend from 2015 to 2017 and then continued to increase until 2019, reaching the highest of 0.150 during the sample period, after which it slightly decreased. However, the overall national intraregional difference increased during the study period, indicating that there was an increasing trend in the regional imbalance of the NUGD system across China.

Considering the regional differences within each area, synergistic development exhibited the largest differences in the east, followed by the western and central regions. There was fluctuating growth in the eastern and western areas, with trends that could be characterized by inverted W and W shapes, respectively, while the differences within the central region decreased overall over time. In detail, Figure 6a shows that the eastern region experienced a gradual upward trend from 2011 to 2016, a declining trend until 2017, a continued increasing trend until 2019 and a slight decreasing trend thereafter, with an average annual growth rate of 0.42%, which indicates that the regional differences

in the east were further expanding. This may be attributed to the high-level economic development effects brought about by the three major urban clusters located in the east, which started the synergistic development of the NUGD system, with continuous and high momentum and a steady improvement in the synergistic process. However, cities in the east, outside the three major urban clusters, are currently attempting to keep pace, but the synergistic level continues to slowly increase, thus widening the gap further.

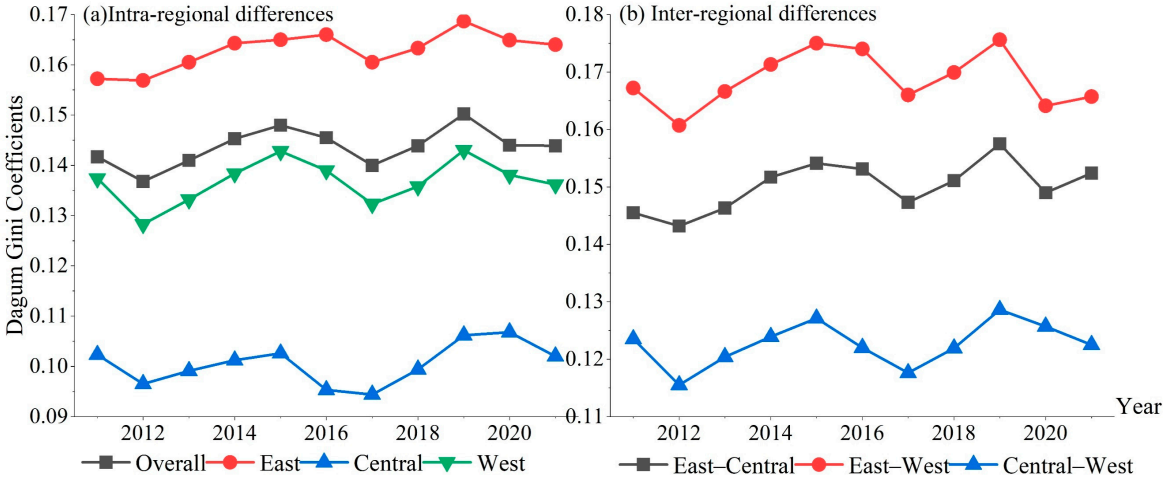


Figure 6. (**a**) Intraregional and (**b**) interregional differences in NUGD system development.

The development trend in the west was consistent with the national synergistic development trend in the NUGD system between 2011 and 2019, with both showing W-shaped patterns. However, there was a significant decline in the western region from 2019 to 2021. The evolutionary trend in the intraregional differences within the central region was similar to that in the west, with regional differences much smaller than those in the western area.

The above reveals that there was an increasing trend in the intraregional differences within the eastern region and the country, while the central and western regions exhibited further decreasing differences. This may have been due to the more extensive implementation of supportive strategies in the western region of China and the rise of Central China, as well as the growing emphasis on the coordinated development of various aspects of the criteria for the evaluation of political performance.

3.3.2. Interregional Differences in the NUGD System

Figure 6b shows that the dynamic evolution trends in the interregional differences could be characterized by a W shape, and all of these trends reached their maximum values within the sample observation window of 2019. Specifically, the interregional differences between the eastern and central regions, as well as between the eastern and western regions, decreased from 2011 to 2012; they then maintained an upward trend until 2015, decreased to 2017 and rebounded in 2019. From 2019 to 2020, the trends again decreased and then increased from 2020 to 2021. However, the differences between the eastern and central regions increased at an average growth rate of 0.464%, while those between the eastern and western regions gradually decreased. However, regarding the numerical values, the difference between the eastern and western regions remained larger than that in the other two, indicating that the national synergistic level of the NUGD system exhibited stepped imbalanced distribution characteristics from east to west. This also indicates that the focus of work to coordinate regional development remained on narrowing the regional gap between the east and west. Throughout the entire examination, the regional imbalance between the central and western parts consistently remained low. Differing from the fluctuations in the eastern–western and eastern–central regional differences from 2019 to 2021, the central–western regional differences showed a downward trend after reaching

a peak in 2019, further verifying the policy dividends of the supportive strategy for the western and central areas in China.

3.3.3. Sources and Contribution Rates of Regional Differences

From 2011 to 2021, the contribution rates of the intensity of the transvariation and interregional differences were more volatile than those of the intraregional ones (Table 4). The intensity of the transvariation consistently exceeded that of the interregional and intraregional differences, with average annual values for the intraregional, interregional and transvariation contribution rates of 31.71%, 30.59% and 37.70%, respectively. This indicates that the regional differences in the synergistic NUGD system were mainly caused by the intensity of transvariation. Specifically, the contribution rate of intraregional differences steadily declined until 2016; it then rebounded to 2019, decreased from 2019 to 2020 and subsequently increased again, with the rate slightly increasing. The rate of interregional differences showed a decreasing trend year by year, with an average annual decline rate of 0.69%. The fluctuations during the study period were as follows: a significant decline from 2011 to 2013, a rebound toward 2015, a decrease from 2015 to 2016, a rise from 2016 to 2017 and a continuous decline to 2020, with the minimum value reached during the sample window period. The level finally rebounded from 2020 to 2021. Moreover, the rate of transvariation generally changed in the opposite manner to that of the interregional differences and increased from 36.77% in 2011 to 38.76% in 2021.

Table 4. Sources and contribution rates in the synergistic development of the NUGD system.

Year	Intraregional (G_w)		Interregional (G_{nb})		Intensity of Transvariation (G_t)	
	Contribution Value	Contribution Rate (%)	Contribution Value	Contribution Rate (%)	Contribution Value	Contribution Rate (%)
2011	0.045	31.75	0.045	31.48	0.052	36.77
2012	0.044	31.83	0.042	30.99	0.051	37.18
2013	0.045	31.74	0.044	30.83	0.053	37.43
2014	0.046	31.64	0.045	31.16	0.054	37.20
2015	0.047	31.51	0.047	31.85	0.054	36.64
2016	0.046	31.36	0.047	32.29	0.053	36.35
2017	0.044	31.53	0.044	31.63	0.052	36.84
2018	0.045	31.56	0.045	31.25	0.054	37.19
2019	0.048	31.67	0.046	30.41	0.057	37.92
2020	0.047	32.34	0.036	25.26	0.061	42.40
2021	0.046	31.84	0.042	29.40	0.056	38.76

3.4. Identification of Obstacles to Synergy in the NUGD System

Figure 7 presents the average obstacle levels from the criterion and indicator layers for the synergy of the NUGD system in Chinese cities from 2011 to 2021, reflecting the top five obstacles and seven factors influencing synergistic development, respectively. Figure 7a shows that the top five obstacles from 2011 to 2021 were social urbanization (B_3), spatial urbanization (B_4), digital infrastructure (B_8), the digital industry input (B_9) and the digital industry output (B_{10}). Specifically, in 2011, B_3 ranked first, indicating that social urbanization played a restrictive role in the synergy of the NUGD at that time. With the exception of 2011 and 2013, B_4 was always ranked first, indicating that spatial urbanization remained the most important obstacle. B_9 and B_{10} consistently ranked at the lowest two positions from 2011 to 2020, indicating that, during this period, the impacts of the digital industry input and digital industry output on the synergistic development of the NUGD system in the cities were relatively small. However, in 2021, B_9 and B_{10} were the fourth and fifth obstacle factors, respectively, and their obstacle degrees increased, indicating that the obstacle roles of these two factors were enhanced at this time.

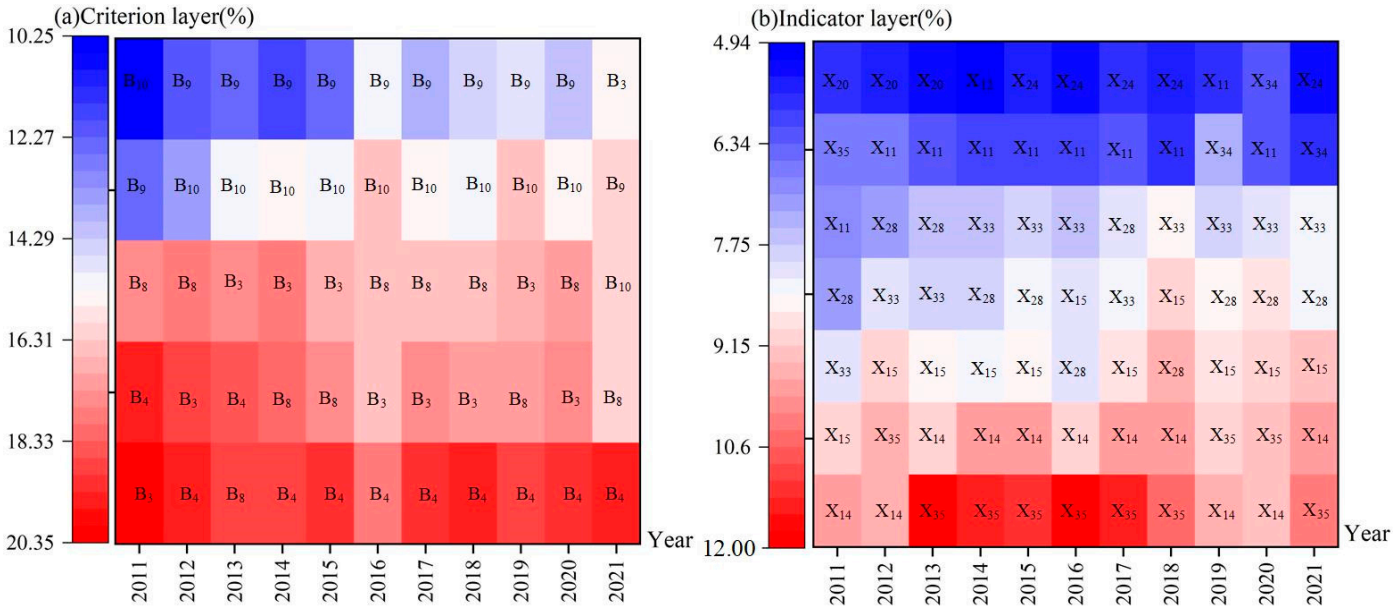


Figure 7. Comparison of the average obstacle degrees of the elements in the criterion (**a**) and indicator layers (**b**) from 2011 to 2021 (%).

The identification of the factors affecting the synergy of the NUGD system based on the criterion layer alone cannot reveal the individual differences between the subindicators. To address this issue, we further calculated the obstacle degree of the indicator layer for synergistic development in Chinese cities from 2011 to 2021 and ranked the main obstacle factors. Figure 7b reflects the top seven main factors in the indicator layer of the synergy of the NUGD system in Chinese cities from 2011 to 2021.

Figure 7b reveals that there were ten factors among the top seven rankings in the indicator layer. First, in the social urbanization dimension, the number of books per 100 people in libraries (X_{11}) and the proportion of college teachers (X_{12}) were major obstacle factors. In terms of their rankings, they were ranked at the bottom and dropped out of the top seven in 2021. Regarding spatial urbanization, the proportion of urban construction land and built-up areas (X_{14} and X_{15}) were major barrier factors. X_{14} ranked first in 2011 and 2012, stabilized at second place from 2013 to 2018, returned to first place in 2019 and 2020 and moved to second place in 2021. The corresponding obstacle level also exhibited fluctuating decline–rise characteristics, identifying X_{14} as a key factor constraining the synergistic development of the NUGD system in Chinese cities. As for X_{15}, its barrier level occurred at an intermediate level, while the magnitude also showed decline–rise characteristics. In the dimension of green living, the number of public transportation vehicles per 10^4 people (X_{20}) was a major obstacle factor from 2011 to 2013, and its obstacle level continuously declined, dropping out of the top seven in the following years, indicating significant progress in urban transportation infrastructure and the transformation toward green and environmental protection. Fourth, considering green ecology, the per capita green park area (X_{24}) was a major obstacle. In terms of its ranking, it ranked seventh from 2015 to 2018 and in 2021, and its obstacle level showed decline–rise evolutionary characteristics. Fifth, in the digital infrastructure dimension, the fiber optic cable density (X_{28}) was a major obstacle factor. In terms of its ranking, the role of X_{28} in constraining the synergistic development of the NUGD system in cities remained at an intermediate level, thereby ranking fourth in most years, ranking fifth in a few years and ranking third in 2015, 2016 and 2018, with the obstacle level further improving. As for the investment in digital industries, the number of higher education students (X_{33}) was a major factor constraining synergistic development in the cities. In terms of its ranking, X_{33} ranked third in 2011, dropped to fourth in 2012 and 2013 and then stabilized at the fifth position, indicating a relatively reduced impact on the synergy of the NUGD system in the cities.

Regarding its numerical value, the obstacle level of X_{33} exhibited fluctuating decline–rise features. The seventh dimension was the output of the digital industry, with the per capita telecommunications business volume (X_{34}) as the main obstacle factor, while the per capita postal business volume (X_{35}) once again became the largest obstacle factor. X_{34} ranked sixth and seventh in 2019 and 2020, respectively, and its obstacle level showed a declining trend, indicating that the internet output of Chinese cities has increased, and that digital development has achieved certain results. Regarding X_{35}, with the exception of 2011, it always occurred within the top two positions, and the obstacle level always remained above 9%.

4. Discussion

4.1. Spatial Disparities in Coupling Coordinated Development across China's Regions

The collaborative development of the NUGD system is vital for Chinese efforts to drive environmentally sound and socially inclusive urbanization practices [63]. By explaining the interaction mechanisms of the three subsystems and referring to existing research, a multielement, multidimensional evaluation indicator was established to uncover the triple synergy of the NUGD system. Moreover, the methods and models used in this study are sound and widely applied in research exploring the coupled coordination between urban ecology and the economy [55,63]. The results reveal that there was continuous improvement and notable agglomeration characteristics in the collaborative development of the NUGD system in China, but the existing regional imbalance was significant. Consistent with the conclusions of most studies on coupling coordination [64], the eastern regions, which benefit from talent resources, policy initiatives and so on, exhibit a greater level of synergy than the other two parts of China. For example, Han et al. (2023) [54] placed the digital economy, technological innovation and ecological environment within the same research framework to examine their temporal and spatial heterogeneity. They found that their coupled coordination level presented the characteristic of "eastern > western" in terms of space. Meanwhile, Ma et al. (2024) [65] considered the coupling coordination level of urbanization and the carbon emission efficiency from a global perspective and systematically analyzed it from three dimensions—the country, developed countries and developing countries—as well as regions, which revealed significant differences in coupling coordination. This is an interesting study that is beneficial for the sustainable development of both individual countries and global cities. Therefore, it is essential to further implement supportive strategies to promote the narrowing of the development gaps between and within regions and countries, ultimately achieving the sustainability of global development.

The analysis of the spatial patterns revealed the static distribution of collaborative development in Chinese cities in multiple dimensions. However, it could not identify the changing features of the triple synergy level in Chinese cities from a dynamic perspective. Therefore, referring to relevant research [59,66], kernel density estimation, including unconditional, spatial static and spatial dynamic kernel density estimation, considering a one-year density, was introduced herein to uncover the distribution dynamics of the synergy of Chinese cities (Figure 8). The unconditional kernel density estimates (Figure 8a) of the probability of the synergistic level of the NUGD system in Chinese cities were distributed along the positive 45° line, which means that, from t to $t + 1$, the synergistic level in Chinese cities has remained relatively stable. However, under static kernel density estimation (Figure 8b), synergistic development revealed significant stage differences in its evolutionary characteristics, showing a fault phenomenon with a boundary at $x = 0.5$. Compared to the spatial static kernel density, the distribution of the dynamic kernel density probability results (Figure 8c) was similar but slightly different, indicating that time indeed impacts the interactions among the different cities regarding synergistic development in China. In conclusion, multidimensional discussions on the spatial disparities in the coordinated development of Chinese urban areas can enrich the related research on new-type urbanization and green and digital development. It also provides new research approaches for cities to reduce regional differences and achieve sustainable and high-quality development.

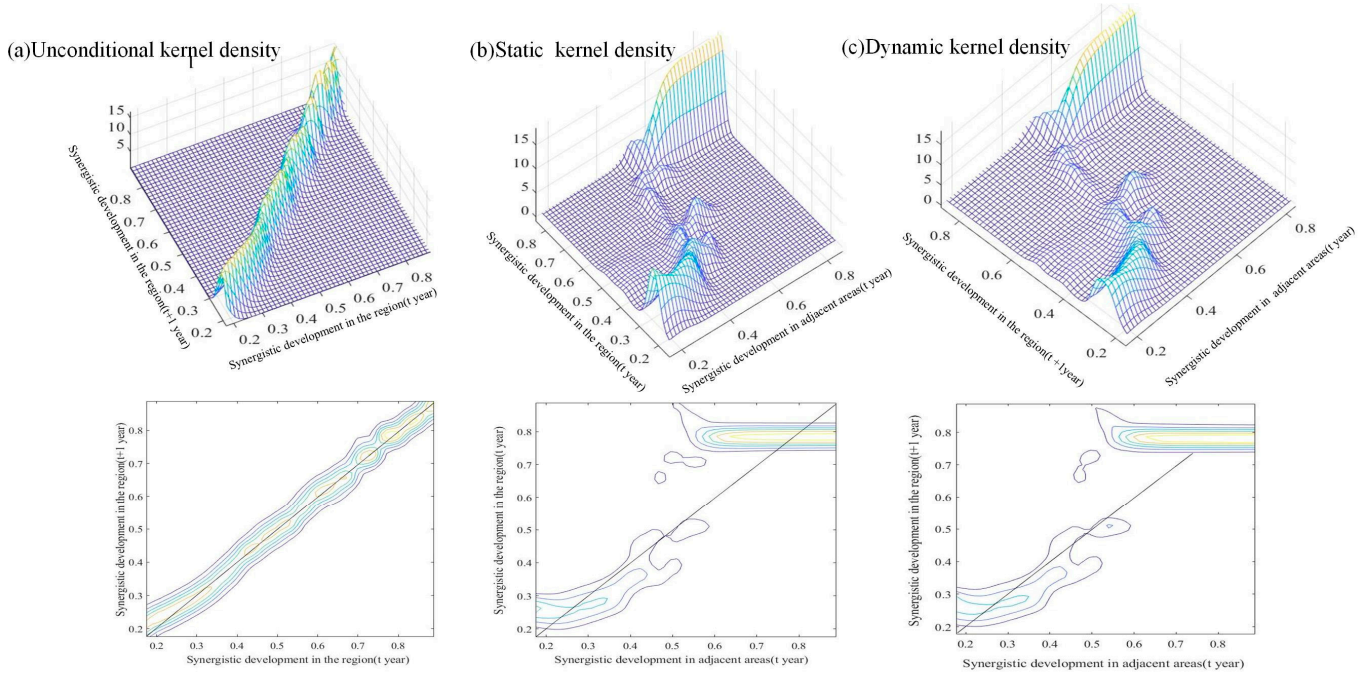


Figure 8. Conditional kernel density and corresponding contour map of NUGD. (**a**) Unconditional kernel density. (**b**) Static kernel density. (**c**) Dynamic kernel density.

Notes: In the kernel density plot, the *X*- and *Y*-axes indicate collaborative development, while the *Z*-axis represents the density (probability) of each point on the *X*–*Y* plane. In the kernel density contour plot, the *X*- and *Y*-axes are the same as those in the kernel density plot. The closer the contour lines are to the center, the greater the value, the denser the contour lines and the greater the change in density, with a convergence trend becoming more evident.

4.2. Major Constraints to the Development of the NUGD System

As previously indicated, regarding the criterion-level factors, the constraint of spatial urbanization (B_4) was the most prominent. Spatial urbanization requires a diversified layout and a coordinated structure, and it can accommodate more of the urban population, promoting urban transportation, culture, entertainment and other municipal and infrastructure construction functions. However, there are still some problems in the process of new-type urbanization, such as the disorderly expansion of urban land and the imbalanced development of the spatial distribution [67]. Moreover, the ratio of urban construction land's occupation to its utilization efficiency has been shown to be negative, further exacerbating the severe situation of urban resource constraints, increased pollution and decreased urban ecological resilience, thus constraining the comprehensive improvement of the synergy of the NUGD system in cities [68]. Moreover, as the city expands and the population increases, the pressure of constructing and maintaining urban infrastructure also grows. In some cases, the pace of urban digital infrastructure development may not reflect the speed of urban expansion, thus affecting the progress of digitalization. Therefore, at present, it is crucial to accelerate the optimization of the spatial layout and structure, improve the efficiency of spatial allocation and consistently implement major regional collaborative development strategies to adapt to the spatial needs for the high-level development of the NUGD system.

In regard to the constraints at the index layer, the proportion of urban construction land (X_{14}) and per capita postal business volume (X_{35}) were major constraints. Due to the Chinese reform and opening-up process, the urban land area has expanded significantly, leading to an increase in the urban heat island effect and global warming, degrading natural landscapes and changing land use patterns [68–70], which in turn has hindered further

improvements in the synergy of the NUGD system in cities. The per capita postal business volume (X_{35}) once became the largest obstacle factor. The reasons for this may be as follows: due to the increasingly prevalent e-commerce, the per capita volume of postal services has increased, while the demand for personnel for logistics services has also increased, failure to optimize logistics and transportation modes may lead to wasted resources and increased CO2 emissions in the logistics process [71]. Moreover, the resource utilization of the existing logistics industry is becoming saturated. Therefore, in addition to providing traditional infrastructure support and hardware and software resources, it is necessary to invest large amounts of funds in new infrastructure construction to promote the digital transformation, expand the logistics resources and optimize resource allocation to finally enhance the supply chain's resilience for the high-level synergy of the NUGD [72,73].

4.3. Limitations and Prospects

In this study of the coupling coordination level of new-type urbanization, greening and digitalization, we have thoroughly demonstrated why and how these three subsystems exhibit synergy. We employed various methods and presented their spatiotemporal differentiation and regional differences in a visual graph format. Finally, we used the obstacle degree model to reveal the main factors affecting the development of this system at the criterion and indicator levels. This is of great significance in enabling China to achieve new progress in economic development, social welfare and the construction of an ecological civilization. In summary, it is essential for the sustainable development of cities. However, the limitations specified below exist.

Firstly, due to the limited knowledge of the levels of urbanization, greening and digitalization in other countries around the world, as well as difficulties in obtaining relevant data, this study mainly took China as an example, which is a shortcoming in the scope of this research. However, we sincerely hope that the research can serve as a reference for other countries and regions facing the adverse impacts of rapid urbanization and eager to achieve sustainable urban development through green transformation and digital empowerment. Secondly, compared to previous studies, our focus was on the interrelationship between new-type urbanization, greening and digitalization. This study did not explore the possible causal relationships among these three areas. Furthermore, our research was not extended to other fields—for example, whether urbanization has increased the mortality rate of birds; whether it has caused changes in reptile communities; and why these phenomena occur. These are all highly interesting research topics that are of great significance to the sustainable development of cities. In the future, we will examine urbanization, green development and digital transformation from a global perspective, extend our research to other fields, further explore these three areas and compare the situation in other countries with that in China in order to draw more universal conclusions.

5. Conclusions and Policy Implications

Based on the realistic goals of improving economic development efficiency, coordinating rural revitalization, promoting green development and fostering harmony between humans and nature, data from 2011 to 2021 for 282 cities in China were adopted herein as a research sample to scientifically uncover the triple synergy effect of the NUGD system in Chinese cities. The basic conclusions of this study are listed below.

First, regarding the comprehensive level of the NUGD system in Chinese cities, the levels of new-type urbanization and green and comprehensive development showed consistent upward trends, while that of digitalization lagged significantly behind that of the other two subsystems, with moderate overall development levels.

Second, regarding the triple synergy effect of the NUGD system in Chinese cities, over time, there has been an upward trend both at the national and regional level, but the overall development quality is not high. In terms of spatial patterns, significant spatial differentiation was observed, with high values in the east and low values in the west. Specifically, cities with primary and higher levels of coordinated development were located

in regions and cities with high development levels, while many central and western cities exhibited a moderate disorder level. Considering spatial agglomeration, the agglomeration level throughout the whole NUGD system remained relatively stable, mainly characterized by the "high–high" and "low–low" types.

Third, regarding regional differences, there were increasing trends at the national and the eastern level, while those in the other two parts were narrowing further. Moreover, the difference between the eastern and western regions was always larger than that between the eastern and central regions and that between the central and western regions, highlighting the need to accelerate their coordinated regional development. Notably, the regional differences in the synergistic development of the NUGD system were mainly caused by the intensity of the transvariation.

Fourth, the obstacle factor analysis revealed that social urbanization (B_3), spatial urbanization (B_4), digital infrastructure (B_8), the digital industry input (B_9) and the digital industry output (B_{10}) were the main obstacle factors at the criterion level, while the proportion of urban construction land and built-up areas (X_{14} and X_{15}) and the per capita postal business volume (X_{35}) were the main obstacle factors at the indicator level.

Policy Implications

For the improvement of the synergy effect of the NUGD system in China, and in order to achieve steady and balanced progress, the following four policy recommendations can be formulated (Figure 9).

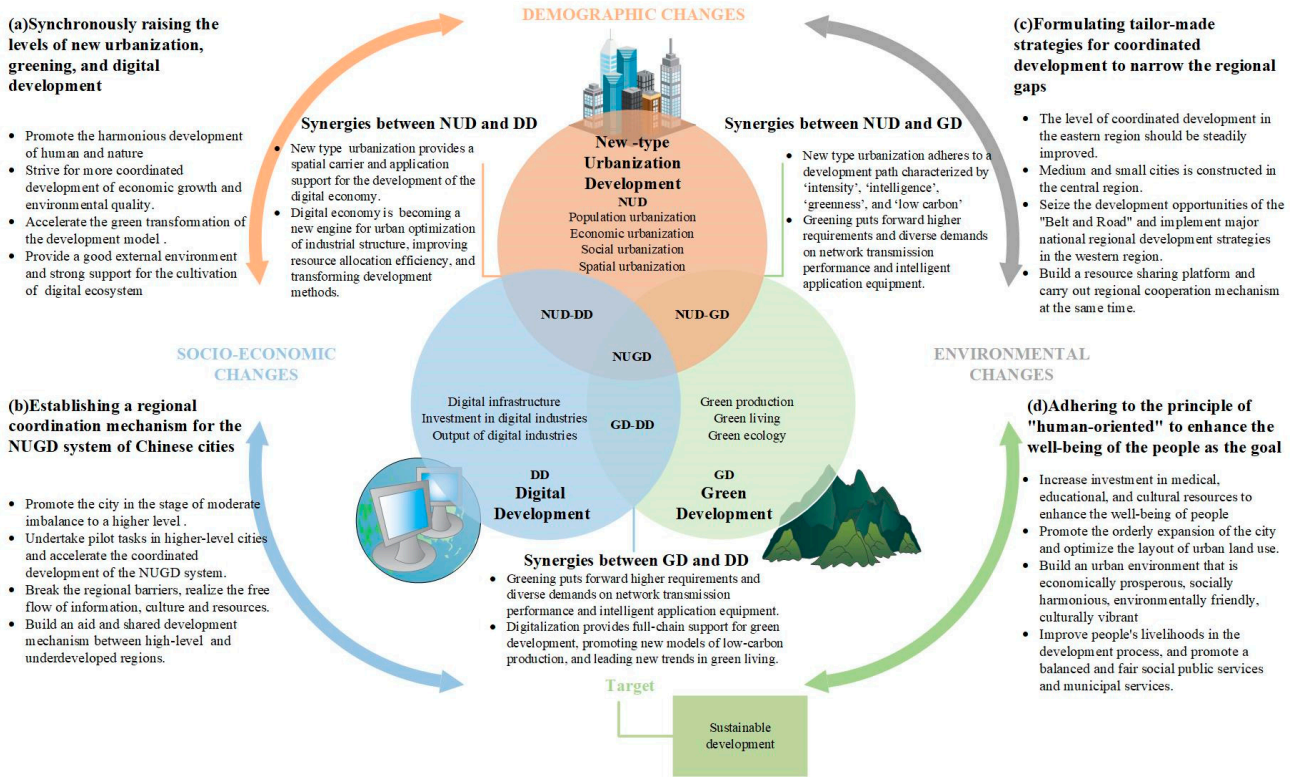


Figure 9. Policy recommendations.

First, efforts should be focused on the synchronous promotion of new-type urbanization, greening and digital development in Chinese cities in order to improve their overall levels and the quality of the synergy and ultimately realize the goals of substantial and sustainable development (Figure 9a). Guided by the five major development concepts, local governments should focus on adhering to urbanization with a human-centered approach, ensuring strong progress in economic growth and eco-quality. Meanwhile, governments should provide strong support to accelerate the green transformation of development

patterns, promoting the formation of environmentally friendly production methods and lifestyles. In addition, they must continuously strengthen the collaborative prevention and control of pollutants, as well as improve the ecological protection compensation system and its levels, thereby enhancing the diversity and stability of ecosystems. Moreover, positive experiences and practices should be actively shared with other countries. Finally, it is essential to provide a favorable external environment and strong support to cultivate a robust digital ecosystem, vigorously promote the industrialization of digital technology and the digitalization of industries and further deepen the integration between the internet and the real economy.

Second, to adhere to a unified national strategy, we should establish a regional coordination mechanism for the NUGD system in Chinese cities (Figure 9b). There were significant agglomeration characteristics in the NUGD system in the Chinese cities studied, and the synergy effect of the NUGD system in neighboring cities significantly impacted the local dynamic evolution. Therefore, we must fully leverage the spatial linkage role of the synergistic development of the NUGD system. Specifically, cities or regions with a higher coordinated development level for the NUGD system should actively take on pilot tasks and accumulate experience and lessons to promote synergistic NUGD system development, providing reference value for cities or regions with lagging levels so as to accelerate synergistic system development. Similarly, countries should enhance cooperation and exchange among themselves, led by developed countries and enabling less developed countries to keep pace, ultimately achieving the sustainable development of the global economic, social and ecological systems. In addition, governments should actively eliminate regional barriers to achieve the free flow of information, culture, resources, etc., between cities, regions and countries. They should promote interregional exchange and cooperation, form a mutually reinforcing complementary system and further construct a mechanism for assistance and shared development between regions with a high synergistic development level for the NUGD system and underdeveloped regions, promoting cities to transition from a moderately imbalanced phase to a higher coordinated development stage.

Third, tailor-made strategies for coordinated development should be formulated to mitigate the regional imbalances in the synergistic NUGD system (Figure 9c). The eastern region should fully leverage its advantages of higher economic development levels, talent aggregation and advanced technology and steadily enhance the synergistic development level of the NUGD system by cultivating interdisciplinary talent and developing high-tech industries. The central region should rely closely on urban clusters and metropolitan areas; eliminate regional barriers; promote the flow of resources, technology and talent; and strengthen its interregional communication and cooperation, thereby constructing a development pattern that encompasses large, medium and small cities to further improve the level and quality of the synergy in the NUGD system. It is vital for the western region to seize its development opportunities, especially the Belt and Road Initiative; implement major national regional development strategies; actively construct a regional cooperation mechanism for resource sharing, platform co-building and talent sharing; and proactively learn from the experiences and lessons of advanced regions regarding the synergistic development of the NUGD system.

Fourth, local governments must take human-centeredness as a premise and increase their investment in medical, educational and cultural resources to enhance the well-being of their citizens (Figure 9d). More importantly, with spatial urbanization, especially urban construction land, becoming the largest obstacle factor, the local government should strive to promote the orderly and rational expansion of cities and optimize the layout of urban land use. This means that, within urban land use, they should control the proportion of production land, ensure living land and increase ecological land. By adjusting the internal structure and layout of urban land use, local governments will be able to build an urban environment that is economically prosperous, socially harmonious, resource-efficient, environmentally friendly, culturally vibrant and ecologically livable. Lastly, the government should ensure and improve the livelihoods of their citizens in the development

process, enable them to fully enjoy the benefits brought by social, public and municipal services, and finally enhance their well-being and improve their quality of life.

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