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Comprehensive Evaluation of China's Green Urbanization Level--Measurement Based on Provincial Panel Data

Pan Wenjie [1] & Mei Daniel Weiyue [2]

[1]School of Economics, Xiamen University, Fujian, China

[2]St. Andrew College, 15800 Yonge Street, Aurora, ON L4G 3H7 Canada

Correspondence: Mei Daniel Weiyue, St. Andrew College, 15800 Yonge Street, Aurora, ON L4G 3H7 Canada.

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Abstract

Along with the shift of China's economy from a high-speed development stage to a high-quality development stage, traditional urbanization is also transforming into the form of green and low-carbon. Based on the connotation of green urbanization, this paper selects 2007-2021 as the research period; measures the green urbanization level of 31 provinces and municipalities directly under the central government through a comprehensive index of indicators and analyzes the relative and absolute differences among different regions with the Dagum Gini coefficient and the dynamic evolution of distribution model. The results show that the overall green urbanization level at the provincial level has been improving, with the characteristics of the eastern region exhibiting high quality, and the central and western regions exhibiting high growth. The results also demonstrate significant intra-regional differences between the eastern and western regions, with the intra-regional differences in the northeast displaying a trend of 'maintenance-expansion-contraction'. While the intra-regional differences in the central and western regions are generally decreasing, the uneven green urbanization level among different regions is also gradually being alleviated; however, more attention must be paid to the long-standing gap between the eastern and other regions in China.

Keywords: green urbanization, comprehensive index, intra-regional differences, inter-regional differences

1. Introduction

Over the past 40 years since the reform and opening-up, China has made remarkable achievements in urbanization. The total urban population increased from 172 million in 1978 to 914 million in 2021[1],with an average annual growth rate of 16.9%. More specifically, the urbanization rate of permanent residents increased from 17.9% in 1978 to 64.72% in 2021[2],an increase of 1.05% per year, far higher than the world average of 0.42%. This rapid urbanization has dramatically promoted the sustainable development of China's economy and society, which changed China's economic structure and social form. However, as China's urbanization mainly relies on population transfer in the process of industrialization, which the government largely dominates, the path of sustainable development in terms of air quality, urban waste, and other environmental issues is vague (Zhou et al., 2013). The continuous and rapid urbanization process in China has brought severe problems such as excessive consumption of resources, environmental pollution, ecological damage, and so on. These serious issues are mainly reflected in the following aspects: First is the contradictive relationship between supply and demand of land, energy, and clean water has become three bottlenecks restricting the urbanization process; second is that there has been a lack of features in urban construction, which causes thousands of cities and towns have similar characters (Gu et al., 2018); third is the social phenomena such as unemployment pressure, shortage of medical resources and insufficient social security have gradually emerged. These issues have led to huge resource and environmental constraints and social equality pressures on China's urbanization as it moves further forward.

[1] Data from "Statistical Bulletin of National Economic and Social Development in 2021" published by the National Bureau of Statistics of China

[2] Data from "Statistical Bulletin of National Economic and Social Development in 2021" published by the National Bureau of Statistics of China

In December 2013, the Central Economic Work Conference of China pointed out that ‘fully integrate the concept and principles of ecological civilization into urbanization process and take a new pathway that is intensive, intelligent, green and low-carbon are of particular importance’ [3]. In March 2014, The National New-type Urbanization Plan (2014-2020) pointed out that it is necessary to “accelerate the construction of green cities” [4] . In April 2015, the research paper Opinions on Accelerating the Construction of Ecological Civilization issued by the State Council of China pointed out that “vigorously promoting green urbanization is highly required.” [5] These documents all indicate that green urbanization has become a strategic choice of China’s urbanization, especially after China’s economy has changed from a high-speed growth stage to a high-quality development stage. Thus, changing the traditional urbanization mode characterized by high expansion, excessive energy consumption, and great emissions to green and low-carbon developments is essential. Under the context of green urbanization in China, this paper attempts to answer the following questions: Firstly, which kind of level has green urbanization developed as a new model that promotes China’s economic transformation and upgrading? Secondly, how significant are the green urbanization development differ between regions? Therefore, this paper studies measuring the development level of green urbanization in China.

The paper’s contribution is reflected in the following two points: first, it develops a theoretical research of green urbanization, positions the structural transformation of urbanization in the high-quality development stage of China's economy, and provides a new explanation for the determinants of green urbanization; second, it investigates the development level of green urbanization in China and its different regions. Appropriate indicators are selected and measured from the four aspects of economic development, social progress, infrastructure, and environmental construction.

The structure is arranged as follows; the second section is a literature review, which mainly summarizes the theoretical interpretation along with the empirical research on green urbanization and its development level; the third section introduces the selection of indicators, index construction, and estimation methods in addition to explain the data sources coupled with the processing of the experiment; the fourth and fifth sections respectively measure the development level of green urbanization, discuss the relative and absolute differences within/between regions in China, and present the empirical study's main results; the sixth section provides the basic conclusions.

2. Literature Review

Green urbanization can be traced back to various ‘green city’ projects implemented in Europe to improve environmental quality, reduce resource consumption, and achieve sustainable development (Mega, 1996). A Green city includes the following elements: controlling the impact of the environment on health, reducing chemical and physical hazards, creating a high-quality living environment for urban residents, etc. (Satterthwaite, 1997). Beatley (2000) put forward the development concept of "green urbanization" based on summarizing the practice of sustainable development of European cities, emphasizing that urbanization must be carried out within the limits of the ecological environment and in a way similar to nature. This concept has been widely considered by the international community because it effectively responds to the problems of resource shortage, environmental pollution, and social integration commonly faced by countries in the process of urbanization. (OECD, 2009; UNEP, 2011a).

The path to green urbanization is multi-dimensional with three aspects. The first aspect is creating a green economic model, including encouraging the development of green sectors, increasing green infrastructure investment, and creating green jobs' employment (UNEP, 2011b). The second aspect is to implement green growth strategies, including establishing an institutional system that encourages environmental protection, implementing tradable permit systems, and applying environmentally related taxes in regions (OECD, 2011). The last aspect is the developments and utilizations of green technology. With the arrival of a new round of industrial technology, internet technology and renewable energy has created a solid new energy infrastructure (Rifkin, 2011). Those new energy infrastructure can be further used in the process of green urbanization. Additionally, the process of green urbanization needs to develop in the direction of ‘intelligent energy’ and ‘innovative environment’ (Angelidou, 2015; Trindade et al., 2017). However, it should be noted that there is no unified model for green urbanization; instead, it is generally related to each country’s development stage,

[3] Central Economic Work Conference Held in Beijing [N] People's Daily. 2013-12-14 (001)

[4] National New-type Urbanization Plan. People's Daily. 2014-03-17 (009)

[5] Opinions of the CPC Central Committee and State Council on Accelerating the Construction of Ecological Civilization. People's Daily 2015-05-06 (001)

institutional environment, policy orientation, and other factors (Yang et al., 2018).

The practice of green urbanization in China started relatively late. At present, it is still in the stage of ‘top-down’ pilot demonstration and ‘bottom-up’ spontaneous exploration. However, as ‘Green urbanization’ becomes more important, relevant research has been more dynamic with promoting experimental practices into real-world practices. Specifically, the research scope of this topic includes defining (Dong et al., 2014), designing (Ameen et al., 2015), governance (OECD, 2013), and managing (Lehmann, 2012). The current empirical research mainly focuses on evaluating the development level of green urbanization in China. It draws on the research methods to comprehensively describe and evaluate sustainable developing urbanization from the aspects of economy, environment, society, etc. (Pearce, 1996; Distaso, 2007). The existing technical method is to build a comprehensive evaluation indicator system from the dimensions of China's population, economy, society, ecology, culture, etc. by selecting various methods such as principal component analysis, factor analysis, and entropy weighting method in order to determine the indicators' weight coefficient, and then using grey correlation analysis, spatial correlation analysis, and natural breaks method to analyze the spatial and temporal evolution patterns of green urbanization.

From the perspective of national evaluation, Zou et al. (2018) constructed a system containing 26 secondary indicators from four aspects of economic development, social progress, good ecological environment, and green city construction to evaluate green urbanization. Taking 291 prefecture-level cities in China as samples, it was found that the level of cities’ green urbanization process in economically developed areas increased rapidly, while that in economically underdeveloped areas was in a negative growth state. Zhou & Zhang (2021) constructed an evaluation system of 14 secondary indicators from four aspects: population transfer, economic growth, infrastructure, and ecological environment. The results showed a noticeable gap in the level of green urbanization in 31 provinces of China, showing a ladder distribution from west to east. From the evaluation of specific regions, Chen et al. (2022) took 41 towns in the Yangtze River Delta region as samples and constructed an evaluation system of 27 secondary indicators from three aspects of the economy, society and ecology. The results showed that the level of green urbanization in the selected region was increasing yearly, but there was a large gap between cities.

Additionally, the evaluation of specific provinces and cities by researchers Song & Peng (2016) constructed 26 secondary indicators from five aspects of population transfer, economic development, ecological livability, urban-rural overall planning, and equalization of basic public services. The results showed that urban radiation capacity, transportation conditions, and regional policies were the most critical factors affecting the level of green urbanization in Jiangxi Province. Ren et al. (2019) took 17 towns in the Shandong Peninsula as samples and constructed an evaluation system of 31 secondary indicators from five aspects of green economy, resource efficiency, eco-environment friendliness, green city construction, and social coordination. The results showed that the three most significant factors affecting green urbanization were: the proportion of the tertiary industry in GDP, the income ratio of urban and rural residents, and the number of effective invention patents per 10,000 people.

The above research from different evaluation systems concluded that with the increasingly rich understanding of green urbanization, the indicator system has also experienced continuous updates. Some old indicators have been replaced, and some new indicators have been added. When determining different indicators, it gradually turns from subjective to objective to avoid the defects of subjective randomness. However, there is still room for improvement in the existing achievements; the correlation between secondary indicators and ‘greening’ needs to be advanced. For example, in terms of indicators for measuring economic development, scholars have adopted conventional indicators such as per capita GDP and per capita disposable income of urban residents, while green economic growth uses indicators such as energy consumption per 10 000 yuan of GDP and carbon dioxide emissions per unit of GDP, which are incompatible with one another. From another perspective, the measurement method for assessing regional differences needs to be broken through. The Dagum Gini ratio method quantitatively analyzes the magnitude and sources of regional relative differences in green urbanization levels. Models of Distribution Dynamics reflect the absolute regional differences in green urbanization levels and their dynamic evolution, so the measurement results are more consistent with reality. Based on this, this paper constructs a comprehensive evaluation index, compares the green urbanization level of each region in China and the relative and absolute differences within/between regions through the application of the econometric model, and then analyzes the spatial and temporal evolution characteristics of green urbanization in China.

3. Green Urbanization Level Measurement

3.1 Indicator System and Data Description

Based on the existing literature, this paper measures the level of green urbanization in China from four aspects:

green economic development, green social development, green urban facilities construction, and green urban environment construction, and the constructed index system contains a total of 26 variables in four first-level indicators. The weights of the secondary indicators (indicator layer) are first calculated by entropy weighting method on the sample data and synthesized to obtain the sub-indexes (criterion layer). Then the weights of the sub-indexes are calculated again by entropy weighting method and synthesized to obtain the comprehensive index. The index system and specific weight calculation results are shown in Table 1.

Table 1. Green urbanization index system

Criteria layer	Sub-criteria layer	Indicator layer	Directionality	Weight
Green Economic Development (0.1952)	Economic growth	GDP per capita (yuan)	Positive	0.2117
		Share of tertiary sector in GDP (%)	Positive	0.2157
		Local fiscal expenditure per capita (yuan)	Positive	0.1799
	Green growth	Energy consumption of 10,000 Yuan GDP (tons of standard coal / 10,000 Yuan)	Negative	0.2045
		Carbon emissions per unit of GDP (kiloton/billion yuan)	Negative	0.1335
		Water consumption per unit of GDP (m3/billion yuan)	Negative	0.0547
Green Social Development (0.3100)	Living standard of residents	Total retail sales of social consumer goods per capita (yuan)	Positive	0.1824
		Per capita disposable income of urban residents (yuan)	Positive	0.1763
		E-commerce sales per capita (yuan)	Positive	0.1214
		City gas penetration rate (%)	Positive	0.0555
	Basic public services	Per capita education, culture and entertainment consumption expenditure of urban households (yuan)	Positive	0.1332
		Number of students enrolled in higher education per 10,000 people (person)	Positive	0.1461
		Number of general practitioners per 10,000 people (person)	Positive	0.1850
Green Urban Facilities Construction (0.2247)	Road traffic	Public transportation vehicles per 10,000 people (standard units)	Positive	0.1293
		Rail and road passenger traffic (million people)	Positive	0.1028
	Ecology	Urban green space area per 10,000 people (hectares)	Positive	0.2014
		Urban park area per 10,000 people (hectares)	Positive	0.0806
		Urban park green space per capita (square meters)	Positive	0.1762
		Greening coverage rate of urban built-up areas (%)	Positive	0.0686
		The proportion of nature reserves in the area of the jurisdiction (%)	Positive	0.2410
Green Urban Environment Construction (0.2701)	Pollution control	Industrial waste gas emissions (billion cubic meters)	Negative	0.1545
		Wastewater emissions (billion tons)	Negative	0.1386
		Industrial pollution prevention and control construction projects completed investment (million yuan)	Positive	0.1572
		Total investment in pollution control (billion yuan)	Positive	0.1642
	Amenities and environment	City sewage daily treatment capacity (million cubic meters)	Positive	0.2018
		Harmless disposal rate of domestic waste (%)	Positive	0.1836

According to the above index system, the original data are taken from the wind database. Considering the data integrity, this paper takes 2007 to 2021 as the sample interval and compiles the green urbanization index and the corresponding first-level indicators for 31 provinces and municipalities at the provincial level. Some missing data are complemented by moving average and mean methods. Based on the measurement and decomposition results, this paper will analyze the spatial and temporal evolution characteristics in two dimensions: time and space. Based on the division criteria of the National Bureau of Statistics of China, this paper divides the 31 provinces and municipalities into eastern[6], northeastern[7], central[8], and western[9] regions.

[6] The eastern region includes the provinces and municipalities as Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan.

[7] The northeastern region includes the provinces and municipalities as Liaoning, Jilin, Heilongjiang.

[8] The central region includes the provinces and municipalities as Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan.

3.2 Measurement Method

As an objective assignment method, the entropy weighting method uses the information provided by evaluation indicators to assign weights and is often used in the study of comprehensive multi-indicator evaluation problems. Following most of the literature (e.g., Yang & Sun, 2015; Yu & Chen, 2019), this paper uses the entropy weighting method to determine the indicator weights.

Assume that for m objects, n indicators, and a sample length of period t, x_{ijk} represents the indicator value of indicator j of object i in period k. First, each indicator is standardized according to the directionality of the indicator. For the positive indicators, the standardization process is as follows:

$$\hat{x}_{ijk} = \frac{x_{ijk} - \min(x_{ijk})}{\max(x_{ijk}) - \min(x_{ijk})} \quad (1)$$

For the negative indicators, the standardization process is as follows:

$$\hat{x}_{ijk} = \frac{\max(x_{ijk}) - x_{ijk}}{\max(x_{ijk}) - \min(x_{ijk})} \quad (2)$$

Since zero in the standardized indicator value is not conducive to the logarithmic calculation in the subsequent step, the coordinate translation is performed by $\hat{x}'_{ijk} = 1 + \hat{x}_{ijk}$. Calculate the indicator weights of indicator j of object i in period k.

$$p_{ijk} = \frac{\hat{x}'_{ijk}}{\sum_k^t \sum_i^m \hat{x}'_{ijk}} \quad (3)$$

Further, calculate the entropy value of indicator j:

$$e_j = -\ln(m * k) \sum_k^t \sum_i^m \hat{x}'_{ijk} \ln(\hat{x}'_{ijk}) \quad (4)$$

Calculate the coefficient of variation of indicator j:

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

The weight of indicator j is:

$$w_j = g_j / \sum_j^n g_j \quad (6)$$

Indexes are obtained by summing with w_j as the weight:

$$Index_{ik} = \sum_j^n w_j \hat{x}_{ijk} * 100 \quad (7)$$

3.3 Analysis of Measurement Results

3.3.1 Green Urbanization Composite Index Characteristics

Table 2 shows the green urbanization composite indices of 31 provinces and municipalities in China between

[9] The western region includes the provinces and municipalities as Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang.

2007 and 2021. In terms of mean values, nine provinces and municipalities in the sample set have a higher historical mean value of the Green Urbanization Composite Index than the whole country. Developed eastern regions such as Beijing, Shanghai, Jiangsu, Zhejiang, and Guangdong have the highest level of green urbanization, while provinces such as Gansu, Guizhou, Hebei, Shanxi, and Yunnan are ranked relatively lower. On another aspect, the average growth rate of the Green Urbanization Composite Index of 18 provinces and municipalities in the sample set is higher than the national average growth rate, with the western region ranking the highest, followed by the central region and the northeastern region. In contrast, the eastern region ranks the lowest, which indicates China’s green urbanization level has the characteristics of high quality in the eastern region and high growth in the central and western regions.

Table 2. Results of green urbanization composite index measurement in some years

Province	2007	2011	2015	2019	2021	Mean Value	Average Growth Rate
Beijing	55.930	67.207	77.607	94.862	94.820	78.232	3.843%
Tianjin	35.729	47.599	53.165	61.014	62.946	51.618	4.128%
Hebei	10.001	23.039	33.391	45.743	45.037	30.951	11.347%
Shanghai	41.921	47.106	65.479	78.864	79.900	61.740	4.715%
Jiangsu	42.180	49.823	62.978	73.952	73.791	59.438	4.076%
Zhejiang	34.474	43.321	58.197	68.884	68.146	54.531	4.988%
Fujian	25.918	36.877	48.562	58.227	58.180	45.244	5.946%
Shandong	32.833	44.185	53.205	66.846	67.332	53.013	5.264%
Guangdong	29.315	45.461	54.019	68.267	69.656	53.869	6.377%
Hainan	25.793	41.682	41.406	48.549	50.025	40.802	4.845%
Liaoning	20.180	35.106	45.231	53.726	54.868	41.310	7.406%
Jilin	12.838	25.032	41.142	52.596	55.040	35.163	10.957%
Heilongjiang	17.210	25.637	42.902	49.189	50.494	35.274	7.992%
Shanxi	8.763	22.984	36.223	43.509	45.281	31.518	12.447%
Anhui	15.950	29.976	41.677	52.478	54.426	37.838	9.163%
Jiangxi	19.786	33.083	39.025	49.133	50.963	38.103	6.991%
Henan	14.351	21.713	33.961	50.001	49.433	33.041	9.236%
Hubei	17.959	26.874	40.316	52.831	55.344	38.450	8.371%
Hunan	16.539	29.296	44.750	53.969	54.669	38.338	8.915%
Inner Mongolia	14.056	33.667	49.251	55.159	54.905	41.424	10.222%
Guangxi	18.496	30.823	40.597	47.973	49.243	37.498	7.245%
Chongqing	22.431	42.021	47.259	54.987	57.142	44.437	6.907%
Sichuan	17.556	33.266	42.229	52.728	54.830	39.947	8.474%
Guizhou	10.181	22.787	32.868	45.892	46.887	30.774	11.526%
Yunnan	17.386	24.107	34.297	44.289	45.096	32.675	7.045%
Tibet	18.527	32.459	40.048	51.107	53.374	38.139	7.851%
Shaanxi	17.077	35.848	44.472	51.041	53.112	40.471	8.442%
Gansu	5.163	17.309	31.319	48.173	48.769	29.828	17.398%
Qinghai	22.920	34.336	39.143	48.969	50.501	38.363	5.805%
Ningxia	11.154	27.059	40.790	50.515	49.766	36.480	11.274%
Xinjiang	10.763	26.993	35.820	48.186	46.653	33.278	11.044%
National	21.399	34.086	44.882	55.537	56.472	41.993	7.177%

As for the changing trend, there is an upward tendency in the green urbanization composite index for the nation and the regions, see Figure 1. The national level increased from 21.399 in 2007 to 56.472 in 2021; the largest change is in the central region, from 115.558 in 2007 to 51.686 in 2021; the slightest change is in the eastern region, from 33.409 in 2007 to 66.983 in 2021. Overall, the green urbanization level in the eastern region has been higher than the national average for years, while the northeastern, central, and western regions are catching up with each other in terms of ranking, but all are lower than the national average. In terms of the growth rate of the index, the growth rate of the green urbanization composite index is slowing down nationwide and by region. The growth rate of green urbanization in the western region was once as high as 43.9% in 2008, partly because of the low level of urbanization in the western region in the early stage, and the low base led to the high growth rate. More importantly, it was due to the ‘Western Development Plan’. Before 2010, it was the stage of laying the foundation for Western Development. The plan effectively drove the economic growth of the western region, and the people’s living standards steadily improved. At the same time, the ecological environment, infrastructure, science and technology education, and other infrastructure construction were the focus of development, thus promoting the rapid development of green urbanization in the western region.

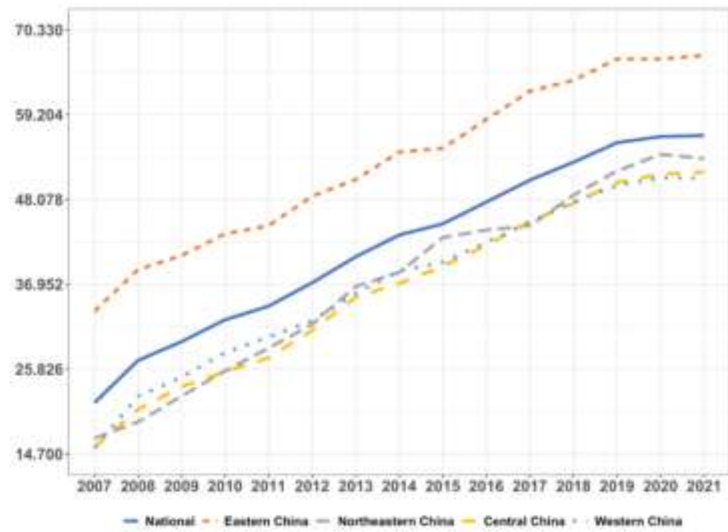


Figure 1. Trends of green urbanization composite index by region in China

3.3.2 Green Urbanization Sub-Index Characteristics

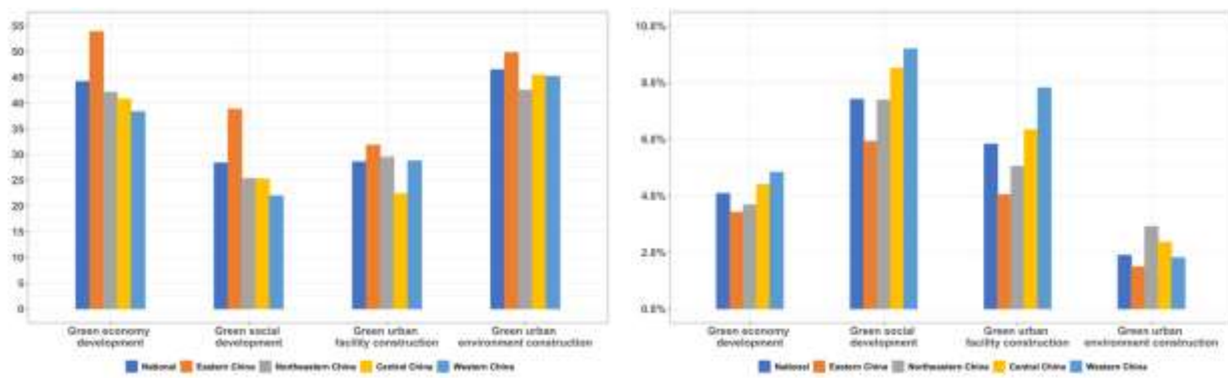
The mean values and average growth rates of the green urbanization sub-index have also been measured for each province and municipality in China from 2007 to 2021, as shown in Table 3. From the aspect of the mean value, green economic development and green social development show a strong correlation, with the correlation coefficient of the historical mean value of each province and municipality reaching 0.8276. The correlation between green social development and green urban facilities construction, and green urban environment construction is also relatively high, reaching 0.5992 and 0.6754, respectively. The correlation of the average growth rate shows a different distribution, with the correlation of the historical average growth rate of the first three sub-indexes ranging from about 0.40 to 0.52, while the correlation of the average growth rate of green urban environment construction with the other sub-indexes is only 0.05 to 0.07. Similar with the composite index, the sub-indexes also show the exact characteristics of high quality in the eastern region and high growth in the western region. Specifically for provinces and municipalities, Beijing is the only municipality leading in all four aspects; eastern regions such as Shanghai, Jiangsu, and Zhejiang perform well in green economic development, green social development, and green urban environment construction but underperforming in green urban facilities construction. The western region stands an opposite path, where the top-ranked provinces in green urban facilities construction are mainly found in the western region, such as Ningxia, Qinghai, and Tibet; however, most of these regions are lagging in the aspects of green economic development, green social development, and green urban environment construction.

Table 3. Mean value and average growth rate of green urbanization sub-indexes from 2007 to 2021

Province	Green Economic Development		Green Social Development		Green Urban Facilities Construction		Green Urban Environment Construction	
	Mean Value	Average Growth Rate	Mean Value	Average Growth Rate	Mean Value	Average Growth Rate	Mean Value	Average Growth Rate
Beijing	75.267	2.832%	63.854	3.680%	45.824	4.940%	54.026	1.143%
Tianjin	58.225	3.386%	42.852	5.350%	23.913	5.644%	49.326	0.325%
Hebei	36.175	5.092%	23.741	7.302%	23.892	6.315%	40.575	2.865%
Shanghai	67.579	3.389%	56.913	4.895%	28.317	4.565%	49.508	1.395%
Jiangsu	53.097	3.953%	41.664	6.534%	35.306	2.511%	54.403	0.836%
Zhejiang	53.110	3.293%	42.978	5.267%	27.707	3.856%	52.077	1.725%
Fujian	48.741	3.249%	31.638	7.125%	26.085	6.525%	48.740	1.304%
Shandong	45.258	3.924%	28.611	7.430%	34.811	3.826%	55.559	1.631%
Guangdong	52.835	2.719%	32.437	7.027%	42.830	4.898%	48.453	2.456%
Hainan	48.813	3.311%	23.578	10.554%	29.632	-0.697%	45.526	1.625%
Liaoning	42.495	3.367%	28.559	7.005%	29.541	5.479%	45.574	2.229%
Jilin	42.969	3.877%	25.359	7.939%	28.505	9.302%	40.384	3.039%
Heilongjiang	40.805	3.794%	22.096	7.237%	30.412	1.926%	41.654	3.515%
Shanxi	31.668	6.985%	24.190	7.807%	21.027	10.250%	43.769	2.379%
Anhui	41.902	3.900%	25.298	9.809%	24.058	5.921%	46.124	2.535%

Jiangxi	42.917	3.805%	24.202	8.014%	25.581	6.537%	45.869	1.447%
Henan	40.138	4.496%	22.921	9.858%	18.888	5.805%	44.887	2.367%
Hubei	44.215	4.344%	29.289	6.873%	22.508	4.547%	45.118	2.910%
Hunan	43.998	3.880%	25.556	9.138%	22.320	6.056%	46.904	2.555%
Inner Mongolia	36.800	4.807%	25.203	7.976%	31.735	8.553%	47.725	2.641%
Guangxi	41.136	3.458%	21.793	9.435%	21.596	5.518%	48.878	1.823%
Chongqing	45.571	4.230%	29.104	8.629%	30.936	8.907%	47.348	0.854%
Sichuan	41.988	4.039%	23.641	9.635%	31.328	6.693%	45.521	2.002%
Guizhou	34.479	7.154%	18.941	13.687%	20.323	11.163%	44.965	1.451%
Yunnan	39.890	4.662%	19.455	10.759%	20.444	7.089%	45.352	0.884%
Tibet	53.001	4.441%	13.685	11.274%	35.617	8.171%	42.815	1.314%
Shaanxi	42.915	3.415%	27.672	7.470%	24.309	6.614%	47.637	2.540%
Gansu	36.639	5.423%	20.889	10.245%	26.209	14.782%	39.279	2.917%
Qinghai	33.829	5.999%	20.284	7.496%	37.242	7.435%	44.451	0.238%
Ningxia	23.222	9.237%	21.623	9.997%	38.170	7.523%	44.111	2.103%
Xinjiang	30.500	5.030%	21.230	6.844%	27.245	4.825%	44.275	3.498%
National	44.199	4.078%	28.363	7.404%	28.591	5.825%	46.478	1.894%

Among the four sub-indexes of green urbanization, green economic development and green urban environment construction develop relatively well, while green social development and green urban facilities construction grow at a relatively high rate, as shown in Figure 2. It is worth noting that despite the great development in green urban environment construction, its average growth rate has been completely lower than the other sub-indexes, and attention should be paid to improving the development momentum of green urban environment construction. From a sub-regional perspective, the eastern region has the best development of the sub-indexes, but the growth rate of each sub-index is lower than that of other regions; the sub-indexes of the northeastern, central, and western regions are less than the national average or barely equal to it. In the first three sub-indexes, the historical average growth rate of the sub-indexes shows a trend of increasing from the northeast to the central and western regions, while the historical average growth rate of the green urban environment construction shows the opposite situation.



(a) Historical Mean value (b) Average growth rate

Figure 2. Historical mean value and average growth rate of green urbanization sub-indexes by region

4. Analysis of Regional Differences in Green Urbanization

4.1 Regional Difference Decomposition Method Based on Dagum Gini Coefficient

Dagum Gini ratio is a measure to calculate regional inequality. Dividing provinces into different regions (eastern, northeastern, central, and western), the inequality can be decomposed into inequality within regions, inequality between regions and the intensity of transvariation between regions (Liu & Zhao, 2012). The intensity of transvariation between regions refers to the inter-regional cross term, i.e., regions with lower levels of development may have certain provinces or municipalities that outperform regions with higher levels of development (Wang et al., 2021).

Assuming that there are n provinces divided into k regions, $n_j(n_h)$ is the number of provinces within $j(h)$ region, $y_{ji}(y_{hr})$ is the Green Urbanization Index of $i(r)$-th province within $j(h)$-th region, and $\bar{y}$ represents the average of the national levels, Dagum Gini ratio is defined as：

$$G = \frac{\sum_{j=1}^{k}\sum_{h=1}^{k}\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}|y_{ji} - y_{hr}|}{2n^2\bar{y}} \tag{8}$$

The Gini ratio within the j-th region can be calculated as:

$$G_{jj} = \frac{\sum_{i=1}^{n_j}\sum_{r=1}^{n_j}|y_{ji} - y_{jr}|}{2n_j^2\bar{y}_j} \tag{9}$$

And the Gini ratio between the j-th region and the h-th region can be calculated as

$$G_{jh} = \frac{\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}|y_{ji} - y_{jr}|}{n_j n_h(\bar{y}_j + \bar{y}_h)} \tag{10}$$

In the calculation process, it is necessary to rank the average of each region from largest to smallest. According to Dagum Gini ratio decomposition method (Dagum, 1997), we can further decompose Dagum Gini ratio into three components of inequality within regions G_w, inequality between regions G_{nb} and the intensity of transvariation between regions G_t, i.e., $G = G_w + G_{nb} + G_t$:

$$G_w = \sum_{j=1}^{k} G_{jj} p_j s_j \tag{11}$$

$$G_{nb} = \sum_{j=2}^{k}\sum_{h=1}^{j-1} G_{jh}(p_j s_h + p_h s_j) D_{jh} \tag{12}$$

$$G_t = \sum_{j=2}^{k}\sum_{h=1}^{j-1} G_{jh}(p_j s_h + p_h s_j)(1 - D_{jh}) \tag{13}$$

where $p_j = \frac{n_j}{n}$, $s_j = \frac{n_j\bar{y}_j}{n\bar{y}}$, $j = 1,2,\dots,k$. D_{jh} represents the relative impact of the Green Urbanization Index between j-th region and h-th region.

$$D_{jh} = \frac{d_{jh} - p_{jh}}{d_{jh} + p_{jh}} \tag{14}$$

Define d_{jh} as the difference in the Green Urbanization Index between j-th region and h-th region, taking the mathematical expectation of the sum of all sample values $y_{ji} - y_{hr} > 0$ in j-th region and h-th region. Define p_{jh} as the first-order moment of transvariation between j-th region and h-th region, taking the mathematical expectation of the sum of all sample values $y_{hr} - y_{ji} > 0$ in region j and h. $F_j(y)$and $F_h(x)$ represent the cumulative density distribution functions of j-th region and h-th region. Then d_{jh} and p_{jh} can be calculated from equation (15) and equation (16) as follows:

$$d_{jh} = \int_0^{\infty} dF_j(y)\int_0^{y}(y - x)dF_h(x) \tag{15}$$

$$p_{jh} = \int_0^{\infty} dF_h(y)\int_0^{y}(y - x)dF_j(y) \tag{16}$$

4.2 Regional Variance Solution Results

The overall Dagum Gini coefficient of green urbanization level shows a decreasing trend, from 0.277 in 2007 to

0.094 in 2020, with a decrease of 66.076%, see Figure 3. Although there's a slight increase in 2021, the inter-provincial differences in green urbanization levels are gradually decreasing, and the overall tendency is toward balanced development among different cities**.** According to the calculation of contribution rate, the uneven development of green urbanization mainly comes from inter-regional differences, followed by intra-regional differences, and the hypervariable density reflects the interaction of inter-regional differences and intra-regional differences, and has the lowest contribution rate to regional differences. The intra-regional difference contribution rate is relatively stable, remaining at 19% to 23%, while the inter-regional difference contribution rate and the hypervariable density contribution rate show opposite change processes; the inter-regional difference contribution rate shows a V-shaped trend, reaching a low of 59.779% in 2013, while the hypervariable density contribution rate shows an inverted V-shaped trend, reaching a high of 18.315% in 2013.

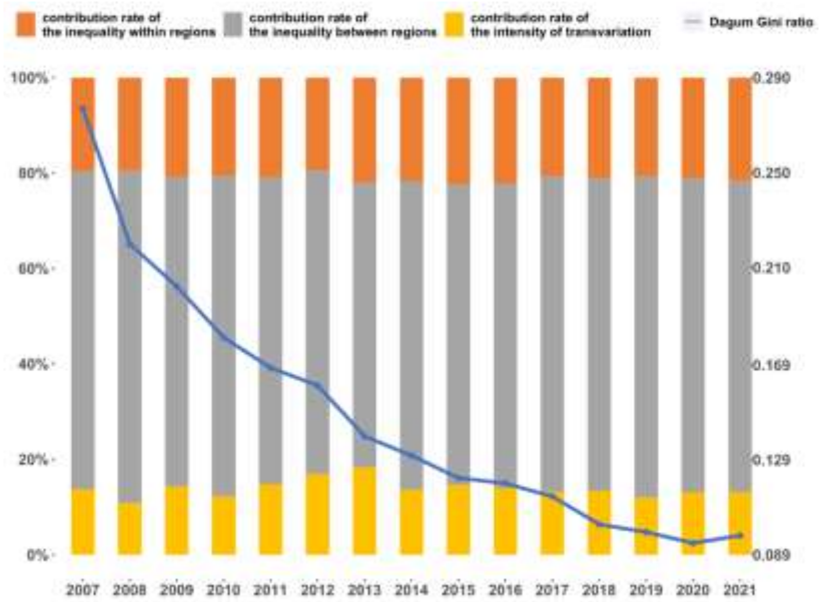
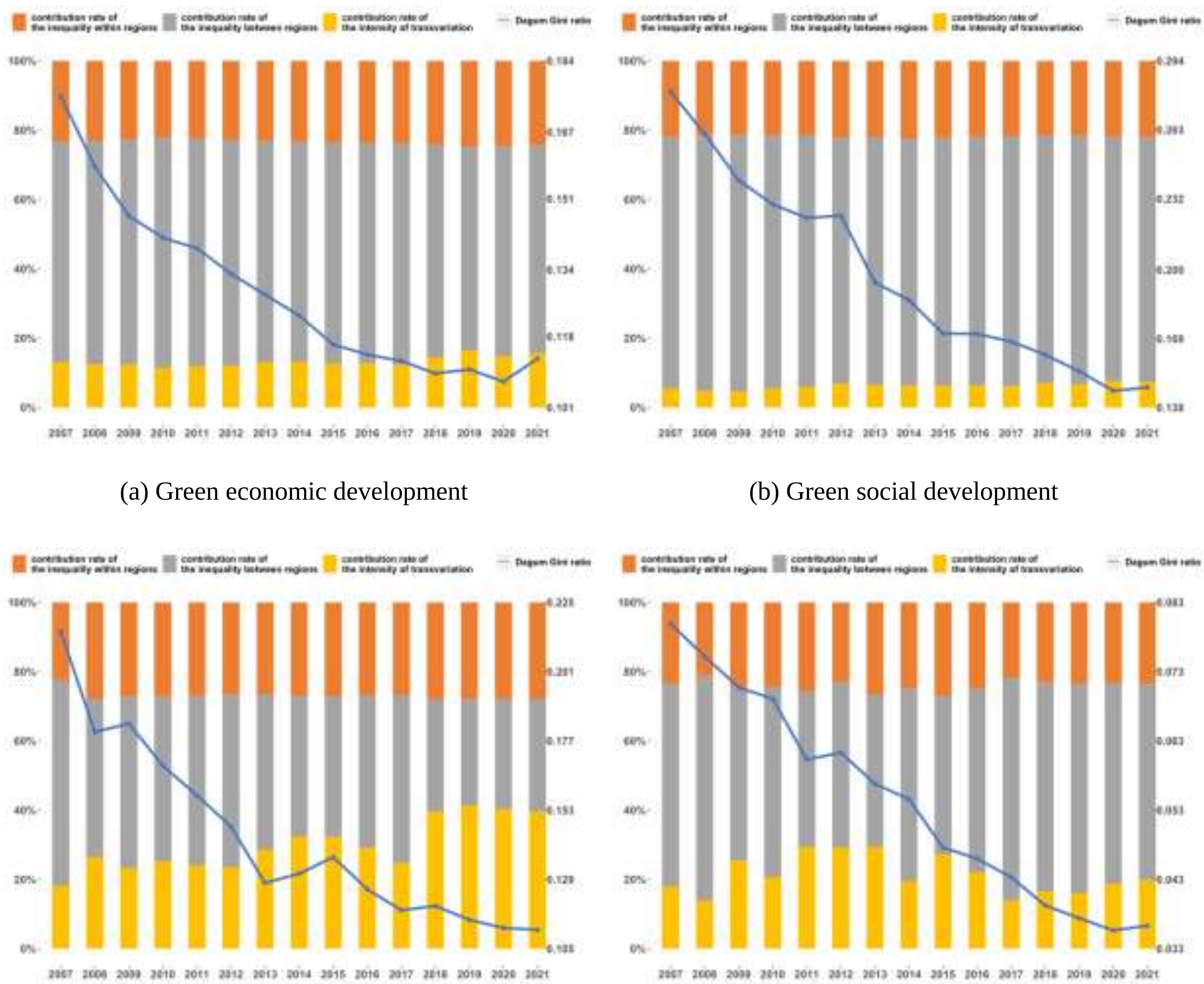


Figure 3. Dagum Gini coefficient and its decomposition for green urbanization composite index

As for the sub-indexes, it could be seen that the regional development imbalance of all four sub-indexes mainly originates from inter-regional differences, and the contribution rate of inter-regional differences and the contribution rate of hypervariable density both show opposite change processes, as shown in Figure 4. The difference is that the contribution rates of inter-regional differences regarding green economic development, green social development, and green urban facilities construction are decreasing overall, while the contribution rates of inter-regional differences in green urban environment construction show a U-shaped trend, with the inflection point located between 2011 and 2015. In addition, the intra-regional difference contribution rate of green economic development and green social development is higher than the contribution rate of hypervariable density for a long time. The intra-regional contribution rate of green urban facilities construction is closer to the contribution rate of hypervariable density between 2007 and 2017, and the contribution rate of hypervariable density has increased since then, with about 12% higher than the intra-regional difference contribution rate. The intra-regional difference contribution rate of green urban environment construction is closer to the hypervariable density contribution rate in the long term.



(a) Green economic development

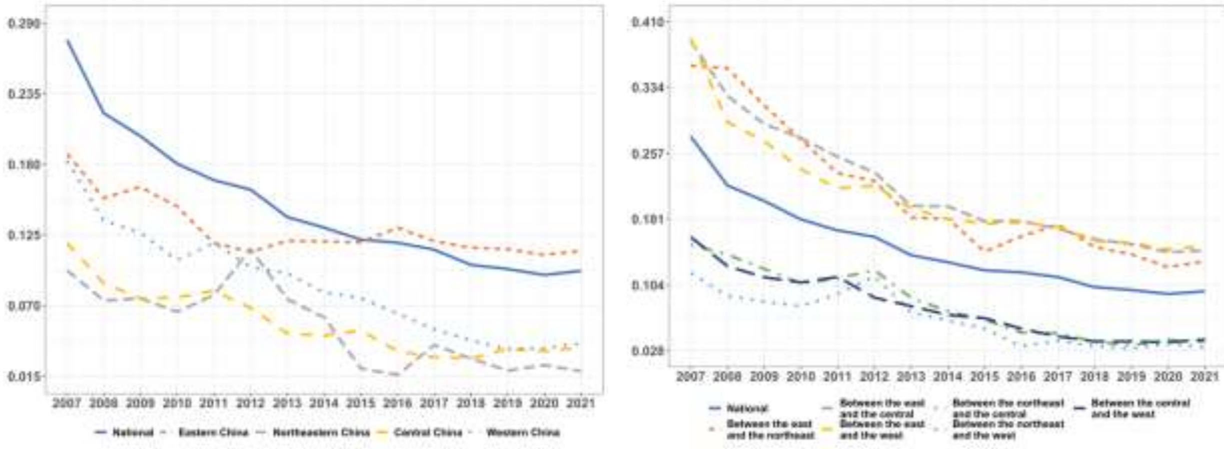
(b) Green social development

(c) Green urban facilities construction

(d) Green urban environment construction

Figure 4. Dagum Gini coefficient and its decomposition for green urbanization sub-indexes

The decomposition results of intra-regional differences in Figure 5(a) show that intra-regional differences in the northeast, central and west are smaller than national differences, and intra-regional differences in the east are larger than national differences after 2015. Horizontally, the intra-regional differences in green urbanization level in the east and west regions are generally larger than the northeast and the center. Longitudinally, the intra-regional difference of green urbanization level in the eastern region did not change significantly in 2013, and the intra-regional difference in the northeast showed a trend of ‘maintenance-expansion-contraction’, while the intra-regional difference in the central and western regions was gradually decreasing. From the decomposition results of inter-regional differences in Figure 5(b), it is obvious that the differences between regions are gradually decreasing, but the differences in green urbanization levels between the eastern and other regions are larger than the national differences, while the differences between the northeast, central and western regions are smaller than the national differences. This indicates that the uneven level of green urbanization among regions is gradually being alleviated, but the long-standing gap between eastern regions and other regions should be taken seriously.



(a) Intra-regional Dagum Gini coefficient (b) Inter-regional Dagum Gini coefficient

Figure 5. Evolution of the intra-regional and inter-regional Dagum Gini coefficients of green urbanization composite index

5. Analysis of the Distribution Dynamic Evolution of Green Urbanization

5.1 Models of Distribution Dynamics

This paper draws on the distributional dynamics model proposed by Quah (1997) to analyze the evolution of the distribution dynamics of green urbanization. The model consists of two main components: Kernel density estimation is used to analyze the overall pattern of green urbanization distribution, which helps to study the stratification and polarization phenomenon of regional development; Markov chain is used to analyze the internal dynamics of distribution (Intra-distribution Dynamics), which can reflect the probability of relative position changes of provinces and cities in the distribution of green urbanization levels.

5.1.1 Distribution Dynamics of Kernel Density Estimation

Kernel density estimation is a nonparametric estimation method that describes the distribution of a random variable through a continuous density profile. The expression of the density function of the random variable is assumed to be as follows:

$$f(x) = \frac{1}{Nh}\sum_{i=1}^{N} K\left(\frac{X_i - \bar{x}}{h}\right) \tag{17}$$

where X_i is the independent and identically distributed observations, containing a total of N observations, and the mean value of the observations is $\bar{x}$; $K(\cdot)$ is the kernel density function, and this paper uses the Gaussian kernel density function for estimation, as shown in Equation (18); h is the bandwidth, the larger the bandwidth, the smoother the density function, the lower the estimation accuracy, and conversely, if the bandwidth is smaller, the less smooth the density function is and the higher the estimation accuracy is. In this paper, the bandwidth of the Gaussian kernel density estimator is chosen by referring to the ‘rule of thumb’ of Yang (1986).

$$K(x) = \frac{1}{\sqrt{2\pi}}\exp(-\frac{x^2}{2}) \tag{18}$$

5.1.2 Markov Chain-based Intra-distribution Dynamics

Markov chain is a Markov process in which both time and state are discrete, and the internal dynamic evolution of the variables is inscribed by constructing a Markov transition probability matrix. A Markov chain is a state space of a stochastic process $\{X(t), t \in T\}$, if for any n values of time t, the Markov chain satisfies:

$$P\{X(t_n) \le x_n \,|X(t_1) = x_1, X(t_2) = x_2, \dots, X(t_{n-1}) = x_{n-1}\} = P\{X(t_n) \le x_n | X(t_{n-1}) = x_{n-1}\} \quad x_n \in R \tag{19}$$

where $X(t_n)$ is the conditional distribution function under condition $X(t_i) = x_i$. Assuming that the green urbanization level change probability is only related to the green township level state i and state j, and is independent of n, the time homogeneous Markov chain can be obtained. A deformation of equation (19) yields:

$$P\{X_{n+1} = j \mid X_0 = i_0, X_1 = i_1, \dots, X_{n-1} = i_{n-1}, X_n = i\} = P\{X_{n+1} = j \mid X_n = i\} \quad (20)$$

Equation (20) shows the probability distribution of the transition of a random variable from state space i to state space j. Assuming that the level of green urbanization is divided into N types, the N-dimensional regime transition probability matrix is obtained as follows:

$$P = [p_{ij}] = \begin{bmatrix} p_{11} & \cdots & p_{1N} \\ \vdots & \ddots & \vdots \\ P_{N1} & \cdots & P_{NN} \end{bmatrix} \quad (21)$$

where $p_{ij} \geq 0$, $\sum_{j \in N} p_{ij} = 1, i, j \in N$. p_{ij} denotes the probability of transferring from state i to state j. The maximum likelihood estimation method is used to calculate the following:

$$p_{ij} = \frac{n_{ij}}{n_i} \quad (22)$$

where n_{ij} represents the number of transfers from state i to state j during the observation period, and n_i denotes the total number of occurrences of state i.

Referring to Zhao & Fang (2019), this paper classifies the green urbanization level into four types: if the level of composite index is below 75% of the mean, it is called the low green urbanization state, denoted as L; if it is at 75%-100% of the mean, it is called the medium-low level state, denoted as ML; if it is at 100%-125% of the mean, it is called the medium-high level, denoted as MH; if it is above 125% of the mean value, it is called high level, denoted as H.

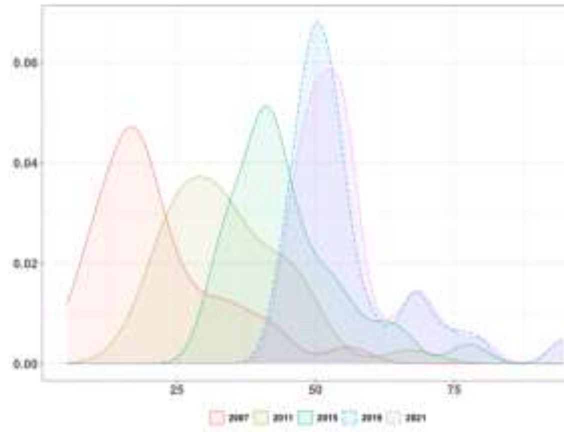
Assuming that a province or municipality is in type i at the beginning, if it remains in type i after the transfer, the transfer is considered smooth; if the type becomes higher after the transfer, it is an upward transfer, and if the type becomes lower after the transfer, it is a downward transfer.

5.2 Analysis of Distribution Dynamics

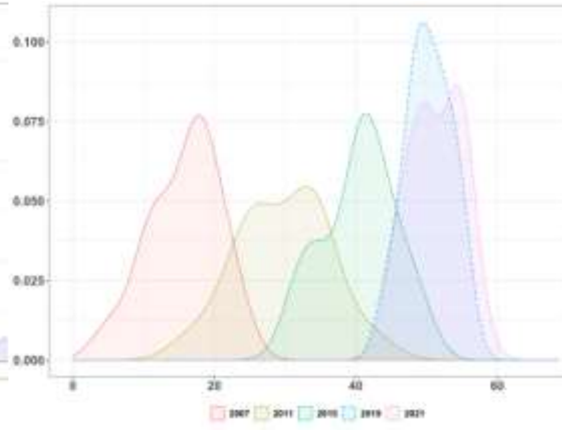
5.2.1 Dynamic Evolution of Overall Shape of the Distribution

The kernel density curve of the green urbanization composite index shifts to the right overall, indicating that the level of green urbanization is increasing, as shown in Figure 6(a). The multi-peaked pattern implies that the green urbanization level shows multi-polar development across the country, and there is a gradual shift from multi-polar development to bipolar differentiation after 2019. During the period from 2007 to 2021, the height of the crest of the kernel density curve goes through the process of falling, rising, and then slightly falling, while the width of the crest widens, narrows, and then slightly widens again, implying that the characteristics of ‘expansion-contraction-re-expansion’ has appeared in the absolute regional differences among provinces.

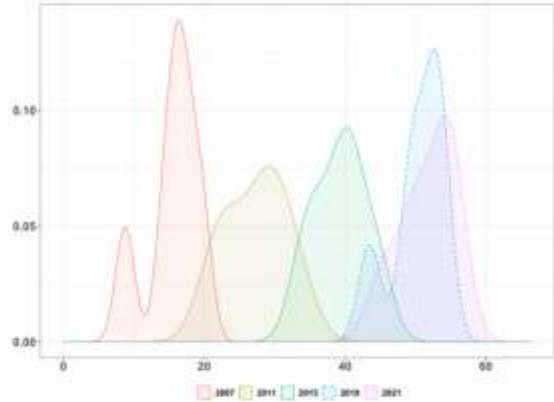
Figures 6(b)-(d) depict the spatial and dynamic evolution of the green urbanization composite index in each region, and the eastern region is combined with the northeastern region here because the northeastern region contains only three provinces and municipalities. Overall, the level of green urbanization is increasing in all regions. In the eastern, northeastern and the central region, there is a polarization phenomenon in the bimodal state for some periods; in the western region, a side peak pattern has appeared in recent years, implying a weak polarization tendency. The absolute regional differences among provinces in each region also show the characteristics of ‘expansion - contraction - re-expansion’, but the change level varies. The absolute difference in the central region expands most significantly from 2007 to 2011, followed by the eastern and northeastern regions; the absolute difference in the western region contracts most significantly from 2015 to 2019 and re-expands most considerably from 2019 to 2021. A cross-sectional comparison reveals that the central region has the largest absolute difference in recent years, while the eastern, northeastern and the western regions are closer in absolute difference.



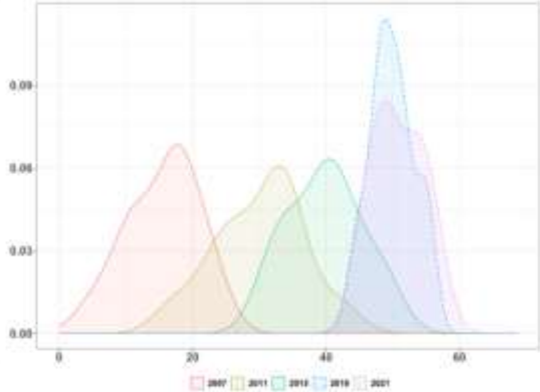
(a) National



(b) Eastern and Northeastern China



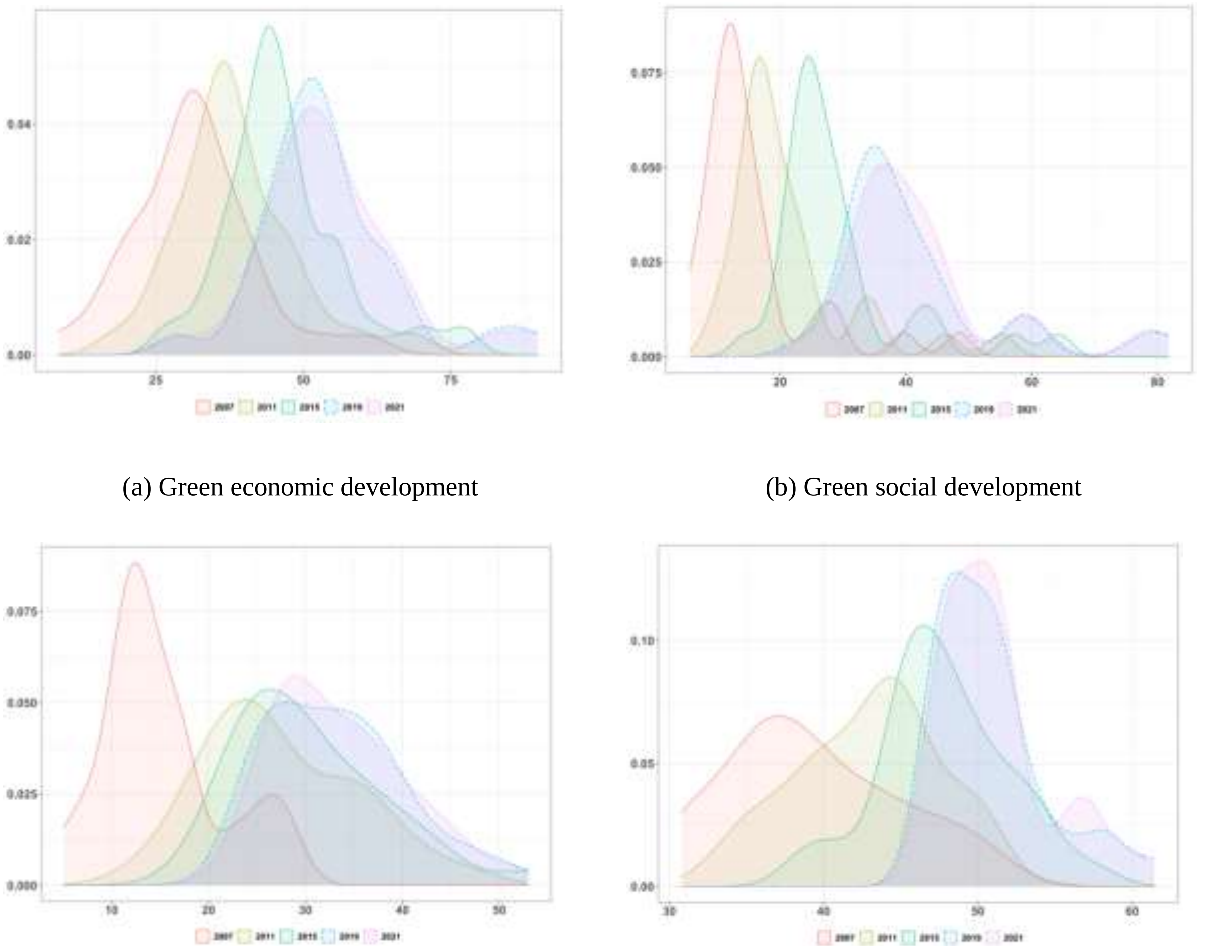
(c) Central China



(d) Western China

Figure 6. Evolution of the distribution pattern of green urbanization composite index by regions in China

As shown in figure 7, it also shows that the absolute regional differences of the four sub-indexes across the country are respectively characterized by ‘contraction-expansion’, ‘expansion-stabilization-expansion’, ‘expansion-contraction-expansion’, and ‘continuous contraction’. In recent years, there is a tendency of polarization in green economic development and green urban facilities construction, and there is a long-term phenomenon of multi-polar development in green social development, while the pattern of polarization in green urban environment construction has basically formed.



(a) Green economic development (b) Green social development

(c) Green urban facilities construction (d) Green urban environment construction

Figure 7. Evolution of the distribution pattern of green urbanization sub-indexes

5.2.2 Dynamic Evolution of Intra-distributional Mobility

The results of the maximum likelihood estimation of the transfer probability of the Markov chain of the inter-provincial green urbanization composite index are presented in Table 4. In the full sample interval, the probability of transfer on the diagonal is significantly higher than that on the non-diagonal, implying that the probability that the inter-provincial green urbanization level remains stable is above 45%. The probability of upward transfer is highest at the medium-low level, reaching 30.69%, while the probability of upward transfer at the medium-high level is only 16.91%, a decrease of about 50%, implying that there may be a bottleneck in the improvement of green urbanization level at the medium-high level. On the other hand, the probability of downward transfer of green urbanization level is relatively high, especially the probability of downward transfer in the high-level state reaches 43.56%, and there is a phenomenon of downward slip across levels.

Since the concept of green urbanization was explicitly introduced in 2015, the sample interval was further divided into two periods: 2007-2014 and 2015-2021. During 2007-2014, the provinces and municipalities in the four states were distributed more evenly, but the probability of downward transfer was higher in the provinces and municipalities in the medium-high level state of green urbanization. After 2015, the concept of green urbanization was emphasized, and the number of provinces and municipalities in the low-level status decreased significantly, but the provinces and municipalities in the medium and high level status had difficulty in maintaining their original status, and the probability of downward transfer was over 50% in both cases.

Table 4. Markov chain transfer probability matrix of inter-provincial green urbanization composite index

period	type	n	L	ML	MH	H	Prob(up)	Prob(keep)	Prob(down)
	L	112	0.7679	0.1696	0.0536	0.0089	0.2321	0.7679	-
	ML	101	0.2376	0.4554	0.2574	0.0495	0.3069	0.4554	0.2376
	MH	136	0.0588	0.2279	0.5441	0.1691	0.1691	0.5441	0.2868
2007-2021	H	101	0.0000	0.0891	0.3465	0.5644	-	0.5644	0.4356
	L	65	0.6154	0.2769	0.0308	0.0769	0.3846	0.6154	-
	ML	64	0.2969	0.4063	0.2188	0.0781	0.2969	0.4063	0.2969
	MH	52	0.1538	0.3269	0.3269	0.1923	0.1923	0.3269	0.4808
2007-2014	H	59	0.0339	0.1017	0.3390	0.5254	-	0.5254	0.4746
	L	13	0.2308	0.6154	0.0000	0.1538	0.7692	0.2308	-
	ML	113	0.0885	0.7080	0.1593	0.0442	0.2035	0.7080	0.0885
	MH	54	0.0370	0.4815	0.4074	0.0741	0.0741	0.4074	0.5185
2015-2021	H	30	0.0000	0.1333	0.4667	0.4000	-	0.4000	0.6000

The common feature of the four sub-aspects is that the probability of downward transfer is too high when a high-level state is reached, as shown in Table 5. After the concept of green urbanization was introduced in 2015, the probability of downward transfer of the high-level state increased significantly, although the number of provinces and municipalities in the low-level state decreased. Taking green urban facilities construction as an example, the proportion of provinces and municipalities with low-level status decreased by 16.37% after 2015, and the probability of upward transfer increased significantly. However, on the other hand, the probability of downward transfer of medium- and high-level status provinces and municipalities also rose abruptly, respectively reaching 52.38% and 85.71%, both much higher than the probability of downward transfer in other aspects. Therefore, while vigorously promoting green urbanization, it is also important to focus on the continuous consolidation of the existing development achievements.

Table 5. Markov chain transfer probability matrix of inter-provincial green urbanization sub-index

		Green economic development					Green social development				
period	type	n	L	ML	MH	H	n	L	ML	MH	H
2007-2021	L	84	0.6190	0.3095	0.0238	0.0476	160	0.8313	0.0938	0.0313	0.0438
	ML	143	0.2378	0.5385	0.1748	0.0490	88	0.2955	0.4659	0.1591	0.0795
	MH	147	0.0544	0.2585	0.5510	0.1361	91	0.0769	0.2967	0.4505	0.1758
	H	76	0.0000	0.0921	0.5132	0.3947	111	0.0180	0.0721	0.3153	0.5946
2007-2014	L	37	0.4865	0.4324	0.0000	0.0811	78	0.6923	0.2308	0.0385	0.0385
	ML	88	0.2386	0.5000	0.1932	0.0682	69	0.3043	0.4348	0.1739	0.0870
	MH	76	0.0526	0.3289	0.5395	0.0789	42	0.1429	0.3571	0.2857	0.2143
	H	39	0.0000	0.1282	0.4615	0.4103	51	0.0392	0.1569	0.3137	0.4902
2015-2021	L	14	0.4286	0.5000	0.0000	0.0714	44	0.5455	0.3409	0.0682	0.0455
	ML	104	0.1058	0.6058	0.2019	0.0865	87	0.2414	0.5402	0.1494	0.0690
	MH	68	0.0147	0.4265	0.5588	0.0000	46	0.0435	0.4783	0.4130	0.0652
	H	24	0.0000	0.3333	0.3750	0.2917	33	0.0000	0.2121	0.3333	0.4545
		Green urban facilities construction					Green urban environment construction				
period	type	n	L	ML	MH	H	n	L	ML	MH	H
2007-2021	L	85	0.6000	0.2118	0.1412	0.0471	20	0.2000	0.8000	0.0000	0.0000
	ML	153	0.1503	0.3791	0.3399	0.1307	172	0.0698	0.6744	0.2558	0.0000
	MH	118	0.0932	0.3559	0.2797	0.2712	245	0.0204	0.1918	0.7551	0.0327
	H	94	0.0426	0.4043	0.2979	0.2553	13	0.0000	0.0769	0.9231	0.0000
2007-2014	L	61	0.5082	0.3115	0.0984	0.0820	8	0.1250	0.5000	0.3750	0.0000
	ML	67	0.1791	0.3284	0.2836	0.2090	106	0.0566	0.6415	0.3019	0.0000
	MH	51	0.2745	0.1961	0.2549	0.2745	118	0.0169	0.3051	0.6186	0.0593
	H	61	0.0820	0.3443	0.2295	0.3443	8	0.0000	0.1250	0.8750	0.0000
2015-2021	L	19	0.3158	0.2632	0.3684	0.0526	0	0.0000	0.0000	0.0000	0.0000
	ML	100	0.0900	0.5000	0.3900	0.0200	112	0.0000	0.7054	0.2946	0.0000
	MH	63	0.0635	0.4603	0.2540	0.2222	98	0.0000	0.3776	0.6224	0.0000
	H	28	0.0000	0.6429	0.2143	0.1429	0	0.0000	0.0000	0.0000	0.0000

6. Main Conclusions

This paper examines the green urbanization levels of 31 provinces and municipalities in China in two dimensions: time and space. Also in four aspects: green economic development, green social development, green urban facilities construction, and green urban environment construction. Based on the provincial panel data from 2007-2021, the relative and absolute differences between and within various regions were compared by the Dagum Gini coefficient and the distribution dynamic evolution model. The following basic conclusions were obtained:

First, the Green Urbanization Composite Index shows that China's green urbanization level has generally been on an upward trend since 2007, which reflects the characteristics of high quality in the eastern region and high growth in the central and western regions. The green urbanization level in the eastern region has been higher than the national average, while the northeastern, central and western regions catch up with each other in terms of ranking. However, all the enlisted regions except eastern region are lower than the national average. From another perspective regarding growth rate index, the growth rate of the green urbanization composite index is slowing down nationwide and by region.

Second, the Green Urbanization Sub-index shows that green economic development and green urban environment construction have developed relatively well, while green social development and green urban facilities construction have grown at a relatively high rate. Interestingly, despite the good development in green urban environment construction, its average growth rate has been completely lower than the other sub-indexes, which indicates that attention should be paid in terms of improving the development momentum of green urban environment construction. Among the first three sub-indexes, the historical average growth rate of the sub-indexes shows an increasing trend from the northeast to the central and western regions, while the historical average growth rate of the green urban environment construction reflects the opposite situation.

Third, the results of the contribution rate measurement of the Dagum Gini coefficient show that the unevenness of green urbanization development mainly comes from inter-regional differences, followed by intra-regional differences. The hypervariable density reflects the interaction of inter-regional differences and intra-regional differences, which has the lowest contribution rate to regional differences. The decomposition results of regional differences of the four sub-indexes have similar characteristics, but the difference is that the contribution rates of inter-regional differences in green economic development, green social development, and green urban facilities construction are decreasing overall. In contrast, the contribution rates of inter-regional differences in green urban environment construction have started to increase since 2015.

Fourth, the decomposition results of intra-regional differences show that the intra-regional differences in the eastern and western regions are larger, and the intra-regional differences in the northeastern region show a trend of "maintenance-expansion-contraction", while the intra-regional differences in the central and western regions are gradually decreasing overall. However, the long-standing gap between eastern regions and other regions should be taken seriously.

Fifth, the absolute regional differences in green urbanization levels among provinces show the characteristics of 'expansion-contraction-re-expansion', and polarization and multi-polar development often occur. The absolute differences among regions are mainly bipolar, with the largest absolute differences in the central region in recent years, while the absolute differences in the eastern, northeastern and the western region are closer. The absolute differences of the four sub-indexes in the country show the characteristics of 'contraction-expansion', 'expansion-stabilization-expansion', 'expansion-contraction-expansion', and 'continuous contraction', and the same phenomenon of polarization and multi-polar development exists.

Sixth, there may be a bottleneck in improving the level status of green urbanization. After the central policy-making level clearly proposed "vigorously promoting green urbanization" in 2015, the number of provinces and municipalities in the low-level status has significantly decreased, but the mid- to high-level status and the high-level status are difficult to maintain their original status, and this phenomenon is common in the four sub-indexes. Therefore, while vigorously promoting green urbanization, China should pay particular attention to continuously consolidating the existing development achievements.

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