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Evaluating the Evolution and Regional Disparities in Green Finance within the Yangtze River Economic Belt: A Longitudinal Analysis from 2007 to 2020

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Abstract: Based on five dimensions, a green finance evaluation indicator system for the Yangtze River Economic Belt was constructed. The Criteria Importance Though Intercrieria Correlation (CRITIC)-entropy weight method was employed to measure the green finance development level across 107 prefecture-level cities and above in the Economic Belt during 2007-2020. Moreover, the Dagum Gini coefficient and kernel density estimation were utilized to reveal the regional disparities and dynamic evolution trends in the development level of green finance. It was discovered that: (i) During the sample inspection period, the development level of green finance in the Economic Belt exhibited a fluctuating upward trend, with the annual growth rates of the three major regions decreasing from downstream to upstream. Provincial capitals such as Shanghai, Nanjing, Hangzhou, Wuhan, and Chengdu were found to have notably higher levels of green finance development. (ii) The overall disparity in the development level of green finance in the Economic Belt showed a widening trend, with transvariation density as the primary source of overall disparity, followed by intra-regional differences, and the smallest contribution coming from inter-regional disparities. (iii) The absolute disparity in the development level of green finance within the Yangtze River Economic Belt was observed to be expanding, with the overall basin and the three major regions experiencing diverse evolutionary paths. A clear polarization trend in the downstream area was identified, accompanied by a "better-get-better" phenomenon.

Keywords: Yangtze River Economic Belt; Green finance; Regional disparities; Dynamic evolution

1. Introduction

The ecological environment serves as the foundational basis for human survival and development. Since the industrial revolution, a growth model driven primarily by factor inputs and extensive development has propelled rapid economic growth in China. However, this has also led to the concentrated eruption of environmental issues, such as the depletion of resources, frequent natural disasters, and the exacerbation of climate warming. Against this backdrop, the active exploration of ecological environment governance paths has become an urgent task for China, aiming to effectively solve the challenge of decoupling economic development from pollutant emissions and resource consumption. As the "lifeblood" of steady economic growth, finance is pivotal in influencing the ecological environment development (Murshed, 2024). As a new market-based tool offering economic and environmental benefits, green finance is significant in terms of bridging the funding gap for environmental protection and promoting the green transformation of the economy and the construction of an ecological civilization. In October 2022, the Chinese government proposed to "improve the financial, fiscal, investment, pricing policies, and standard systems supporting green development," thereby strategically advancing the green finance development. In December 2023, the Chinese government included "vigorously developing green finance" in the "beautiful China construction guarantee system," further providing top-level support for the green finance development.

As a pioneering demonstration zone for national ecological civilization construction, the Yangtze River Economic Belt bears the significant mission of achieving carbon peak and neutrality ahead of schedule (Li et al., 2023). However, affected by a long-term extensive development model, the region has faced a series of environmental issues, such as frequent occurrences of heavy industrial pollution around the river, aggravated smog and air pollution, and rigid growth in carbon emissions, severely constraining the sustainable economic and social development. There is an urgent need to leverage green finance to improve the ecological environment. Concurrently, the problem of unbalanced and insufficient development of green finance in the basin remains prominent, with financial resources concentrated and the development of green finance clearly advantaged in the Yangtze River Delta region. By the end of 2020, Jiangsu and Zhejiang provinces alone contributed one-fifth of the national green bond issuance volume, indicating that the development of green finance in the midstream and upstream regions is relatively lacking. Thus, under the dual context of "actively implementing the dual carbon target tasks and deeply implementing the regional coordinated development strategy," scientifically assessing the development level of green finance in the Yangtze River Economic Belt and thoroughly analyzing its regional differences and distribution dynamics hold significant importance for optimizing the overall development level of green finance in the Economic Belt and even nationwide, thereby promoting the sustainable economic and social development.

With green finance elevated to a national strategy, widespread attention has been garnered among scholars, with related research primarily focusing on three aspects: First, the interpretation of the definition of green finance. Emerging against the backdrop of environmental pollution, green finance, also known as sustainable finance (Qin et al., 2022), has been a subject of formal discourse since the 1990s. Scholars domestically and internationally have interpreted its essence from various perspectives. From the supply side, green finance is identified as financial activities aimed at promoting the coordinated development of economy, resources, and environment, focusing on providing more credit support to green projects and industries, thereby facilitating a "greening" of financial resource flows (Aneja et al., 2023; Ouazad & Kahn, 2022; Wang & Wang, 2021). From the demand side, investment needs centered around climate change mitigation drive the sustained development of green finance, further giving rise to various green financial policies like green credit and insurance, safeguarding improvements in environmental quality and the transfer of environmental risks (Muganyi et al., 2021). In 2016, China explicitly defined the meaning of green finance from a national policy perspective for the first time, identifying it as economic activities that support environmental improvement, climate change response, and the efficient use of resources, standardizing the domestic interpretation of green finance and offering a critical theoretical basis for subsequent studies.

Second, the quantitative evaluation of green finance. Reasonable evaluation methods form the basis for the development level measurement of green finance, with existing measurement methods primarily focusing on core variable methods and composite indicator methods. The core variable method, emphasizing the credit allocation function of green finance, primarily uses indicators such as the proportion of loans to energy-saving and environmental protection enterprises (Wen et al., 2022) and the proportion of interest expenses of six major high-energy-consuming industries (Chen et al., 2023) to characterize the development level of green finance. However, despite its ability to measure the green finance development level from a single dimension deeply, this method offers a somewhat unilateral measurement, making it challenging to assess the development level of green finance in a comprehensive and systematic manner. Therefore, many scholars prefer to use the composite indicator method, constructing an indicator system for measurement. Current research, guided by the "Guidelines for Green Financial System Construction," typically selects multiple indicators from dimensions such as green investment, green credit, green securities, and carbon finance to calculate the development level of green finance (Ip et al., 2023; Lee et al., 2024; Zhang & Zhao, 2023), with a few scholars also designing evaluation indicator systems from perspectives such as industrial development (Li et al., 2021), regional coordinated development (Lv et al., 2021), and input-output (Wu & Ang, 2022), to quantify the level of green finance development. Third, the exploration of trends in the evolution of green finance. As the construction of green finance steadily progresses, the studies have gradually focused on exploring evolutionary trends instead of quantitative analysis. Existing studies have conducted trend analyses at various levels, including provinces, city clusters, regions along the "Belt and Road," and countries, yielding rich research findings. For example, scholars have explored the spatial and temporal evolutionary trends of green finance development levels in Chinese provinces using descriptive statistics and exploratory spatial data analysis, finding that within the Yangtze River Economic Belt, Shanghai leads in green finance development, while Jiangxi and Hubei provinces lag behind (Wang & Liu, 2023); within the Yellow River Basin, Shandong Province performs well in green finance, while Gansu Province and the Ningxia Hui Autonomous Region are at lower levels of development (Meng, 2024). Such phenomena reflect the significant variations in the development levels of green finance across regions due to the interplay of economic foundations, geographical environments, and other factors.

In summary, current studies of the green finance development are extensive, yet opportunities for further exploration remain. Current studies have predominantly focused on a national or provincial scale, with relatively scant attention to the municipal scale, and there is a lack of research on the distribution dynamics and spatial variations in the development level of green finance. Given this context, this study makes potential marginal contributions in two aspects: Firstly, it transcends the limitations of research units by refining the research object to the city level, based on the foundation of existing achievements. In conjunction with the actual development situations of cities, the optimization of the evaluation indicator system aims to assess the development level of green finance in various cities in a scientific and accurate manner. Secondly, it expands the quantitative research on the development of green finance. Starting from both static and dynamic perspectives, methods, such as the kernel density estimation and Dagum Gini coefficient, are employed to comprehensively reveal the regional differences and dynamic evolution characteristics of green finance development, providing empirical support for enhancing the level of green finance development and exploring differentiated improvement paths.

2. Data Sources and Research Methodologies

2.1 Indicator System Construction

The primary task in scientifically measuring the development level of green finance in the Yangtze River Economic Belt is the selection of appropriate measurement indicators to construct a comprehensive, scientific, and objective evaluation indicator system. Drawing upon existing literature, a green finance evaluation indicator system was constructed for the Economic Belt based on policy foundations, theoretical foundations, and practical bases as selection criteria. The policy foundation refers to interpretations of the essence and objectives of green finance in important meetings and documents of the party and government, such as the "Guidelines for Green Financial System Construction" jointly issued by the People's Bank of China, the Ministry of Finance, and other departments, the "Guidelines of Green Finance for the Banking and Insurance Industries" released by the National Financial Regulatory Administration in 2022, and the Central Financial Work Conference in 2023. The theoretical foundation pertains to academic achievements in defining the connotation of green finance and its implementation paths. The practical basis involves selecting proxy indicators based on the real demands for carbon reduction, pollution reduction, expansion of green areas, and growth. On these principles, considering factors such as the operability, effectiveness, and data availability of indicators, this study selects indicators from five dimensions, namely, green investment, green credit, green securities, green insurance, and carbon finance, to construct the evaluation indicator system for the development level of green finance (Table 1).

Table 1. Evaluation indicator system for the green finance development level

Objective Layer	Criterion Layer	Indicator Layer	Measurement Unit	Indicator Calculation Method	Attribute	Reference Basis
Green finance development index	Green investment	Proportion of energy conservation and environmental protection costs	%	Energy conservation and environmental protection costs/total fiscal costs	Positive	Ma & Fei, (2024)
	Green credit	Balance of green credit	Ten thousand Yuan	(Balance of various loans by local financial institutions/balance of different loans by national financial institutions) * national balance of green credit	Positive	Xiao & Hu, (2023)
	Green securities	Market value proportion of high-energy-consuming industries	%	Market value of six main high-energy-consuming industries/total market value of A-shares	Negative	Ma & Fei, (2024)
		Market value proportion of environmental protection enterprises	%	Market value of environmental protection enterprises/total market value of A-shares	Positive	Zhou et al., (2020)
	Green insurance	Proportion of agricultural insurance scale	%	Agricultural insurance incomes/property insurance premium incomes	Positive	Ye et al., (2022)
		Agricultural insurance claim rate	%	Agricultural insurance costs/agricultural insurance incomes	Positive	Gao et al., (2023)
	Carbon finance	Carbon emission loan intensity	Ton/Yuan	Carbon emission volume/balance of various loans by financial institutions	Negative	Wu & Ang, (2022)

Specifically, (i) For green investment, the proportion of energy conservation and environmental protection expenditure to total fiscal expenditure was chosen for the green investment measurement, reflecting the government's focus on environmental governance to a certain degree. (ii) The balance of green credit was used for the development status measurement of green credit in various cities. The increase or decrease in credit limits not only reflects changes in the constraints of corporate green credit but also indicates the sensitivity of credit to corporate green innovation actions, indirectly measuring the greenness of the loan structure. (iii) For green securities, the market value ratios of high-energy-consuming industries and environmental protection companies were used for the development status measurement of green securities. By comparing the financing capabilities of high-energy-consuming industries with those of energy-saving environmental protection ones in the capital market, the actual development of green finance was more objectively reflected. (iv) Regarding green insurance, directly related insurance types include environmental liability insurance. However, China began to implement environmental liability insurance at the end of 2013, leading to insufficient data disclosure. The mainstream practice in academia is to use agricultural insurance, which is more closely related to the environment, as a substitute for environmental liability insurance. Since agriculture is sensitive to weather and environmental pollution, climate deterioration and environmental pollution can lead to claims in agricultural insurance, roughly reflecting the green insurance development. Thus, the proportion of agricultural insurance scale and the claim ratio of agricultural insurance were selected as indicators to measure green insurance. (v) In terms of carbon finance, the ratio of carbon dioxide emissions to the balance of various loans by financial institutions was chosen to reflect the development level of the carbon finance market.

2.2 Data Sources and Processing

On one hand, considering the consistency of statistical calibers, the availability, and completeness of data, certain cities were excluded from this study. Specifically, due to the administrative changes in 2011 where Bijie and Tongren regions in Guizhou Province were reorganized into prefecture-level cities, and Chaohu city in Anhui Province was dissolved, along with the difficulty in obtaining green investment data for Pu'er City in Yunnan Province, these cities were excluded. Consequently, 107 cities at the prefecture-level and above within the Yangtze River Economic Belt were selected as the research sample. On the other hand, the starting year of the study was set to 2007, marking the issuance of the first policy concerning green finance by the State Environmental Protection Administration and other departments in July 2007, which is considered the beginning of green finance practices.

Data were primarily sourced from the "China City Statistical Yearbook," "China Insurance Yearbook," "China Energy Statistical Yearbook," Wind database, various provincial and municipal statistical yearbooks, and statistical bulletins. For cases where certain indicators were unclearly categorized or data were missing, three main methods were employed: Firstly, for unclearly categorized indicators, authoritative classification methods within the industry were referenced. For instance, in the absence of a unified method for selecting environmental protection enterprises, the approach of the Institute of Green Finance International, Central University of Finance and Economics was followed. Based on the industry classification standard of Shenwan Hongyuan Securities (The classification standard targets all A-share listed companies, primarily categorizing them based on their products and services. Currently, this classification system encompasses 31 primary industries, 134 secondary industries, and 346 tertiary industries.), companies within the primary industry categories of environmental protection equipment, engineering, and services were analyzed as environmental protection enterprises. Secondly, where certain indicators were constrained by the availability of municipal-level data, estimation methods were applied. For example, when city-level green credit data were not disclosed, the practice of using the proportion of loans by city financial institutions to national financial institutions as a weight to indirectly estimate the green credit balance of each city was adopted. Thirdly, for cities with minor statistical data missing, geometric mean and linear interpolation method were used to supplement the data based on adjacent years' data (The linear interpolation method leverages existing data information to form a linear relationship, thereby filling missing values within an interval. Specifically, if the data for (y_1, x_1), (y_3, x_3) and x_2 are known, and y_2 is the missing value, then $y_2 = [(y_3 - y_1)/(x_3 - x_1)](x_2 - x_1) + y_1$.).

2.3 Research Methods

2.3.1 CRITIC-entropy weight method

The entropy weight method, a widely applied weighting method, is founded on the principle of assigning objective weights based on the dispersion of data itself. This approach effectively avoids errors introduced by subjective weighting. However, it does not fully consider the inter-correlation among indicators, which can diminish the accuracy of evaluation results to some extent. In contrast, the CRITIC method determines weights based on the degree of variation within indicators and the correlation among indicators, effectively compensating for the shortcomings of the entropy weight method. Therefore, this study combines these two weighting methods by constructing a CRITIC-entropy weight composite weight model to determine the weights of indicators, ultimately obtaining a weighted evaluation index for subsystems. The calculation steps are as follows:

$$W_j^1 = \frac{\sigma_j \sum_{h=1}^{n}(1-|r_{hj}|)}{\sum_{j=1}^{n}\left[\sigma_j \sum_{h=1}^{n}(1-|r_{hj}|)\right]} \tag{1}$$

$$W_j^2 = \frac{1-e_j}{\sum_{j=1}^{n}(1-e_j)}, \text{ where, } e_j = -(\ln m)^{-1}\sum_{i=1}^{m} p_{ij}\ln p_{ij}, \quad p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{2}$$

$$W_j = (W_j^1 + W_j^2)/2 \tag{3}$$

$$Z = \sum_{j=1}^{n} W_j \times x_{ij} \tag{4}$$

where, W_j^1 is the weight of the j-th indicator for the CRITIC method, σ_j represents the standard deviation of the j-th indicator, n is the number of evaluation indicators, r_{hj} denotes the correlation coefficient between the h-th and j-th indicators, W_j^2 represents the weight of the j-th indicator according to the entropy weight method, x_{ij} is the data for the j-th indicator of the i-th city post range normalization, p_{ij} is the proportion of the i-th city's value under the j-th indicator relative to the total value of that indicator, m is the quantity of cities, e_j is the entropy value of the j-th indicator, Z is the composite evaluation index obtained through linear weighting, and W_j is the comprehensive weight of the j-th indicator derived through the CRITIC-entropy weight method.

2.3.2 Kernel density estimation

Kernel density estimation, an important non-parametric estimation method, is favored for its ability to produce a continuous probability density curve based on the data's own distribution characteristics without imposing any assumptions on data distribution. This allows for an intuitive display of the variable's temporal evolution trend. The Gaussian kernel function, the most widely used in academia, was selected in this study for analysis. The dynamic evolution process and trajectory of variable distribution were identified by examining the main peak location, shape, and its extensiveness of the kernel density curve. The function is expressed as follows:

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{X_i - \bar{x}}{h}\right), \text{ where, } K(x) = \frac{1}{\sqrt{2\pi}}\exp\left(-\frac{x^2}{2}\right) \tag{5}$$

where, $f(x)$ is the probability density function, n is the quantity of cities, h is the bandwidth (the smoothing parameter of the curve), X_i is the sample observation value, $\bar{x}$ is the sample mean, and $K(x)$ represents the basic form of the Gaussian kernel function.

2.3.3 Dagum Gini coefficient

Given that methods such as the coefficient of variation, Theil index, and traditional Gini coefficient for analyzing regional disparities are predicated on assumptions that samples follow a normal distribution and homoscedasticity and do not account for overlapping sub-samples, their precision and reliability are somewhat lacking. The Dagum Gini coefficient, by decomposing total disparity into intra-regional disparity (G_w), inter-regional disparity (G_{nb}), and transvariation density (G_t), effectively eliminates the interference of sub-sample overlap on research results and accurately identifies the primary sources of regional differences, increasingly becoming a core tool for measuring regional disparities. The overall Gini coefficient is calculated as follows:

$$G = G_w + G_{nb} + G_t = \frac{\sum_{j=1}^{k}\sum_{h=1}^{k}\sum_{i=1}^{n_j}\sum_{r=1}^{n_h} |y_{ji} - y_{hr}|}{2n^2\bar{y}} \tag{6}$$

where, G is the overall Gini coefficient; k represents the number of regions studied, with $k = 3$; y_{ji} and y_{hr} denote the development levels of green finance in the i-th city of the j-th region and the r-th city of the h-th region, respectively; n is the total number of cities; n_j and n_h are the total numbers of cities in the j-th and h-th regions, respectively; and $\bar{y}$ signifies the overall average level of green finance development in the Yangtze River Economic Belt.

3. Analysis of the Measurement Results of Green Finance Development Level

3.1 Temporal Distribution Characteristics

Based on the evaluation indicator system and measuring methods designed earlier, the green finance development levels across 107 cities in the Yangtze River Economic Belt were calculated. This study first depicted the bar trend of the average and median levels of overall green finance development during 2007-2020 (Figure 1), aiming to intuitively present the evolutionary trend of development levels in the Economic Belt. Secondly, to facilitate the examination of the dynamic trends in the development levels of green finance from a regional perspective, line graphs of the average development levels for the entire Economic Belt and its three major regions were drawn (Figure 2). Lastly, considering that regional-level analysis might mask the heterogeneity in the development levels of green finance among cities, Table 2 reports the cities that ranked in the top 20 in green finance development levels in the Economic Belt for 2007, 2010, 2015, and 2020.

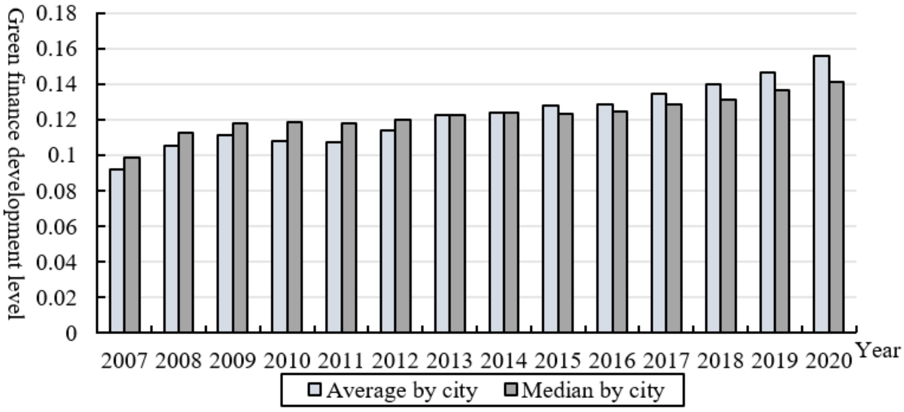


Figure 1. The trend of the average value and medium numbers of green financial development levels in the Yangtze River Economic Belt from 2007 to 2020

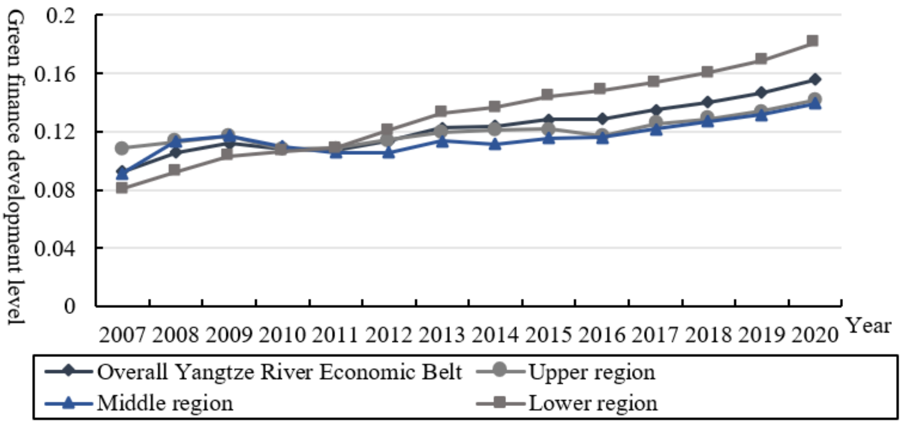


Figure 2. Trends in green finance development levels in the Yangtze River Economic Belt and its three major regions from 2007 to 2020

From an overall perspective, it was calculated that within the study period, both the average and median levels of green finance development among the 107 cities in the Yangtze River Economic Belt exhibited fluctuating upward trends. Specifically, in 2007, the average and median were recorded at 0.092 and 0.098, respectively, and by 2020, these figures had increased to 0.156 and 0.142, with annual growth rates of 2.84% and 4.14%, respectively, showing some progress in the development of green finance across the Economic Belt. However, the overall growth remains modest and significant potential for improvement exists. Comparing the average- and median-level green finance development over the years revealed that the average was always less than the median in the early stages of the study. However, post-2015, the average consistently exceeded the median, indicating a gradual shift from a left-skewed to a right-skewed distribution. This suggests that as time progressed, a few cities demonstrated notable levels of green finance development, while the majority remained below the average, highlighting substantial disparities in the development levels of green finance among cities.

From a regional perspective, the long-term evolution trend of the average development levels of green finance across the three major regions aligned with the overall trend. The period from 2007 to 2016 saw a fluctuating upward trend, which turned into a continuous growth from 2017 to 2020. This could be attributed to the "Guidelines for Green Financial System Construction" jointly released by the People's Bank of China, the Ministry of Finance, and other departments in 2016, which provided a clear direction and pathway for regions to actively explore green finance models and deepen financial services, thereby significantly propelling the green finance development. Specifically, the annual growth rates of green finance development in the upper, middle, and lower regions were 2.07%, 3.03%, and 6.41%, respectively, presenting a characteristic of "lower region > middle region > upper region" in terms of average annual growth rate. The differences could be due to the varying financial foundations and resource endowments across regions, with the lower region leveraging its advantageous location and business environment to attract a large number of environmental protection enterprises and nurture a robust green finance market, hence achieving a more pronounced improvement in green finance development.

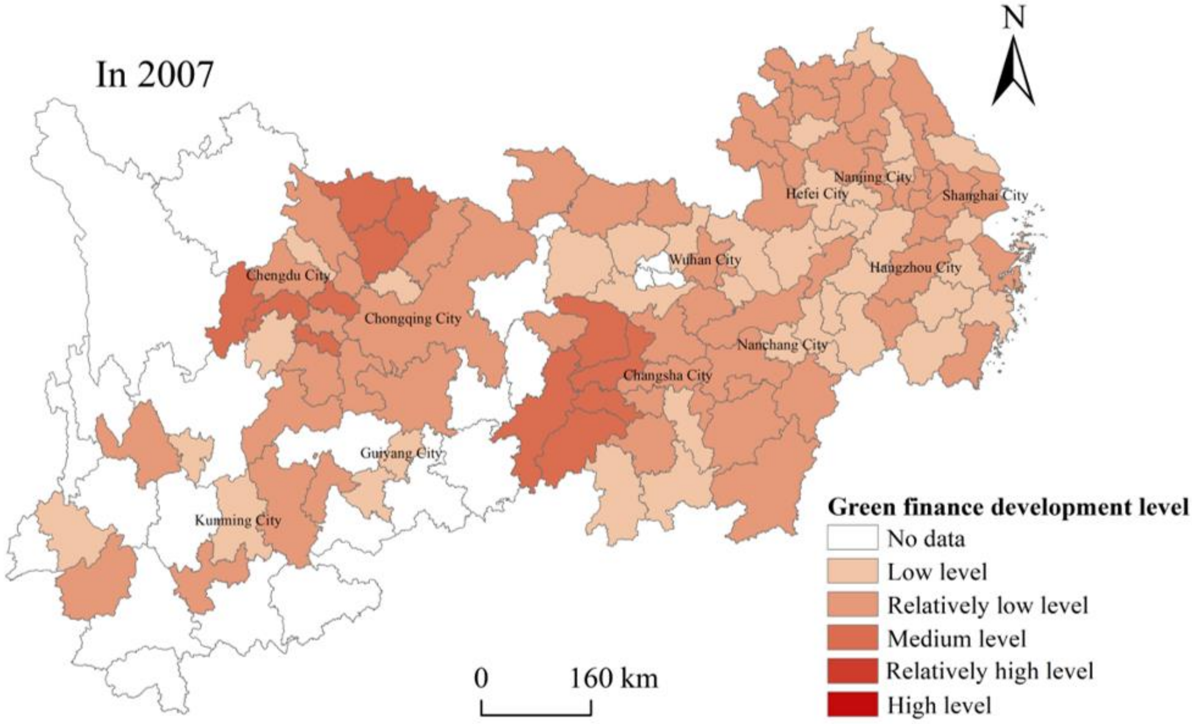
From the perspective of city-level analysis, cities like Ziyang, Yiyang, and Bazhong ranked at the forefront in green finance development in 2007, primarily due to their initiation of policy-oriented agricultural insurance pilot projects in 2007, which led to rapid development in green insurance, thereby driving the overall level of green finance. Following the successive implementation of the Eleventh, Twelfth, and Thirteenth Five-Year Plans, provincial capitals such as Shanghai, Hangzhou, and Chongqing took proactive measures. Leveraging their unique administrative and economic advantages, these cities drove rapid development in green finance and consistently ranked in the top three in 2015 and 2020, with the regional ranking becoming more stable overall. Additionally, it was observed that the disparity in green finance development levels between cities widened significantly, with the gap between the city ranked first and the city ranked twentieth expanding from 0.0661 in 2007 to 0.5298 in 2020, with an annual growth rate of 17.36% in the disparity. This reflects an uneven development trend in green finance levels among cities throughout the study period.

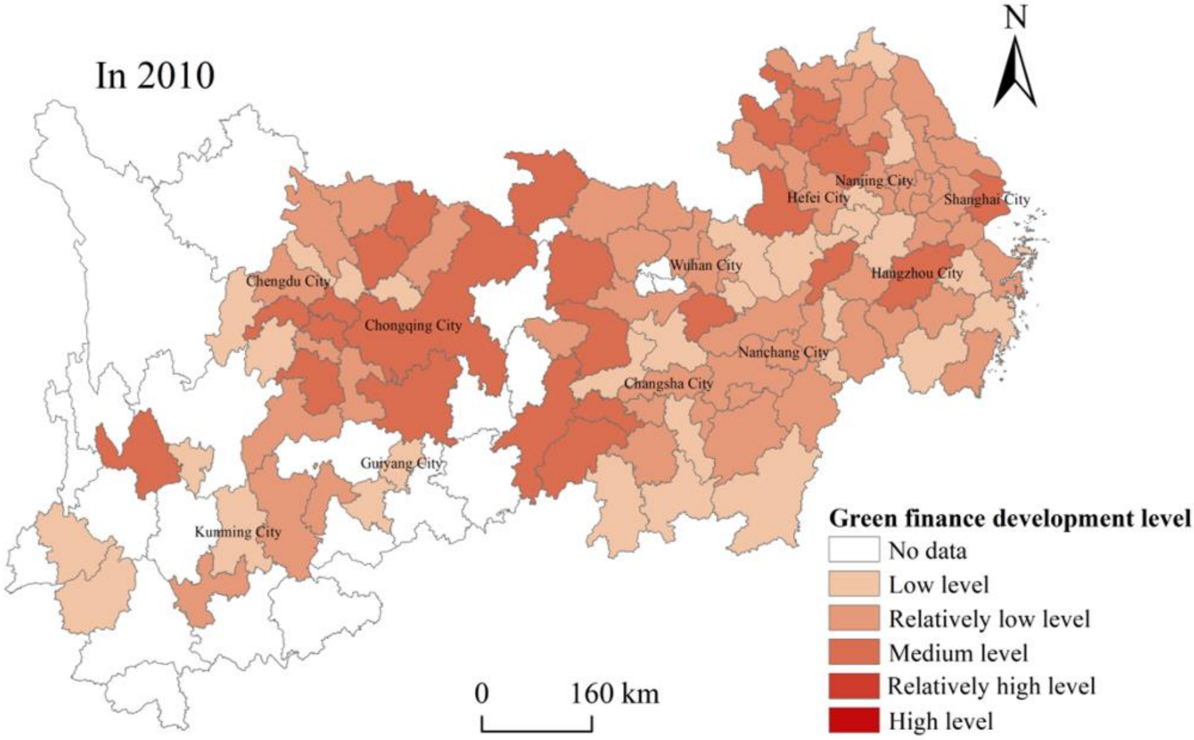
Table 2. Green finance development levels in selected cities of the Economic Belt

Rank	2007		2010		2015		2020	
	Cities	Green Finance Development Level	Cities	Green Finance Development Level	Cities	Green Finance Development Level	Cities	Green Finance Development Level
1	Ziyang	0.1857	Shanghai	0.1892	Shanghai	0.5453	Shanghai	0.7090
2	Yiyang	0.1825	Chongqing	0.1667	Hangzhou	0.3188	Hangzhou	0.4864
3	Bazhong	0.1732	Suzhou	0.1616	Chongqing	0.3038	Chongqing	0.4141
4	Guangyuan	0.1691	Changde	0.1601	Chengdu	0.2730	Chengdu	0.4016
5	Changde	0.1615	Hangzhou	0.1600	Suzhou	0.2665	Nanjing	0.3906
6	Ya'an	0.1546	Ziyang	0.1578	Nanjing	0.2604	Wuhan	0.3711
7	Nanchong	0.1545	Bengbu	0.1547	Wuhan	0.2386	Suzhou	0.3646
8	Shaoyang	0.1539	Yichang	0.1537	Ningbo	0.2275	Changsha	0.3009
9	Loudi	0.1510	Shaoyang	0.1476	Changsha	0.2001	Ningbo	0.2984
10	Meishan	0.1501	Lijiang	0.1471	Yichang	0.1999	Hefei	0.2565
11	Huaihua	0.1448	Meishan	0.1467	Wuxi	0.1907	Nanchang	0.2342
12	Zigong	0.1385	Nanchong	0.1462	Hefei	0.1889	Wenzhou	0.2268
13	Dazhou	0.1345	Xianning	0.1445	Wenzhou	0.1874	Wuxi	0.2254
14	Yibin	0.1338	Neijiang	0.1441	Kunming	0.1748	Anqing	0.2244
15	Neijiang	0.1287	Bozhou	0.1435	Nanchang	0.1563	Guiyang	0.2212
16	Mianyang	0.1252	Chuzhou	0.1426	Changde	0.1556	Kunming	0.2106
17	Zhangjiajie	0.1245	Yibin	0.1406	Nantong	0.1550	Nantong	0.2056
18	Lijiang	0.1242	Chizhou	0.1404	Guangyuan	0.1490	Lijiang	0.1953
19	Hengyang	0.1224	Lu'an	0.1397	Guiyang	0.1482	Changzhou	0.1850
20	Shanghai	0.1196	Zunyi	0.1381	Ziyang	0.1461	Changde	0.1792

3.2 Spatial Distribution Characteristics

Drawing upon existing research (Yin et al., 2023), the development levels of green finance were classified into five categories using the Jenks natural breaks method in ArcGIS 10.8 software, namely, low, relatively low, medium, relatively high, and high. The green finance development indices of cities for the years 2007, 2010, 2015, and 2020 were then spatially visualized (Figure 3) to analyze the spatial distribution characteristics of green finance development levels across the Yangtze River Economic Belt.


In 2007
N
Chengdu City
Chongqing City
Wuhan City
Hefei City
Nanjing City
Shanghai City
Hangzhou City
Nanchang City
Changsha City
Guiyang City
Kunming City
Green finance development level
No data
Low level
Relatively low level
Medium level
Relatively high level
High level
0
160 km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Green finance development level
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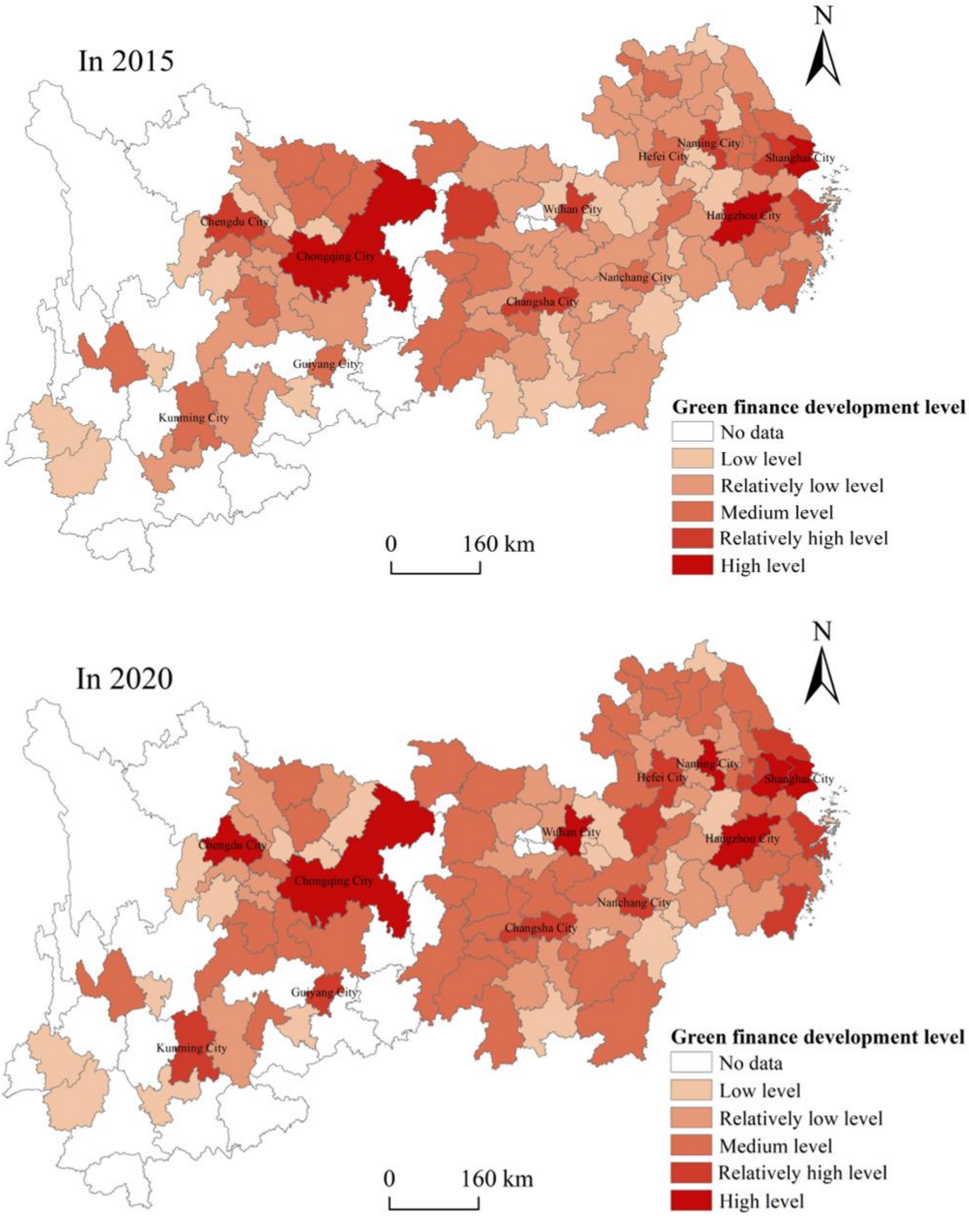


Figure 3. Spatial differentiation map of green finance development levels in the Economic Belt

Overall, the level of green finance development in the Yangtze River Economic Belt has improved, yet significant spatial heterogeneity within the region remains evident. Initially dominated by low and relatively low development levels, by the end of the study period, most cities had transitioned to relatively high levels of development, exhibiting a spatial evolution characterized by expanded high-value areas and contracted low-value ones. The following specific conditions can be observed:

(i) In 2007, the green finance development in the Economic Belt was uneven, with some cities in the upper and middle regions at a medium development level, while all cities in the lower reaches were categorized as low or relatively low. This could be attributed to the initial stages of green finance exploration, where the lower reaches had a weaker awareness and atmosphere for green development, still prioritizing high-energy-consuming industries as the main body, leading to heavy industrial emissions and lower green finance development levels.

(ii) By 2010, the green finance development level across the Economic Belt had improved, with a noticeable increase in the number of cities at a medium level of development from 12 in 2007 to 24 in 2010. This spread gradually from the upper and middle reaches to the lower ones, possibly related to the accelerated financial system reforms and actively developed environmental protection industry in the "Eleventh Five-Year Plan" period, which, promoted the green finance development in the region to some extent.

(iii) In 2015, the green finance development level underwent qualitative improvement. Cities with relatively high- and high-level green finance development achieved a breakthrough, with cities such as Nanjing, Suzhou, Ningbo, Wuhan, Yichang, Changsha, and Chengdu entering the ranks of cities with relatively high levels of development for the first time. Shanghai, Hangzhou, and Chongqing transformed into cities with high levels of green finance development. It is evident that cities with rapid increases in green finance development were predominantly economically developed provincial capitals. These cities, with advantages in resource ownership, market construction, and policy support, could effectively strengthen green finance services and continuously push for the deep green finance development.

(iv) By 2020, after the key development periods of the "Eleventh, Twelfth and Thirteenth Five-Year Plans," the green finance level in the Economic Belt was further enhanced. The majority of cities were at medium or higher development levels, with the number of cities at a high development level continuously increasing, mainly in provincial capitals with point-like distributions such as Shanghai, Nanjing, Hangzhou, Wuhan, and Chengdu. Although the number of cities at low and relatively low levels of development decreased, they still accounted for 44.86% of the total study sample, indicating that the regional development of green finance overall remains unbalanced, with significant differences still existing between cities.

4. Regional Disparities in the Development Level of Green Finance

By showcasing the spatio-temporal evolution trends of green finance development levels across the Yangtze River Economic Belt, a macroscopic perspective reveals the existence of spatial non-uniformity in green finance development. To more precisely measure the magnitude of these disparities and explore their sources, this study employs the Dagum Gini coefficient and its decomposition method to investigate the variations and sources of green finance development levels both within regions (among cities) and between regions (among the three major areas). This approach further clarifies the impact of intra- and inter-regional disparities on the overall variations in green finance development across the Economic Belt, ultimately providing decision-making references for the coordinated development of regional green finance. The specific measurement results are presented in Table 3.

Table 3. Dagum Gini coefficient and the decomposition results

Year	Gini coefficient (G)	Intra-Regional Disparity (G_w)			Inter-Regional Disparity (G_{nb})			Transvariation Density (G_t)	Contribution Rate (%)		
		Upper Region	Middle Region	Lower Region	Upper-Middle Regions	Upper-lower Regions	Middle-lower Regions		G_w	G_{nb}	G_t
2007	0.233	0.200	0.241	0.217	0.230	0.250	0.244	0.096	31.261	27.727	41.013
2008	0.200	0.199	0.196	0.182	0.217	0.206	0.190	0.089	32.089	23.379	44.532
2009	0.182	0.194	0.172	0.166	0.193	0.188	0.170	0.092	32.989	16.645	50.366
2010	0.187	0.195	0.208	0.155	0.206	0.177	0.185	0.117	33.338	4.361	62.301
2011	0.199	0.172	0.216	0.204	0.200	0.189	0.213	0.126	33.422	3.331	63.247
2012	0.219	0.198	0.227	0.223	0.217	0.216	0.227	0.114	33.553	14.230	52.217
2013	0.229	0.192	0.231	0.249	0.216	0.229	0.244	0.115	33.768	15.963	50.269
2014	0.241	0.211	0.230	0.258	0.226	0.247	0.249	0.112	33.668	19.955	46.377
2015	0.245	0.205	0.242	0.264	0.227	0.248	0.260	0.110	33.673	21.323	45.004
2016	0.257	0.213	0.276	0.261	0.248	0.252	0.282	0.113	33.316	22.720	43.964
2017	0.256	0.217	0.262	0.267	0.243	0.255	0.275	0.114	33.580	21.752	44.669
2018	0.266	0.207	0.278	0.286	0.248	0.261	0.294	0.120	33.589	21.246	45.165
2019	0.266	0.214	0.280	0.279	0.251	0.262	0.292	0.117	33.520	22.322	44.158
2020	0.276	0.218	0.284	0.295	0.255	0.274	0.303	0.120	33.550	22.940	43.510
Avg.	0.233	0.203	0.239	0.236	0.227	0.232	0.245	0.111	33.237	18.421	48.342

4.1 Overall Disparity and Intra-Regional Disparity

Firstly, the overall disparity in the development level of green finance across the Yangtze River Economic Belt was examined. Figure 4 depicts the overall disparity and its evolution trend in the development level of green finance across the Economic Belt. On the whole, the average Gini coefficient for overall disparity stands at 0.233, with an observed increase during the study period, indicating significant disparities in the overall development level of green finance across the Economic Belt, with the degree of disparity showing an expanding trend.

Specifically, the evolution trend of the overall disparity's Gini coefficient was summarized in two stages: the first stage from 2007 to 2009, where the Gini coefficient showed a rapid declining trend, obtaining its lowest value of 0.182 in 2009 with an annual decrease of 11.59% on average; the second stage between 2010 and 2020, during which the Gini coefficient exhibited a gradual upward trend, peaking at 0.276 in 2020 with an average annual increase of 3.96%.

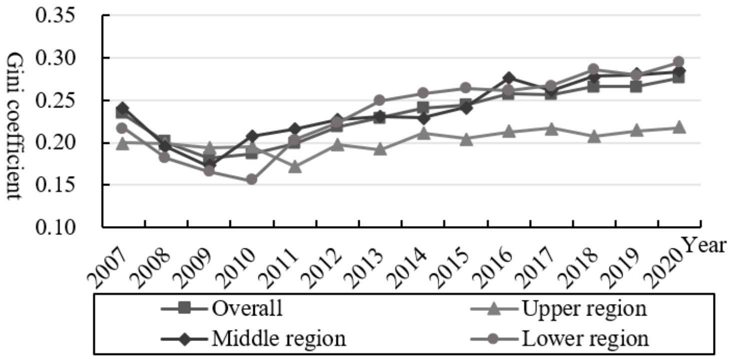


Figure 4. Evolution trend of overall and intra-regional disparity in green finance development levels across the Yangtze River Economic Belt

Subsequently, the intra-regional disparities in the green finance development level across the three major regions were examined. As for the average Gini coefficient, intra-regional disparities, in descending order, were observed as follows: the middle (0.239), lower (0.236), and upper (0.203) regions. Regarding the growth magnitude of the coefficient, the lower region experienced the largest increase, reaching 35.77%, with an average annual growth of 2.38%; the middle region achieved an increase of 17.78%, with an annual growth of 1.27% on average; the upper region recorded the smallest increase at 8.87%, with an annual growth of 1.30% on average. As for the evolution trend of the coefficient, the changes in the lower region broadly aligned with the overall disparity across the Economic Belt, exhibiting a two-phase evolution characteristic of “rapid decline-steady rise.” The disparities in the middle region showed a trend of “slight decrease-fluctuating increase.” The Gini coefficient in the upper region ranged between 0.172 and 0.218, indicating relatively stable intra-regional disparities. Moreover, comparing the three regions reveals that, up to 2011, the upper-region internal disparities were mostly higher than the internal disparities in the lower region; this situation reversed afterward. The initial phase might be attributed to the lower region's adherence to traditional economic development models, failing to effectively integrate green finance and other credit instruments into the trading market. However, when the "Twelfth Five-Year Plan" was introduced in 2011, which advocated using fiscal and financial means to vigorously develop the circular economy, a clear path was provided for regions to achieve sustainable development. Additionally, some cities in the lower region, with robust economic foundations, were able to quickly unleash development potential and drive efficient operation of green finance. During this process, such cities were more likely to aggregate quality resource elements, with the resulting agglomeration and scale effects further promoting the green finance development, thereby generating significant relative disparities within the region.

4.2 Inter-Regional Disparities

Figure 5 shows the inter-regional disparities and evolution trends in green finance development levels among the three major regions. Initially, looking at the average Gini coefficient values for inter-regional disparities, the differences between the middle and lower regions (0.245) were noticeably higher than those between the upper and lower regions (0.232), and the upper and middle regions (0.227). Furthermore, the trend of Gini coefficient changes indicates a similar pattern of variation across the disparities between the upper-middle, upper-lower, and middle-lower regions, primarily exhibiting a trend of initial decrease followed by an increase. Specifically, the disparity between the upper and middle regions fluctuated slightly, with the Gini coefficient increasing from 0.230 in 2007 to 0.255 in 2020, with an annual growth rate of 0.8% on average. The disparity between the upper and lower regions showed a "U-shaped" change, roughly divided into two phases. In the first phase from 2007 to 2010, the degree of regional disparity declined annually, with an average annual decrease of 10.83%, reaching its lowest in 2010 at 0.177. The second phase from 2011 to 2020 saw continuous expansion in regional disparity, with an annual growth of 4.19% on average, peaking in 2020 at 0.274. Similar to the disparity trends between the upper and middle regions, the disparity between the middle and lower regions also exhibited a "U-shaped" characteristic, which can be analyzed in two phases: the first phase from 2007 to 2009, where regional disparities significantly decreased, with an average annual decrease of 16.41%, reaching its lowest in 2009 at 0.170; the second phase from 2010 to 2020, where the Gini coefficient underwent an increase-decrease process, overall showing a fluctuating upward trend, with an average annual increase of 5.06%, peaking in 2020 at 0.303. Additionally, over time, the disparity between the middle and lower regions was noticeably higher compared with that between the upper and middle regions as well as the upper and lower regions, with the gap widening. This indicates significant disparities in the green finance development levels among regions within the Economic Belt, with the phenomenon of uneven regional development intensifying.

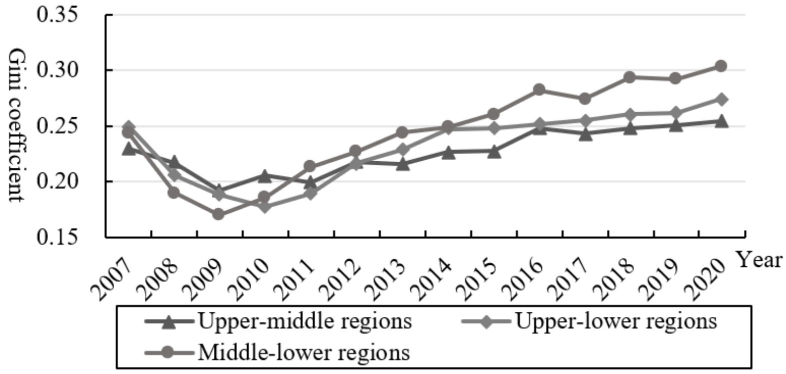


Figure 5. Evolution trend of inter-regional disparities in green finance development levels across the Yangtze River Economic Belt

4.3 Sources of Disparity and Their Contributions

Figure 6 depicts the sources of overall disparities in the development levels of green finance across the Yangtze River Economic Belt and their contribution rates. Observing the evolution of disparity sources, the contribution rates of intra-regional disparities in the upper, middle, and lower regions remained relatively stable, whereas the contribution rates of transvariation density and inter-regional disparities exhibited larger fluctuations, with their curves showing a symmetrical distribution of reciprocal changes. Specifically, the changes in the contribution rate of intra-regional disparities were minimal, maintaining around 33%, with the rate increasing from 31.26% in 2007 to 33.55% in 2020, marking an annual growth of 0.55% on average. The contribution rate of transvariation density showed an inverted "U-shaped" trend, with the smallest contribution in 2007 at 41.01%, peaking in 2011 at 63.25%. The changing trend of the contribution rate of inter-regional disparities was symmetrical to that of transvariation density, exhibiting a "U-shaped" characteristic, with the peak contribution rate in 2007 at 27.73% and the minimum in 2011 at 3.33%. Regarding the magnitude of contribution rates over the period studied, transvariation density consistently had the highest contribution rate, averaging 48.34%. The intra-regional disparities had a contribution rate of 33.24% on average. Finally, inter-regional disparities had a contribution rate of 18.42% on average. This indicates that the primary cause of disparities in green finance development levels across the Economic Belt is attributed to transvariation density, suggesting that there is no absolute advantage among the three major regions. Each region can still rely on its highlands of green finance development to cultivate new growth poles. Furthermore, the impact of intra-regional disparities on overall disparities cannot be underestimated, highlighting that reducing disparities within regions and promoting balanced and coordinated internal development are critical future directions.

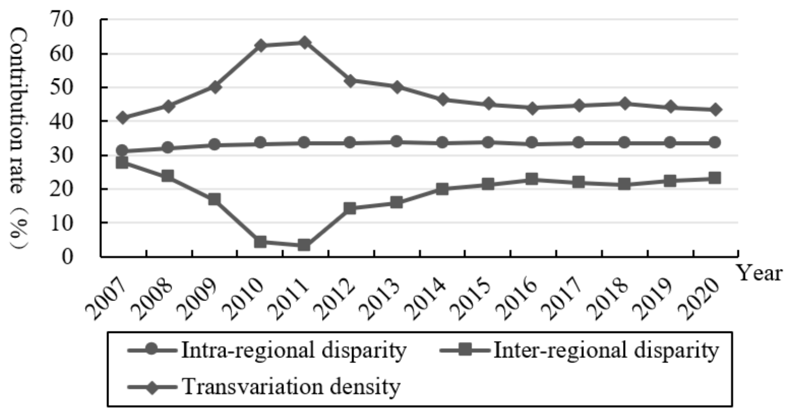
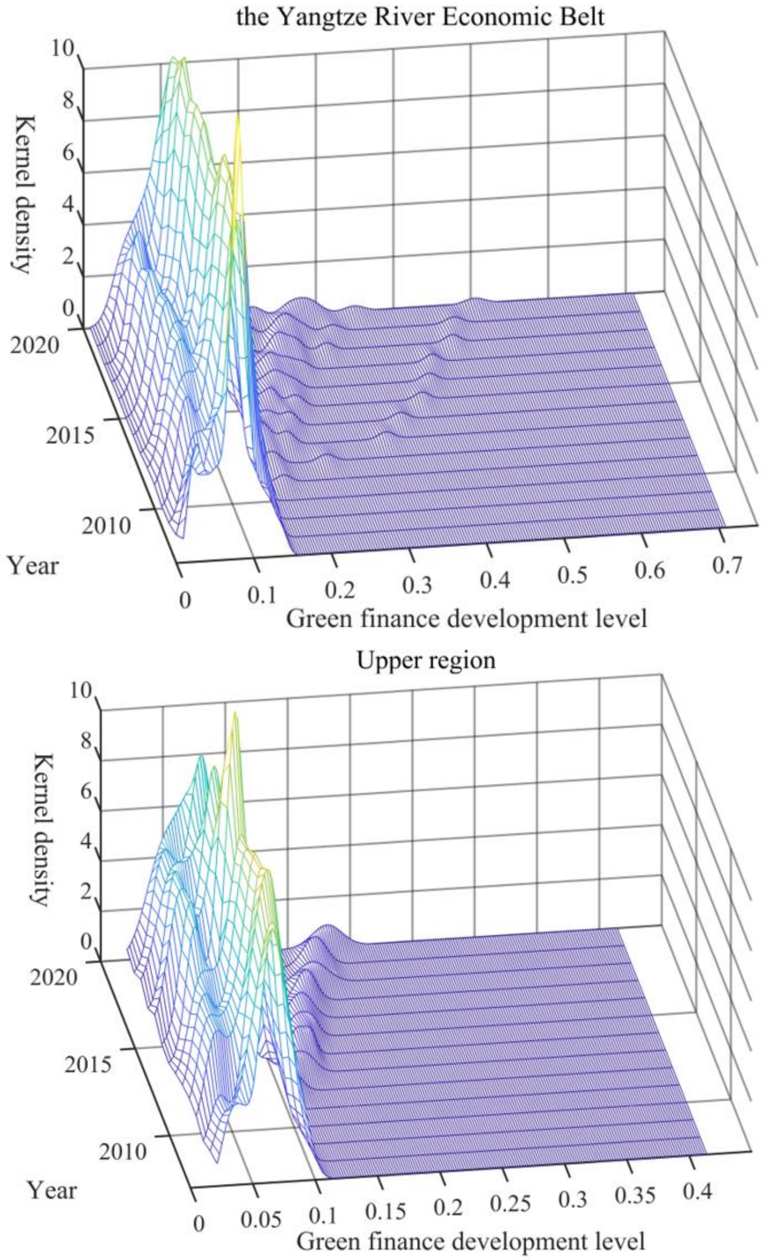


Figure 6. Evolution trend of regional disparity sources and contribution rates in the green finance development level across the Economic Belt

5. Dynamic Evolution of Green Finance Development Distribution

Building on the Dagum Gini coefficient analysis, detailed insights have been provided into the magnitude and sources of disparities in the development levels of green finance across the Yangtze River Economic Belt. However, these findings only reflect the relative disparities in green finance development levels within the Yangtze River Economic Belt, failing to depict the absolute disparities and their dynamic evolution. Therefore, the kernel density estimation was further employed in this study to explore the distribution location, shape, extension, and polarization trends of green finance development levels in the Yangtze River Economic Belt and its three major regions, as shown in Figure 7.

Observing the distribution location, the kernel density curves for the overall Economic Belt and its three major regions all exhibit a slight rightward shift, indicating a modest increase in green finance development levels over time, aligning with previous analyses. Specifically, the movement direction of the kernel density curves in the three major regions is consistent with that of the overall trend, but the magnitude of movement varies across regions. The lower region's curve shifts rightward the most, while the upper and middle regions experience lesser shifts, suggesting that the lower region's green finance development level is increasing more rapidly compared to the more gradual pace of the upper and middle regions. Therefore, future efforts should focus on enhancing the upper- and middle-region strength of green finance.



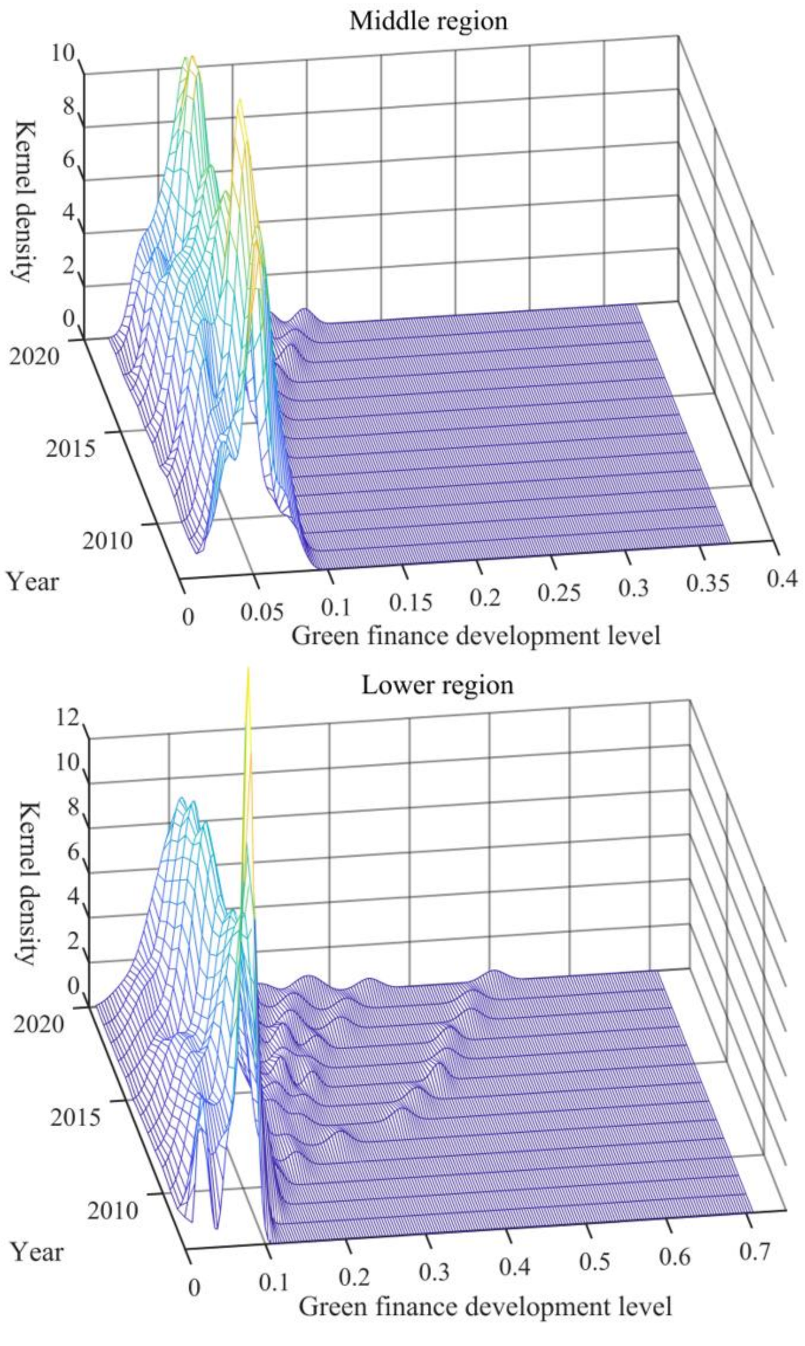


Figure 7. Dynamic distribution of green finance development levels across the Yangtze River Economic Belt and its three major regions

The distribution of the overall kernel density curve of the Economic Belt exhibits a cyclic fluctuation in peak height from "high to low." In 2007, the peak's width and height were at their narrowest and highest, indicating that the disparity in green finance development levels among cities within the Economic Belt was at its lowest. However, from 2017 to 2020, the curve's main peak continuously declines in value and broadens in width, reflecting an expanding trend in the absolute disparity of development levels within the region. By region, the peak height of the upper region's curve initially rises then falls, overall decreasing, with the peak width first narrowing then expanding, generally broadening; the middle region's peak height fluctuates frequently, with a slight increase in width; the lower region's peak height undergoes a "continuous decline-fluctuating rise" process, overall decreasing, with the curve's coverage width showing a slight broadening characteristic similar to the middle region. This indicates that, in the three major regions, the trends in absolute disparity changes in green finance development levels vary, but most regions show signs of expanding internal absolute disparities.

In terms of distribution extension, the overall kernel density curves for the Economic Belt evolves from left-skewed to right-skewed, indicating the presence of cities significantly below the average development level at the beginning of the period, which shifts towards cities significantly exceeding the average by the end. Regionally, the upper region initially displays a marked left-skewed pattern, which then transitions to a combination of left and right skewness, eventually showing some right-skewed characteristics towards the end. The middle region also starts with a left skewness, albeit to a lesser extent, ultimately evolving into a slight right skewness, suggesting a modest increase in green finance development levels throughout the period with substantial room for growth. The lower region undergoes an evolution from a gradually shortening left skewness to an extended right skewness, culminating in a pronounced right skewness. This indicates a decreasing number of cities in the lower development level and an increasing number of cities in the higher development level, with the disparity in green finance levels among cities gradually widening. Cities with higher levels of green finance development have further progressed, showing an "improvement of the better" effect within the region.

As for the entire Economic Belt and its three major regions, the kernel density curves initially exhibit a bimodal pattern, indicating a polarization phenomenon in the green finance development levels for cities within the region. The main peaks are significantly higher than the side peaks across the regions, indicating a gradient effect in the development levels of green finance within cities, with places like upper-region Chongqing, middle-region Wuhan, and lower-region Shanghai and Hangzhou serving as regional "front-runners" with evident leadership effects. Over time, the right side of the curves for the entire Economic Belt and its three major regions develops a certain convexity, with the distance between the right side peak and the main peak gradually widening and the width of the side peak broadening, indicating an evolution from polarization to a mild multipolarization of green finance development levels. The overall Yangtze River Economic Belt and the lower region, in particular, saw a significant increase in the number of peaks during the study period, transitioning from a "primary-secondary" to a "primary-multiple" scenario, highlighting a clear pattern of multipolar differentiation.

6. Conclusions and Recommendations

The CRITIC-entropy weight method was used for the development level measurement of green finance across the Yangtze River Economic Belt. In addition, the Dagum Gini coefficient and kernel density estimation were employed among other methods to reveal the regional disparities and dynamic evolution patterns of green finance development. The following main conclusions have been drawn:

First, from an empirical perspective, the green finance development level within the Economic Belt during the sample period grows in fluctuations and is spatially imbalanced. In terms of temporal changes, the overall green finance development in the Economic Belt shows a fluctuating upward trend. In addition, the development speed ranks from the lower region to the middle and upper regions. Spatially, although many cities have transitioned from lower to higher development levels, the imbalance in green finance development has not fundamentally changed. Cities with high levels of green finance development are mainly distributed as dots in municipalities and provincial capitals, whereas cities with medium and low levels are more commonly found in non-provincial capitals.

Second, regarding regional disparities, the overall disparity in the development level of green finance in the Economic Belt shows a widening trend. As for intra-regional disparities, the lower region experiences the greatest increase in the Gini coefficient, followed by the middle and upper regions. Inter-regionally, the disparity between the middle and lower regions is significant, while the disparity between the upper and middle regions is less obvious. In terms of contribution rates, transvariation density is the primary source of overall disparity, followed by intra-regional disparities, and finally, inter-regional disparities.

Third, in terms of dynamic evolution characteristics, the development trends of green finance in the Yangtze River Economic Belt and its three major regions are largely consistent. The centers of the kernel density curves all move rightward, with the "right tail" broadening, and the number of peaks increasing to some extent. This indicates that the overall level of green finance development in the Yangtze River Economic Belt is improving. However, the absolute disparity is widening, and the development level of green finance is gradually evolving into a multipolar differentiation trend.

The conclusions of this study indicate that during the inspection period, the level of green finance development in the Yangtze River Economic Belt has improved, yet the characteristic of spatial imbalance is pronounced. Minimizing the regional disparities in green finance development becomes a pressing issue that demands attention at this stage. In response to these conclusions, the following recommendations are offered:

First, with a long-term perspective, there should be continuous efforts to elevate the development level of urban green finance. In recent years, the development level of green finance in various cities within the Economic Belt has achieved improvements to varying degrees, yet substantial room for progress remains. Cities should execute the national strategy for green development and establish a long-term development mechanism. On one hand, relying on government policies and market trading mechanisms, efforts should be made to actively construct a comprehensive financial system for the entire basin, dominated by banks and supplemented by private capital, to effectively scale up green finance. On the other hand, by leveraging the power of financial technology, the flow of funds in green projects should be fully traceable, and corporate environmental information disclosure should be strengthened to collectively address the challenge of "greenwashing" projects, thereby actively promoting the application of green finance products and improving green finance services.

Second, differentiated strategies should be applied to promote balanced development across regions of the Economic Belt. As a crucial ecological barrier of the Yangtze River Basin, the upper region has relatively weaker economic environment. Therefore, it could focus on implementing special actions to get green and low-carbon enterprises listed, and relying on the Chengdu-Chongqing economic circle, actively promote the mutual recognition and cross-regional settlement services for financing collaterals. The middle region, being a traditional manufacturing base of the nation with a solid foundation in high-energy-consuming industries, should concentrate on developing low-carbon environmental industries such as hydrogen energy, direct current electricity, and green lighting, to accelerate the transition towards green and low-carbon development. With a relatively stronger financial foundation, the lower region could innovate green financial products like tea loans, homestay loans, and "carbon accounts", and establish a "1+N" green industry development system integrating green finance with green manufacturing, green building, green transportation, green energy, and green agriculture and forestry.

Third, an integrated approach should be adopted to create a coordinated development pattern for green finance. The Economic Belt should adhere to a unified development approach, employing multiple measures to promote vertical and horizontal linkages in green finance development across regions, effectively solving the problem of unbalanced regional development. On one hand, an active effort should be made to establish a joint mechanism for green finance policies, involving banks, non-bank financial institutions, and enterprises in policy-making, to boost the efficiency and execution of green finance policies. On the other hand, efforts should focus on breaking down administrative barriers between cities and regions, vigorously advancing cross-departmental, cross-organizational, and cross-regional collaboration in green finance. By constructing a big data platform, it's possible to achieve shared green finance information, monitoring, evaluation, and regulatory coordination, addressing the issue of unbalanced and inadequate green finance development across regions.

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Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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