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Spatio–Temporal Evolutionary Features and Drivers of Green Competitiveness of Cities Surrounding the Yellow River

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Abstract: Based on the scientific concept of city green competitiveness, an integrated evaluation indicator system was established to use the entropy method in order to measure the green competitiveness index of 78 cities surrounding the Yellow River (YR) from 2006 to 2020. Further, the spatio–temporal features and drivers of city green competitiveness were analyzed using various methods. The research found the following: (1) Although the green competitiveness of cities surrounding the YR has been growing steadily, the overall level is not high. (2) The green competitiveness of cities surrounding the YR can be spatially characterized as "downstream > midstream > upstream"; the absolute and relative differences between cities are both increasing, and overall differences stem mainly from the hypervariable density. (3) The positive spatial correlation between the green competitiveness of cities surrounding the YR is significant, with the "cold spot" in southeastern Gansu and the "hot spot" in the Shandong Peninsular city cluster. (4) The level of city infrastructure construction, the level of urbanization, and science and technology innovation are the main drivers of the green competitiveness of cities surrounding the YR. In addition, the interaction forces of each factor were found to be much stronger than the effects of individual factors.

Keywords: Yellow River Basin; cities; green competitiveness; spatio–temporal features

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1. Introduction

The city is an important vehicle for regional economic development and residents' quality of life. In the context of the changing global green era, city green development is the path towards sustainable economic and social development [1]. In July 2022, the National Development and Reform Commission (NDRC) released the Implementation Plan for the New Type of Urbanization of the 14th Five-Year Plan, which proposed to transform the city development mode and create green cities. Green competitiveness reflects the comprehensive power of cities to sustain their competitive advantage by adopting a green approach model that conserves resources and is environmentally friendly, creating material resources, ecological wealth, and social welfare in the process of competition. Therefore, improving a city's green competitiveness is a key way to achieve prosperity for the city, optimize the city environment, and enhance social wellbeing. The Yellow River Basin (YRB) is a main area of economic development and population movement in China and is a vital barrier to eco-safety for the whole country, playing an irreplaceable strategic role in the national development pattern. In September 2019, the ecological conservation and high-quality development of the YRB rose to the level of an important national strategy priority [2] and was mentioned several times in the report of the 20th National Congress of the Communist Party of China. At present, the YRB's fragile ecosystem; the traditional development model of "high pollution, high emissions, high energy consumption, and low utilisation", which is difficult to change completely; and the uncoordinated development of the region remain prominent problems. In 2021, in the YRB, soil erosion covered an area of approximately 259,300 square kilometers, and energy carbon emissions exceeded

30% of the national total. Enhancing the green competitiveness of cities surrounding the YR can reduce environmental risks, optimize industrial and energy structures, and contribute to efficient and synergistic regional development. Therefore, in the context of the increasing incompatibility between ecology and development in the YRB, a study of the spatio–temporal patterns and drivers of the green competitiveness of cities surrounding the YR will not only help to improve the level of green competitiveness of these cities, but also to reduce regional differences between the upstream, midstream, and downstream, and thus achieve high-quality economic, social, and environmental development across the basin.

2. Literature Review

Current research on green competitiveness focuses on the following four areas:

(1) On the meaning of green competitiveness. Most scholars believe that regional green competitiveness, referring to green development as the main task, with the goal of achieving a harmonious symbiotic effect between human development and nature, to create an environmentally friendly and green eco-type region with a unique green competitive advantage [3], is a synthesis involving various aspects such as resource environment, society, and economy [4]. Enhancing regional green competitiveness not only emphasizes the green transformation of traditional industries, but also the innovative development of green industries [5]. Strengthening the level of ecological protection is a prerequisite for enhancing regional green competitive advantages [6], while regional economic growth and equitable distribution should also be considered [7,8].

(2) On green competitiveness indicator systems. Advances have been made in the construction of an index system of green competitiveness: Some scholars have established a green competitiveness index evaluation system at the national level based on the three dimensions of green nature, green economy, and green society [9]; some scholars have also constructed a provincial green competitiveness index system comprising the six aspects of environmental protection factor, ecological factor, recycling factor, low-carbon factor, health factor, and sustaining factor [10] or the five aspects of green high-quality growth competitiveness, resource saving and emission reduction competitiveness, city ecological and environmental quality competitiveness, green lifestyle competitiveness, and green investment competitiveness [11]. Other scholars have evaluated the development level of the green competitiveness of municipalities based on four dimensions [12], namely economic green development, social green development, resource green development, and environmental green development, or three dimensions [13], namely green economy, green investment, green utilization, and green security. In addition, Wang et al. (2022) constructed a comprehensive evaluation index system for green competitiveness in rural China based on the "green growth—green wealth—green welfare" framework [14].

(3) On the spatio–temporal patterns of green competitiveness. There is extensive research on the spatio–temporal pattern of regional green competitiveness, with numerous research methods such as the coefficient of variation [1], the Thiel index [15,16], the Dagum Gini coefficient (DGC) [11], the convergence model [1], the spatial exploratory model [17], and the coupling and coordination model [18], which have been widely used. Studies show that China's regional green competitiveness continues to improve, with the green competitiveness of the eastern region being much higher than that of the other regions, and the regional differences are characterized first by an increase and then a decrease; the coupling coordination degree of China's regional green competitiveness system exhibits significant spatial dependence, forming a high-coupling coordination degree agglomeration with Shanghai as the center spreading to the south and a low-coupling coordination degree agglomeration with Qinghai as the center spreading to the east [11]. Wang et al. (2022) analyzed the spatial and temporal characteristics and drivers of China's rural green competitiveness through spatial

autocorrelation (SA) analysis and GeoDetector and found that China's rural green development presents a spatial differentiation feature that is high in the eastern region and low in the central and western regions [14]. Ma et al. (2023) analyzed regional differences in China's green competitiveness through methods such as coefficient of variation analysis and found that the coefficient of variation in green competitiveness of China's 30 provinces and the eastern, central, and western regions show an inverted U-shape trend of first increasing and then decreasing [19]. Li et al. (2022) explored the changing characteristics of the green development level in Hunan Province based on the DPSIR model and proposed that there are significant spatial differences in the level of green development in counties in Hunan Province, showing a pattern of "strong in the east and weak in the central and western parts of the country" [20].

(4) On factors influencing green competitiveness. FDI [21], transport systems [22], finance [23–25], green innovation, environmental regulation [26–28], green logistics [29], and environmental innovation strategies [30] are widely recognized by academics as key elements influencing green competitiveness. Some studies also suggest that the circular economy constrains the creation of green competitiveness of enterprises [31], and at the same time, the circular economy and the core competitiveness of enterprises form a connecting link between the preceding and the following [32], which can help to promote the green innovation of enterprises, optimize the strategic layout of their development, and improve their green competitiveness and digital transformation as a new form of economic development. Furthermore, it can improve the green competitiveness of enterprises by increasing the production of green products, enhancing the level of technological innovation and promoting green investment, although this effect is subject to the constraints of environmental uncertainty [33]. A few other scholars believe that to enhance industrial competitiveness, it is necessary to improve the rationality and sophistication of the industrial structure [34,35], to construct an institutional system to match the regional green development, and to provide an institutional environment for green innovation of the industry [36]. Meanwhile, regional green competitiveness is affected by factors such as the digital economy [37], industrial agglomeration [38–40], public pressure [41], human capital [42], the environmental management system [43], technological innovation [44], urbanization [45], and environmental policy [46]. At the same time, the factors affecting regional green competitiveness exhibit spatial variations and peculiarities [47].

In summary, there is still limited research on green competitiveness by domestic and international scholars. This paper seeks to make a breakthrough in three areas: First, most scholars have studied green competitiveness from the enterprise, industry, and regional dimensions. Few scholars have considered this from the perspective of a watershed, where the watershed is a relatively independent geographic unit, and the natural, economic, social, and cultural elements within it are closely interrelated, together forming a composite system. Therefore, the 78 prefecture-level cities surrounding the YR were used as research objects to analyze the trends in evolution of the spatio–temporal patterns of green competitiveness in the YRB overall and up-, mid-, and downstream, which helps to reduce the differences in the development of green competitiveness among regions. Second, this paper constructs a more scientific and comprehensive evaluation index system for city green competitiveness. In the previous literature, the indicator system used mainly explains the level of regional green development and does not fully cover the feature of "competitiveness". By further disaggregating the three systems of economy, society, and environment into two parts—foundation and efficiency— this paper explains more clearly the "effectiveness" of the process of city green development. Third, most scholars have analyzed the spatio–temporal characteristics of city green competitiveness but have neglected the driving factors that form these characteristics. Further exploring the factors that form the spatio–temporal characteristics is fundamental to solving the problem of spatial differences. With a focus on the specific circumstances of the YRB, targeted indicators were selected to explore the drivers of spatial differences in the green competitiveness of cities in this region and

to provide a reference for improving the overall level of the green competitiveness of these cities.

3. Materials and Methods

3.1. Research Area

The YR originates in the Bayankara Mountains and flows through nine provinces in China, and then into the Bohai Sea. Due to the fact that the main body of Sichuan Province belongs to the Yangtze River Basin, and that the natural watershed of the YR covers a wide and irregular area, taking into account the continuity of the geographic units, the completeness of the provincial administrative units, and the availability of data, and referring to Xu et al. (2023) [48], the object of study was defined as 78 prefecture-level cities in eight provinces along the Yellow River route: Qinghai, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, and Shandong. Among them, the upstream area of the YR includes 18 prefecture-level cities in three provinces (autonomous regions), namely, Qinghai, Gansu, and Ningxia; the midstream area of the YR includes 27 prefecture-level cities in three provinces (autonomous regions), namely Inner Mongolia, Shaanxi, and Shanxi; and the downstream area of the YR includes 33 prefecture-level cities in two provinces, namely, Henan and Shandong.

3.2. Indicator System

Based on the prior studies, this study combines the concept of regional green competitiveness with the principles of scientificity, objectivity, comprehensiveness, and accessibility to reconstruct a green competitiveness evaluation indicator system for cities surrounding the YR (Table 1).

Table 1. Green Competitiveness Indicator System for Cities surrounding the YR.

Target Level	System Level	Guideline Level	Indicator Name
Green competitiveness	Economic system	Economic foundation	GDP per head (RMB 10,000/person)
			Percentage of production value in the secondary and tertiary sectors (%)
			Regional fiscal revenue per head (RMB)
			Investment in fixed assets (RMB 10,000)
			Science and technology expenditure as a percentage of public finance expenditure (%)
			The amount of people employed in science and technology and services (persons)
			Number of green patents granted per million population (cases/million people)
		Economic efficiency	Industrial wastewater emissions per unit GDP (tons/RMB 10,000)
			Domestic waste generation per unit GDP (tons/RMB 10,000)
			Energy consumption per unit GDP (10,000 tons of standard coal/RMB 10,000)
			CO_2 emissions per unit GDP (tons/RMB 10,000)
			Industrial sulfur dioxide emissions per unit GDP (tons/ RMB 10,000)
			Water consumption per unit GDP (tons/ RMB 10,000)
			Land use per unit GDP (tons/ RMB 10,000)

Table 1. *Cont.*

Target Level	System Level	Guideline Level	Indicator Name
Green competitiveness	Social system	Social foundation	Length of natural gas supply pipeline (km)
			Number of buses per 10,000 people (standard units)
			Number of hospital beds (beds)
			Public library collections (10,000 volumes)
			Number of university students per 10,000 population (persons)
			City road area (10,000 $m^{2)}$
		Social efficiency	City disposable income per head (RMB 10,000)
			City registered unemployment rate (%)
			Urbanization rate (%)
			Carbon emissions per head (tons/person)
			Gas penetration rate (%)
			Engel coefficient (/)
			Variations in income levels between city and rural areas (/)
	Environmental system	Environmental foundation	Forest coverage (%)
			Greening coverage of built-up areas (%)
			City green space (hectares)
			Length of city drainage pipes (km)
			Public toilets (seats)
			Total number of vehicles and equipment dedicated to amenities and sanitation (units)
		Environmental efficiency	Annual percentage of days with air quality at level 2 and above (%)
			Share of clean energy in energy consumption (%)
			Industrial water reuse rate (%)
			The integrated utilization rate of industrial solid waste (%)
			City domestic wastewater treatment rate (%)
			City waste disposal rate (%)
			City road sweeping and cleaning area (m^2)

City green competitiveness is a comprehensive measure of the level and hierarchy of green development in different cities, reflecting the ability of different cities to achieve economic growth, create social welfare, and improve environmental conditions in an efficient, clean, resilient, and sustainable manner [18]. The integrated evaluation indicator system of city green competitiveness in this paper is based on the three dimensions of economy, society, and environment. Referring to the study of Xu et al. (2023) [48], this paper divided the three dimensions into two parts: foundation and efficiency. Foundation reflects the underlying strength of city green competitiveness, and efficiency reflects the growth capacity and development potential of city green competitiveness.

In the economic system, the economic foundation mainly consists of economic development and science and technology (S&T) progress, in which S&T progress, from the input–output perspective, selecting the input of funds and talents and the output of patents,

comprises a total of seven indicators. The economic efficiency covers the efficiency of the use of resources in the process of economic development, taking into account mainly undesired outputs in the process of industrial production, residential life, and city construction, with a total of seven indicators. In the social system, the social foundation is the guarantee of social progress, reflecting the livelihood security of city residents in terms of infrastructure, health care, and education, with a total of six indicators. The social efficiency is the driving force of social progress, reflecting the state of social development in terms of the degree of social equity, socio-demographic characteristics, and the level of city services, with a total of seven indicators. In the environmental system, the environmental foundation can be characterized by the cityscape, reflecting the environmental status of the city in terms of three major aspects, namely, resources, greening, and sanitation, with a total of six indicators. The environmental efficiency, which reflects the city's ability to develop in a sustainable manner, can be characterized by the city's air quality, the proportion of clean energy, and the area covered by road sweeping, with a total of seven indicators.

3.3. Research Methodology

3.3.1. Entropy Weighting Method

The green competitiveness system is a comprehensive system composed of three subsystems: green economic competitiveness, green environmental competitiveness, and green social competitiveness. The entropy weighting method is chosen to measure the green competitiveness system and the three subsystems comprehensively, using the following formula:

(1) Standardization of indicators. The formula is as follows:

$$\text{positive indicators}: X_{\theta ij} = \frac{x_{\theta ij} - \min(x_{\theta ij})}{\max(x_{\theta ij}) - \min(x_{\theta ij})}, \theta = 1 \cdots r; i = 1, 2 \cdots n; j = 1, 2 \cdots m \quad (1)$$

$$\text{negative indicators}: X_{\theta ij} = \frac{\max(x_{\theta ij}) - x_{\theta ij}}{\max(x_{\theta ij}) - \min(x_{\theta ij})}, \theta = 1 \cdots r; i = 1, 2 \cdots n; j = 1, 2 \cdots m \quad (2)$$

where $x_{\theta ij}$ is the initial value of the indicator, $X_{\theta ij}$ is the standardized value of the indicator, $\min(x_{\theta ij})$ is the minimum value of the indicator, $\max(x_{\theta ij})$ is the minimum value of the indicator, n is the number of cities, m is the number of indicators, and r is the total number of study years.

(2) For calculating the proportion of the region i-th under indicator j in year θ-th of the indicator, the following formula is used:

$$P_{\theta ij} = X_{\theta ij} / \sum_{\theta} \sum_{i} X_{\theta ij} \quad (3)$$

(3) For calculating the indicator of entropy, the following formula is used:

$$e_i = -k \sum_{\theta} \sum_{i} p_{\theta ij} \cdot \ln(p_{\theta ij}) \quad (4)$$

where e_j denotes the indicator entropy value and the value range of e_j is [0,1]; $k = 1/\ln(rn)$.

(4) For calculating the weights of the w_j indicators within the city green competitiveness system and the three major subsystems, the formula is as follows:

$$w_j = (1 - e_j) / \sum_{j=1}^{n} (1 - e_j) \quad (5)$$

(5) For calculating the level of city green competitiveness and the combined development of green economic competitiveness, green social competitiveness, and green environmental competitiveness, the formula is as follows:

$$U_{\theta i} = \sum_{j} w_j \cdot X_{\theta ij} \tag{6}$$

where $U_{\theta i}$ is the city green competitiveness and the comprehensive evaluation index of the three major subsystems.

3.3.2. Kernel Density Estimation (KDE)

The KDE method is a non-parametric estimation method used to examine the evolution of the distribution of regional variables by estimating the probability density of a random variable, which in turn describes its dynamic evolution using a smooth continuous density profile. This paper adopts the KDE method to examine the dynamic evolution features of the green competitiveness of cities surrounding the YR.

$$f(x) = \frac{1}{Nh}\sum_{i=1}^{N} K\left(\frac{X_i - \overline{X}}{h}\right) \tag{7}$$

$$K(x) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right) \tag{8}$$

$$\begin{cases} \lim\limits_{x\to\infty} K(x)\cdot x = 0 \\ K(x) \geq 0, \int_{-\infty}^{+\infty} K(x)dx = 1 \\ \sup K(x) < +\infty, \int_{-\infty}^{+\infty} K^2(x)dx = 1 \end{cases} \tag{9}$$

Equation (7) represents the probability density function, f(x), of the observations X at point x. Equation (8) is a Gaussian kernel function that calculates the dynamic evolution of the green competitiveness of cities surrounding the YR. N is the count of observed value, X_i is an observed value that is independent and identically distributed, $\overline{X}$ is the mean value, and h is the bandwidth, reflecting the degree of smoothing and estimated precision of the density function. Equation (9) is the condition that the kernel function should satisfy.

3.3.3. Dagum Gini Coefficient

The DGC is an analysis function for examining the relative differences in the green competitiveness of cities surrounding the YR and sources of those differences. On the basis of the sub-sample decomposition analysis method, the overall differences are derived from the sum of the three contributions of hypervariable density and intra-region vs. inter-region differences [49].

$$G = \frac{\sum_{j=1}^{k}\sum_{h=1}^{k}\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}\left|y_{ji} - y_{hr}\right|}{2n^2\overline{y}} \tag{10}$$

$$\overline{y_h} \leq \cdots \leq \overline{y_j} \cdots \leq \overline{y_k} \tag{11}$$

$$G_{jj} = \frac{\frac{1}{2\overline{y_j}}\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}\left|y_{ji} - y_{hr}\right|}{n_j n_h(\overline{y_j} + \overline{y_h})} \tag{12}$$

$$G_w = \sum_{j=1}^{k} G_{jj} p_j s_j \tag{13}$$

$$G_{jh} = \frac{\sum_{i=1}^{n_j} \sum_{r=1}^{n_h} \left| y_{ji} - y_{hr} \right|}{n_j n_h (\overline{y_j} + \overline{y_h})} \tag{14}$$

$$G_{nb} = \sum_{j=2}^{k} \sum_{h=1}^{j-1} G_{jh} (p_j s_h + p_h s_j) D_{jh} \tag{15}$$

$$G_t = \sum_{j=2}^{k} \sum_{h=1}^{j-1} G_{jh} (p_j s_h + p_h s_j)(1 - D_{jh}) \tag{16}$$

$$s.t. p_j = \frac{n_j}{\overline{y}} \quad s_j = \frac{n_j \overline{y_j}}{n\overline{y}} (j = 1, 2, \cdots, k) \tag{17}$$

$$D_{jh} = \frac{d_{jh} - m_{jh}}{d_{jh} + m_{jh}} \tag{18}$$

$$d_{jh} = \int_0^{\infty} dF_j(y) \int_0^{y} (y - x) dF_h(x) \tag{19}$$

$$m_{jh} = \int_0^{\infty} dF_h(y) \int_0^{y} (y - x) dF_j(x) \tag{20}$$

Equation (10) represents the overall Gini coefficient. Equation (11) is a ranking of the order of regions by the average of the city green competitiveness. Equations (12) and (13) are the Gini coefficient and the contribution to differences within region j, respectively. Equations (14) and (15) represent the Gini coefficient and the contribution made by the net value differences between regions j and h, respectively. Equation (16) represents the hypervariable density. The relationship between the three satisfies the following equation: $G = G_w + G_{nb} + G_t$. In the previous equatons, y_{ji} represents the green competitiveness of city i(r) of region j(h), y represents the average of green competitiveness for each city, n is the number of cities, k is the count of regions, n_j is the number of cities within region j(h), $\overline{y}_i$ is the mean value of the green competitiveness of each city within region j(h), d_{ij} (m_{jh}) is the mathematical expectation of all $y_{ji} > y_{hr}$ ($y_{hr} > y_{ji}$) between the j-th and hth regions, and F_i and F_h are the cumulative density distribution functions of green competitiveness for the i-th and h-th regions, respectively.

3.3.4. Spatial Autocorrelation

The SA model is an analysis function for exploring the spatial correlation (SC) features of green competitiveness of cities surrounding the YR. Global SA and local SA are denoted by Global Moran's I and Getis-Ord Gi*, respectively. The former is used to examine the similarity of spatially neighboring or adjacent study units, while the latter enables a more detailed characterization of the spatial differentiation of study units within a region.

$$I = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij} (x_i - \overline{x})(x_j - \overline{x})}{S^2 \sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij}} \tag{21}$$

$$G_i^*(d) = \frac{\sum_{j=1}^{n} W_{ij} x_j}{\sum_{j=1}^{n} x_j} \tag{22}$$

where W_{ij} represents the adjacency matrix for each city, n represents the count of cities in the sample, x is the observed value, and S^2 is the variance of the sample. In Equation (21), I takes values in the range of -1 to 1, and if $I > 0$, the regional SC is positive; if $I = 0$, the regional SC is randomly distributed, and if $I < 0$, the regional SC is negative. In Equation (22), if $Gi^*(d) > 0$, then it is a high-value agglomeration area; if $Gi^*(d) < 0$, then it is a low-value agglomeration area.

3.3.5. GeoDetector

GeoDetector can detect the spatial divergence of elements and reveal the formation mechanism of the spatial distribution of geographical features. This paper introduces the GeoDetector method to quantitatively detect the formation mechanism of city green competitiveness. The formula used is as follows:

$$q = 1 - \frac{1}{n\sigma^2} \sum_{h=1}^{m} n_h \cdot \sigma_h^2 \tag{23}$$

As shown in Equation (23), the deterministic force indicator, q, measures the extent to which factors influence the spatio–temporal evolution of the green competitiveness of cities surrounding the YR. For $q \in [0,1]$, a higher q value indicates that the variable X_i has stronger explanatory power for the spatio–temporal evolution of the city's green competitiveness. If $q = 0$, variable X_i cannot explain the spatial distribution; if $q = 1$, variable X_i is consistent with the spatial distribution. Where $h = 1,2,\ldots, m$ is a subregion into which the dependent variable Y or the independent variable X is drawn, n represents the overall number of samples within a region, σ_2 is the total discrete variance of the region, n_h is the number of samples in subregion h, and $\sigma^2{}_h$ is a discrete variance of Y in subregion h. The interaction detector detects the magnitude and direction of a bivariate interaction and estimates whether the interaction can affect the explanatory power of an individual variable, X_i, on the spatial variance of Y. The core idea is to compare the q value of an individual variable with the q value of the two superimposed on each other.

3.4. Data Sources

Panel data for 78 cities surrounding the YR from 2006 to 2020, obtained from statistical yearbooks on China Urban Construction, China City, China Energy, and various provinces (autonomous regions) and cities, were used for empirical analysis. Data on the number of days with air quality at Level 2 and above were sourced from the China Air Quality Online Inspection and Analysis Platform, and the number of green patents granted was sourced from the National Intellectual Property Rights Database. Because specific energy consumption and carbon emission data have not been officially published at the city scale, this paper drew on the practice of Chen et al. (2020) [50] and Shi et al. (2020) [51] to first count the energy consumption and carbon emissions of the eight provinces surrounding the YR; then, we used the NPP-VIIRS, i.e., nighttime lighting data, to downscale the eight provinces surrounding the YR, calculated the carbon emissions of the counties surrounding the YR, and finally obtained the carbon emissions for 78 cities by summing them up. Missing indicators in individual areas were supplemented by interpolation.

4. Results

4.1. Temporal Evolutionary Features

The green competitiveness of cities surrounding the YR and the three major subsystems were measured, using Equations (1)–(6), during the study period. From Figure 1, the mean value of green competitiveness of cities surrounding the YR during the study period showed a continuous rise, increasing from 0.2425 to 0.3701 between 2006 and 2020, with a growth rate of 52.63%. Comparing time periods, the growth rate from 2006 to 2011 was relatively slow, with a 2.89% annual average growth, while the growth rate from 2011 to 2020 was relatively rapid, with an annual average growth of 3.01%. This is primarily

because of the continuous increase in energy and resource consumption resulting from the industrialization and urbanization of China before 2011, which led to frequent haze in most cities surrounding the YR, emissions of air pollutants far exceeding the environmental capacity, and an obvious deterioration of air quality, as well as drawing significant government attention to environmental management. In September 2013, China's State Council promulgated the "Ten Atmospheric Articles", which were aimed at preventing and curbing local air pollution, and the Battle of the Blue Sky was launched. In the following years, relevant government policies have been successively introduced to promote the Battle of the Blue Sky, which has had a positive effect on the green competitiveness of cities surrounding the YR.

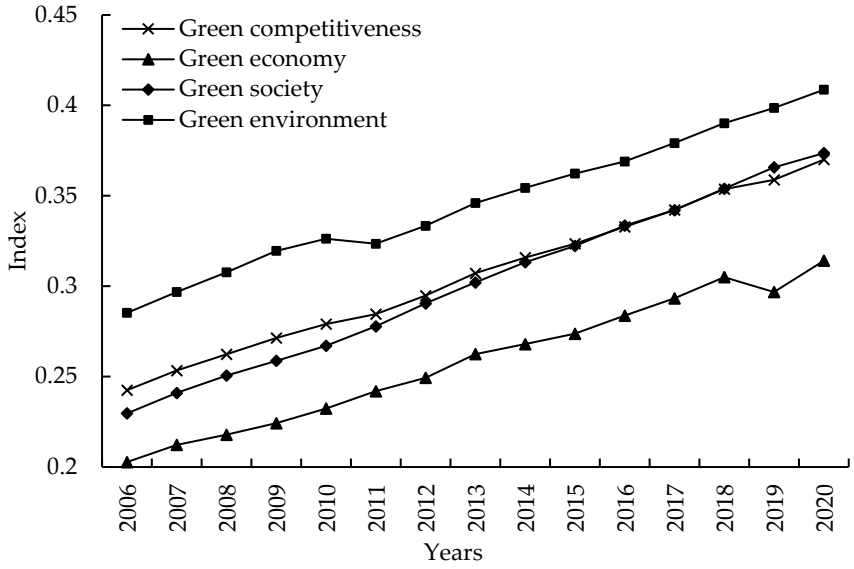


Figure 1. Green competitiveness of cities surrounding the YR.

To further examine the reasons for the low level of green competitiveness of cities surrounding the YR, this paper broke down the green competitiveness of these cities into three components: green economy, green society, and green environment. Overall, over the period under study, the green society index (G-SO-I) showed a continuous increase, rising from 0.2296 to 0.3736 between 2006 and 2020, with a 4.18% average annual growth. The green environment index (G-EN-I) and green economy index (G-EC-I) remained volatile and rising. The G-EN-I increased from 0.2852 to 0.4087 between 2006 and 2020, with a 2.89% average annual growth, and the G-EC-I rose from 0.2027 to 0.3141 between 2006 and 2020, with a 3.67% average annual growth. The mean value of the G-EN-I was consistently higher than that of the G-SO-I and G-EC-I, and the growth rates of the three ranked as follows: G-SO-I > G-EC-I > G-EN-I. Economic development and environmental pressure showed a weakly decoupled type of relationship [52], with unstable decoupling [53], as most cities surrounding the YR have experienced economic development at an environmental cost. In addition, the development of the economy and society in the YRB is unbalanced and insufficient, with the poor population mainly concentrated in the up- and midstream areas. The lagging development of green society and green economy is the main reason for the low level of green competitiveness of cities surrounding the YR.

To further characterize the evolution of the green competitiveness of cities surrounding the YR, the kernel density of the sample data of the green competitiveness of these cities was estimated for four years, namely, 2006, 2011, 2016, and 2020, using Equations (7)–(9). Their distribution features and evolutionary trends, including the position, shape, extension, and polarizing trends of the kernel density curves, were analyzed. The results are shown in Figure 2. In regard to the distributed position, the position of the kernel density curve continued to shift to the right from 2006 to 2020, indicating that the green competitiveness

of cities surrounding the YR has been significantly enhanced during the period under study. With regard to the distribution feature of the primary peaks, the primary peak of the kernel density curve underwent a continuous decline, and the width tended to continuously increase. Compared with 2006, the primary peak was flatter and smaller in 2020, which means that the absolute difference between the green competitiveness of cities surrounding the YR had widened. Concerning distribution extensibility, the right-hand side of the kernel density curve trailed more than the left-hand side, a phenomenon caused by the presence of very high-value areas within the basin. At the same time, the right-hand trailing edge tended to become longer and thicker over time. This is due to the growing number of cities in the high-value zone and the larger share of cities in this zone, indicating that the green competitiveness of the high-value zone has increased and a further widening of the gap with the average in the basin has occurred, and that there is a "stronger by stronger" effect. Concerning the polarizing trend, the green competitiveness of cities surrounding the YR showed a weak multipolar differentiation trend. In 2006, two incipient peaks appeared in the high green competitiveness area on the right side of the kernel density curve, and the secondary peaks of the curve gradually leveled off and became fewer in 2011, 2016, and 2020, indicating that the green competitiveness of cities surrounding the YR had shown a trend of change from multipolar to unipolar. Overall, there are significant spatial differences in the green competitiveness of cities surrounding the YR, and the overall differences tend to increase. In summary, in recent years, although the green competitiveness of cities surrounding the YR has increased, there are obvious differences in the level of development among various subsystems within the city green competitiveness system, as well as significant regional imbalances; furthermore, there are signs of further amplification of polarization between regions.

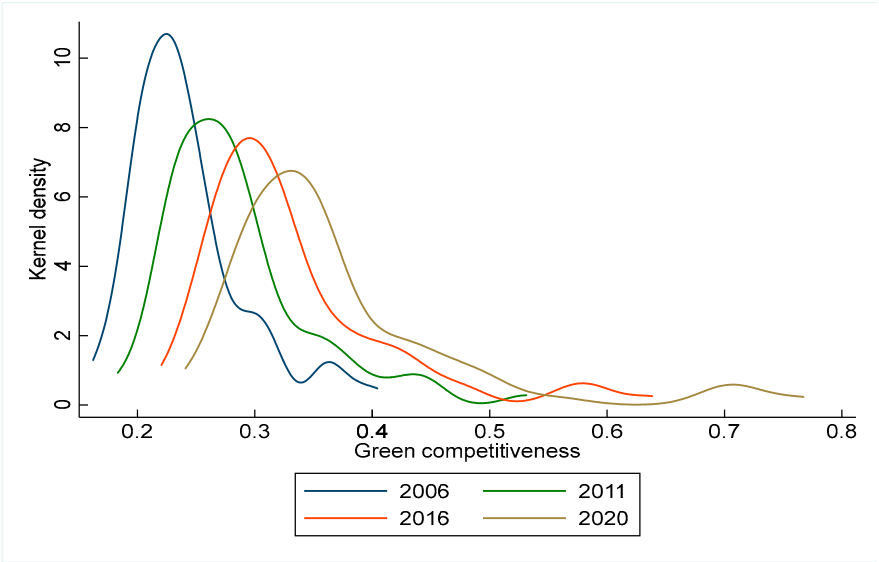


Figure 2. Dynamic evolution of the green competitiveness of cities surrounding the YR.

4.2. Spatial Evolutionary Features

4.2.1. Three Regional Levels

To compare the development of green competitiveness in different regions surrounding the YR, this paper examined the status of and trends in green competitiveness in cities surrounding the up-, mid-, and downstream areas of the YR (as shown in Figure 3). The green competitiveness of cities surrounding the up-, mid-, and downstream areas of the YR all showed a continuous upward trend, but there were significant differences between the three regions, with the green competitiveness of cities surrounding the downstream area being obviously and consistently stronger than that surrounding the midstream area, and the green competitiveness of cities surrounding the midstream area is stronger than that

surrounding the upstream area. This is because the downstream provinces of Shandong and Henan have well-developed transportation, a strong industrial base, superior geographical location, strong eco-environmental protection, rapid advancement of green transformation, and cultivation and formation of several industry chains with an outstanding leading role and strong support. Since 2000, the midstream region has been carrying out ecological management projects such as returning agricultural land to forestry and small watershed management, which has significantly increased the regional vegetation cover and improved the ecological environment. In addition, the "Rise of Central China" and other regional coordinated development strategies have provided unprecedented opportunities for green economy development in the central region. However, the region's fragile eco-environment and abundant fossil energy make it difficult to transform the economic development model of high input, pollution and emissions, and low utilization in a short time, and the promotion of high-quality development is still severely restricted. Although the upstream region has excellent ecological resources, there is a long-term contradiction between the lack of land available for construction and the increasing demand for land for economic and social development due to the unique natural landscape, limited ecological capacity, and poor matching of water and soil resources, which has led to strong barriers to the upstream region in promoting the coordinated development of economy, society, and environment. In addition, the green technology level in the upstream region is low, the industrial structure is not sufficiently optimized, the efficiency of the transition from old to new dynamism is low, and green development encounters technical bottlenecks.

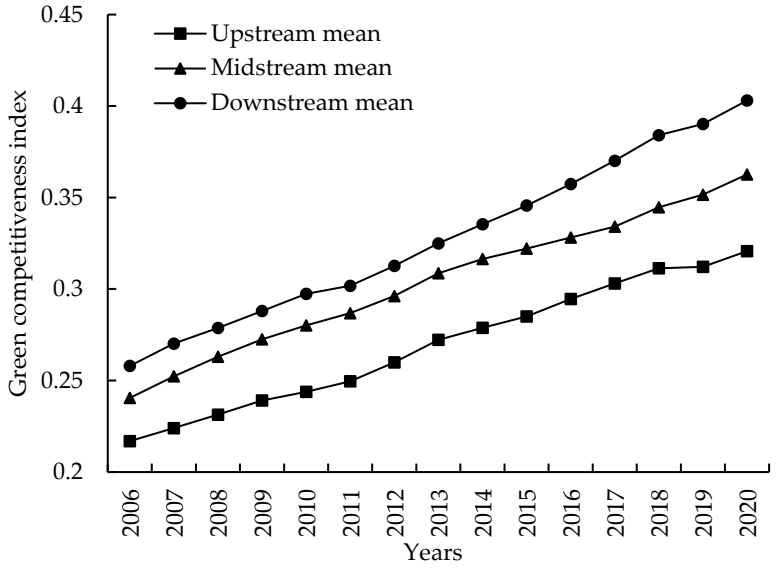


Figure 3. Average green competitiveness of cities surrounding the up-, mid-, and downstream areas of the YR.

4.2.2. City Level

To further explore the spatial evolution features of the green competitiveness of cities surrounding the YR, this paper used ArcGis 10.8 software to visually represent the green competitiveness levels of cities in 2006, 2011, 2016, and 2020 (Figure 4). The green competitiveness type of cities surrounding the YR is classified into low tier, lower tier, medium tier, higher tier, and high tier by a natural breakpoint method according to their green competitiveness index. Specifically, in 2006, the green competitiveness of five major provincial capitals, namely, Qingdao, Jinan, Zhengzhou, Xi'an, and Taiyuan, was in the medium tier; the green competitiveness of provincial capitals such as Huhehaote, Lanzhou, Xining, and Yinchuan and their surrounding individual cities and most coastal cities were in the lower tier; and most remaining cities were in the low tier. From 2006 to 2011, the green competitiveness of four provincial capitals, Qingdao, Jinan, Xi'an, and

Zhengzhou, entered the higher tier, while the green competitiveness of Taiyuan remained in the medium tier. The green competitiveness of the remaining provincial capitals, except for Xining and cities such as Weihai, Yantai, and Zibo, rose to the medium tier. The number of cities in this tier increased from five in 2006 to eight in 2011, while the number of cities in the lower tier of green competitiveness increased from 11 to 28, and the corresponding regional range extended from the eastern seaboard to inland. From 2011 to 2016, four provincial capitals, namely, Qingdao, Jinan, Xi'an, and Zhengzhou, moved into the high tier of green competitiveness and continued to lead in the basin. Three provincial capitals, Taiyuan, Huhehaote, and Lanzhou, and Weihai, Yantai, and Zibo, rose to a higher tier of green competitiveness. The number of cities in the medium tier of green competitiveness increased to 10, with a regional spread from downstream to midstream areas. The number of cities in the lower tier of green competitiveness increased to 47, with the regional scope mainly concentrated in the mid- and downstream areas of the YR. At this stage, the number of cities with low-tier green competitiveness reduced to 11, with the regional scope mainly distributed in the upstream areas of the YR. From 2016 to 2020, Qingdao, Jinan, Xi'an, and Zhengzhou continued to maintain their high-tier green competitiveness and further consolidated their leadership, which can be seen in the fact that these four provincial capitals were the green development leaders in the basin. Weifang, Dongying, Jining, Luoyang, and Baotou, which also joined the ranks of the higher-tier green competitive cities, together with Taiyuan and Huhehaote, played a supporting role in the synergistic improvement of the green competitiveness of cities surrounding the YR as the backbone of green development. The number of cities in the medium-tier green competitiveness increased to 16, with a spatial pattern of provincial capitals radiating to neighboring cities. There were still 45 cities in the lower tier of the green competitiveness type, mainly in the midstream and upstream areas. Thus, none of the cities surrounding the YR were in the lower tier of green competitiveness, except for Dingxi and Longnan, surrounding the upstream area. On the whole, the high-value areas of the green competitiveness index were primarily clustered in the provincial capitals and several coastal cities, while the rest of the cities still remained in the medium and lower tiers of green competitiveness. As time has progressed, the eastern coastal region has extended to the western inland region and high-value cities, such as provincial capitals, have radiated to surrounding cities. In addition, the green competitiveness index for high-value cities has grown at a disproportionate rate, far outpacing low-value cities, and absolute regional differences have widened. In summary, there are obvious differences in green competitiveness among cities surrounding the up-, mid-, and downstream areas of the YR during the study period, with the downstream area having a significant advantage. Provincial capitals and some coastal cities have achieved excellent development results and have spatial radiation characteristics, but although most of the remaining cities have also shown a certain degree of development, the level is still low and the differences between cities are still expanding.

4.3. Spatial Differences

The spatial differences in each region and contributing sources of green competitiveness of cities surrounding the YR were measured, through Equations (10)–(20), in order to reveal the extent and causes of spatial differences in the green competitiveness of cities surrounding the YR. The results are shown in Table 2. Overall, the Gini coefficient showed a continuous increase over the period under study, which means that the spatial differences in the green competitiveness of cities surrounding the YR was continuously increasing. The reason for this is that cities with strong green competitiveness have strong capital, sufficient human resources, and strong technological innovation capabilities, and the difference between high-value and low-value cities in terms of the rate of improvement of green competitiveness is widening because of the cumulative return effect of the cycle. In terms of intra-regional differences, the up-, mid, and -downstream areas of the YR were ranked as midstream (0.113) > upstream (0.109) > downstream (0.105). Furthermore, the trends were different, with intra-regional differences in the mid- and downstream areas increasing over

time, while intra-regional differences in the upstream first increased and then decreased over time. This is because the cities of Qingdao, Jinan, Xi'an, and Zhengzhou surrounding the mid- and downstream areas have achieved particularly remarkable results in green development, with their advantages expanding under the cumulative effect of the cycle, while other cities were developing at a slower pace. However, the high-value cities surrounding the upstream area, Lanzhou and Yinchuan, as provincial capitals, were quick to respond to national green development policies and took the lead in the early development phase. However, because of the constraints of location, environment, and resources, it was difficult to achieve higher levels of development in the short term, and they were unable to widen the gap with other cities in the region at a later stage, requiring fundamental changes in the existing development model. In terms of inter-regional differences, the mean Gini coefficients between the midstream and upstream areas, the midstream and downstream areas, and the upstream and downstream areas of the YR were 0.118, 0.112, and 0.121, respectively, with the differences between the downstream and mid- and upstream areas expanding, indicating the rapid development of green competitiveness of cities surrounding the downstream area of the YR. In terms of the contribution to the overall differences, the mean value of the contribution of hypervariable density was 34.99%, the mean value of the contribution of inter-regional differences was 32.47%, and the mean intra-regional contribution to differences was 32.55%. This shows that hypervariable density contributed the most to the overall differences in the basin during the study period. In summary, there were significant spatial differences in the green competitiveness of cities surrounding the YR, with a continuous increase overall. Among them, the greatest spatial difference in green competitiveness was found in the midstream area of the YR, and the hypervariable density was the main source of the overall differences.

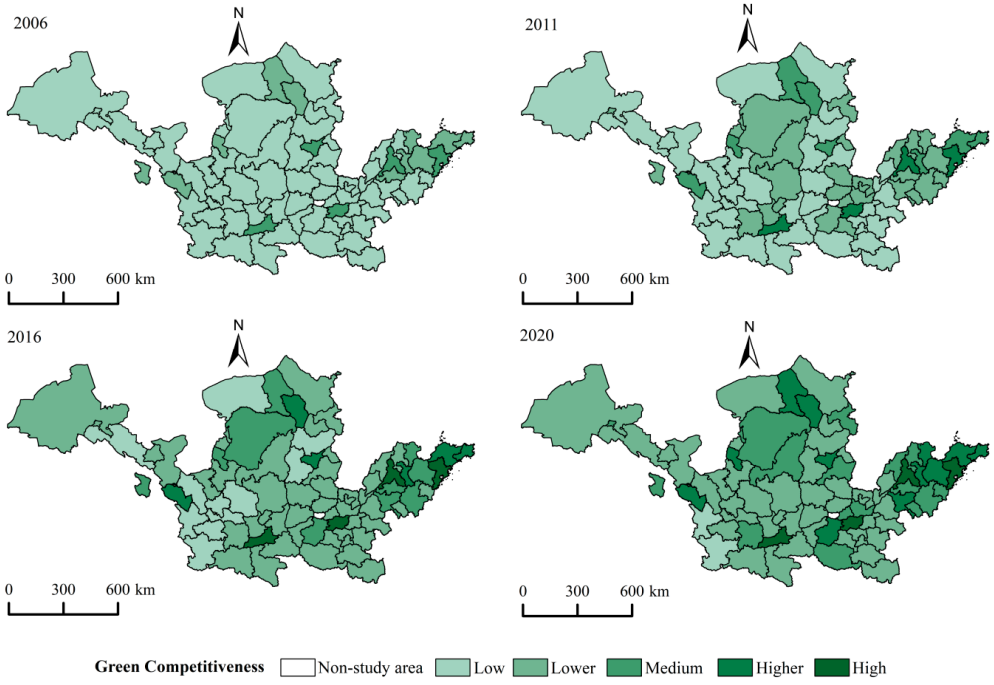


Figure 4. Spatial features of green competitiveness of cities surrounding the YR.

Table 2. Gini coefficient of green competitiveness of cities surrounding the YR.

Year		2006	2011	2016	2020	Average Value
Overall differences		0.106	0.115	0.123	0.132	0.119
Intra-regional differences	Upstream	0.103	0.110	0.111	0.103	0.109
	Midstream	0.102	0.112	0.116	0.125	0.113
	Downstream	0.088	0.097	0.113	0.126	0.105
Inter-regional differences	Midstream/upstream	0.108	0.119	0.119	0.121	0.118
	Midstream/downstream	0.097	0.106	0.118	0.130	0.112
	Upstream/downstream	0.107	0.116	0.126	0.134	0.121
Differential contribution rate	Intra-regional	31.89%	32.32%	33.03%	33.35%	32.55%
	Inter-regional	32.96%	31.39%	31.92%	35.47%	32.47%
	Hypervariable density	35.15%	36.30%	35.05%	31.18%	34.99%

4.4. Spatial Autocorrelation

4.4.1. Global SA Analysis

Equation (21) was used to calculate the green competitiveness Global Moran's I of cities surrounding the YR from 2006 to 2020, and to analyze the SC features of city green competitiveness (Table 3). As shown in Table 3, all were positive during the study period and passed the test of significance at the 5% level. This means that the SC feature of green competitiveness among the 78 cities surrounding the YR was positive, i.e., cities with higher green competitiveness tended to agglomerate, as did cities with lower green competitiveness. In terms of specific value changes, Global Moran's I shows a volatile downtrend throughout the study, mainly because of the differences in economic base, resource environment, and other conditions, which causes the green development of each region to show differentiated features.

Table 3. SA Statistics for the green competitiveness of cities surrounding the YR.

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
I	0.170	0.182	0.181	0.170	0.188	0.183	0.170	0.147	0.155	0.161	0.148	0.144	0.133	0.134	0.126
Z	2.390	2.551	2.550	2.401	2.646	2.576	2.411	2.125	2.222	2.296	2.125	2.090	1.934	1.959	1.867
P	0.008	0.005	0.005	0.008	0.004	0.005	0.008	0.017	0.013	0.011	0.017	0.018	0.027	0.025	0.031

4.4.2. Local SA Analysis

Global SA can only indicate that green competitiveness is relevant in general and cannot demonstrate agglomeration features between cities. Therefore, the Getis-Ord Gi*of green competitiveness of cities surrounding the YR in 2006, 2011, 2016, and 2020 was calculated using Equation (22) to analyze the agglomeration state of their green competitiveness, and the cold-spot and hot-spot values were classified into seven types: high, moderate, and low significance area of hot spots (SAH); high, moderate, and low significance area of cold spots (SAC); and randomly distributed areas (Figure 5).

Throughout the study period, there was a significant "polarization" of the green competitiveness of cities surrounding the YR, with hot spots clustered mainly in the Shandong Peninsular city cluster and cold spots clustered mainly in southeastern Gansu Province, with the cold spots and hot spots showing an "opposing distribution between the east–west ends of the basin" pattern. This is because the Shandong Peninsular city cluster has been guided by policies such as the Work Programme for Low Carbon Development in Shandong Province (2017–2020) and the Opinions of the People's Government of Shandong Province on Coordinated Promotion of Ecological and Environmental Protection and High-Quality Economic Development, with the aim of optimizing its industrial and energy structures, speeding up the transition from old to new dynamism and the transformation and upgrading of transportation, and ensuring coordinated economic, social, and environmental development. However, the southeastern part of Gansu Province is deeply inland, with complex terrain and a diverse climate, a fragile ecological environment, serious industrial

pollution, and a backward economic development model, making it difficult to take the ecological environment in the development process into account.

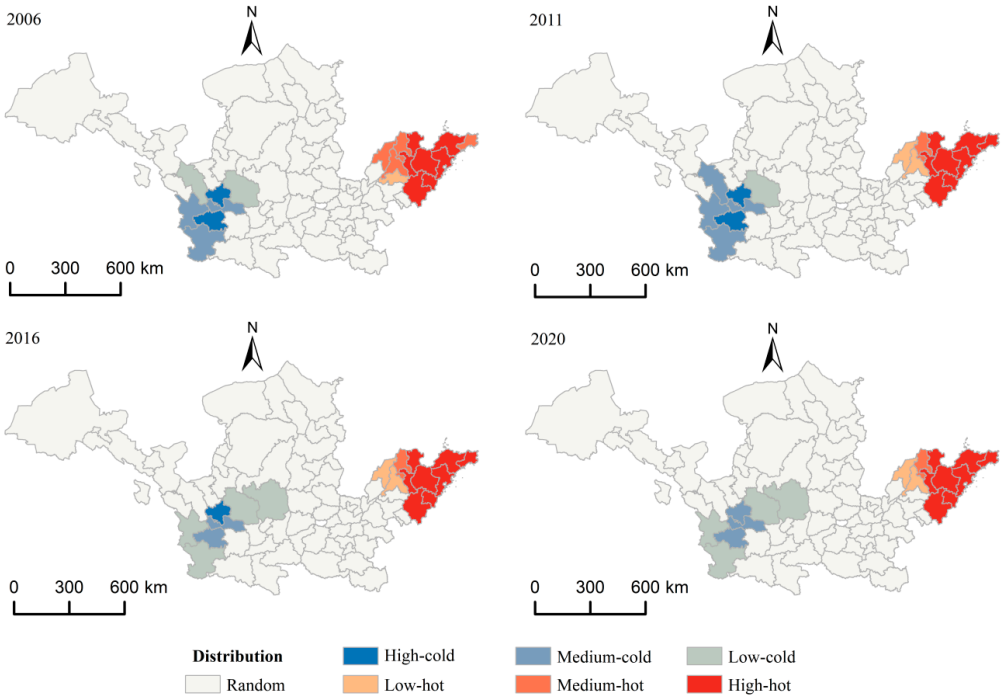


Figure 5. Evolution of cold spots and hot spots of the green competitiveness of cities surrounding the YR.

Specifically, the center of gravity of the green competitiveness cold spots has evolved from south to north, and its significance has changed from strong to weak. In 2006, the overall pattern of SAC was "southern high, northern low", with Tianshui in the south-central part of the region and Guyuan in the north-central part forming an "opposing distribution of high SAC in the north and south" pattern, Longnan in the south of the region and Pingliang and Dingxi in the central part forming an agglomeration of the moderate SAC, and Baiyin and Qingyang in the north of the region standing on the east and west ends as low SAC. In 2011, the SAC shifted to a "high medium and low north-south" pattern, with Tianshui in the south-central part of the region and Guyuan in the north-central part remaining as the high SAC, Baiyin in the north-western part of the region becoming the moderate SAC, and the aggregation of moderate SAC beginning to spread to the north of the region, while Qingyang in the northeast continued to maintain the status of moderate SAC. In 2016, the SAC began to contract in the northwest, turning to spread to the northeast, forming a circular structure, with Guyuan, which is a high SAC, as the center. This was surrounded by a circular area with moderate SAC in Tianshui and Pingliang and low SAC in Longnan, Dingxi, Qingyang, and Yan'an. The overall cold-spot significant degree of the region has decreased. The extent of the SAC in 2020 remained unchanged compared with 2016, but the high SAC disappeared and the overall regional cold-spot significance decreased further, with Guyuan entering moderate SAC and the cold-spot significance of the rest of the region remaining unchanged. In addition, the coverage of green competitiveness hot spots shrank further during the study period and showed a pattern of increasing significance from "west to east". In 2006, the high SAH was dominated by the Ludong and Luzhong regions, including seven cities such as Qingdao and Yantai. The moderate SAH included four cities, i.e., Jinan, Weihai, Dezhou, and Binzhou. Tai'an was low SAH. In 2011, Tai'an entered the randomly distributed area, Jinan and Dezhou receded to low SAH, and Weihai entered high SAH. After that, the coverage and distribution pattern of hot-spot areas in 2016 and 2020 remained unchanged from 2011.

In summary, although the rapid increase in the green competitiveness of some cities has led to some changes in the overall distribution pattern of the cold-spot and hot-spot areas, the low-value green competitiveness agglomeration area has been located in the southeast of Gansu Province, while the high-value green competitiveness agglomeration area has always been distributed in the east of Shandong Peninsula, with obvious spatial stickiness.

4.5. Driver Selection and Analysis

The development of a city's green competitiveness is affected by multiple factors. On the basis of extant studies' findings [14], the reality of the development of green competitiveness of cities surrounding the YR, and the indicator weights in the previous index system, the level of urbanization X1 (urbanization rate), industrial structure upgrading X2 (proportion of tertiary industry output value), S&T innovation X3 (S&T spending as a percentage of total fiscal spending), government regulation and control ability X4 (financial expenditure per capita), the level of city infrastructure construction X5 (length of city drainage pipes), and financial support X6 (the balances of deposit and loan held by financial institutions at the end of the year as a percentage of GDP) were selected as the six indicators of green competitiveness drivers for cities surrounding the YR.

The factors were rasterized and reclassified in ArcGIS 10.8, and, using Equation (23), the individual-factor driving forces (Table 4) and two-factor interactive forces (Table 5) of each factor on the green competitiveness of cities surrounding the YR were calculated. The results of the calculation of the individual-factor driving forces passed the test of significance at the 1% level. Overall, the driving forces of each driver on green competitiveness of cities surrounding the YR during the sample period were ranked as follows: the level of city infrastructure construction (0.7312) > the level of urbanization (0.5751) > S&T innovation (0.3649) > financial support (0.1839) > industrial structure upgrading (0.1708) > government regulation and control ability (0.0848). The level of city infrastructure construction and urbanization were identified as drivers with a high impact on city green competitiveness in all four years, and the impact of other factors on the city green competitiveness varied in different periods.

Table 4. Individual factor detection results.

	2006	2011	2016	2020	Means
X1	0.6836 ***	0.4986 ***	0.6057 ***	0.5126 ***	0.5751 ***
X2	0.1288 ***	0.1171 ***	0.2260 ***	0.2114 ***	0.1708 ***
X3	0.0581 ***	0.5362 ***	0.4142 ***	0.4512 ***	0.3649 ***
X4	0.0399 ***	0.0929 ***	0.0978 ***	0.1084 ***	0.0848 ***
X5	0.6789 ***	0.6539 ***	0.8222 ***	0.7696 ***	0.7312 ***
X6	0.2723 ***	0.2088 ***	0.1481 ***	0.1062 ***	0.1839 ***

Note: *** indicates significance at the 1% levels.

Table 5. Interaction factor detection results.

Driver	X1	X2	X3	X4	X5	X6
X1	0.6070					
X2	0.7129	0.2904				
X3	0.7762	**0.7909**	0.4975			
X4	**0.7519**	**0.7128**	**0.6955**	0.0477		
X5	0.9185	0.9147	0.8576	**0.9085**	0.7849	
X6	0.7858	**0.5929**	0.7792	**0.6062**	0.8902	0.2255

Note: Values in bold represent non-linear enhancement effects.

The specific driving mechanisms are as follows: (1) Promoting urbanization can generate market demand for environmentally friendly products and services, thus stimulating the vitality of green production in city enterprises, promoting the construction of green industrial chains, and improving production efficiency, while providing a good development

environment for city green development. Additionally, the promotion of urbanization is conducive to improving living quality for inhabitants and enhancing their wellbeing. As can be seen from Table 4, the driving force of urbanization level declined from 0.6836 in 2006 to 0.5126 in 2020 over the sample period, mainly because the continued development of urbanization may lead to city difficulties such as traffic congestion, energy constraints, and employment difficulties. First, too rapid a pace of urbanization will be accompanied by rapid consumption of resources and energy, generating large amounts of greenhouse gases such as carbon dioxide and reducing the benefits of low-carbon development. Second, the waste generated by the rapid expansion of the population will also lead to serious environmental pollution problems. (2) As an important foundation for city green development, greening the industrial structure will force traditional industries to pursue green technological innovation, contribute to the development of regional green industries, and facilitate co-ordination between economic development and environmental conservation. As shown in Table 4, the driving force of industrial structure upgrading increased from 0.1288 in 2006 to 0.2114 in 2020 during the sample period, mainly because the YRB has made significant breakthroughs in industrial structure transformation and the transition from old to new dynamism in recent years, and the beneficial impact of industrial structure on city green competitiveness development has become increasingly apparent. (3) As the first productive force, S&T innovation is the heart of city green development and a fundamental way to enhance the green competitiveness of cities. S&T innovation can break through green technology bottlenecks, achieve green technology upgrading, and provide advanced technology and equipment for enterprise production, residents' life, and city governance, making enterprise production cleaner, residents' life more convenient, and city governance more efficient. This is conducive to steadily promoting economic growth and environmental protection at the same time. As can be seen from Table 4, the driving force of S&T innovation rose from 0.0581 in 2006 to 0.4512 in 2020 during the sample period, representing a large increase. As an important strategic region, the YRB has actively responded to the call of the central government to increase its investment in S&T innovation and achieved many results in this regard. However, the driving force of S&T innovation is still not high, mainly because most of China's existing green patents are focused on pollution control and treatment links, lacking in green innovation and core green technologies including alternative energy, energy conservation, and emissions reduction. (4) The government is the leader of city green development initiatives and an important guarantor of the promotion of city green competitiveness. Unlike in the development of the city system itself, the government acts as the "invisible hand" to provide city green development efforts with sufficient financial and political support, while optimizing the spatial layout of the city through scientific city planning methods to ensure the orderly development of city green competitiveness. As can be seen from Table 4, the driving force of the government regulation and control ability continued to rise from 0.0399 in 2006 to 0.1084 in 2020 during the sample period, and the government's role in enhancing the green competitiveness of cities surrounding the YR has been increasing. (5) Infrastructure is the basis for city green development and a key vehicle for supporting the free flow of different green elements within cities. It can reduce the time and space needed for the flow of green elements through the construction of a superior transportation and information network, so that capital, materials, and information can be fully regulated; broaden and deepen the effective integration of green resource elements across regions; and achieve the optimal allocation of green resource elements. As shown in Table 4, the driving force of the level of city infrastructure construction during the sample period rose from 0.6789 in 2006 to 0.7696 in 2020, mainly because the provinces along the YR have been increasing their efforts in regard to city infrastructure construction, especially in the case of Shandong Province, which encouraged diverting social capital toward the construction of nine key areas such as municipal infrastructure in 2015, and, in the following years, made policy requirements on infrastructure construction such as the development of building mobile communications and comprehensive three-dimensional transportation networks. (6) Finance is a significant

driver of city green development, providing funding for green infrastructure development and green technology research and development (R&D), while regulating the direction of funding to push forward high-quality development in the energy sector and achieve the "double carbon" goal. As can be seen from Table 4, the driving force of financial support decreased from 0.2723 in 2006 to 0.1062 in 2020. This was because of the long lead time, high investment, and slow effect of technology R&D and infrastructure construction, which causes the driving effect of financial support lag and makes it difficult to achieve obvious direct benefits in the short term.

The interactions between the drivers were obtained by averaging the drivers for 2006, 2011, 2016, and 2020 and inputting them into the GeoDetector (Table 5). Overall, each driver interaction was stronger than itself, with a non-linear enhancement effect in eight sets of variable interactions. The interaction between the government regulation and control ability and the other five drivers had a non-linear enhancement effect, and its interaction with the level of city infrastructure construction yielded a value q of 0.9085, indicating that the government, as a significant leader of city green development, has a key role in improving the city green competitiveness. At the same time, the interaction of industrial structure upgrading and technology innovation with the other three drivers had a non-linear enhancement effect, and the interaction of industrial structure upgrading and technology innovation generated a value q of 0.7909. It can be seen that, although the individual factor driving force of government regulation, control ability, and industrial structure upgrading was low, interaction with other factors can generate a strong driving force. The same effect was also observed for the interaction between the level of urbanization, government regulation, and control ability, which shows that urbanization can have great potential when properly guided by the government. In addition, the remaining 13 groups of variables showed a two-factor enhancement effect when interacting. It is evident that the city green competitiveness is the result of the interaction of multiple factors, and that there is a significant enhancement effect after the interaction of the variables. In summary, the level of city infrastructure construction, urbanization, and S&T innovation contribute significantly to the process of the development of green competitiveness of cities surrounding the YR. In addition, the interaction force of each factor is much stronger than the effect of the individual factor, reflecting the complexity of the driving mechanisms of the green competitiveness of these cities.

5. Conclusions and Recommendations

5.1. Conclusions

The above analysis leads to the following conclusions:

(1) From a temporal perspective, the green competitiveness of cities surrounding the YR has grown steadily, and the relationship between the city's economy, society, and environment continues to be optimized. The growth rate of the green competitiveness of these cities was slower from 2006 to 2011 and faster from 2011 to 2020, which indicates that the policies promulgated by the government, such as the "Ten Rules on Atmosphere", have played an obvious role in improving the ecological environment of the YRB. In addition, the G-EC-I, G-SO-I, and G-EN-I all maintained an upward trend in the system, and the growth rates of the three were ranked as G-SO-I > G-EC-I > G-EN-I. The lagging development of the green economy and green society was the main reason for the lower green competitiveness, which indicates that there is an imbalance between ecological environmental protection and high-quality economic and social development in the YRB, and that there is a heavy load and a long road to achieve the coordinated development of high-quality development and ecological protection in the YRB.

(2) From a spatial perspective, the spatial features of the green competitiveness of cities surrounding the YR were notably unbalanced, with a spatial distribution of downstream > midstream > upstream. Provincial capitals and sub-provincial cities such as Qingdao, Jinan, Xi'an, and Zhengzhou had higher green competitiveness, while most

other cities were relatively less competitive. This is due to the obvious differences in resource endowment, geographical location, and other conditions in different regions and cities. In addition, both the absolute and relative differences in green competitiveness among cities showed a continuously widening trend, and overall differences stemmed mainly from the difference in hypervariable density between regions, which indicates that there is a lack of well-developed coordination and complementary mechanisms between upstream, midstream, and downstream areas, and between provincial capitals and other cities.

(3) In terms of correlation features, the green competitiveness of cities surrounding the YR was above 0 during the study period and passed the significance test. This indicates that the green competitiveness of these cities had a positive SC, but the correlation was continuously decreasing; in other words, cities with similar levels of green competitiveness are spatially clustered, but this phenomenon has changed as China's transport infrastructure, such as roads, railways, and airways, as well as information network infrastructure, such as 5G base stations, has become increasingly sophisticated. The spatial clustering features of green competitiveness were mainly in the "cold-spot area" in southeastern Gansu and the "hot-spot area" in the Shandong Peninsula city cluster, and the area of both the cold spots and the hot spots is shrinking. The distribution of hot spots and cold spots indicates that coastal cities have greater advantages over inland cities in terms of economic development, policy benefits, openness, and communication, and are able to efficiently aggregate key elements for developing green competitiveness.

(4) In terms of the drivers, the factor detection showed that the level of city infrastructure construction, the level of urbanization, and S&T innovation were the most significant drivers of the green competitiveness of cities surrounding the YR. Apart from the level of city infrastructure construction and the level of urbanization, the other factors differed to a certain extent in their effects on green competitiveness in different periods, indicating that the enhancement of the green competitiveness of cities surrounding the YR depends largely on economic and social foundations, and that cities with good foundations are more likely to enhance their green competitiveness, while those with weak foundations find it difficult to catch up through later efforts. This also confirms the importance of preemptive action to gain first-mover advantages in the face of fierce competition. The interaction of the driving factors included two types of non-linear enhancement and two-factor linear enhancement, and the interaction between different driving factors was stronger than the effect of individual factors, indicating that the driving mechanism of green competitiveness of cities surrounding the YR is complex in nature.

5.2. Recommendations

Premised on the relevant findings above, the following countermeasures are proposed to optimize the green competitiveness of cities surrounding the YR as follows:

(1) The coordination of the developmental relationship between the economy, society, and environment is of paramount importance in bolstering the green competitiveness of the city. Firstly, it pertains to enhancing the city's green economic competitiveness and effectively improving the ecological sustainability of economic growth. Enterprises, for instance, ought to cultivate a subjective consciousness regarding green innovation, augment investments in R&D, and enhance the input–output ratio. This necessitates a constant optimization of the industrial structure, with a particular focus on the degree of greening in technology R&D. Therefore, economic growth can be propelled by technological progress and product differentiation. The government, on the other hand, should introduce corresponding policies that incentivize and subsidize green technological innovation. Enterprises that demonstrate a commitment to green technological innovation should be granted certain incentives and financial subsidies. This will stimulate the vibrancy of green technology innovation and allevi-

ate the burden on corporate R&D. Simultaneously, the government should create a conducive research and innovation environment for scientific research institutes at the forefront of scientific R&D. This will help overcome the bottleneck of green technology and rectify the current situation where China's green technology innovation is predominantly focused on traditional end-of-pipe treatment. Secondly, it is crucial to enhance the city's green social competitiveness and promote new urbanization with green development concepts. This can be achieved through the scientific planning of the spatial layout of industrial, commercial, agricultural, residential, transportation, and ecological areas within the city. Such planning will enhance the effectiveness of multifunctional mixed land use, thereby improving the operational efficiency of city production and life while simultaneously reducing resource and energy consumption as well as carbon emissions. Additionally, an assessment of the city's natural conditions should be conducted, and ecological parks with city-specific ecological features should be established accordingly to increase green carbon sinks. Moreover, abandoned construction land surrounding the city should be ecologically restored and transformed to facilitate soil carbon sinks. Finally, it is crucial to enhance the city's green environmental competitiveness and strengthen green infrastructure. This involves the development of ecological landscapes, green space systems, and ecological corridors to expand the leisure space available to residents and enhance their quality of life. Concurrently, traditional infrastructure and technical equipment should be upgraded and transformed. High-emission and energy-consuming production processes and equipment should be transitioned towards greener alternatives. Advanced green technological achievements should be applied to the green transformation of infrastructure, facilitated by the national comprehensive service platform for the transformation of ecological and environmental R&D achievements. This will expedite the process of infrastructure greening.

(2) Promotion of synergistic city development and the reduction of regional gaps in city green competitiveness are of paramount importance. Firstly, it is necessary to acknowledge the significant spatial differences in the green competitiveness of cities surrounding the YR. Therefore, it is necessary to foster exchanges and cooperation in green initiatives among cities and regions. Emphasizing the leadership role of the downstream region, particularly the Shandong Peninsular city cluster, in propelling the midstream and upstream regions is crucial. Additionally, bolstering the supportive role of the midstream region in facilitating green development across the basin and enhancing the capacity of the upstream regions to learn and emulate are essential. Simultaneously, harnessing the synergistic driving force of city clusters and metropolitan areas, accurately positioning city functions, and harnessing the radiating effect of central cities such as Qingdao, Jinan, Zhengzhou, and Xi'an are necessitated. By expanding knowledge and technology spillovers, the aim is to narrow the regional gaps in city green competitiveness. Secondly, it is critical to align with the economic and social development realities and natural resource conditions of each region. This can be achieved by implementing localized and time-sensitive measures to address shortcomings, for instance, enhancing the R&D capacity of green core technologies in downstream regions to elevate the upper limit of city green competitiveness. Moreover, transitioning the economic development model of midstream regions from resource-intensive industries to innovation-driven and eco-friendly industries is vital. Thus, accordingly, optimizing the industrial structure of upstream regions, increasing the proportion of tertiary industries, and vigorously promoting the development of eco-tourism and other lifestyle services are key steps towards transforming ecological advantages into economic advantages.

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