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Research on Spatiotemporal Characteristics and Heterogeneity of Green Industry Development in China: Based on the Geographically Weighted Regression Method

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Abstract

In this paper, the Moran index and LISA (Local Indicator of Spatial Association) saliency distribution method are used to study the spatial autocorrelation and spatial agglomeration characteristics of green industry development in 30 provinces and cities in China (except Tibet) from 2011 to 2020. For the first time, the geographically weighted regression method in the spatial variability coefficient model is used to study the spatial heterogeneity of green industry development. The results show that: First, the development level of China's green industry grows steadily with the increase of years, the development level of green industry in economically developed areas is relatively high, and the development level of green industry in areas with low economic development level is relatively backward; Second, the development of green industries in various regions has spatial autocorrelation, and the spatial agglomeration patterns are different; Third, there are differences in the intensity of the impact of high technology industries, economic development, urban green construction and other influencing factors on the development of green industries in the eastern, central and western regions.

Keywords

Green Industry Development; Spatial Autocorrelation; Geographically Weighted Regression Model; Heterogeneity Analysis.

1. Introduction

In recent years, with the continuous development of the economy and society, China's energy consumption is serious, and the problems of the ecological environment have become increasingly prominent. At present, China is in an important stage from high-speed development to high-quality development, and in order to achieve high-quality development in China, it is necessary to establish green and low-pollution development. The development of green industry is inevitable, while promoting economic growth, the green industry can improve the quality of the ecological environment, reduce energy consumption, achieve low-carbon, efficient and sustainable development, and can promote China's industrial structure adjustment, and achieve green technology innovation.

1.1. Green Industry Development.

From the perspective of green industry development, most scholars are focusing on certain industries. Gunno and Jina (2010) [1] explored the multi-dimensional effects of entry conditions and corporate strategies in emerging solar cell industries, and showed that after entering the market, the cooperation strategy of enterprises is positively correlated with innovation performance. Jaber et al. (2019) [2] divided the boundary between sustainable and green construction in the construction industry, explored the green construction factors in the construction industry, and found that the green construction factors in the construction

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industry can improve sustainable performance; Indrayani et al. (2020) [3] believe that the batik industry must apply green industry principles, use more environmentally friendly raw materials, and choose low-carbon energy, so that the batik industry can not only achieve economic growth, but also become an environmentally friendly industry.

China's green industry is currently in its infancy. The development of green industries can help improve the country's economy, and Alan et al. (2006) [4] estimate the impact of green industries on the national economy. Chen et al. (2016) [5] evaluated the contribution of the green industry to China's social and economic development and found that the growth of the green industry is highly correlated with national economic growth, but the role of employment is not significant. Zhu (2011) [6] believes that the goal of evaluating the development level of regional green industries needs to be able to consider the operation status, change trends, and management decisions of regional green industries, and puts forward the principle of constructing a model for evaluating the health and sustainable development of green industries.

1.2. Research on Influencing Factors of Green Industry.

There are many influencing factors for the development of green industries, and many countries have long begun to use public policies to stimulate the development of green industries. Yin (2010) [7] and William (2013) [8] scholars believe that renewable resources policies have a positive impact on the development of green industries. Yi (2014) [9] studied the growth of green enterprises in various states in the United States through fixed-effect regression analysis of panel data, and found that the adoption of renewable energy policies (RPS) has a positive impact on the number of green enterprises and the development of green industries. Dong et al. (2016) [10] believe that the national policy of attaching importance to the development of local renewable energy industry is conducive to the implementation and promotion of the sustainable and healthy development of China's renewable energy industry. Sanya (2009) [11] argues that the implementation of renewable energy policies (RPS) is not an important predictor of the percentage of renewable energy generated. Manuel et al. (2010) [12] point out that the feed-in tariff of Germany's RPS policy brings high costs and has no positive impact on energy security and emission reduction. Oliver (2016) [13] argues that local content demand (LCR) could be an effective tool to promote local manufacturing, taking India's national solar energy as an example that LCR can promote green industries. Allan (2021) [14] argues that the rise of green industrial policies injects purpose and competition into global environmental politics, helping to generate the technological and political momentum needed to accelerate global decarbonization. Zhou et al. (2022) [15] found that the implementation of carbon emission trading policies has a significant role in promoting the improvement of green total factor productivity in China's manufacturing industry. Geert (2013) [16] found that renewable green industries can be promoted through the use of economic instruments such as taxes and subsidies. Rob et al. (2013) [17] believe that government subsidy policies can improve the speed of green innovation in industries, and Raphael (2014) [18] believes that government subsidies can promote the market diffusion of renewable energy technologies.

In summary, most of the research on the development of green industries is based on the development planning of specific green industries. Most of the models used in the study of heterogeneity of green industry are based on traditional econometric models, and such models cannot well study the intensity of the influence of various influencing factors on green industries. So far, no scholar has used nonparametric methods to study the spatial heterogeneity of the development level of green industries. Because of this, combined with the green industry development data of 30 provinces (except Tibet) in China from 2011 to 2020, the spatiotemporal characteristics and spatial heterogeneity of green industry development in different regions are studied, and the geographically weighted regression in the spatial variability coefficient model is used to study its internal influence relationship.

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2. Green Industry Development Data Index System

2.1. Construction of Green Industry Development Index System.

A total of 25 evaluation indicators at the level of four indicators are selected to describe the development level of the green industry, namely green production, green consumption, green economy and green environment. Tibet was not included in the scope of this study due to the serious lack of data, and the data analyzed came from the data released by the National Bureau of Statistics and the EPS global statistics. Table 1 is the detailed indicators of the comprehensive evaluation system of the development level of the green industry.

Table 1. Comprehensive evaluation index system of green industry development level.

Metrics layer	index	Metric properties
Green production	The total capacity of industrial wastewater treatment	Positive
	The tertiary industry accounts for the proportion of GDP	Positive
	The amount of chemical fertilizer applied per unit cultivated area	Negative
	Pesticide usage per unit cultivated area	Negative
	Investment in industrial pollution control completed	Positive
	Sulfur dioxide emissions	Negative
	Total NOx emissions	Negative
	The treatment capacity of industrial waste gas treatment facilities	Positive
Green consumption	Total passenger traffic by bus and tram	Positive
	Gas penetration rate	Positive
	Water reuse	Positive
	Investment in urban environmental infrastructure	Positive
	Harmless treatment rate of domestic waste	Positive
	Green energy consumption accounts for a proportion of total energy consumption	Positive
Green economy	Full-time R&D personnel in industrial enterprises above the designated size	Positive
	R&D funding for industrial enterprises above the designated size	Positive
	Number of patent applications granted	Positive
	Industrial added value	Negative
	Effective irrigation area	Positive
	Technology market turnover	Positive
Green environment	The amount of pollution-free treatment of municipal waste	Positive
	Total COD of chemical oxygen demand emissions from wastewater	Negative
	Municipal sewage treatment rate	Positive
	Investment in environmental pollution control accounts for a proportion of the GDP	Positive
	Forest cover	Positive

2.2. Construction of Indicator System of Influencing Factors of Green Industry.

The four influencing factors of the development level of green industry are economic development, high technology industry, ecological environment, and urban green construction, as shown in Table 2. Economic development is an important indicator of the development level of the green industry; The green industry has obvious high technology characteristics, and it needs to continuously improve the technical level and improve the process in the process of development, to reduce energy consumption and reduce pollution emissions; Urban green construction can promote the development of green industries, and at the same time protect the urban environment and reduce pollution; The ecological environment is the foundation of the development of green industries, and areas with good the ecological environment are more conducive to the development of green industries.

Table 2. Index system of factors influencing the development level of the green industry.

Influencing factors	index	Metric properties
Economic development	The tertiary industry accounts for the proportion of GDP	Positive
	GDP per capita	Positive
	Disposable income of residents	Positive
	GDP value added	Positive
High technology industry	Number of enterprises in high technology industries	Positive
	R&D personnel full-time equivalent	Positive
	Number of new product development projects	Positive
	Number of domestic patents in force	Positive
	Expenditure on technological transformation	Positive
Ecological environmental protection	Sulfur dioxide emissions	Negative
	Total NOx emissions	Negative
	Investment in environmental pollution control accounts for a proportion of the GDP	Positive
	Forest cover	Positive
	Water reuse	Positive
	Harmless treatment rate of domestic waste	Positive
	Total sewage treatment capacity	Positive
Urban green construction	The urban green space area	Positive
	Investment in urban environmental infrastructure	Positive
	Gas penetration rate	Positive
	The green coverage rate of built-up areas	Positive
	Total passenger traffic by bus and tram	Positive

3. Main Problems

3.1. Research Structure.

In this paper, the spatiotemporal characteristics and heterogeneity of the development of China's green industry are studied, and the structure of this paper is as follows: (1) Explain the background of China's promotion of green industry development, the development status of green industry at home and abroad, and the influencing factors of green industry development; (2) Establishment of index system. Based on the research results of the connotation of green industry, an evaluation index system of the development level of green industry and its influencing factors is constructed; (3) Research methods and data analysis results. The entropy weight method was used to measure the development level of green industries in various provinces and cities from 2011 to 2020, the spatial agglomeration characteristics of China's green industry development were analyzed through global autocorrelation and local autocorrelation, and the spatial heterogeneity analysis was carried out by geographic weighted regression (GWR) in the spatial variable coefficient model, and the influence intensity of high technology industries, economic development, urban construction and other influencing

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factors on the development of green industries in various regions was studied; (4) Research conclusions and related policy recommendations

3.2. Research Methods.

3.2.1. Measurement Method of Green Industry Development Level.

This paper uses the entropy-weighted method to measure the development level of green industry, and the basic steps are as follows:

Step 1: Non-negative data processing. When calculating entropy, you need to take the natural logarithm to ensure that the data are all positive. If there are negative values in the data, they can be handled by adding absolute values.

Step 2: Standardize relevant indicators. Suppose there are n regions and m indicators, where X_{ij} is the j indicator data of the i region, C_{ij} is the standardized indicator data of X_{ij} , the standardized treatment of positive indicators and negative indicators is different, where the positive indicator formula is:

$$C_{ij} = \frac{X_{ij} - \min(X_{1j}, X_{2j}, \cdots, X_{nj})}{\max(X_{1j}, X_{2j}, \cdots, X_{nj}) - \min(X_{1j}, X_{2j}, \cdots, X_{nj})}, (i = 1, 2, \cdots, n, j = 1, 2, \cdots, m). \quad (1)$$

The negative indicator formula is:

$$C_{ij} = \frac{\max(X_{1j}, X_{2j}, \cdots, X_{nj}) - X_{ij}}{\max(X_{1j}, X_{2j}, \cdots, X_{nj}) - \min(X_{1j}, X_{2j}, \cdots, X_{nj})}, (i = 1, 2, \cdots, n, j = 1, 2, \cdots, m). \quad (2)$$

In order to avoid meaningless zero values after the data is logarithmic, the normalized data is shifted to the right:

$$C_{ij}' = C_{ij} + 0.001. \quad (3)$$

Step 3: Calculate the entropy value S of each indicator.

$$S_j = -(\ln n)^{-1} \sum_{i=1}^{n} p_{ij} \ln(p_{ij}). \quad (4)$$

$$p_{ij} = \frac{C_{ij}'}{\sum_{i=1}^{n} C_{ij}'}, (i = 1, 2, \cdots, n, j = 1, 2, \cdots, m). \quad (5)$$

Step 4: Calculate the difference coefficient d for the j indicator and the weight coefficient λ_j .

$$d_j = 1 - S_j, (j = 1, 2, \cdots, m). \quad (6)$$

$$\lambda_j = \frac{d_j}{\sum_{j=1}^{m} d_j}. \tag{7}$$

Step 5: Calculate the comprehensive evaluation value of the development index for the i region, Y_i.

$$Y_i = \sum_{j=1}^{m} \lambda_j \times C_{ij}', (i = 1, 2, \cdots, n). \tag{8}$$

Where, Y_i in this article represents the green industry development level value of the i province in a certain year. From the above steps, we can calculate the level of green industry development in China's 30 provinces and cities (except Tibet) from 2011 to 2020.

3.2.2. Research Methods on Spatiotemporal Characteristics of Green Industry Development.

In order to study whether there is spatial autocorrelation between the development level of green industries in various regions, this paper uses the global autocorrelation model and LISA saliency distribution to analyze the spatial correlation of the development level of green industries.

(1) Global Autocorrelation Model. Under normal circumstances, areas with high levels of green industry development have correspondingly high levels of green industry development in their surrounding areas, and areas with low levels of green development have lower levels of green industry development in their surrounding areas. Therefore, the Moran index ($Moran's\ I$) can be used to test the global autocorrelation of the development level of green industry[19]. The formula for $Moran's\ I$ is as follows:

$$Moran's\ I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(Y_i - \overline{Y})(Y_j - \overline{Y})}{\left(n\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}\right)\sum_{i=1}^{n}(Y_i - \overline{Y})^2}. \tag{9}$$

Where, Y_i and Y_j represent the level of green industry development in i and j cities, n is the total number of regional space units, In this paper, $n = 30$, W_{ij} is the spatial weight matrix after row normalization, which is constructed based on adjacencies. $\overline{Y} = \frac{\sum_{i=1}^{n} Y_i}{n}$ $Moran's\ I \in [-1, 1]$, When $Moran's\ I < 0$, it indicates that the development level of green industry is diffused or evenly distributed, when $Moran's\ I = 0$ shows irregular distribution, when $Moran's\ I > 0$, it indicates that the development level of green industry shows aggregation distribution. The larger the absolute value of $Moran's\ I$, the stronger the spatial autocorrelation.

The significance test for Moran index usually uses the Z statistic test, where the formula for the Z test statistic is:

$$Z(I)=\frac{I-E(I)}{\sqrt{VAR(I)}}. \quad (10)$$

where $E(I)$ represents the mathematical expectation of $Moran's\ I$ and $VAR(I)$ represents the variance of $Moran's\ I$.

(2) LISA Saliency Distribution. Global autocorrelation analysis cannot obtain the spatial association characteristics between the eigenvalues of local spatial elements, so it is necessary to calculate the local spatial autocorrelation index to further reflect the correlation between two adjacent spatial elements. LISA saliency distribution is a method to measure local autocorrelation, and LISA saliency distribution can reflect spatial heterogeneity and spatial aggregation between spatial units and adjacent units. The formula for the LISA significance distribution is:

$$I=\frac{n(Y_i-\bar{Y})\sum_{j=1}^{n}W_{ij}(Y_j-\bar{Y})}{\sum_{i=1}^{n}(Y_i-\bar{Y})^2}. \quad (11)$$

The LISA heat map obtained by local autocorrelation analysis can divide the spatial agglomeration patterns into four types[20], the first is high-high agglomeration, that is, HH agglomeration, which means that the characteristic values of regional spatial units and their neighboring spatial units are high; The second is low-low agglomeration, that is, LL-type agglomeration, which means that the characteristic values of regional spatial units and their adjacent spatial units are low; The third is high-low agglomeration, that is, HL-type agglomeration, which refers to the agglomeration form in which the spatial elements with eigenvalues at high values are surrounded by spatial units with eigenvalues at low values; The fourth type is low-high agglomeration, that is, LH type agglomeration, which refers to the agglomeration form in which the spatial elements with eigenvalues at low values are surrounded by spatial elements with eigenvalues at high values.

3.2.3. Research Methods on Spatial Heterogeneity in the Development of Green Industries.

The spatial variable coefficient model assumes that the regression coefficient in the linear regression model is a function of the spatial position of the observation point, incorporates the spatial position information of the data into the model, and uses the estimated value of the regression coefficient function at each spatial position to analyze the spatial change characteristics of the regression relationship. Geographically weighted regression (GWR) is based on the spatial variability coefficient model, using the function of the distance between observation points as a weight estimation method[21], the GWR model is as follows:

$$Y_i=\beta_0(u_i,v_i)+\beta_1(u_i,v_i)M_{i1}+\cdots+\beta_p(u_i,v_i)M_{ip}+\varepsilon_i, i=1,2,\cdots,n. \quad (12)$$

Where, Y is the dependent variable, that is, the development level of green industry, $M_1,M_2,\cdots,M_p$ is the independent variable, and $M_1,M_2,\cdots,M_p$ in this paper is the influencing factor of the development of green industry. $(Y_i;M_{i1},M_{i2},\cdots,M_{ip})$ is the observed value of the dependent variable and the independent variable at the geographic location (u_i,v_i)

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$(i=1,2,\cdots,n)$, and $\beta_j(u,v)$ $(j=0,1,2,\cdots,p)$ is the unknown function of the spatial geographic location; $\varepsilon_i(i=1,2,\cdots,n)$ is an independent and homogeneous error term, and $E(\varepsilon_i)=0, Var(\varepsilon_i)=\sigma^2$.

Let (u_0,v_0) be any point in the geographic area under study, u_0 and v_0 be latitude and longitude data, and d_{0i} be the distance between (u_0,v_0) and the geographic location of group i observations $(Y_i;X_{i1},X_{i2},\cdots,X_{ip})$, so construct a set of weights at point (u_0,v_0) as follows:

$$w_i(u_0,v_0)=K(d_{0i}/h),\ \ i=1,2,\cdots,n. \tag{13}$$

where K is the kernel function, w_i is the weight, and h is the bandwidth, the solution method is the same as the fitting method of the variable coefficient model. The estimated value of the coefficient can intuitively reflect the intensity of the change of the dependent variable of the respective variable, so as to analyze the spatial variation characteristics of the regression relationship.

3.3. Analysis of Results

3.3.1. Measurement Results and Analysis of Green Industry Development Level.

Table 3. The weight of each indicator of the development level of green industry.

Metrics layer	index	Metric properties	weight
Green production	The total capacity of industrial wastewater treatment	Positive	0.0467
	The tertiary industry accounts for the proportion of GDP	Positive	0.0205
	The amount of chemical fertilizer applied per unit cultivated area	Negative	0.0071
	Pesticide usage per unit cultivated area	Negative	0.0116
	Investment in industrial pollution control completed	Positive	0.0515
	Sulfur dioxide emissions	Negative	0.0066
	Total NOx emissions	Negative	0.0093
	The treatment capacity of industrial waste gas treatment facilities	Positive	0.1213
Green consumption	Total passenger traffic by bus and tram	Positive	0.0325
	Gas penetration rate	Positive	0.0048
	Water reuse	Positive	0.0124
	Investment in urban environmental infrastructure	Positive	0.0405
	Harmless treatment rate of domestic waste	Positive	0.0051
	Green energy consumption accounts for a proportion of total energy consumption	Positive	0.0302
Green economy	Full-time R&D personnel in industrial enterprises above the designated size	Positive	0.0927
	R&D funding for industrial enterprises above the designated size	Positive	0.0875
	Number of patent applications granted	Positive	0.1110
	Industrial added value	Negative	0.0064
	Effective irrigation area	Positive	0.0466
	Technology market turnover	Positive	0.1381
Green environment	The amount of pollution-free treatment of municipal waste	Positive	0.0446
	Total COD of chemical oxygen demand emissions from wastewater	Negative	0.0099
	Municipal sewage treatment rate	Positive	0.0048
	Investment in environmental pollution control accounts for a proportion of the GDP	Positive	0.0278
	Forest cover	Positive	0.0306

This paper evaluates the overall development level of green industries in 30 provinces and cities in China (except Tibet) from 2011 to 2020, selects a total of 25 indicator data at four levels from 2011 to 2020, uses the entropy value method to determine the weights (see Table 3 for details), and calculates the annual green industry development level values of 30 provinces and cities.

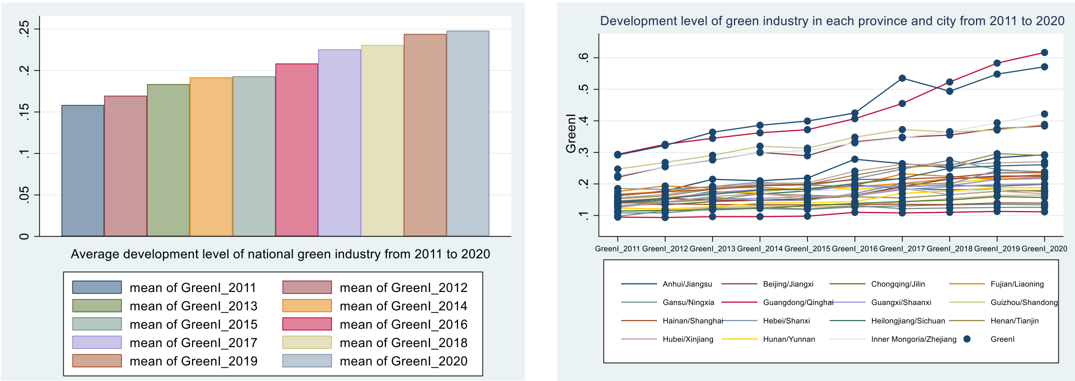
The proportions of the above four levels of indicators are: 0.2746 (green production), 0.1255 (green consumption), 0.4823 (green economy), 0.1177 (green environment).

Calculating the evaluation value of the annual green industry development level of each province and city (see Table 4 for details), it can be seen from the table that the development level of green industries in various provinces and cities has basically shown an upward trend. In 2020, the level of green development in Jiangsu, Zhejiang, Guangdong and other regions is relatively high, while the level of green industry development in Tianjin, Jilin, Hainan, Guizhou, Yunnan, Qinghai, Ningxia and other regions is low, and the development of green industries is relatively backward.

Table 4. Evaluation values of the annual green industry development level of each province and city.

Region	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Beijing	0.2212	0.2547	0.2760	0.3000	0.2892	0.3335	0.3478	0.3549	0.3752	0.3837
Tianjin	0.1386	0.1418	0.1500	0.1685	0.1641	0.1593	0.1555	0.1654	0.1767	0.1794
Hebei	0.1855	0.1822	0.1911	0.2059	0.1950	0.2158	0.2467	0.2752	0.2457	0.2365
Shanxi	0.1297	0.1423	0.1576	0.1471	0.1479	0.1697	0.2012	0.1994	0.2431	0.2388
Inner Mongoria	0.1403	0.1539	0.1734	0.1838	0.1782	0.1811	0.1858	0.1740	0.1830	0.1790
Liaoning	0.1759	0.1934	0.1870	0.1891	0.1806	0.1950	0.2318	0.2240	0.2145	0.2211
Jilin	0.1143	0.1160	0.1176	0.1229	0.1312	0.1381	0.1439	0.1488	0.1599	0.1570
Heilongjiang	0.1389	0.1496	0.1767	0.1679	0.1778	0.1966	0.1846	0.1815	0.1835	0.1761
Shanghai	0.1633	0.1752	0.1826	0.1943	0.1991	0.2137	0.2156	0.2205	0.2350	0.2360
Jiangsu	0.2917	0.3220	0.3639	0.3860	0.3993	0.4248	0.5352	0.4938	0.5481	0.5714
Zhejiang	0.2258	0.2548	0.2776	0.2995	0.3064	0.3303	0.3464	0.3659	0.3938	0.4217
Anhui	0.1625	0.1778	0.2147	0.2099	0.2185	0.2782	0.2643	0.2514	0.2832	0.2924
Fujian	0.1673	0.1756	0.1927	0.1944	0.1965	0.1907	0.2015	0.2162	0.2207	0.2297
Jiangxi	0.1400	0.1547	0.1481	0.1479	0.1527	0.1620	0.1920	0.2156	0.2248	0.2248
Shandong	0.2470	0.2679	0.2906	0.3197	0.3134	0.3479	0.3723	0.3646	0.3709	0.3886
Henan	0.1533	0.1620	0.1835	0.1966	0.1984	0.2279	0.2532	0.2587	0.2959	0.2901
Hubei	0.1559	0.1670	0.1858	0.2013	0.2032	0.2404	0.2619	0.2617	0.2665	0.2706
Hunan	0.1434	0.1567	0.1710	0.1737	0.1904	0.1836	0.1936	0.2039	0.2160	0.2228
Guangdong	0.2936	0.3255	0.3446	0.3621	0.3719	0.4069	0.4550	0.5231	0.5830	0.6168
Guangxi	0.1405	0.1441	0.1525	0.1539	0.1600	0.1620	0.1820	0.1910	0.1982	0.2003
Hainan	0.1307	0.1369	0.1347	0.1342	0.1338	0.1353	0.1353	0.1344	0.1397	0.1392
Chongqing	0.1427	0.1337	0.1440	0.1483	0.1533	0.1642	0.1917	0.1954	0.1927	0.1988
Sichuan	0.1440	0.1534	0.1671	0.1803	0.1835	0.2009	0.2176	0.2496	0.2571	0.2608
Guizhou	0.1139	0.1138	0.1257	0.1301	0.1274	0.1301	0.1423	0.1533	0.1637	0.1648
Yunnan	0.1234	0.1203	0.1275	0.1397	0.1408	0.1439	0.1700	0.1778	0.1880	0.1877
Shaanxi	0.1463	0.1541	0.1722	0.1824	0.1822	0.1924	0.1928	0.1947	0.2140	0.2170
Gansu	0.0975	0.1145	0.1227	0.1219	0.1190	0.1271	0.1300	0.1340	0.1353	0.1336
Qinghai	0.0947	0.0934	0.0962	0.0962	0.0977	0.1098	0.1080	0.1099	0.1128	0.1116
Ningxia	0.1083	0.1080	0.1204	0.1252	0.1206	0.1306	0.1216	0.1236	0.1255	0.1257
Xinjiang	0.1253	0.1421	0.1601	0.1687	0.1569	0.1635	0.1861	0.1655	0.1775	0.1688

Figure 1 below shows the bar chart of the annual green industry development level (referred to as Green I in the figure) and the outline chart of the annual green industry development level of each region. As can be seen from Figure 1(a), the development level of China's green industry is generally on the rise, and the growth trend is relatively stable. As can be seen from the outline chart of Figure 1(b), the development level of green industries in various regions basically increases with the increase of years, and Beijing, Guangdong, Jiangsu, Shandong and other regions have grown faster and green industries have developed better.



(a)China annual green industry development bar chart.

(b)Outline map of the development level of green industry in each region.

Figure 1. Green industry development bar chart and contour chart.

The classification results of China's provinces and cities in 2020 are obtained by classifying the green industry development level score, as shown in Figure 2:

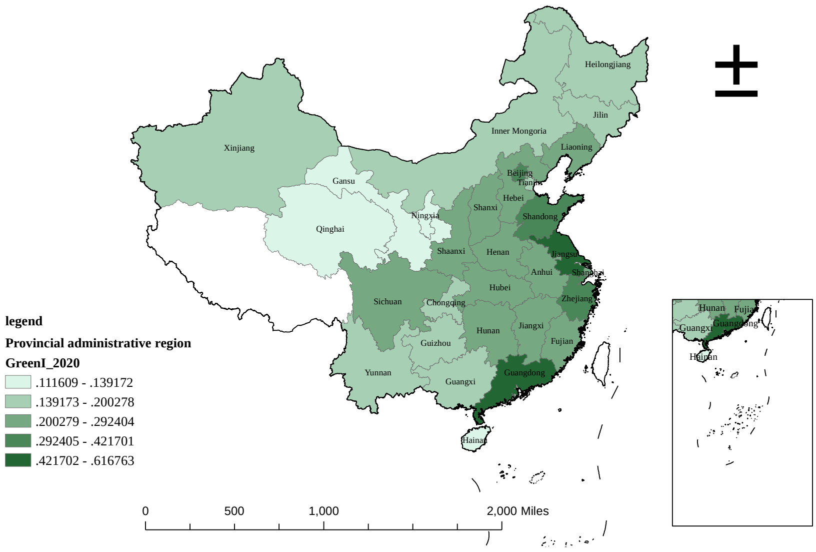


Figure 2. Spatial characteristics of the development level of green industries in various provinces and cities.

Using the natural interruption point grading method, the development level of green industry is divided into five categories: very high, high, medium, low and very low (see Figure 2 for details).

3.3.2. Spatial Distribution Characteristics of China's Green Industry Development Level

(1) Global Spatial Autocorrelation Features. In order to study whether there is a spatial correlation between the green development levels of various provinces and cities in China, this paper calculates the annual global Moran index based on the green industry development level of each province and city from 2011 to 2020, as shown in Table 5:

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Table 5. Global Moran Index of the development level of green industries from 2011 to 2020.

Year	Global Moran index	Z	p
2011	0.2722	2.4875	0.0129
2012	0.2393	2.2151	0.0268
2013	0.2255	2.1040	0.0354
2014	0.2226	2.0724	0.0382
2015	0.2517	2.3224	0.0202
2016	0.2487	2.2681	0.0233
2017	0.2169	0.0459	0.0379
2018	0.2092	1.9962	0.0459
2019	0.2005	1.9486	0.0500
2020	0.2091	2.0228	0.0430

As can be seen from Table 5, the global Moran index is greater than 0, passing the 5% significance test, indicating that the spatial correlation of green industry development is significant and the spatial agglomeration effect is obvious. It can be seen from the annual global Moran index that its changes show M-shaped characteristics, the overall form of decline, the degree of spatial aggregation has a decreasing trend, and the spatial manifestation is more scattered in the high-value area or low-value area.

(2) Local Spatial Autocorrelation Features. This paper uses local autocorrelation analysis to further determine whether there is a spatial correlation between provinces and cities for the development of green industries.

In this paper, the agglomeration mode of green industries in various provinces and cities in China in 2020 is analyzed by using the saliency distribution of LISA, and the LSA agglomeration map of the development level of green industries in various provinces and cities in China in 2020 is drawn (see Figure 3 for details), and then judge whether the agglomeration mode is statistically significant.

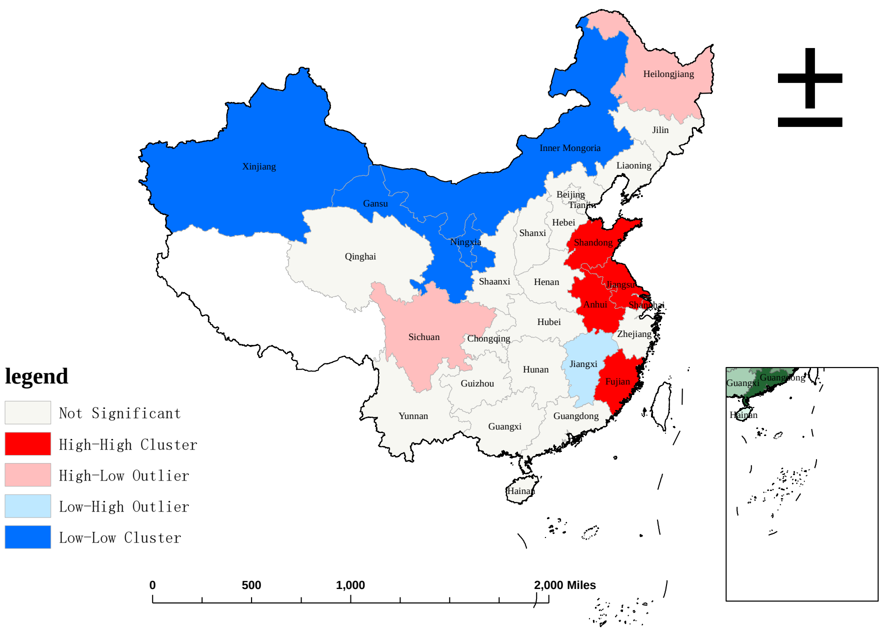

Figure 3. LISA agglomeration map of the development level of green industry in various provinces and cities in China in 2020.

It can be seen from Figure 3 that the local spatial autocorrelation characteristics of the development level of green industry in 2020 are: (1) Fujian, Shanghai, Anhui, Shandong and other regions are high-level agglomeration areas for green industry development, indicating that these provinces themselves and neighboring provinces have a high level of green industry development and a small degree of spatial difference; (2) Heilongjiang and Sichuan are high and low agglomeration areas for green industry development, indicating that there is a large gap between themselves and their neighboring provinces in the development level of green industry, and the degree of spatial difference is large; (3) There is only one Jiangxi Province in China that belongs to the low-high agglomeration mode, indicating that its own development level is low, the green industry development capacity in the surrounding areas is high, the spatial difference degree is large, and it has development potential; (4) The development capacity of green industries in Qinghai, Ningxia, Gansu, Xinjiang and Inner Mongolia and their surrounding areas is low, indicating that the degree of spatial difference is small and the development of green industries is relatively slow.

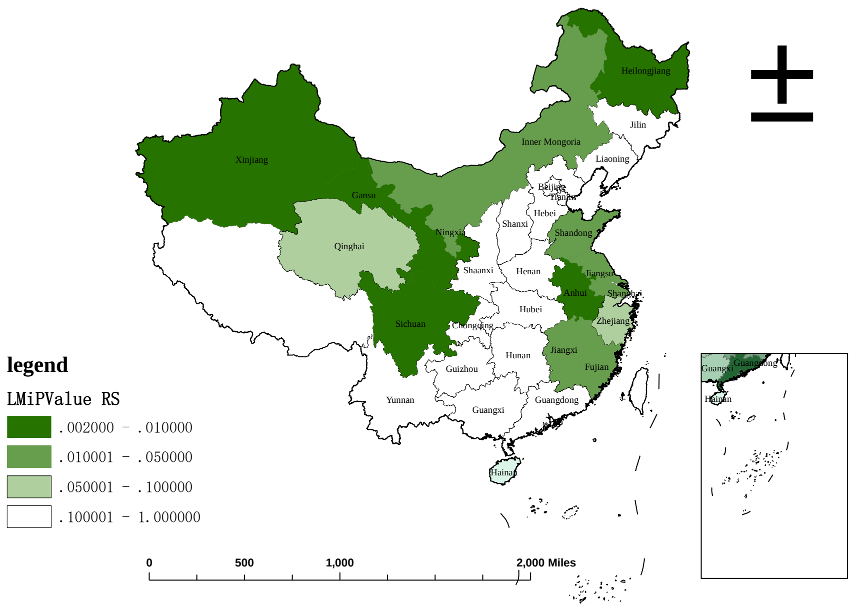

Figure 4. LISA saliency level of the development level of green industries in various provinces and cities in China in 2020.

As can be seen from Figure 4, the above four agglomeration mode regions are significant at the 5% significance level, indicating that the above LISA agglomeration mode analysis results passed the significance test and are statistically significant.

3.3.3. Regression Analysis of Green Industry Development Level.

This paper divides the influencing factors of green industry into four levels (see above) to study the heterogeneity of these four influencing factors in various regions.

(1) General Linear Regression Analysis Results. Firstly, the above four influencing factors are analyzed by linear regression, and the variables that are not significant by the test are removed. Then, according to the geographically weighted regression method, the variables with variance inflation factor (VIF) less than 7.5 are removed, and finally high technology industry, economic development and urban green construction are determined as the influencing factors of the development level of green industry. Table 6 below shows the results of linear regression analysis of the influencing factors of green industry development from 2011 to 2020.

Table 6. Linear regression analysis results.

Year	Intercept	High technology industry	Economic development	Urban green construction	R^2	Adjust R^2
2011	0.0853	0.2131	0.1012	0.2048	0.9527	0.9472
2012	0.0811	0.2191	0.1154	0.2244	0.9602	0.9556
2013	0.0846	0.1801	0.0878	0.2726	0.9504	0.9446
2014	0.0798	0.1840	0.0809	0.3078	0.9620	0.9576
2015	0.0783	0.2433	0.0925	0.2916	0.9652	0.9612
2016	0.0738	0.1585	0.0590	0.3968	0.9591	0.9544
2017	0.0652	0.2120	0.0748	0.4274	0.9272	0.9188
2018	0.0724	0.1621	0.0635	0.4372	0.9585	0.9537
2019	0.0698	0.1899	0.0960	0.4229	0.9426	0.9360
2020	0.0654	0.2106	0.1060	0.4480	0.9485	0.9425

(2) Geographically Weighted Regression Analysis Results. Taking the development level of green industry in 30 provinces and cities in China (except Tibet) from 2011 to 2020 as the explanatory variable, and the high technology industry development, economic development and urban construction of each province as the explanatory variables, a geographically weighted regression analysis was carried out to obtain the range of influence intensity coefficients of the influencing factors of green industry development in 30 provinces and cities in China (except Tibet) from 2011 to 2020 (see Table 7 for details). The range of variable influence intensity coefficients calculated by the geographically weighted regression model and the R^2-value of the model are given in the table.

Table 7. GWR model regression analysis results.

Year	High technology industry	Economic development	Urban green construction	R^2	Adjust R^2
2011	$[0.1553, 0.2704]$	$[0.0775, 0.1392]$	$[0.1596, 0.2244]$	0.9663	0.9533
2012	$[0.1703, 0.2438]$	$[0.1081, 0.1343]$	$[0.2108, 0.2428]$	0.9646	0.9555
2013	$[0.0954, 0.2297]$	$[0.0765, 0.1154]$	$[0.2591, 0.2938]$	0.9545	0.9424
2014	$[0.0430, 0.2206]$	$[0.0582, 0.1070]$	$[0.2794, 0.3543]$	0.9666	0.9578
2015	$[0.1813, 0.3178]$	$[0.0709, 0.1354]$	$[0.2766, 0.3176]$	0.9730	0.9630
2016	$[-0.1529, 0.4103]$	$[-0.2597, 0.2457]$	$[0.2200, 0.6477]$	0.9871	0.9663
2017	$[-0.4408, 0.7472]$	$[-0.0351, 0.2906]$	$[0.2245, 0.7520]$	0.9906	0.9760
2018	$[-0.5008, 0.5365]$	$[-0.0176, 0.2098]$	$[0.2237, 0.7066]$	0.9844	0.9608
2019	$[-0.5827, 0.7052]$	$[-0.1843, 0.2962]$	$[0.1917, 0.7145]$	0.9860	0.9605
2020	$[-0.4630, 0.6131]$	$[-0.0500, 0.3624]$	$[0.1640, 0.7716]$	0.9873	0.9663

3.3.4. Heterogeneity Analysis of Influencing Factors for the Development of Green Industry.

This paper plots the box plot of the influence intensity of three influencing factors: high technology industry (see Figure 5(a)), economic development (see Figure 5(b)), and urban green construction (see Figure 5(c)) from 2011 to 2020.

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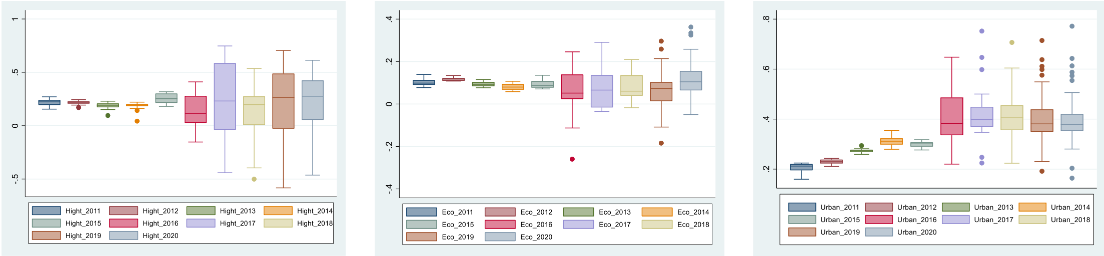

(a) (b) (c)

Figure 5. Influence intensity plot of influencing factors from 2011 to 2020.

From the three boxplots, it can be seen that the impact intensity of high technology industry (referred to as Hight in the figure), economic development (referred to as Eco in the figure), and urban green construction (referred to as Urban in the figure) has gradually expanded since 2015. It can be seen from Figure 5(a) that high technology industrial factors have a strong role in promoting the development of green industries; It can be seen from Figure 5(b) that the impact intensity range of economic development is also gradually expanding, which is generally promoted, but this degree of expansion is small, indicating that economic development has promoted the development of green industries to a certain extent, and the environmental pollution problems brought about by economic development at the same time have inhibited the development level of green industries, so the intensity of the effect on the development of green industries is low; It can be seen from Figure 5(c) that the development and change of the promotion effect of urban green construction on green industry from low to high and then slightly reduced, indicating that the impact of urban construction on the development of green industry is intense, and this intensity gradually increases and tends to stabilize with the growth of the year.

4. Conclusion and Recommendations

4.1. Main Conclusion

(1) It can be seen from the value of the development level of green industry that the development level of China's green industry has steadily increased with the growth of the year; From the perspective of cities, the development of green industries in the central and eastern regions is relatively developed, but the development level of green industries in the western region is still at the middle and lower levels. The level of green industry in each region is classified, Jiangsu and Guangdong are in high-level areas, Qinghai, Gansu and Ningxia are in low-level areas, and the regional development of green industries is uneven. The level of green industry in each region is classified, Jiangsu and Guangdong are in high-level areas, Qinghai, Gansu and Ningxia are in low-level areas, and the regional development of green industries is uneven.

(2) There is spatial autocorrelation in the development of green industries in various provinces and cities in China (except Tibet). Fujian, Shanghai, Anhui and Shandong are high-rise agglomeration areas for green industry development, and these provinces and neighboring provinces have high green industry development capacity and small spatial differences. Heilongjiang and Sichuan are high and low agglomeration areas, and the gap between themselves and their neighboring provinces is large, and the degree of spatial difference is large; Jiangxi Province belongs to the low-high agglomeration model, its own development level is low, the green industry development ability of surrounding cities is high, and the degree of spatial difference is large. Qinghai, Ningxia, Gansu, Xinjiang and Inner Mongolia have low green industry development capacity and small spatial differences, and the development of green industries is relatively slow.

(3) In the heterogeneity analysis of influencing factors, from the perspective of time, before 2015, the intensity of high technology industry and economic development was relatively stable, and the influence intensity of each influencing factor gradually increased in 2015, which is related to the relevant ecological civilization construction policies issued by the state in 2015. The influencing factors of high technology industry have a certain role in promoting the development of green industry in the overall situation, and are the core driving force for the development of green industry. Economic development has promoted the development of green industry to a certain extent, but the impact of environmental pollution and other impacts brought by economic development has also inhibited the development level of green industry, so the intensity of economic development has a small degree of expansion; The promotion effect of urban green construction on green industry has undergone development and change from low to high to slightly reduced, and its impact on the development of green industry is relatively strong, and this intensity gradually increases and stabilizes with the growth of the year.

4.2. Related Recommendations

4.2.1. Promote the Integrated Development of High Technology and Green Industries.

Through the integrated development of scientific innovation technology and green industry, green technology innovation can not only reduce the pollution emissions of enterprises, but also promote the green specificity of traditional industries and promote sustainable economic development; High technology is the core driving force for the development of green industry, so we should promote the development of green environmental protection high technology enterprises, promote the birth of green innovative products, arouse people's attention to the development of green industry, and improve environmental awareness.

4.2.2. Improve the Green Industry System and Promote the Development of Green Industry.

In order to promote the development of green industry, China has also issued relevant green industry policies, but the threshold of these policies is low, many enterprise knowledge in order to obtain government subsidies and not really for the development of green industry, so we must improve the green industry system, especially the green technology property rights protection system and green technology property rights sharing and sharing system, not only can protect green technology property rights, but also to a certain extent can make green technology can be promoted, further promote the development of green industry.

4.2.3. Promote Exchanges among Regions and Narrow Regional Development Gaps.

Due to the different development bases of regional economies, the development of green industries in various regions is not coordinated, so promoting exchanges between regions, sharing relevant technologies and experiences in green industry development, and narrowing the development gap between regions; At the same time, there are significant differences between different enterprises in different regions, and when learning from the green development experience of other regions, it is necessary to adapt measures to local conditions and prescribe the right medicine.

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References

[1] P. Gunno, K. Jina: Entry conditions, firm strategies and their relationships to the innovation performance of an emerging green industry: The case of the solar cell industry, Asian Journal of Technology Innovation, Vol.18 (2010) No.4, p.21-42.

[2] S. Jaber, H. Matloub, K. Mehmood: Green and sustainable practices in the construction industry, Engineering Construction and Architectural Management, Vol.26 (2019) No.6, p.1063-1086.

[3] L. Indrayani, M. Triwiswara: The implementation of green industry standard batik industry to develop eco-friendly, IOP Conference Series: Materials Science and Engineering, Vol.980 (2020) No.1, p.012081.

[4] W. Alan, H, R. H. Charles, J. H. John: The Economic Impact of the Green Industry in the United States, HortTechnology, Vol.16 (2006) No.2, p.345-353.

[5] W. H. Chen, J. C. Chen, D. Y. Xu, J. C. Liu, N. N. Niu: Assessment of the practices and contributions of China's green industry to the socio-economic development, Journal of Cleaner Production, Vol.153 (2016) p.648-65.

[6] C. H. Zhu, T. Ma: Research on the evaluation of the development effect of regional green industry, Economics and Management Studies, (2011) No.3, p.64-70.

[7] H. T. Yin, N. Powers: Do state renewable portfolio standards promote in-state renewable generation, Energy Policy, Vol.38 (2010) No.2, p.1140-1149.

[8] M. William, B, P. Sunjoo, A. E. Joel: Empirical Estimates of the Influence of Renewable Energy Portfolio Standards on the Green Economies of States, Economic Development Quarterly, Vol.27 (2013) No.4, p.338-351.

[9] H. T. Yi: Green businesses in a clean energy economy: Analyzing drivers of green business growth in U.S. states, Energy, Vol.68 (2014), p.922-929.

[10] L. Dong, H. W. Liang, Z. Q. Gao, X. Luo, J. Z. Ren: Spatial distribution of China's renewable energy industry: Regional features and implications for a harmonious development future, Renewable and Sustainable Energy Reviews, Vol.58 (2016), p.1521-1531.

[11] C. Sanya: State renewable energy electricity policies: An empirical evaluation of effectiveness, Energy Policy, Vol.37 (2009) No.8, p.3071-3081.

[12] F. Manuel, R. Nolan, M. Christoph, S, V. Colin: Economic impacts from the promotion of renewable energy technologies: The German experience, Energy Policy, Vol.38 (2010) No.8, p.4048-4056.

[13] J. Oliver: Promoting green industrial development through local content requirements: India's National Solar Mission, Climate Policy, Vol.16 (2016) No.2, p.178-195.

[14] B. Allan, J. I. Lewis, T. Oatley: Green Industrial Policy and the Global Transformation of Climate Politics, Global Environmental Politics, Vol.21 (2021) No.4, p.1-19.

[15] Z. Zhou, Z. C. Ma, X. W. Lin: Carbon emissions trading policy and green transformation of China's manufacturing industry: Mechanism assessment and policy implications, Frontiers in Environmental Science, (2022), Article ID 9846122.

[16] T. S. Gert: ENVIRONMENTAL REVIEWS AND CASE STUDIES: From a Brown to a Green Economy: How Should Green Industries Be Promoted, Environmental Practice, Vol.15 (2013) No.1, p.72-78.

[17] A. Rob, S. Victoria, K. Viktória: Innovation policy for directing technical change in the power sector, Energy Policy, Vol.63 (2013), p.1240-1250.

[18] B. Raphael: Innovation in the energy sector: Lessons learnt from R&D expenditures and patents in selected IEA countries, Energy Policy, Vol.73 (2014), p.733-747.

[19] W. Zhao, H. Z. Liu, H. X. Pu: The Spatiotemporal evolution and socio-economic driving forces of air quality in China during the 13th Five-Year Plan period, Journal of Southwest University (Natural Science Edition), Vol.44 (2022) No.9, p.1-11.

[20] B. Hou, W. Z. Yue, T. F. Wang: Spatiotemporal heterogeneity pattern and influencing factors of carbon emission in metropolitan areas of China：a case of Shanghai, Economic geography,Vol.40 (2020) No.9, p.82-90.

ISSN: 2688-9323

[21] B. B. Lu, Y. Ge, K. Qin, J. H. Zheng: A review on geographically weighted regression, Geomatics of Wuhan University (Information Science Edition), Vol.45 (2020) No.9, p.1356-1366.