Original Research

Research on the Measurement and Spatial Distribution of Cultural and Creative Industry Agglomeration under the Background of Energy Conservation and Emission Reduction: Evidence from Tianjin

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Abstract

Due to the extensive use of fossil fuels such as raw coal, coke, oil, and natural gas, the greenhouse effect caused by carbon dioxide emissions has drawn attention, and pollution reduction and carbon emission reduction have become important research issues. Tianjin is a traditional industrial city in China. High-pollution and high-energy-consuming industries have caused serious air pollution problems. Therefore, pursuing a green transformation has become an inevitable path. This article selects typical pollution reduction and carbon emission reduction industries in Tianjin as the research object, collects panel data for Tianjin from 2013 to 2022, and conducts an empirical study on the agglomeration level and spatial characteristics of the pollution reduction and carbon emission reduction industries by comprehensively applying multiple methods such as location entropy, standard deviation ellipse analysis, kernel density estimation, spatial autocorrelation analysis, and the geographically weighted regression model. The research results reveal that: (1) The sample industries exhibit spatial agglomeration characteristics in terms of spatial distribution. According to the calculation, the average value of the location entropy index is higher than 0.5. (2) There are spatial correlations among different sample industries. (3) The sample industries have spatially heterogeneous characteristics. With the central urban area of Tianjin as its core, it exhibits a circular and radial distribution pattern, characterized by "large dispersion and small aggregation". Therefore, implementing pollution reduction and carbon emission reduction measures in a manner that suits local conditions has become a crucial strategy for effective urban governance.

Keywords: dual carbon target, reduce pollution and carbon emissions, agglomeration level, spatial distribution pattern, geographically weighted regression model

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Introduction

With the rapid development of human activities and urban society, air pollution, environmental pollution caused by excessive energy consumption, and climate change issues have increasingly drawn attention. How to effectively address the issue of carbon emissions has become a difficult problem that urgently needs to be solved globally. To effectively control the massive emissions of greenhouse gases, achieving green development through the formulation of policies, technologies, and other means is an inevitable choice for current development. To address climate issues, in 2020, the Chinese government put forward the strategic goal of "peaking carbon emissions by 2030 and achieving carbon neutrality by 2060".

As a developing country, we are committed to addressing environmental pollution issues, especially the control of carbon emissions. Due to the development of polluting industries, China's carbon emissions have shown an increasing trend. As shown in Fig. 1, from 1997 to 2021, China's overall carbon emissions increased from 2,924 million tons to 10,356 million tons, with an average annual growth rate of 310 million tons. Specifically, the carbon emissions from raw coal, coke, oil, and natural gas are relatively large. In terms of carbon emissions from raw coal and coke, the emissions in 1997 were 1,837 million tons, and in 2021, they were 5,356 million tons, an increase of 3,519 million tons. Therefore, energy conservation and emission reduction have become key issues that need to be urgently addressed.

At present, the Chinese government is taking a variety of measures to implement energy conservation and emission reduction and has achieved certain results. According to the "Action Plan for Energy Conservation and Carbon Reduction 2024-2025" released by the Chinese government in 2024, by 2024, energy consumption per unit of GDP and carbon dioxide emissions will be reduced by approximately 2.5% and 3.9%, respectively, and energy consumption per unit of added value of industrial enterprises above the designated size will be reduced by approximately 3.5%. The proportion of non-fossil energy consumption reached around 18.9%. Energy conservation and carbon reduction renovations in key areas and industries achieved energy savings of approximately 50 million tons of standard coal and reduced carbon dioxide emissions by about 130 million tons. In addition, according to the plan, by 2025, the proportion of non-fossil energy consumption will reach around 20%, and energy conservation and carbon reduction renovations in key areas and industries will result in energy savings of approximately 50 million tons of standard coal and carbon dioxide emissions reduction of about 130 million tons.

To achieve the dual carbon goals, the Chinese government has developed a systematic energy conservation and emission reduction plan through various forces such as policies, markets, and technologies. Against this backdrop, the main directions include two aspects: on the one hand, controlling carbon emissions from highly polluting and energy-consuming industries; on the other hand, vigorously developing non-polluting and low-emission green industries, such as new energy vehicles, new energy industries, intelligent manufacturing, cultural creativity, and other emerging industries. Therefore, vigorously developing industries that reduce pollution and carbon emissions has become the main direction for current environmental pollution control and management.

Tianjin is a municipality directly under the Central Government of China and one of the economic centers in the north. In the traditional industrial structure, high-pollution and high-energy-consuming industries dominated, which led to serious air pollution problems. For instance, severe weather conditions such as smog occurred from time to time, adversely affecting the health of residents. To address these issues, Tianjin has vigorously developed green industries such as
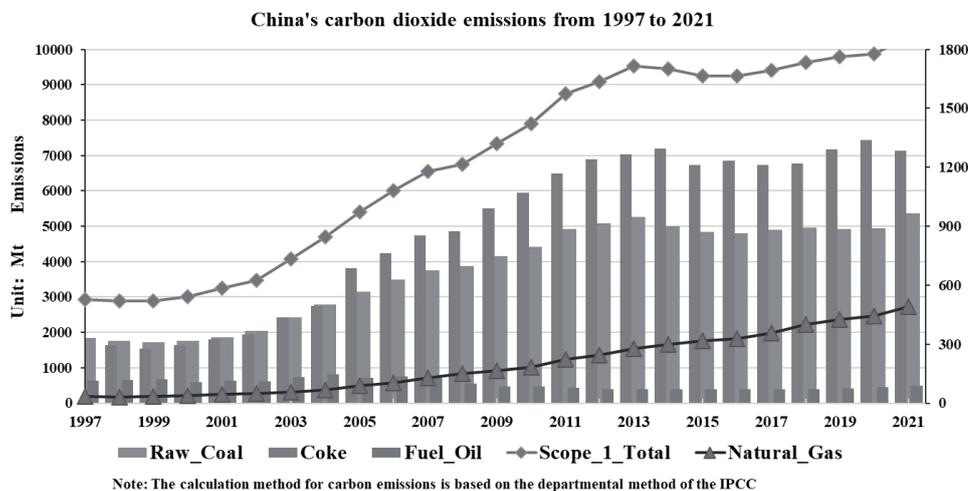

Fig. 1. China's carbon emission changes from 1997 to 2021.

cultural innovation, aiming to promote the optimization and upgrading of the economic structure through low-energy consumption, low-pollution, and high-value-added industrial models, and achieve a win-win situation for economic growth and environmental protection. The cultural and creative industry, with its characteristics of innovation-driven development, resource conservation, and environmental friendliness, has become an important part of the green industry. Through forms such as film and television, design, art, and digital content, the cultural and creative industry can not only disseminate environmental protection concepts but also promote the transformation of traditional industries toward green and low-carbon directions. Therefore, this article selects the cultural and creative industry in Tianjin as a typical representative of the pollution reduction and carbon emission reduction industry, analyzes its development level and spatial distribution, and provides a reference for the development of pollution reduction and carbon emission reduction industries.

Regarding issues such as the "dual carbon goals", "pollution reduction and carbon emission reduction", and "environmental governance", scholars at home and abroad have conducted extensive research. The main contents of the research results related to this article are as follows.

First, there have been abundant research achievements related to the "dual carbon goals", which have led to a consensus in the academic community on pollution reduction and carbon emission reduction. Xu et al. (2025) constructed the NEMO-China-Flexibility model to analyze the effect of power system flexibility on reducing carbon emissions [1]. Zheng et al. (2025) considered the issue of transformation risks in the process of achieving the dual carbon goals and evaluated the role of the dual carbon policy effects using the complex network paradigm [2]. Zeng et al. (2025) studied the prediction problem of civil aviation pilots under the dual carbon goals [3]. Wang et al. (2025) studied the hot and cutting-edge issues in aviation carbon emissions under the dual carbon goals [4]. These studies systematically explored the impact of carbon reduction under the background of the dual carbon goals through methods such as modeling, empirical research, and bibliometrics. In addition, Zhao et al. (2025), Zhang et al. (2025), and Kong et al. (2025) further explored the issue of achieving the dual carbon goals from multiple perspectives, such as land space utilization, climate policies, and carbon reduction scenarios [5-7].

Second, research on "pollution reduction and carbon emission reduction" mainly focuses on multiple dimensions such as technology, market, and policy. Li and Cui (2025) constructed an evaluation model for pollution reduction and carbon emission reduction from the perspective of the DPSIR model [8]. Zheng et al. (2025) constructed a carbon emission inventory for Shaanxi Province using statistical data and simultaneously studied its synergistic emission reduction effect [9]. Ma et al. (2025) studied the impact of green technological progress on the synergy of pollution reduction and carbon emission reduction [10]. LV et al. (2025) explored the impact of new quality productivity on pollution reduction and carbon emission reduction [11]. Wu et al. (2025) studied the synergistic relationship among carbon reduction, pollution reduction, green expansion, and growth [12]. Ma et al. (2025) studied the multi-dimensional role of technological progress in the synergy of pollution reduction and carbon emission reduction [13]. Tian et al. (2024) studied the spatio-temporal effects of the synergistic effects of pollution reduction and carbon emission reduction in heavily polluting enterprises [14]. Tan et al. (2024) studied the impact of the digital economy on pollution reduction and carbon emission reduction effects [15]. These studies focus on issues such as the influencing factors and synergy effects of pollution reduction and carbon emission reduction, and have significant reference value for solving practical problems.

Thirdly, research related to green-driven energy conservation and emission reduction strategies has become a current focus of attention. With the enhancement of environmental protection awareness, how to achieve environmental governance through green drive and sustainable development has become a hot issue in the academic circle. Zhang et al. (2025) studied the issue of energy conservation and carbon reduction paths in transportation based on the dual carbon goals [16]. Xiang et al. (2025) studied the impact of energy conservation and emission reduction policies on green productivity [17]. Hao et al. (2023) studied the impact of economic agglomeration on green total factor productivity [18]. Wang et al. (2022) studied the impact of the digital economy on green development [19]. Li et al. (2022) studied the issue of industrial green growth efficiency [20]. Wang and Su (2020) employed multiple models to study the measurement and impact of energy conservation and emission reduction efficiency [21]. Most of these studies have conducted analyses based on specific practical data and put forward targeted strategies and suggestions.

From the above-mentioned literature, it can be seen that there are abundant research achievements on issues such as the dual carbon goals, pollution reduction and carbon emission reduction, and energy conservation and emission reduction, and many scholars have achieved explicit results [22, 23]. However, few studies have focused on Tianjin as a typical case, especially when it comes to emerging and green industries. Different from previous studies, this paper will select the cultural industry in Tianjin as a typical representative of pollution reduction and carbon emission reduction industries and analyze its current development status and spatial distribution characteristics.

Therefore, the research of this paper mainly focuses on the following aspects: (1) Under the new scenarios and the dual carbon background, this paper

selects the typical industries for pollution reduction and carbon emission reduction in Tianjin as the main research objects and attempts to analyze their spatial agglomeration problems by using the latest statistical data; (2) By comprehensively applying various models such as location entropy, kernel density estimation, and spatial correlation analysis, a systematic analysis is conducted on multiple issues including the agglomeration level, spatial characteristics, and spatial distribution pattern of typical industries for pollution reduction and carbon emission reduction in Tianjin, to facilitate high-quality industrial development and provide references for scientific decision-making.

Materials and Methods

Data Sources

The main object of this article is the green industry, specifically focusing on the data from Tianjin's cultural and creative industries. According to the "Classification of Culture and Related Industries" released by the National Bureau of Statistics in 2018 and the standards of the China Cultural and Creative Industry Network, this article divides the research objects into five categories: The first is news and information services, which serve as the forefront of cultural communication and undertake the functions of information collection, organization, and dissemination. The second is content creation and production, which focuses on the original production of cultural content, which can be regarded as the core driving force of the cultural and creative industry. The third is creative design services, which combine creativity with design to endow cultural products with unique aesthetic value and practical functions. The fourth is the cultural dissemination channel, which builds a bridge for cultural products from the production end to the consumption end, ensuring the widespread dissemination of cultural content. The fifth category is cultural investment and operation, which drives the cultural and creative industries toward scale and sustainability from the perspectives of capital operation and industry management. The above five categories of industries further cover the three major categories of cultural manufacturing, cultural design services, and cultural creative media. As key components of the cultural and creative industries, they demonstrate irreplaceable value in areas such as technological innovation, artistic interpretation, and market promotion.

The data studied in this article mainly come from the latest official statistical yearbooks, including the Tianjin Statistical Yearbook (2013-2022), the Tianjin National Economic and Social Development Yearbook, etc. As of the end of 2013, the total number of cultural and creative industry institutions in Tianjin was 710, and as of the end of 2022, the total number of cultural and creative industry institutions in Tianjin was 11,495.

Furthermore, based on the locations of various cultural and creative industry institutions, the author used Baidu Maps API to obtain the latitude and longitude of the cultural and creative industry institutions, and then imported them into ArcGIS software to establish a spatial database of the cultural and creative industries. The author also created a spatial weight matrix to explore the spatial agglomeration level of the cultural and creative industries in Tianjin from 2013 to 2022, using these cultural and creative industry institutions as the analysis objects. A corresponding indicator system was built based on the collected data.

Model Construction

Analysis of Pollution Reduction and Carbon Emission Reduction Industries Based on the Location Entropy Index Method

Location entropy is a key indicator for evaluating the spatial distribution of regional factors [24]. Referring to existing research, this paper adopts location entropy to quantify the agglomeration degree and spatial distribution characteristics of pollution reduction and carbon emission reduction industries within a specific region. Therefore, the calculation formula for the location entropy of Tianjin's cultural industry is as follows:

$$LQ_{ij} = \frac{e_{ij} \Big/ \sum_{i=1}^{n} e_{ij}}{E_j \Big/ \sum_{i=1}^{n} E_i}$$

$$E_i = \sum_{k=1}^{s} E_i^k$$

Among them, i represents the cultural and creative industries of various districts in Tianjin, and j represents the year. LQ_{ij} is the location entropy of the cultural and creative industries in i district in the j year, where e_{ij} is the number of employees in cultural and creative industry institutions in i district in the j year. E_j is the number of employed people in all cultural and creative industries in the j year, $\sum_{i=1}^{n} e_{ij}$ refers to the number of employed people in the cultural and creative industries in j year; $\sum_{i=1}^{n} E_i$ is the relevant indicator for all industries. This article divides the cultural and creative industries into three categories: cultural manufacturing, cultural services, and cultural media. E_i^k represents the number of employed people in the k industry in the j year of Tianjin's i district (where the industry is a subdivision of various industries involved in

Table 1. Evaluation index system for pollution reduction and carbon emission reduction industries.

First-level indicator	Secondary indicators	Third-level indicators
Production Factors	Capital resources	Fixed assets investment in the cultural and creative industries
	Human resources	Number of employees in the cultural and creative industries
	Cultural resources	Number of legal entities in the cultural and related industries above the designated size in each district
		Per capita collection of books
		Per capita number of cultural relic collections
		Number of publishing and distribution institutions
		Coverage rate of radio and television programs
Demand Conditions	Economic demand	Per capita GDP
	Market demand	Per capita consumption of the cultural and creative industries
	Employment demand	Proportion of the cultural industry employees in total urban employment
	Environmental requirements	Air Pollution Index (PM$_{2.5}$ Index)
		Financial support for energy conservation and environmental protection
Enterprise Structure	Talent structure	Number of professional talents in the cultural and creative industries
	R&D investment	Funds invested by enterprises in the research and development of cultural and creative products
	Number of patents	Number of patent applications by cultural and creative enterprises
	Market share	Market share of cultural and creative enterprises
Related Industries	Service industry	Net profit margin of service enterprise assets
	Tourism	Number of regional tourists
	Education industry	Proportion of higher education institutions
	Manufacturing	The quantity of the cultural and creative products
Policy support and public services	Government support	The government supports funds for the cultural and creative industries
		The government has introduced preferential policies for the cultural and creative industries
	Public cultural services	Number of performances in cultural and artistic activities
		Number of library staff turnovers

the cultural and creative industry), and then $E_i = \sum_{k=1}^{s} E_i^k$

(k is the total number of industry categories).

In this formula, e_{ij} is the number of employees in cultural and creative industry institutions in j year of Tianjin's i district, e_{ij}^l represents the number of employees in the l cultural and creative industry field in

the j year of Tianjin's i district, and $e_{ij} = \sum_{l=1}^{t} e_{ij}^l$ (t is the total number of sub-sectors in the cultural and creative industry). The formula for location entropy is further expressed as:

$$Q_{ij} = \frac{\dfrac{\sum_{l=1}^{t} e_{ij}^l}{\sum_{i=1}^{n} \sum_{l=1}^{t} e_{ij}^l}}{\dfrac{\sum_{K=1}^{s} E_i^K}{\sum_{i=1}^{n} \sum_{K=1}^{s} E_i^k}}$$

Generally speaking, the higher the Q_{ij} value, the higher the level of cultural and creative industry agglomeration in the area. When $Q_{ij} > 1$, it can be considered that the i cultural and creative industries in the district have advantages in Tianjin.

Considering the complex characteristics of the spatial layout and development of the sample industries for pollution reduction and carbon emission reduction in Tianjin, it is necessary to conduct an analysis from a spatial perspective. This article constructs a standard deviation ellipse (SDE) model [25], which can accurately distinguish the overall characteristics and dispersion of different elements in multiple directions. Referring to relevant research results, the calculation formula is as follows [26]:

(1) Spatial distribution center of gravity:

$$\overline{x} = \frac{\sum_{i=1}^{n} v_i x_i}{\sum_{i=1}^{n} v_i}$$

$$\overline{y} = \frac{\sum_{i=1}^{n} v_i y_i}{\sum_{i=1}^{n} w_i}$$

(2) The long half axis (m) and short half axis (z) are respectively:

$$m = \sqrt{\frac{\sum_{i=1}^{n} v_i \left[(x_i - \overline{x}) \cos\theta + (y_i - \overline{y}) \sin\theta \right]^2}{\sum_{i=1}^{n} v_i}}$$

$$z = \sqrt{\frac{\sum_{i=1}^{n} v_i \left[-(x_i - \overline{x}) \sin\theta + (y_i - \overline{y}) \cos\theta \right]^2}{\sum_{i=1}^{n} v_i}}$$

(3) Rotation angle:

$$\tan(2\theta) = \frac{\sum_{i=1}^{n} v_i (x_i - \overline{x})(y_i - \overline{y})}{\sum_{i=1}^{n} v_i \left[(x_i - \overline{x})^2 - (y_i - \overline{y})^2 \right]}$$

In the above equation, x_i and y_j are the coordinate values of element i, and $(\overline{x}, \overline{y})$ is the relative coordinate of the centroid of the elliptical distribution; v_i represents weight, expressed as the number of cultural and creative industries in each district of Tianjin. θ is the rotation angle of the standard deviation ellipse.

Spatial Characteristics of Pollution Reduction and Carbon Emission Reduction Sample Industries Based on Kernel Density Estimation

Kernel density estimation, as a nonparametric method [27], fits the distribution function based on the characteristics of the data itself, thereby avoiding the errors that may be introduced by artificially preset

function shapes [28] and demonstrating unparalleled superiority over traditional estimation methods. Therefore, using the kernel density estimation method can further analyze the distribution characteristics of Tianjin's green industry. The specific calculation model is described as follows:

$$F(a) = \frac{1}{Nh} \sum_{i=1}^{n} K\left(\frac{a - a_i}{h}\right)$$

$$K(a) = \exp\left(\frac{-a^2}{2}\right) / \sqrt{2\pi}$$

Among them, $K(\bullet)$ is the kernel function, and a_i represents the geographic coordinates of point ($i \approx 1, 2 \dots$ n); The larger the $F(a)$ value, the higher the kernel density. N represents the number of points within the search radius, and h is the kernel density bandwidth parameter. The high or low kernel density value reflects the tightness of the distance between points. The larger the value, the stronger the clustering of point data and the denser the spatial distribution.

Research on the Spatial Distribution Pattern of Sample Industries for Pollution Reduction and Carbon Emission Reduction

Spatial Weight Matrix

The spatial adjacency matrix has a value of 1 if two urban areas are adjacent, and 0 if they are not adjacent; that is, $H^1_{ij} = 0$ (i, j two urban areas are adjacent), $H^1_{ij} = 0$ (i, j two urban areas are not adjacent). The economic distance matrix, where e_i and e_j represent the economic development level of the two urban areas i and j, is measured by the per capita regional GDP of each area. The economic distance matrix is represented by the reciprocal of the absolute difference in economic distance between the two urban areas, $H^2_{ij} = 1/|e_i - e_j|$. Among them, i and j represent different urban areas. The geographical-economic nested matrix, considering geographical location and economic distance, is $H^3_{ij} = H^1_{ij} \times H^2_{ij}$. Among them, i and j represent different urban areas. This article selects the spatial geographic economic weight matrix,

$$H_{ij} = \begin{cases} \dfrac{1}{\left|GDP_i - GDP_j\right|} & (i \neq j) \\ 0 & (i = j) \end{cases}$$

Global Spatial Pattern Analysis

The global spatial autocorrelation reveals the average connectivity state of observations in the study domain [29]. The global Moran's index, as a quantitative

indicator, is used to determine the interrelationships between entities within a specific spatial range [30]. After variance normalization, its value is standardized to fall between -1.0 and 1.0. The formula is as follows:

$$Moran'sI = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n}w_{ij}(y_i-\bar{y})(y_j-\bar{y})}{\sum_{i=1}^{n}\sum_{j=1}^{n}w_{ij}\sum_{i=1}^{n}(y_i-\bar{y})^2}$$

Among them, n is the total number of urban areas in Tianjin, y_i is the i cultural and creative industry agglomeration degree of the district, y_j is the j cultural and creative industry agglomeration degree of the district, $\bar{y}$ is the average cultural and creative industry agglomeration degree of each district in Tianjin, and w_{ij} is the spatial weight matrix. Generally speaking, Moran's I>0 indicates positive spatial correlation, while the opposite indicates negative correlation.

Local Spatial Pattern Analysis

The local Moran index tests whether there is a phenomenon of variable clustering in a local area [31], highlighting different spatial heterogeneity and reflecting the spatial correlation of a certain region. For a specific regional unit i, the local Moran index is used to measure its spatial correlation with surrounding regional units [32]. The formula is as follows:

$$I_i = \frac{n\sum_{j=1}^{n}w_{ij}(y_i-\bar{y})(y_j-\bar{y})}{\sum_{j=1}^{n}(y_j-\bar{y})^2}$$

Among them, I_i represents the local Moran index, y_i is the i observation value of the region, and w_{ij} is the spatial weight. Usually, a positive I value indicates high value clustering (high high) or low value clustering (low low). Negative I values indicate that low values are surrounded by high values (low high) or high values are surrounded by low values (high low).

Geographically Weighted Regression Model

The Geographically Weighted Regression (GWR) model is an innovative extension of the classical linear regression framework, which incorporates spatial location as a key factor to characterize the dynamic relationships among variables as they change with geographic position [33]. Using the GWR model to analyze the spatial heterogeneity of the factors influencing the cultural and creative industries in Tianjin, the formula is as follows [34]:

$$y_i = \beta_0(v)+\beta_1(v)x_{1i}+\beta_2(v)x_{2i}+\cdots+\beta_p(v)x_{pi}+\varepsilon_i$$

Among them, (v) is the spatial coordinate of the i sample point, $\beta_j(v)(j = 0, 1, ..., p)$ is the regression coefficient at position (v), and ε_i is the random error term at position v.

This article takes the cultural and creative industry in Tianjin as the research object and explores the heterogeneity of the impact of population size, the air pollution index, per capita GDP, and tourist numbers. Based on the availability of data, four variables are selected from production factors, demand conditions, enterprise structure, related industries, policy support, and public services. The coordinates of the i point in the cultural and creative industry of a sample point in a certain district in a certain year are (a_i, b_i), and the constructed GWR model is:

$$y_i = \beta_0(a_i,b_i)+\beta_1(a_i,b_i)x_1+\beta_2(a_i,b_i)x_2$$
$$+\beta_3(a_i,b_i)x_3+\beta_4(a_i,b_i)x_4+\varepsilon_i$$

In the formula, x_1 represents the population (in 10000 people), air pollution index ($PM_{2.5}$ index), per capita GDP (in yuan), and number of tourists (in 10000 people) in each urban area. $\beta_1(a_i, b_i)$, $\beta_2(a_i, b_i)$, $\beta_3(a_i, b_i)$, $\beta_4(a_i, b_i)$, is the regression coefficient of each variable and a constant term. $\beta_0(a_i, b_i)$ is the random error term of position v.

Results and Discussion

Measurement of the Spatial Agglomeration Level of Green Industries in Tianjin

Analysis of Tianjin Green Industry Location Entropy Index

(1) Regional analysis

By using the location entropy index model and introducing data from 2013 to 2022, the location entropy index of Tianjin's green industry can be obtained, and its agglomeration level can be determined through the location entropy index. The relevant calculation results are shown in Table 2.

Based on the calculation results, a hierarchical graphical analysis is conducted, as shown in Fig. 2a). From the perspective of the linkage of core urban areas, Heping District, Hexi District, and Hebei District all showed a high starting point for industrial agglomeration in the early stages of development. In 2013, the location entropy of Heping District reached 1.440, Hexi District was 1.301, and Hebei District was 1.373. In the subsequent development, they all experienced varying degrees of fluctuations. Heping District fell to 0.782 in 2016 and then rebounded, Hedong District gradually

climbed from the low point in 2016, and Hebei District also experienced ups and downs. The four districts of Jinnan, Beichen, Wuqing, and Baodi underwent significant transformation and leapfrogging from 2013 to 2022. Wuqing District and Baodi District started from almost zero foundation. In 2013, the location entropy of Wuqing District was only 0.275, while Baodi District was 0.072. With strong policy support and large-scale industrial park construction, they attracted a large number of cultural and creative resources to gather and rapidly climbed. By 2022, they reached 2.047 and 3.555 respectively, becoming new engines for the city's industrial development and reshaping the regional industrial pattern. The rise of these four districts provides a reference blueprint for the transformation of surrounding areas.

As the leading development area in the city, Binhai New Area relies on its strong comprehensive strength. Its location entropy was 1.273 in 2013 and fluctuated between 0.8 and 0.9 in subsequent years, maintaining a stable agglomeration trend. On the one hand, it provides high-end element resources, cutting-edge technological support, and an international perspective for the development of the city's cultural and creative industries, such as being unique in the fields of digital creativity and cultural technology integration. On the other hand, it radiates and drives surrounding urban areas, such as providing industry spillover opportunities for Ninghe District, Jinghai District, etc., and promoting regional coordinated development. Ninghe District gradually increased from 0.281 in 2013 to 1.432 in 2022. The

location entropy changes of Jinghai District and Jizhou District are similar. In the process of undertaking the industrial transfer of Binhai New Area, Jinghai District combines local ecological, agricultural, and other characteristic resources to achieve the characteristic development of cultural and creative industries, forming a close industrial linkage chain with Binhai New Area. Jinghai District relies on the deep development of mountainous tourism resources to integrate cultural and creative industries into rural tourism, folk experience and other fields, achieving a leap from the edge to the forefront, enriching the diverse formats of the city's cultural and creative industries together with other urban areas, and promoting the overall coordinated development of Tianjin's cultural and creative industries to a higher level.

(2) Industry analysis by sector

Furthermore, the cultural and creative industries are divided into three categories: cultural manufacturing, cultural design services, and cultural creative media. Industry location entropy is calculated, as shown in Fig. 3b). In terms of cultural manufacturing, Jinghai District leads with a location entropy index of 4.014, followed closely by Baodi District with 3.329. These two regions demonstrate strong agglomeration capabilities in the software manufacturing industry. This is closely related to the deep foundation of the manufacturing industry in the western region. The long-term accumulated industrial foundation, relatively complete upstream and downstream industrial chains, and low factor costs have attracted a large number of software

Table 2. Results of Tianjin green industry location entropy index (2013-2022).

| Region	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Heping District	1.440	1.232	0.973	0.782	0.753	1.463	0.611	0.458	1.041	1.120
Hedong District	0.559	2.098	0.725	0.508	0.453	1.214	0.588	0.303	0.703	0.515
Hexi District	1.301	1.064	1.335	2.088	0.567	1.072	0.599	0.357	0.876	0.794
Nankai District	0.738	2.058	1.179	0.978	0.501	0.749	0.657	0.392	1.418	1.437
Hebei District	1.373	3.099	0.578	0.499	1.134	1.081	0.500	1.098	0.552	0.703
Hongqiao District	0.527	1.976	1.150	0.818	0.498	0.680	0.562	0.269	1.226	1.108
Dongli District	0.753	2.481	0.811	1.309	0.679	0.902	0.422	0.482	0.675	0.686
Xiqing District	0.318	3.193	0.908	1.234	0.518	1.008	0.340	0.262	0.741	0.781
Jinnan District	0.307	2.130	0.522	0.437	0.329	0.585	0.218	0.169	1.042	1.041
Beichen District	1.948	1.680	0.650	0.423	2.094	1.236	0.791	0.845	0.854	0.794
Wuqing District	0.275	10.065	0.941	0.776	0.955	0.800	0.992	0.714	1.854	2.047
Baodi District	0.072	7.221	0.787	0.677	0.335	0.655	0.148	0.134	3.286	3.555
Binhai New Area	1.273	5.766	1.238	1.223	0.961	1.174	1.667	1.896	0.835	0.817
Ninghe District	0.281	0.978	0.705	0.927	0.185	0.862	0.259	0.071	1.335	1.432
Jinghai District	0.109	4.704	0.906	0.782	0.157	0.680	0.141	0.132	1.853	2.176
Jizhou District	0.134	2.107	0.769	0.906	0.103	1.059	0.142	0.073	1.602	1.857
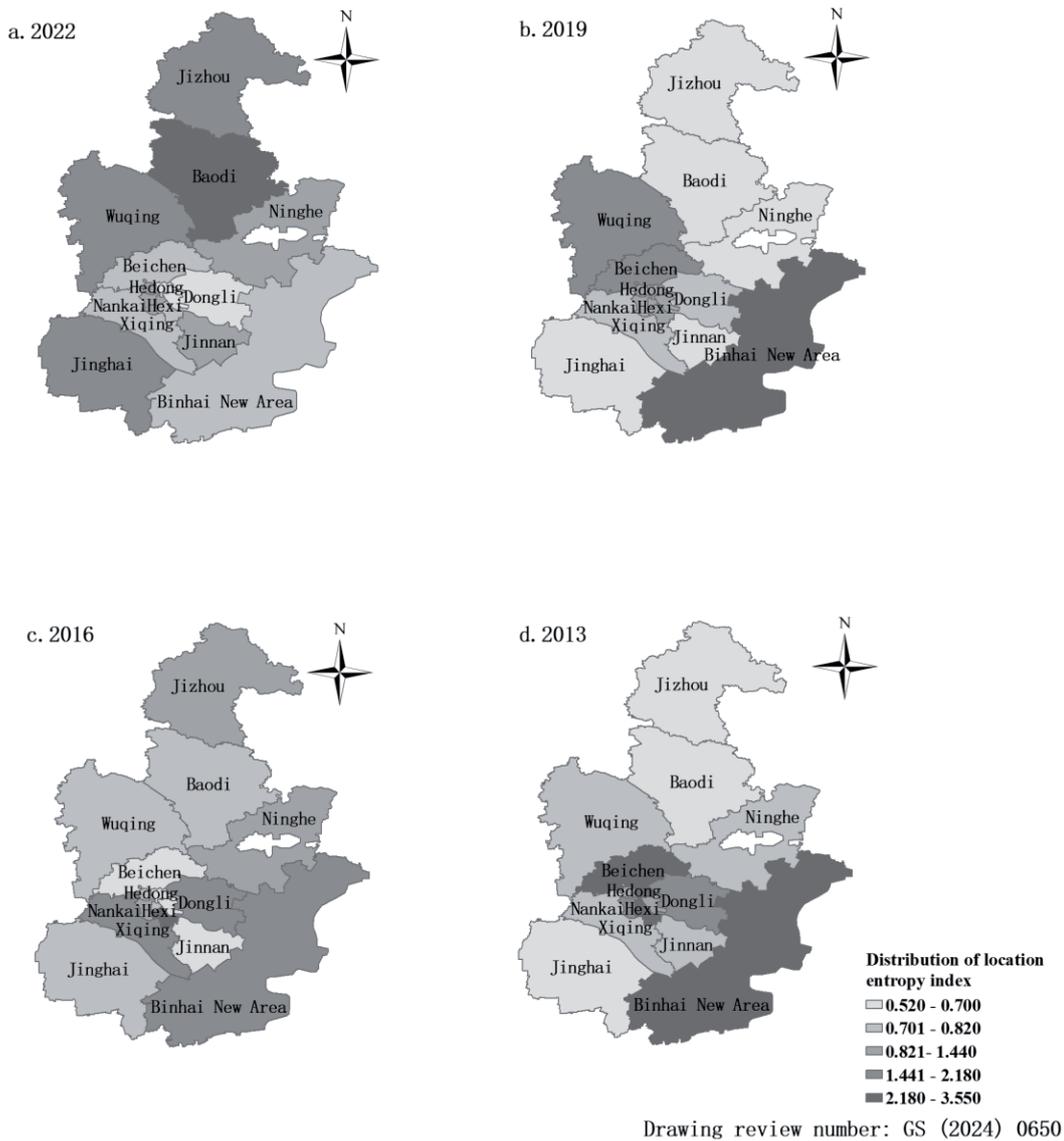
Fig. 2. Location entropy index of different regions.

manufacturing enterprises to settle in, resulting in a high concentration of industries and prominent economies of scale in the region. Ninghe District, at 2.933, and Jizhou District, at 2.723, have also performed well, relying on their own resource advantages to achieve certain results in undertaking industrial transfer and developing characteristic software manufacturing, gradually forming regional competitiveness. The location entropy of Heping District and Hongqiao District is 0, while areas such as Hexi District, at 0.363, Hebei District, at 0.389, and Binhai New Area, at 0.338, have some development, but their values are relatively low and are in the initial accumulation stage. They have not yet formed a scale agglomeration and are exploring the integration of urban functional positioning. For example, Binhai New Area is utilizing its advantages in scientific and technological innovation, while Hexi District is cultivating new forms of software manufacturing through the opportunity of cultural and business integration.

In the field of cultural design services, Hongqiao District ranks among the top at 1.757, Nankai District at 1.355, and Hexi District at 1.318. These urban design enterprises can fully draw inspiration from this, closely cooperate with universities, and constantly innovate, resulting in a continuous increase in industrial agglomeration and a significant improvement in the specialization level in the region. Dongli District, at 1.622, and Baodi District, at 1.757, also performed outstandingly. Dongli District, relying on the construction of the airport economic zone and industrial park, has attracted a group of innovative cultural design enterprises. Baodi District, on the other hand, has vigorously promoted the development strategy of the cultural industry in recent years by creating cultural and creative parks and introducing preferential policies. Although some urban areas, such as Hedong District, at 0.586, Hebei District, at 0.753, and Binhai New Area, at 0.722, may not be as advanced as the

previous urban areas, they are steadily developing. With the help of urban transformation and urban renewal projects, they are gradually increasing the integration of cultural design elements and enhancing their industrial agglomeration capabilities.

In the cultural, creative, and media industry, Binhai New Area has taken the lead with an average location entropy of 1.278. Over the years, it has continuously invested in building a media industry cluster, leveraging its port advantages to introduce international media resources and gather a group of influential media enterprises. Coupled with sound infrastructure and policy support, it has maintained a leading position in the cultural, creative, and media field, with the highest and most stable level of aggregation. Heping District, at 1.203, Hedong District, at 1.241, and Hebei District, at 1.254, also have a high degree of agglomeration. As the core areas of the city, these urban areas are densely populated and have a huge consumer market, providing broad space for the development of the media industry. Traditional media institutions are deeply rooted, and the entrepreneurial atmosphere of new media is becoming increasingly strong. Through various cultural activities and measures such as creating media districts, the advantages of industrial agglomeration are constantly consolidated. However, in areas such as Baodi District, at 0.089, Jinghai District, at 0.168, and Jizhou District, at 0.266, the agglomeration level is relatively low and fluctuates significantly, mainly limited by factors such as regional economic development level, population size, and a weak media

industry foundation. It is still necessary to break through the situation by exploring local cultural resources and strengthening cooperation with external media giants to enhance industrial agglomeration.

Overall, each district in Tianjin has its own strengths in the subdivision of cultural and creative industries. There are regional differences caused by resource endowment and historical development paths, as well as a good trend of competing in their respective advantageous fields and gradually optimizing the industrial structure. In the future, each district should strengthen collaborative linkage, leverage comparative advantages, and promote the diversified and high-quality development of the city's cultural and creative industries (Table 3).

Standard Deviation Ellipse

The standard deviation ellipse method is an important method commonly used to characterize the spatial features of geographic elements. It can describe the centrality, distribution, and other characteristics of objects. Therefore, this article uses this method to analyze the spatial characteristics of Tianjin's green industry. The analysis mainly relies on the ArcGIS tool for standard deviation ellipse analysis, and the relevant results are shown in Fig. 3.

From the results, it can be seen that the center of the spatial distribution ellipse of Tianjin's green industry gradually shifted from (117.268, 39.141) in 2013 to

Table 3. Entropy index of different industrial locations (2022).

	Cultural manufacturing industry	Cultural service industry	Cultural media industry
Heping District	0.000	1.296	1.203
Hedong	0.605	0.586	1.241
Hexi District	0.363	1.318	1.090
Nankai	0.389	1.355	1.071
Hebei District	0.389	0.753	1.254
Hongqiao District	0.000	1.757	1.064
Dongli District	2.095	1.622	0.491
Xiqing District	2.374	0.676	0.696
Jinnan District	1.702	1.153	0.748
Beichen District	2.605	1.604	0.347
Wuqing District	1.638	0.930	0.834
Baodi District	3.329	1.757	0.089
Binhai New Area	0.338	0.722	1.278
Ninghe District	2.933	1.216	0.368
Jinghai District	4.014	0.832	0.168
Jizhou District	2.723	1.757	0.266

(117.271, 39.292) in 2022. The elliptical distribution range reveals the spatial coverage of cultural and creative industries, showing a "large dispersion, small agglomeration" characteristic of dense central and sparse edges. The central urban areas (such as Heping, Hexi, Nankai, etc.) firmly occupy the elliptical core, with dense concentrations of points over the years, showing a high degree of agglomeration, and are key gathering places for the digital cultural industry. This is due to the economic prosperity, abundant funds, advanced technology, abundant creative resources, efficient resource allocation, and convenient knowledge acquisition in the central urban area, which provides many advantageous conditions for the development of cultural and creative industries. The areas of Dongli and Jinnan are relatively sparse compared to the central urban area in each year, and there is a certain distance from the center of the ellipse, indicating that their agglomeration density is relatively small and the development level of cultural and creative industries is relatively low. This may be limited by factors such as their own foundation and weak ability to gather resource elements.

Jizhou, Jinghai, Wuqing, Baodi, and other regions have the lowest distribution density on the map and are far away from the center of the ellipse, reflecting that these regions are relatively lagging behind in the development of cultural and creative industries and have insufficient attractiveness to the industry. However, over time, there may be development potential and room for improvement.

Analysis of Nuclear Density Estimation Results

Fig. 4a) shows the core density analysis results of Tianjin's cultural and creative industries. Fig. 4a) clearly depicts the overall spatial layout of Tianjin's cultural and creative industries, presenting a circular, radial distribution with the central urban area as the core, exhibiting a "large dispersion, small agglomeration" pattern with dense central areas and sparse edges. There are significant differences in the distribution of digital cultural industries among different districts and counties. Central urban areas such as Heping, Hexi, Nankai, and Hedong have high agglomeration densities and are the main gathering places for digital cultural industries; Dongli and Jinnan have lower density; the distribution density of Jizhou, Jinghai, Wuqing, and Baodi is the lowest. This is attributed to the high requirements of the digital cultural industry for resources such as talent, technology, and capital. The central urban area, with its advantages of economic prosperity, abundant funds, advanced technology, abundant creative resources, and efficient resource allocation, has become an ideal gathering place. In contrast, peripheral urban areas have limited attractiveness to the digital cultural industry due to weak foundations and weak resource aggregation capabilities. Therefore, the spatial structure of Tianjin's cultural and creative industries needs to be optimized, and the surrounding urban areas have great potential for development in the digital cultural industry.

Fig. 4b) reveals the spatial layout of the cultural manufacturing industry, mainly concentrated in the central area and urban area composed of Jizhou,
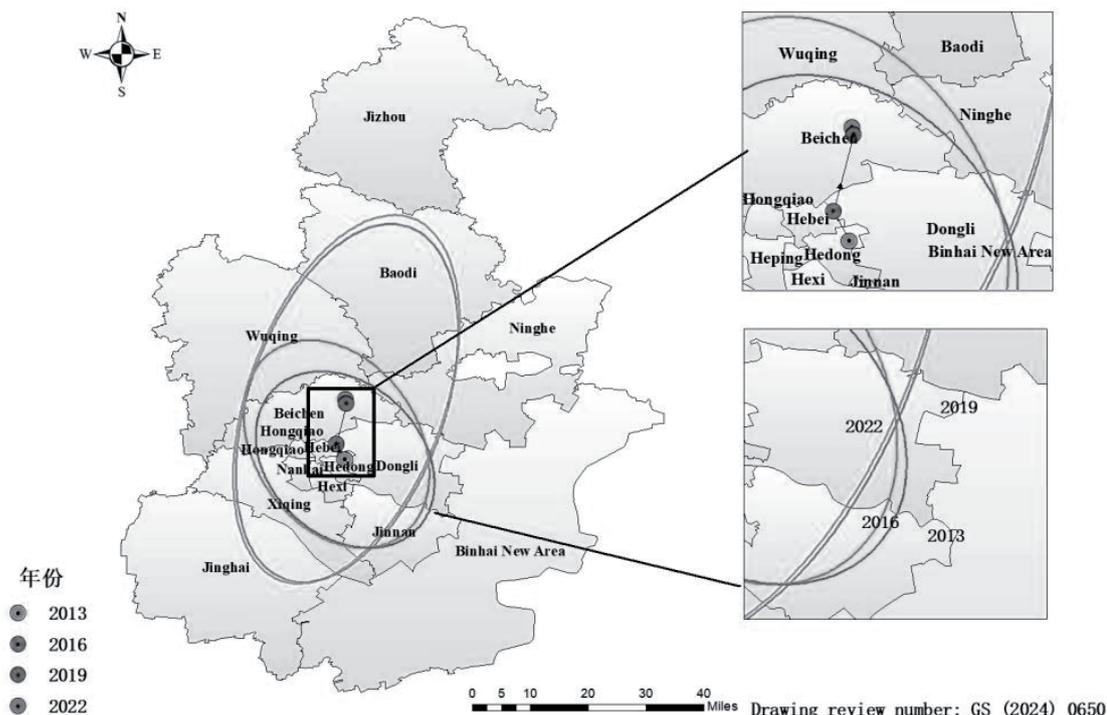

Fig. 3. Elliptical plot of standard deviation in different regions.

Baodi, and Wuqing, presenting a distinct "point-like" agglomeration pattern. The central urban area relies on abundant digital technology resources and comprehensive digital infrastructure, such as the high-tech park in Binhai New Area, which lays a solid foundation for the development of other digital cultural activities and industries.

Fig. 4c) shows the spatial distribution of the cultural service industry, which is significantly concentrated in central urban areas such as Heping, Hedong, Hexi, and Nankai, forming a "point-like" agglomeration. At the same time, there are also small-scale agglomerations in each district, with significant regional differences. The industrial density in the central urban area is extremely high.

Fig. 4d) depicts the spatial distribution of the cultural and media industry, which is mainly concentrated in central urban areas such as Heping, Hedong, Hexi, and Nankai, and presents a "belt-like" trend extending from the central urban area to the eastern urban area. The transformation of industrial relics into industrial parks in Heping District is one of the key factors in the agglomeration of digital cultural industries. In addition, due to its vigorous development in recent years, Binhai New Area has attracted numerous cultural and media enterprises to establish branch offices, promoting the development of the cultural industry in the region.

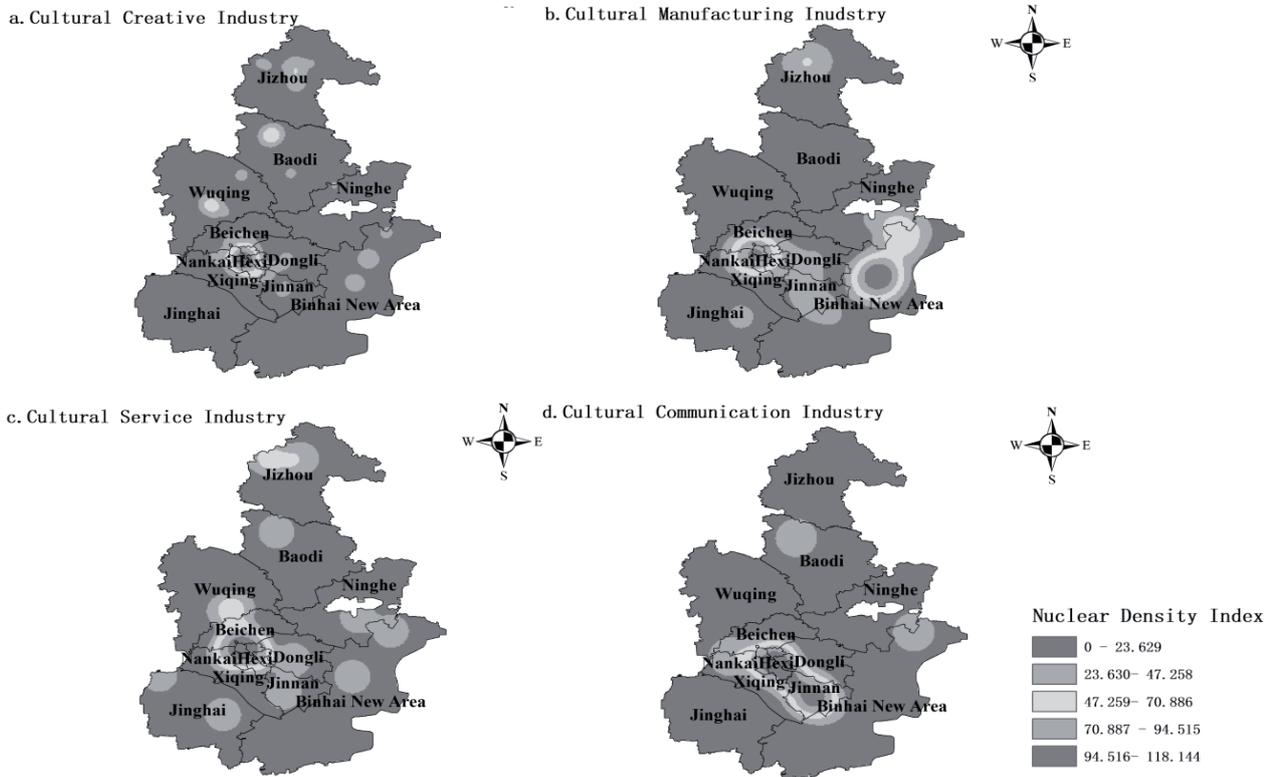## Spatial Distribution Pattern of Green Industries in Tianjin

Global Moran Index Analysis

Table 4 shows the spatial correlation of cultural and creative industries in Tianjin. The data show that the Moran's indices for the overall cultural and creative industry, the cultural manufacturing industry, the cultural service industry, and the cultural media industry are 0.102, 0.149, 0.080, and 0.207, respectively, all of which are greater than zero, indicating a negative correlation clustering distribution of Tianjin's cultural and creative industry, with significant spatial correlation. Furthermore, through Z-value testing, the overall Z-values (2.564, 3.276, 2.218, 4.322) of Tianjin's digital cultural industry and various major categories exceeded the upper limit of the uniform distribution by 1.65. However, there are differences in the degree of spatial agglomeration among various industrial categories, with the cultural service industry showing the most prominent agglomeration. The agglomeration degree of cultural manufacturing and cultural media industries is relatively high, reflecting the high dependence of these three industries on cultural resources and technological conditions, and often showing a concentrated distribution trend.

Local Moran Index Analysis

The Moran scatter plot is applied to examine the local spatial correlation of cultural and creative industry

Fig. 4. Estimation results of nuclear density in different industries.

Table 4. Calculation results of the Global Moran Index.

	Population	Cultural manufacturing industry	Cultural wholesale and retail industry	Cultural service industry
Moran's index	0.086	0.089	0.191	0.114
Expectation Index	-0.066667	-0.066667	-0.066667	-0.066667
Variance	0.066	0.065	0.076	0.068
Z score	2.306	2.386	3.410	2.673
p-value	0.011	0.009	0.000	0.004

growth (Table 5). Fig. 5 shows that the growth of the cultural and creative industries in Tianjin presents a relatively dispersed agglomeration trend. In the scatter plots of the cultural manufacturing and cultural media industries, the growth of cultural industries gradually tends towards the first and third quadrants, indicating that the economic growth of these two industries gradually shows characteristics of high-high agglomeration and low-low agglomeration, showing a significant positive spatial agglomeration state and strong local spatial correlation. The spatial agglomeration characteristics of the cultural manufacturing industry in Tianjin are obvious, with the "H-H agglomeration type" urban areas mostly being the central urban areas, and the "L-L agglomeration type" urban areas mostly being the western urban areas. This is consistent with the layout of industrial manufacturing as the main industry in the central and western regions of Tianjin's overall plan, indicating that cities with higher or lower cultural and creative industry agglomeration are more likely to form agglomeration in space. This further confirms that the spatial differences in the growth of Tianjin's cultural and creative industries are relatively small, providing a basis for this article to study their growth from a spatial dimension.

Interpretation of GWR Analysis Results

The analysis results show that the R^2 value of the OLS model reached 0.954158, indicating a high degree of fit to the data and being able to explain approximately 95.42% of the variation in the dependent variable. The R^2 value of the GWR model is 0.954204, slightly higher than that of the OLS model, indicating that the GWR model has slightly stronger overall explanatory power for the data and can capture more factors that affect changes in the dependent variable (Table 6). The adjusted R^2 takes into account the number

Table 5. Calculation results of the Local Moran Index.

Each district of Tianjin city	Ii	E(Ii)	sd(Ii)	z	p-value*
Heping District	0.612	-0.067	0.321	2.116	0.017
Hedong District	0.524	-0.067	0.324	1.82	0.034
Hexi District	0.409	-0.067	0.329	1.445	0.074
Nankai District	0.379	-0.067	0.358	1.245	0.107
Hebei District	0.608	-0.067	0.314	2.15	0.016
Hongqiao District	0.565	-0.067	0.317	1.991	0.023
Dongli District	0.039	-0.067	0.214	0.492	0.311
Xiqing District	-0.289	-0.067	0.282	-0.787	0.216
Jinnan District	0.024	-0.067	0.215	0.420	0.337
Beichen District	0.010	-0.067	0.292	0.261	0.397
Wuqing District	-0.994	-0.067	0.200	-4.647	0.000
Baodi District	-0.044	-0.067	0.175	0.129	0.449
Binhai New Area	-0.271	-0.067	0.244	-0.837	0.201
Ninghe District	-0.011	-0.067	0.178	0.311	0.378
Jinghai District	-0.046	-0.067	0.218	0.095	0.462
Jizhou District	-0.131	-0.067	0.231	-0.278	0.391

（a）Overall and local Moran index plot

（b）Local Moran Index chart of the cultural manufacturing industry

（c）The local Moran index chart of cultural wholesale and manufacturing

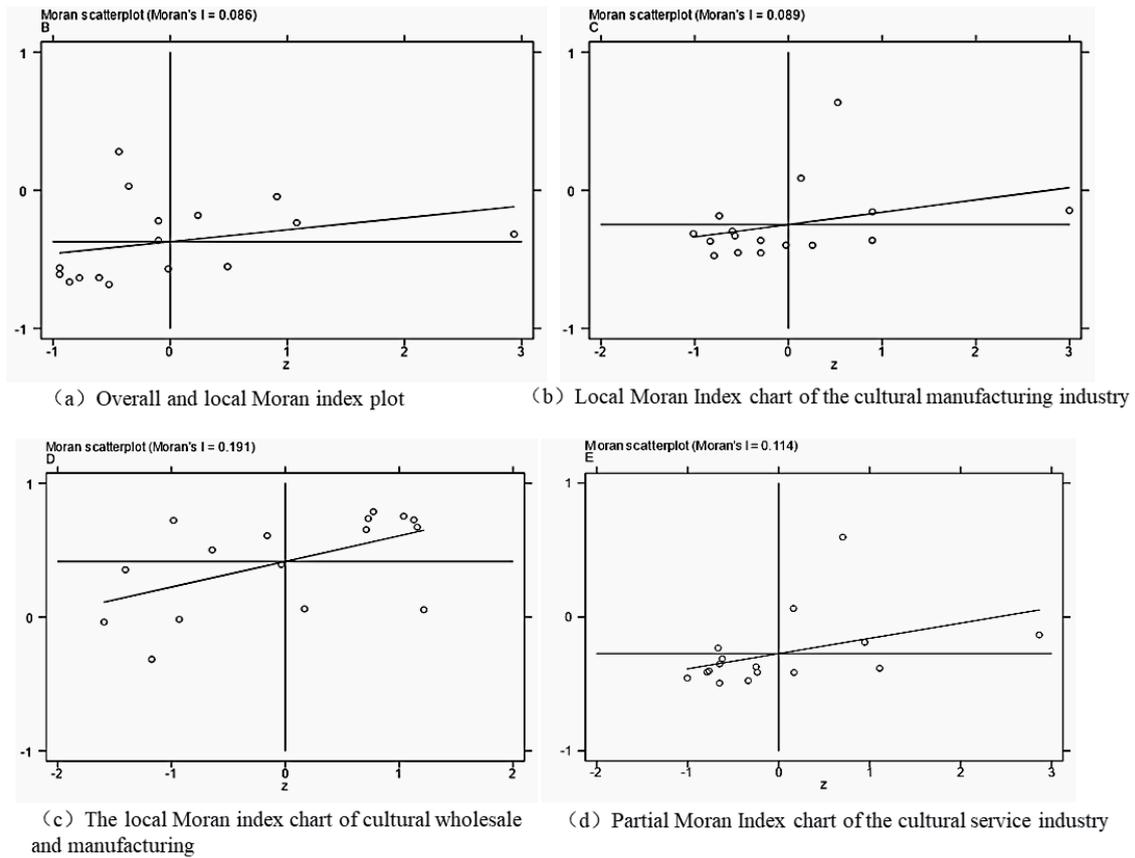（d）Partial Moran Index chart of the cultural service industry

Fig. 5. Local Moran Index results for different industries.

of independent variables in the model to avoid overestimating the goodness of fit due to excessive independent variables. Compared to the OLS model, the GWR model has a slight advantage in this indicator, indicating that, taking into account factors such as the number of independent variables, the GWR model can more effectively use the independent variables to explain the changes in the dependent variable, and its model architecture may better reflect the characteristics

of actual data. The difference in AIC values between the two models is minimal, indicating that the overall performance of the two models is not significantly different in this regard. The regression standard deviation reflects the average degree of error between the predicted values of the model and the actual observed values. The smaller regression standard deviation of the GWR model means that its prediction accuracy is relatively higher, and the error generated by the model

Table 6. GWR Model estimation results.

	OLS	GWR		
Multiple coefficients of determination (R^2)	0.954	0.954		
Adjusted R^2	0.931	0.931		
Akaike Information Criterion (AIC)	167.957	167.964		
Regression standard deviation (Sigma)	24.708	24.277		
Model variable	GWR			
	Minimum value	Median	Maximum value	Mean value
Population (10000 people)	41.070	63.855	156.310	72.581
GDP (yuan)	32044.280	78770.390	446667.400	114194.700
air pollution index	0.027	0.062	0.143	0.061
Number of tourists (10000 people)	100.000	322.000	4415.000	942.500

is relatively smaller compared to the OLS model. The changes in the independent variables and the population (in tens of thousands) in the GWR model indicate that there are certain differences in the population size of different regions in the sample. The population size of different regions will have varying degrees of impact on the model results. The GWR model can capture the changes in the relationship between population size and the dependent variable caused by different geographical locations. GDP shows significant differences in economic development levels among regions. The GWR model adjusts the weight of the dependent variable based on the specific GDP situation of different regions, reflecting the spatial differences in their impact. The air pollution index indicates that the air quality conditions vary in different regions, and in the GWR model, it will differentially affect the dependent variable based on the air pollution situation at different spatial locations. The number of tourists reflects significant differences in tourism popularity among different regions, and the GWR model can reflect the different influences of tourist numbers in different areas.

Conclusions

With the acceleration of industrialization and the rapid development of the global economy, environmental pollution problems are becoming increasingly serious. Promoting green transformation and reducing environmental pollution have become a global consensus. With the increasing global attention to sustainable development, Tianjin is vigorously promoting industrial transformation and upgrading, as well as green development. The cultural and creative industry is a typical representative of the green industry, and Tianjin attaches great importance to the high-quality development of this industry.

Against this background, the article selects the cultural and creative industries as samples, collects panel data for Tianjin from 2013 to 2022, and comprehensively uses various methods, such as location entropy, standard deviation ellipse analysis, kernel density estimation, spatial autocorrelation analysis, and a geographically weighted regression model, to empirically study the agglomeration level and spatial characteristics of green industries. The following conclusions are drawn:

(1) From 2013 to 2022, the location entropy of the cultural and creative industries in various districts of Tianjin showed dynamic changes. From the location entropy index, the cultural and creative industries in various regions of Tianjin showed an increasingly strong trend of agglomeration development. The early core urban areas of Heping District, Hexi District, and Hebei District had a high starting point for industrial agglomeration due to their profound cultural heritage, superior geographical location, and early industrial layout. However, they all encountered varying degrees

of fluctuations in their subsequent development. The location entropy of Hedong District and Dongli District fluctuated within a certain range, while Xiqing District steadily increased year by year from a lower starting point. The four districts of Jinnan, Beichen, Wuqing, and Baodi have undergone significant transformation leaps in the later stage, starting from almost zero foundation and achieving rapid development by 2022. The Binhai New Area continues to demonstrate a steady development trend, while Ninghe District, Jinghai District, and Jizhou District are also gradually promoting the development of their cultural and creative industries.

(2) The cultural and creative industries in Tianjin are centered around the central urban area, presenting a circular and radial distribution with the characteristics of "large dispersion and small aggregation". The cultural manufacturing industry is clustered in a "point-like" manner in the central and urban areas of Jizhou, Baodi, and Wuqing, and there are significant differences in the level of development of cultural and creative industries between the regions, forming a "point-like" distribution with a small amount of aggregation in other areas. The cultural and media industry is also concentrated in the above-mentioned central urban areas and extends in a "belt-like" manner toward the eastern urban areas. Dongli and Jinnan have lower densities, while Jizhou, Jinghai, Wuqing, and Baodi have the lowest densities. Due to weak infrastructure and resource aggregation capabilities, their attractiveness to the cultural and creative industries is limited, and their industrial distribution is sparse.

(3) There are significant differences in the development level of cultural and creative industries between different regions. The development of core urban areas started early, and some urban areas faced fluctuations in the development process, while some emerging areas, such as Wuqing and Baodi, achieved a rapid rise in the later stage through policy support and industrial park construction. In segmented industries, each region has its advantages. For example, Jinghai District and Baodi District have prominent advantages in cultural manufacturing, while Hongqiao District and Nankai District lead in cultural services. The location entropy of the cultural manufacturing, cultural service, and cultural media industries varies in different regions, reflecting differences in industry agglomeration capacity and development stages. The clustering of the cultural service industry is the highest among all categories of overall cultural and creative industries, and the clustering degree of the cultural manufacturing and cultural media industries is relatively high, indicating that these industries have a strong dependence on cultural resources, technological conditions, and market demand, and are more likely to concentrate and develop in specific regions.

Conflict of Interest

The authors declare no conflict of interest.

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