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Research article

Analysis of the spatiotemporal evolution and influencing factors of green development level in the manufacturing industry

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ABSTRACT

The manufacturing sector is the main battlefield of energy saving and carbon reduction in China, and vigorously promoting energy saving and carbon reduction in manufacturing and enhancing the green development level are the key links to support China's realization of the dual-carbon goal. The article adopts the SBM-GML model to measure the level of green development of the manufacturing industry in China. Based on this, it analyzes the spatio-temporal characteristics and the evolution law of the level of green development of the manufacturing industry by using the Dagum Gini Coefficient and Kernel Density Estimation. Using a spatial econometric model to explore the influencing factors of the level of green development of the manufacturing industry. The study finds that the green development level of the manufacturing industry has achieved remarkable results in recent years, but there are differences in the development level of each region. The regional differences in the level of green development of the manufacturing industry are significant. The optimization of manufacturing structure is a key factor influencing the level of green development of the manufacturing industry, and there is a positive spatial spillover effect of manufacturing structure optimization. However, The green development of the manufacturing industry shows a negative spatial spillover effect. The article proposes optimization paths based on the requirements of dual-carbon targets and regional characteristics, which is an important inspiration and reference for the green development level of the manufacturing industry in the world.

1. Introduction

Since the reform and opening up, as the pillar of the national economy, the manufacturing industry has ignored the protection of the environment in the process of rapid development, which has an impact on the needs of the people for a better life, and also restricts the sustainable development of the regional economy. Practice shows that the past extensive mode of economic development can not be sustained, and the realization of green production is the only way to transform and upgrade the manufacturing industry. Striving to achieve a carbon peak by 2030 and carbon neutrality by 2060 (the dual-carbon target) is a major strategic decision made by the Party and the State to coordinate the domestic and international situations, and it is an inevitable choice for solving the problem of resource and environmental constraints and promoting high-quality development. The continuous implementation of various environmental policies is also to achieve green development, and the most important way of green development is to improve the green total factor productivity of the manufacturing industry. As the pillar of China's economic and social development, the manufacturing industry is

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also the main source of carbon emissions [1–3]. Vigorously promoting energy conservation and carbon reduction in the manufacturing industry, and upgrading the level of green development of the manufacturing industry are the key links to support China's realization of the dual-carbon goal on schedule [4–6],It is of great significance to improve the level of green development of manufacturing industry. The process of green development of manufacturing industry also considers industrial efficiency and ecological benefits, and improving the level of green development of manufacturing industry can promote economic development, resource utilization, environmental benefits and sustainable development as a whole. To this end, in-depth promotion of manufacturing environmental pollution prevention and control, enhancing the level of green development of the manufacturing industry, has become an important issue of China's environmental governance. However, from the current reality of China's manufacturing industry green development, due to the vastness of China, the level of energy consumption and technological progress in various regions vary [7]. The degree of economic and social development and environmental pollution control is still a big gap [8], China's manufacturing industry as a whole green development to improve the effectiveness of the solidity of the results is not strong, the level of green development and the construction of a beautiful China is still a gap between the goals [9].

Hence, the scientific assessment of the manufacturing industry's green development level and the rational comparison of this level across different regions can effectively delineate the economic and environmental disparities among these regions [10]. Analyzing the key factors influencing the green development of the manufacturing industry is crucial for improving environmental governance performance and promoting green development. In this context, the present study evaluates China's manufacturing industry's green development level using the SBM-GML model. It further examines the spatial and temporal characteristics and evolutionary trends of the industry's green development level through the Dagum Gini coefficient and kernel density estimation. Additionally, spatial econometric modeling is employed to investigate the influencing factors of the manufacturing industry's green development level. These analyses can facilitate the promotion of multi-principal environmental co-management and the decoupling of economic development and social welfare improvement from environmental degradation, thereby holding significant practical implications for enhancing the manufacturing industry's green development level.

2. Literature review

In the context of the dual-carbon goals, the green development of the manufacturing industry is not only a necessary means to advance the construction of a robust manufacturing sector and realize high-quality industrial development but also a strategic imperative for proactively addressing the new wave of scientific and technological revolution and industrial transformation [11–14]. Furthermore, it represents a paramount priority to drive the comprehensive green transformation of the economy and society and fulfill commitments to carbon peaking and neutrality. It has been suggested that the improvement of the total factor productivity of manufacturing industry is the main reason for China's economic growth, and this promotion mechanism is long-term effective [15]. Early studies mainly analyzed the development and time evolution characteristics of total factor productivity from the overall level of a country or region, and mainly involved two types of labor and capital when considering input factors of production [16]. In the process of realizing green and sustainable development, the data envelopment method is mainly used to measure whether the production process is scientific and effective, and the environmental pollution limiting variable is taken as the undesirable output [17]. On this basis, relevant research on the temporal and spatial characteristics and evolution law of production level has become an important research content of the current green development of manufacturing industry [18,19]. As the understanding of the essence of green development continues to evolve, various domestic and international organizations, along with scholars, have endeavored to establish diverse green development indicator systems [20–22]. For instance, the International Organization for Economic Cooperation and Development (OECD) pioneered the proposal of a flexible and applicable green growth indicator system in 2010, while the United Nations Environment Programme (UNEP) introduced an evaluation indicator system for transitioning to a green economy. The United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) presented a green growth indicator system. Scholars have conducted numerous studies on green development, primarily focusing on environmental optimization and other dimensions, exploring the conceptual connotations of green development, constructing evaluation systems, measuring developmental levels, assessing developmental benefits, analyzing spatial patterns, and examining driving factors [23,24]. Specifically, existing literature predominantly manifests research in two main aspects.

In terms of delineating the connotation and analyzing the measurement of green development level, scholars have expounded on the multi-dimensional aspects of industrial green development, encompassing industrial structural transformation, energy structural adjustment, and optimization of the ecological environment [25–27]. The study emphasizes the necessity of adhering to the concept of green development and complying with stringent green development standards, particularly in traditional energy industries [28]. To facilitate the realization of green industry transformation and upgrading, as well as to enhance the efficiency of green development [29,30]. In measuring the green development level, as a flexible production efficiency model, DEA is widely used to measure total factor productivity (TFP). Liu et al. calculated the total factor productivity level and its decomposition value based on DEA Malmquist productivity index [31]. Some scholars also use directional distance function DDF and ML index combined with relaxation measure SBM model to measure the level of factor productivity [32,33]. Some scholars combine SBM model [34] and GML index with super-SBM model [35]. Environmental factors are incorporated into the input-output productivity function when measuring green total factor productivity. These elements provide accurate estimates of resource efficiency losses [36]. The majority of studies utilize the SBM model to gauge green total factor productivity [37–39], decompose it through the ML index, and underscore the significant influence of technological progress on green development efficiency [40,41]. This approach helps mitigate potential spurious regression, thereby enhancing the accuracy and objectivity of the measurement.

In the analysis of factors influencing the level of green development, Exploring the paths affecting the level of green development of the manufacturing industry can not only promote the transformation and upgrading of the industrial structure of the manufacturing industry but also provide theoretical reference for the realization of the dual-carbon target [42,43]. It is found that the impact of environmental regulations on the green development level of manufacturing industry is non-linear [44], and flexible regulatory policies are conducive to the green development of manufacturing industry. Some scholars have pointed out that green industry policy and carbon emission trading policy are conducive to the green transformation of China's manufacturing industry [45,46]. Foreign investment promotes the green development level of the manufacturing industry [47], while the agglomeration of the manufacturing industry has a negative impact on the green development level of the manufacturing industry, and has a negative spatial spillover effect on the surrounding areas [48]. The majority of scholars emphasize technological innovation as a key factor in promoting industrial green development. Some scholars have empirically demonstrated that industrial structural upgrading and environmental regulation are important factors affecting the level of green development [49–52]. Additionally, some scholars have pointed out that strengthening government support, enhancing cooperation and exchange between industries, and promoting the use of renewable energy are important factors influencing the level of industrial green development [53–55]. However, some researchers have indicated that the impact of industrial structural adjustment on the level of green development is limited [56,57].

From the existing research, scholars on the level of green development are mostly focused on the traditional energy industry, and there is little literature to analyze the level of green development of the manufacturing industry, however, the manufacturing industry, as the main body of the national economy, the level of its green development is crucial to the realization of the dual-carbon goals; the research on green development focuses more on the calculation of the green development index, analyzes the differences in the spatial pattern of the uni-dimensional factors, and ignores the spatial correlation of the composite multi-factors between regions and within the region.

Given this, this paper combines the SBM directional distance function and the GML index, constructs relatively reasonable influencing factor indicators from input factors, desired outputs, and non-desired outputs, and measures the level of green development of China's manufacturing industry more comprehensively and scientifically, and re-measures the level of green development of the manufacturing industry. Secondly, taking China's eight comprehensive economic zones as the main research body, the dynamic evaluation of the green development level of the manufacturing industry is carried out, based on the Dagum Gini coefficient, kernel density analysis, and the analysis of the temporal and spatial change characteristics and evolution law of the green development level of the manufacturing industry. Finally, based on the consideration of spatial factors, the spatial measurement model is used to analyze the key factors affecting the level of green development of the manufacturing industry and discuss the direct effect and spatial spillover effect of the influencing factors.

3. Materials and methods

3.1. SBM-GML model

In this paper, considering the specificity of the panel data and the inclusion of non-expected outputs, the traditional SBM model is combined with the GML index to construct the SBM-GML model for effective measurement of green total factor productivity in the manufacturing industry. Combining the global SBM directional distance function that covers the non-expected output, the measurement model that includes energy and resource constraints is constructed, and the SBM model is first defined, specifically as shown in equations (1) and (2).

$$\vec{S}_{VG}\left(x_{ik'}, y_{ik'}, b_{ik'}; g_x, g_y, g_b\right) = \max_{s_x, s_y, s_b} \frac{\frac{1}{N}\sum_{i=1}^{N}\frac{S_{nx}}{g_{nx}} + \frac{1}{M+I}\left(\sum_{m=I}^{M}\frac{S_{my}}{g_{my}} + \sum_{i=I}^{I}\frac{S_{ib}}{g_{ib}}\right)}{2} \tag{1}$$

$$s.t\left\{\begin{array}{c}\sum_{t=I}^{T}\sum_{k=I}^{K} z_{kt}x_{knt} + s_{nx} = x_{k'nt}, \forall n; \sum_{t=I}^{T}\sum_{k=I}^{K} z_{kt}y_{kmt} - s_{my} = y_{k'mt}, \forall m; \\ \sum_{t=I}^{T}\sum_{k=I}^{K} z_{kt}b_{kit} + s_{ib} = b_{k'it}, \forall i; \sum_{k=I}^{K} z_{kt} = I, z_{kt} \geq 0, \forall k; \\ s_{my} \geq 0, \forall m; s_{ib} \geq 0, \forall i\end{array}\right\} \tag{2}$$

Consider each province as a decision unit (DUM), where V represents the direction vector of the evaluated decision unit projected onto the production preamble; (g_x, g_y, g_b) denote the direction vectors of inputs, desired outputs, and non-desired outputs, respectively; and (S_{nx}, S_{my}, S_{ib}) are the slack vectors, which denote the quantities of over-inputs, under-desired outputs, and over-expired outputs, respectively, and if all of these values are greater than 0 then it means that the actual inputs and non-desired outputs are greater than the bounded inputs and outputs, while the desired outputs are less than the bounded desired outputs; g_{nx}, g_{my} and g_{ib} denote the direction vectors of the nth input, the mth desired output and the ith non-desired output, respectively; and Z_{kt} is the weight of the observations of each decision unit in each period, and the original decision unit is denoted in this function species as k '.

Then this paper combines the SBM directional distance function with the GML index, based on the SBM directional distance function, defines the GML index of any decision-making unit from period t to period t+1, and constructs the SBM-GML model as shown in equation (3).

$$GML_t^{t+I} = \frac{1+\overrightarrow{S}_{VG}(x_t, y_t, b_t; g_x, g_y, g_b)}{1+\overrightarrow{S}_{VG}(x_{t+I}, y_{t+I}, b_{t+I}; g_x, g_y, g_b)} \tag{3}$$

$\overrightarrow{S}_{VG}(x_t, y_t, b_t; g_x, g_y, g_b)$ and $\overrightarrow{S}_{VG}(x_t, y_t, b_t; g_x, g_y, g_b)$ denote the global SBM directional distance function in period *t* and period *t+1*, respectively, and the GML index represents the change of green total factor productivity of the manufacturing industry in period *t+1* relative to period t. It is further calculated to obtain the green total factor productivity of the manufacturing industry, GTFP, which denotes the green development level of the manufacturing industry. The specific calculation formula is shown in equation (4).

$$GTFP_{t+1} = GML_t^{t+I} \times GTFP_t \tag{4}$$

in this paper, energy consumption, capital input, and labor input are used as input indicators for calculating the level of green development of the manufacturing industry; meanwhile, the desired output indicators are selected as industrial-added value, and the non-desired output indicators are selected as industrial soot and dust emissions, industrial sulfur dioxide emissions, industrial chemical oxygen demand emissions, and industrial ammonia nitrogen emissions.

3.2. Dagum Gini Coefficient

Dagum Gini coefficient can accurately calculate the level of regional differences and sources of differences, and is widely used to evaluate the level of regional differences and analyze the sources of regional differences, so this paper uses the Dagum Gini coefficient to analyze the spatial differences in the level of green development of the manufacturing industry and the sources of the differences, as shown in equation (5).

$$G = \left(\sum_{i=1}^{k} \sum_{m=1}^{k} \sum_{j=1}^{hi} \sum_{n=1}^{hj} |y_{im} - y_{jn}| \right) \Big/ 2h^2 \overline{y} \tag{5}$$

where *i* and *j* are different regional subscripts, *m*, and *n* are different provincial subscripts, *k* is the number of regions, *hi* (*hj*) denotes the number of provinces in regions *i* and j, y_{im} (y_{jn}) is the level of green development of the manufacturing industry of the province *m* (*n*) in region *i* (*j*), and *y* denotes the mean value of the level of green development of the manufacturing industry in all provinces. Further, the overall Gini coefficient is decomposed into intra-region Gini coefficient, inter-region Gini coefficient, and hypervariable density. The specific formulae are shown in equations (6)–(10).

$$G = G_w + G_{nb} + G_l \tag{6}$$

$$G_w = \sum_{i=1}^{k} G_{ii} P_i S_i, G_{ii} = \left(\frac{1}{2\overline{y}_i} \sum_{m=1}^{hi} \sum_{n=1}^{hi} |y_{im} - y_{jn}| \right) \Big/ h^2 \tag{7}$$

$$G_{nb} = \sum_{i=2}^{k} \sum_{j=1}^{i-1} G_{ij}(p_i s_j + p_j s_i) D_{ij}, G_{ij} = \left(\sum_{m}^{hi} \sum_{n}^{hj} |y_{im} - y_{jn}| \right) \Big/ h_i h_j (\overline{y}_i + \overline{y}_j) \tag{8}$$

$$G_l = \sum_{i=2}^{k} \sum_{j=1}^{i-1} G_{ij}(p_i s_j + p_j s_i)(1 - D_{ij}) \tag{9}$$

$$D_{ij} = \frac{d_{ij} - p_{ij}}{d_{ij} + p_{ij}}, d_{ij} = \int_0^\infty dF_i(y) \int_0^y (y-x) dF_j(x), p_{ij} = \int_0^\infty dF_j(y) \int_0^y (y-x) dF_i(x) \tag{10}$$

G_{ii} and *Gw* denote the Gini coefficient and intra-region difference in region *i*, respectively, G_{ij} and G_{nb} denote the inter-region Gini coefficient and inter-region net difference in regions *i* and *j*, and G_l denotes the hypervariance density. In this paper, *Dij* is defined as the relative impact of the growth of the level of manufacturing development between regions *i* and *j*, F_i, and F_j are the cumulative density distribution functions of regions *i* and *j*, respectively, d_{ij} is the difference in the growth of the level of manufacturing development between regions, and p_{ij} is the hypervariable first-order moment.

3.3. Kernel density estimation

In this paper, the Gaussian kernel function is used to study the characteristics of the changes in the level of green development of the manufacturing industry in the country and the regions, and the kernel density expression is shown in equations (11) and (12).

$$f(x) = \frac{1}{Nb} \sum_{i=1}^{N} K\left(\frac{X_i - x}{h}\right) \tag{11}$$

$$K(x)=\frac{1}{\sqrt{2\pi}}\exp\left(-\frac{x^2}{2}\right) \tag{12}$$

f(x) is the density function of the green development level of the manufacturing industry, *K* is the random kernel function, *N* is the number of samples, *Xi* is the green development level of the manufacturing industry in the ith province, *x* is the mean value of the sample value, and *h* is the sample broadband.

3.4. Measurement models

According to the theory of resource allocation efficiency and the theory of environmental economics, there are differences in the demand for and utilization efficiency of resources in different industries. By optimizing the industrial structure, the resource utilization efficiency can be improved and the waste of resources can be reduced; and by optimizing the industrial structure, the proportion of high-pollution and high-energy-consumption industries can be reduced, the proportion of green industries can be increased, the environmental pollution and resource consumption can be reduced, and the environmental efficiency can be improved, to improve the green total factor productivity and promote the green development level of manufacturing industry. It can be found that the optimization of the industrial structure of the manufacturing industry is an important factor affecting the level of green development of the manufacturing industry. Therefore, This paper constructs the econometric model shown in equation (3) to empirically test the influence of manufacturing structure optimization on the green development level of the manufacturing industry.

$$y_{it}=\alpha_0+\alpha_1 iso_{it}+\alpha_2 X_{it}+u_i+\lambda_t+\varepsilon_{it} \tag{13}$$

i and *t* denote the provincial and time dimensions, respectively; the explanatory variable *y* is the level of green development of the manufacturing industry; the core explanatory variable iso is the index of structural optimization of the manufacturing industry, and *X* is the number of columns of control variables; u denotes an individual fixed effect, λ denotes a time fixed effect, and ε denotes a random error term.

Further considering that the level of green development of the manufacturing industry has spatial autocorrelation, it is proposed to use a fixed-effects-based spatial econometric model to empirically test the spatial spillover effect of optimization of manufacturing structure to promote the level of green development of the manufacturing industry, and the spatial measurement model is shown in equation (14).

$$y_{it}=\rho w_{ij}y_{it}+\beta_0 x_{it}+\beta_1 wz_{it}+u_i+\lambda_t+\varepsilon_{it}, \varepsilon_{it}=\delta w_i\varepsilon_t+v_{it} \tag{14}$$

W is the spatial neighborhood weight matrix, *y* is the explanatory variable, *x* is the explanatory variable, *Zit* is the spatially lagged explanatory variable, β_0 is the regression coefficient, ρ, β_1, and δ are the spatial autocorrelation coefficients, $W\beta$ is the spatially lagged term of the explanatory variable, *u* denotes the individual fixed effect, λ denotes the time fixed effect, and ε denotes the random error term. The model is a spatial Durbin model if $\delta = 0$, a spatial autoregressive model if $\delta = \beta1 = 0$, and a spatial error model if $\rho = \beta1 = 0$.

In the above model, the measurement method and results of the explanatory variable y are shown before; the explanatory variable manufacturing industry structure optimization, this paper measures from the two dimensions of manufacturing structure rationalization (*SI*) and manufacturing structure sophistication (*SH*), using the Tel index to indicate the rationalization of the manufacturing structure, and using the ratio of high-end manufacturing output and terminal manufacturing output to indicate the level of sophistication of the manufacturing industry; the control variables mainly include the level of technological innovation (*IL*), the level of human capital (*HC*), the level of opening up (*OP*) and government support (*GS*). The level of technological innovation is expressed by the number of domestic patent applications authorized; the level of human capital is expressed by the number of years of education per capita; the level of openness to the outside world is expressed by the amount of foreign investment; and the level of government

Table 1
2005–2020 The green development level of the manufacturing industry in eight regions.

Year	North Coast	Northeast	East	Yellow River	South Coast	Northwest	Southwest	Yangtze River	National Average
2005	1.0992	1.1436	0.9505	1.0574	1.1150	1.1799	0.9903	1.1836	1.0899
2006	1.0710	1.1897	0.9955	1.1654	1.1495	1.3106	1.0849	1.2203	1.1484
2007	1.2086	1.4278	1.1006	1.3633	1.2653	1.5266	1.2553	1.4208	1.3210
2008	1.4319	1.6821	1.2276	1.6143	2.1082	1.7872	1.3927	1.8014	1.6307
2009	1.2423	1.4947	1.1049	1.4866	1.2701	1.5560	1.2861	1.6237	1.3830
2010	1.3847	1.6176	1.2766	1.7842	1.5147	1.8457	1.4536	1.9649	1.6052
2011	1.4626	1.7723	1.3329	1.9113	1.6405	2.0674	1.6951	2.2212	1.7629
2012	1.3749	1.7884	1.3373	1.9204	1.6532	2.0710	1.6719	2.3555	1.7716
2013	1.4314	1.7476	1.2847	1.8599	1.5367	1.9718	1.6640	2.3489	1.7306
2014	1.5712	1.8249	1.4322	1.8995	1.6488	2.0003	1.8409	2.5407	1.8448
2015	1.5184	1.6940	1.3771	1.6929	1.7381	1.8046	1.9096	2.5910	1.7907
2016	2.0956	1.9727	1.7721	2.0289	1.8588	2.0089	2.2121	2.9267	2.1095
2017	4.1348	2.5248	2.5964	3.1867	3.1065	2.4519	2.6728	4.1382	3.1015
2018	3.8586	2.9883	3.2352	4.7054	3.1896	3.0909	3.5803	5.2232	3.7339
2019	4.5716	2.9902	3.2352	5.0015	3.1803	3.3151	4.9320	5.2313	4.0572
2020	4.4879	2.8756	3.2352	4.3067	3.1176	3.0941	4.5312	4.6382	3.7858
Average	2.1215	1.9209	1.7184	2.3115	1.9433	2.0676	2.1358	2.7143	2.1167

support is expressed by the ratio of fiscal expenditures to GDP. The data are mainly obtained from the China Urban Statistical Yearbook, provincial and municipal statistical yearbooks, and EPS database, and linear interpolation is used to fill in individual missing values. To avoid the problem of multicollinearity, absolute variables are logarithmized.

4. Results

4.1. Measurement and analysis of the green development level of the manufacturing industry

According to the Development Research Center of the State Council, China is divided into eight comprehensive economic zones, of which the northern coastal region includes Beijing, Tianjin, Hebei, and Shandong; the eastern coastal region includes Shanghai, Jiangsu, and Zhejiang; the southern coastal region includes Fujian, Guangdong, and Hainan; the northeastern region includes Jilin, Liaoning, and Heilongjiang; the middle reaches of the Yellow River include Shaanxi, Shanxi, Henan, and Inner Mongolia; and the middle reaches of the Yangtze River include Hubei, Hunan, Jiangxi, Anhui; Southwest region including Guangxi, Yunnan, Guizhou, Sichuan, Chongqing; Northwest region including Gansu, Qinghai, Ningxia, Xinjiang (Tibet region is not included in the sample scope of this study due to the serious lack of data) using MaxDEA 8.0 software to measure the level of green development of manufacturing industry in each province and region and analyze the level of green development at the national and regional levels, as shown in Table 1.

From the national level, the average value of China's manufacturing green development level from 2005 to 2020 is 2.1167, indicating that the level of manufacturing green development is low, and the level of manufacturing green development needs to be further improved. During the sample observation period, the evolution of the manufacturing green development level can be divided into two phases: the first phase (2005–2015) is a stable period, and the manufacturing green development The level of green development of the manufacturing industry has not changed much over time, and the highest level of green development of the manufacturing industry in the observation period is 1.8448, and the lowest is 1.0899; this is in line with China's economic development policy, and this period is a key period for the manufacturing industry to promote economic development, and the main direction of the manufacturing industry's development is to enhance the level of economic development, and it does not pay much attention to the environment and ecology, which results in the green development level of the manufacturing industry in this period is not high, and has been in a long time in a low position. development level is not high and has been at a stable level for a long time. The second stage (2016–2020) is an upward period, the green development level of the manufacturing industry in this period has a clear upward trend, the green development level of the manufacturing industry has risen from 2.1095 in 2016 to 4.0532, the reason for this is that the environmental problem has been paid attention to by the government at all levels, and the strategy of ecological civilization promotes the development of China's environmental governance to a higher level, and the traditional mode of development has been changed, and The level of green development of the manufacturing industry has been improved.

Analyzing from the regional level, during the sample observation period, the green development level of the manufacturing industry in the eight comprehensive economic zones shows different characteristics, specifically, the green development level of the manufacturing industry in the middle reaches of the Yangtze River, the middle reaches of the Yellow River and the southwestern region is higher than that of the whole country in most of the years, and the green development level of the manufacturing industry in the eastern coast, the northeastern region and the southern coast is lower than that of the whole country in most of the years. It can be seen that the region with lower level of green development of manufacturing industry is mainly concentrated in the region with higher level of economic development, the main reason is that the east coast, the eastern region, and the southern coast are the leading regions of economic development in China, and China's manufacturing industry is mainly concentrated in these regions, although the overall level of development of the manufacturing industry is high, but due to the scale of the manufacturing industry and the influence of the transformation process, the level of green development of the manufacturing industry is lower.

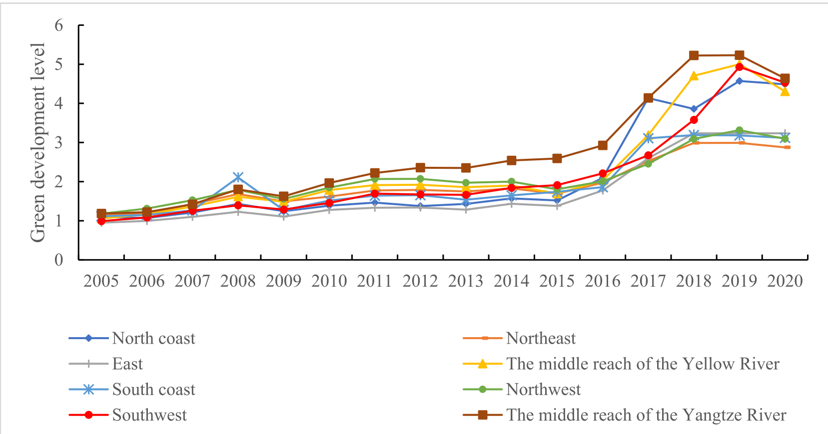

Fig. 1. 2005–2020 Level of greening of manufacturing in the eight regions.

4.2. Temporal and spatial evolution law of green development level of manufacturing industry

4.2.1. Temporal characteristics of the green development level of the manufacturing industry

As can be seen from the calculation results presented in Fig. 1, the overall trend of the eight comprehensive economic zones manufacturing development level from 2005 to 2020 is the same, the manufacturing development level from 2005 to 2015 is in a stable state, and the manufacturing development level in each region from 2016 to 2020 has shown a clear upward trend, among which, the regions with the most obvious upward trend include the middle reaches of the Yangtze River, the middle reaches of the Yellow River, and the southwestern region. The main reason is that the transformation and development of the manufacturing industry in these regions have achieved remarkable results, and new modernized manufacturing industries are constantly transferring to these regions, while traditional manufacturing industries are transferring to the northwest and other regions, so that the green development level of the manufacturing industry has been greatly improved, and the green development level of the manufacturing industry is on a clear upward trend. The eastern region, the southern coast, the eastern coast, and other regions of the manufacturing industry are concentrated, the manufacturing industry is based on a strong foundation, and the transformation and upgrading process is slower, so the level of green development of the manufacturing industry in these regions lags behind the central region.

Adopting the kernel density function estimation method, the nodes of manufacturing green development level in 2005, 2010, 2015, and 2020 were selected to draw the two-dimensional map of kernel density, and by comparing the kernel density curve maps in different periods, we analyzed the characteristics of the temporal change of the manufacturing industry's green development level. Specific kernel density trends are shown in Figure (2). From the perspective of position, the center of the kernel density curve of the green development level of the manufacturing industry in the four years shows a rightward trend, indicating that the green development level of the manufacturing industry shows a gradual improvement, especially in 2020, the center of the kernel density curve has a large movement, indicating that since 2015, the green development level of the manufacturing industry has been substantially improved. From the perspective of shape, the main peak of the kernel density curve has slowed down, the peak value has declined, and the width has increased, which indicates that the difference in the level of green development of the manufacturing industry in various provinces has gradually become larger, and the polarization phenomenon has appeared, mainly because of the foundation of the manufacturing industry development in various provinces, and the differences in the degree of transformation, which is affected by the structure, and the level of green development of the manufacturing industry has shown a good trend, but polarization phenomenon has appeared in a short period.

4.2.2. Spatial characteristics of the level of green development of the manufacturing industry

To further analyze the spatial differences in the level of green development of the eight comprehensive economic zones in China and their sources, the spatial differences in the level of green development of the eight comprehensive economic zones and their contribution rates were measured by using the Dagum Gini coefficient, and the results are shown in Table 2.

As can be seen from Table 2, the mean value of the overall difference in the level of green development of the manufacturing industry in the eight comprehensive economic zones from 2005 to 2020 is 0.1425, which shows a fluctuating upward trend during the sample observation period, with the total difference increasing from 0.0742 in 2005 to 0.2390 in 2020. This indicates that there is an imbalance between the level of green development of the manufacturing industry in various regions of China, and the imbalance phenomenon is constantly expanding. In terms of the contribution rate of intra- and inter-regional differences, the differences in the level of green development of the manufacturing industry in various regions of China mainly come from inter-regional differences, with the contribution rate fluctuating between 40.8681 % and 79.5930 %. The contribution rate of intra-regional differences is relatively low, mainly fluctuating between 7.4213% and 11.1905 %, basically in a stable state. The contribution rate of hypervariable density fluctuates between 12.9856% and 47.9414 %, which means that the formation of the differences in the level of green development of China's manufacturing industry is related to the problem of cross overlap between different regions. It can be found

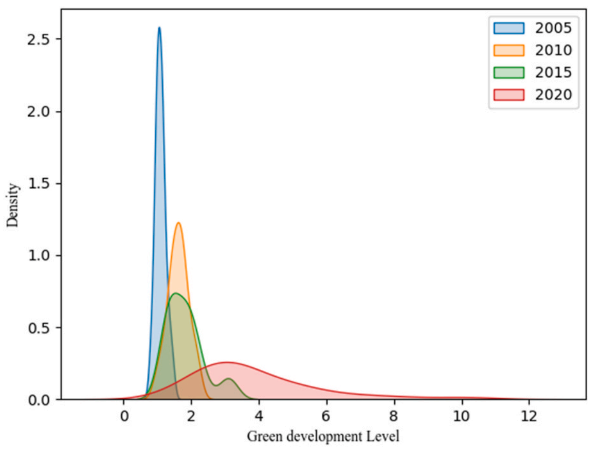

Fig. 2. Kernel density plot of greening level of manufacturing in major years.

Table 2
2005–2020 Dagum Gini of green development level of manufacturing industry.

year	G-Total	Intraregional		Interregional		Intensity of transvariation	
		Source	Rate of contribution	Source	Rate of contribution	Source	Rate of contribution
2005	0.0742	0.0074	9.9800	0.0412	55.5445	0.0256	34.4755
2006	0.0630	0.0053	8.4348	0.0442	70.1786	0.0135	21.3866
2007	0.0743	0.0060	8.1149	0.0536	72.1175	0.0147	19.7676
2008	0.1355	0.0116	8.5503	0.0851	62.8054	0.0388	28.6443
2009	0.0929	0.0073	7.8248	0.0667	71.8064	0.0189	20.3688
2010	0.1035	0.0078	7.4985	0.0795	76.7889	0.0163	15.7126
2011	0.1181	0.0092	7.7982	0.0880	74.5716	0.0208	17.6302
2012	0.1269	0.0094	7.4213	0.1010	79.5930	0.0165	12.9856
2013	0.1346	0.0110	8.1929	0.0993	73.7665	0.0243	18.0406
2014	0.1300	0.0115	8.8706	0.0888	68.2940	0.0297	22.8354
2015	0.1567	0.0149	9.4811	0.0950	60.6240	0.0468	29.8949
2016	0.1523	0.0156	10.2406	0.0758	49.7470	0.0610	40.0123
2017	0.2267	0.0236	10.4186	0.1126	49.6721	0.0905	39.9093
2018	0.2171	0.0230	10.6007	0.1093	50.3267	0.0848	39.0726
2019	0.2355	0.0259	11.0036	0.1148	48.7689	0.0947	40.2275
2020	0.2390	0.0267	11.1905	0.0977	40.8681	0.1146	47.9414
Average	0.1425	0.0135	9.1013	0.0845	62.8421	0.0445	28.0566

that the differences in the level of green development of the manufacturing industry are mainly caused by inter-regional differences and hypervariable density.

To realize the green and balanced development of the manufacturing industry, we should focus on solving the gap in green development of the manufacturing industry between regions, at the same time, the increase in the contribution rate of hypervariable density shows that the level of green development of the manufacturing industry of the Yangtze River Basin, the Yellow River Basin is not all ahead of other regions, and we should pay attention to the coordination relationship between the level of green development of the manufacturing industry in the central region and that in the coastal region.

4.3. Analysis of factors affecting the level of green development of manufacturing industry

4.3.1. Benchmark model regression

The baseline model (equation (13)) is estimated to test the effect of manufacturing structure optimization on the level of green development of the manufacturing industry, and the results are shown in Table 3. Controlling for time-fixed effects and individual fixed effects, respectively, columns (1) and (2) are the results of the impact of manufacturing structure rationalization on the level of green development of the manufacturing industry, and the results show that the level of rationalization of the manufacturing structure significantly promotes the level of green development of the manufacturing industry, and this conclusion is not affected by the control variables. Columns (3) and (4) are the results of the influence of the level of advanced manufacturing structure on the level of green development of the manufacturing industry, and the results show that the level of advanced manufacturing structure can also significantly promote the level of green development of the manufacturing industry. Columns (5) and (6) are the results of

Table 3
Benchmark regression results.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
SI	0.0132** (0.0060)	0.0135**(0.0059)			0.0126** (0.0059)	0.0131** (0.0058)
SH			0.2999*** (0.7780)	0.2425*** (0.0881)	0.2957*** (0.0775)	0.2365*** (0.0877)
IL		0.0036(0.0043)		−0.0042 (0.0063)		−0.0028 (0.0049)
HC		0.7091***(0.2135)		0.6322*** (0.2128)		0.6702*** (0.2124)
OP		9.4004***(3.2136)		6.8043** (3.3345)		6.9331** (3.3191)
GS		−4.8202***(1.2866)		−5.3402*** (1.2888)		−5.1857*** (1.2845)
constant term	0.7937*** (0.1916)	−4.3774** (1.7266)	0.6564*** (0.1756)	−3.6362** (1.7016)	0.3805* (0.2176)	−4.2482** (1.7148)
Time-fixed	Yes	Yes	Yes	Yes	Yes	Yes
Individual-fixed	Yes	Yes	Yes	Yes	Yes	Yes
N	480	480	480	480	480	480
R^2	0.6555	0.6866	0.6632	0.6881	0.6667	0.6918

Note: ***, **, and * denote 1 %, 5 %, and 10 % significance levels, respectively, with clustering standard errors in parentheses, below.

simultaneously testing the impact of rationalization and advanced manufacturing structure on the level of green development of the manufacturing industry, and the results show that the optimization of manufacturing structure can significantly promote the level of green development of the manufacturing industry.

The main reason that the optimization of manufacturing structure can promote the green development level of the manufacturing industry is that the rationalization of manufacturing structure and the serialization of manufacturing structure are the optimization and adjustment of manufacturing industry structure, and by eliminating the backward manufacturing industry, the non-expected output can be reduced, and the damage to the environment caused by the development of manufacturing industry can be reduced. On the other hand, the vigorous development of the modern manufacturing industry can improve the production efficiency of the manufacturing industry and reduce the waste of resources, so the optimization of the manufacturing structure promotes the level of green development of the manufacturing industry.

There may be endogeneity problems due to reverse causality between manufacturing structure optimization and the level of green development of the manufacturing industry, as well as endogeneity problems due to the omission of important variables, the latter of which is mitigated by the fact that individual fixed effects have been controlled for in the empirical study. Therefore, there is a need to find reasonable instrumental variables for manufacturing structure optimization to mitigate the endogeneity problem. Since the disturbance term is unobservable, it is difficult to find an instrumental variable that is not strictly related to the disturbance term but highly correlated with the endogenous variable. Considering that the lagged term of the endogenous variable is highly correlated with the current endogenous variable in time but not correlated with the current disturbance term, it satisfies the correlation and homogeneity requirements of the instrumental variable and can be used as an instrumental variable. The results of 2SLS estimation with the lagged term of endogenous variables as an instrumental variable are shown in Table 4.

Applicability test of instrumental variables, the Anderson LM test P-value is less than 0.00 respectively, rejecting the non-identifiability of instrumental variables, the instrumental variables for rationalization of manufacturing structure Cragg-Donald Wald F-test values are 40.36 and 221.41 respectively, which are greater than the critical value of 16.38; the instrumental variables for advanced structuralization of manufacturing industry Cragg- Donald Wald F-test values are 41.81 and 687.58 respectively, which are greater than the critical value of 16.38 can ensure that there is no weak instrumental variable problem, i.e. the instrumental variables are valid. Table 4 shows the 2SLS regression results of the instrumental variable method, which indicate that both rationalization and advanced manufacturing structure have significant promotion effects on the green development level of the manufacturing industry, which is consistent with the estimation results of the benchmark model.

The robustness of the model results has been initially reflected in the above benchmark model by adding control variables and controlling for individual fixed effects and time-fixed effects. However, there are still uncertainties in the research sample characteristics and variable settings, etc. To further enhance the credibility of the model estimation results, this paper re-tests the samples and variables after a series of treatments by the following two methods. (1) Replacement of explanatory variables, this paper takes into account that enterprises are variable in size in the time series when calculating the level of green development of the manufacturing industry, so it uses the VRS model to measure the total factor productivity of the manufacturing industry, and further assumes that the enterprises are under a fixed size, measures the productivity of the manufacturing industry, and obtains the level of green development of the manufacturing industry, and carries out regression analysis. (2) Reduced-tail processing. To avoid the influence of possible extreme values on the regression results, this paper adopts a 1 % shrinking tail method to deal with continuous variables. Re-estimate the model. The specific test results are shown in Table 5, and it can be seen that after the one-column robustness test, the test results are still basically consistent with the benchmark regression results, so the research design and results of this paper are robust.

4.3.2. *Analysis of spatial effects*

The regional Moran Index and Moran scatter plot were used to construct the adjacent spatial weight matrix, and the spatial autocorrelation of the green development level of the manufacturing industry was tested. As shown in Table 6, the Moran index of each year had significant statistical significance, indicating that the green development level of the manufacturing industry as a whole had a spatial positive correlation and an obvious spatial dependence. In view of this, this study chooses the spatial Durbin model based on fixed effects to empirically test the spatial spillover effects of manufacturing structure factors on the green development level of manufacturing industry.

Table 7 shows the spatial effect of manufacturing structure rationalization on the green development level of the manufacturing

Table 4
Results of instrumental variable estimation.

Variable	SI		SH	
	Phase I	Phase II	Phase I	Phase II
	0.5964***	0.0196***	0.8013***	0.2113**
	(0.0939)	(0.0073)	(0.1239)	(0.0924)
control variables	Yes	Yes	Yes	Yes
Time-fixed	Yes	Yes	Yes	Yes
Individual-fixed	Yes	Yes	Yes	Yes
Anderson LM		8.54***		10.43***
Cragg-Donald Wald		221.41 [16.38]		687.58 [16.38]
N	450	450	450	450

Table 5
Robustness test results.

Variable	Replacing explanatory variables		Shrinkage treatment	
SI	0.0122*** (0.0033)		0.0140** (0.0064)	
SH		0.0968* (0.0505)		0.2518*** (0.0843)
control variables	Yes	Yes	Yes	Yes
Time-fixed	Yes	Yes	Yes	Yes
Individual-fixed	Yes	Yes	Yes	Yes
N	480	480	480	480
R^2	0.7117	0.7050	0.7031	0.7059

Table 6
Moran index of green development level of manufacturing industry.

Year	Moran index	P	Year	Moran index	P
2005	0.012	0.049	2013	0.019	0.004
2006	0.029	<0.001	2014	0.016	0.017
2007	0.033	<0.001	2015	0.032	<0.001
2008	0.023	<0.001	2016	0.05	<0.001
2009	0.030	<0.001	2017	0.048	<0.001
2010	0.017	0.009	2018	0.026	<0.001
2011	0.010	0.084	2019	0.021	0.002
2012	0.013	0.043	2020	0.038	<0.001

industry. Table 8 shows the spatial effect of the advanced manufacturing structure on the green development level of the manufacturing industry. The results show that the spatial autoregressive coefficient ρ is significantly negative at the 1 % significant level, indicating that there is indeed a spatial spillover effect on the level of green development of the manufacturing industry and that the enhancement of the level of green development of the local manufacturing industry will inhibit the enhancement of the level of green development of the manufacturing industry in the surrounding areas. The spatial lag term associated with the optimization of manufacturing structure exerts a noteworthy influence on the green development level of the manufacturing industry, signifying a positive spatial spillover effect of manufacturing structure optimization on the green development level of the manufacturing industry in adjacent cities. Furthermore, the study reveals that the direct, indirect, and overall effects of manufacturing structure optimization are markedly positive, underscoring the presence of a spatial spillover effect that substantially enhances the green development level of the manufacturing industry within the region and its proximate areas. Therefore, optimizing the manufacturing structure plays an important role in enhancing the green development level of the manufacturing industry, and regions should take the adjustment of the manufacturing structure as the main driving force to promote the green development level of the regional manufacturing industry.

Considering that different spatial weight matrices may have different effects on the spatial measurement model, the spatial measurement model is further tested by using the geographical distance matrix and the economic distance matrix. The test results show that under different spatial weight matrices, the structural factors of manufacturing industry all have a spatial spillover effect on the green development level of manufacturing industry. The specific test results are shown in Table 9.

Table 7
Spatial spillover effects of structural rationalization.

Variable	*x*	*Wx*	LR-Direct	LR-Indirect	LR-Total
SI	0.0093 (0.0057)	0.0301** (0.0121)	0.0078 (0.0061)	0.0240** (0.0103)	0.0319*** (0.0093)
IL	0.0072 (0.0047)	−0.0221*** (0.0073)	0.0084* (0.00480	−0.0202*** (0.0067)	−0.0118** (0.0053)
HC	0.6605*** (0.1965)	0.5211 (0.4280)	0.6639*** (0.1947)	0.2783 (0.3530)	0.9422*** (0.3487)
OP	5.4855* (3.0880)	−16.2000** (6.7439)	6.3956** (2.9639)	−14.5726*** (5.6140)	−8.1770 (6.3374)
GS	−5.4234*** (1.3987)	−1.2973 (2.2481)	−5.4411*** (1.4802)	0.1702 (2.0908)	−5.2709*** (1.5499)
ρ	−0.2554*** (0.0636)				
Variance	04263*** (0.0279)				
N	480				
R^2	0.3056				

Table 8
Spatial spillover effects of structural sophistication.

Variable	*x*	*Wx*	LR-Direct	LR-Indirect	LR-Total
SH	0.2367*** (0.0872)	0.3657* (0.1904)	0.2209** (0.0887)	0.2674* (0.1513)	0.4883*** (0.1754)
IL	0.0032 (0.0052)	−0.0334*** (0.0079)	0.0049 (0.0054)	−0.0292*** (0.0070)	−0.0243*** (0.0062)
HC	0.6045*** (0.1971)	0.7149* (0.4271)	0.5945*** (0.1958)	0.4568 (0.3491)	1.0513*** (0.3477)
OP	3.7986 (3.1986)	−18.6455*** (7.1630)	4.8339 (3.1798)	−16.3813*** (6.0905)	−11.5474* (6.4693)
GS	−5.4085*** (1.3985)	−3.7973 (2.3317)	−5.2778*** (1.4743)	−1.9986 (2.1454)	−7.2764*** (1.6272)
ρ	−0.2569*** (0.0658)				
Variance	0.4285*** (0.0281)				
N	480				
R^2	0.2773				

5. Research conclusions and policy recommendations

5.1. Research conclusions

Promoting the realization of the dual-carbon target as scheduled is the overall orientation of the comprehensive green and low-carbon transformation of China's manufacturing industry. Under the vision of dual-carbon target, this paper adopts the SBM-GML model to measure the green development level of manufacturing industry in the eight comprehensive economic zones, based on which the spatial and temporal characteristics and the evolution law of the green development level of manufacturing industry are explored through the Gini coefficient and the kernel density estimation, and the spatial econometric model is used to empirically test the key factors affecting the level of green development of the manufacturing industry and the spatial spillover effect. Specific research conclusions are as follows.

(1) From the results of the SBM-GML model measurement, during the sample period, the green development level of China's manufacturing industry has experienced two phases: 2005–2015 is the stable period, the green development level of the manufacturing industry is stable near 1.5526, and the overall changes are small. 2015–2020 is the upward trend, and the green development level of the manufacturing industry is steadily rising to 3.7858. Therefore, during the observation period, the overall green development level of the national manufacturing industry shows an upward trend, which means that the green development level of China's manufacturing industry is gradually improving. In terms of specific subregions, The green development level of the manufacturing industry in the middle reaches of the Yangtze River, the middle reaches of the Yellow River and the southwest is higher than the national level in most years, while the green development level of the manufacturing industry in the eastern coastal region, the northeast region and the southern coastal region is lower than the national development level in most years, and the room for improvement of the green development level of the manufacturing industry is large.

(2) From the perspective of the temporal and spatial characteristics of the green development level of the manufacturing industry, the overall change trend of the green development level of the manufacturing industry in the eight comprehensive economic zones from 2005 to 2020 is the same, and the green development level of the manufacturing industry in the eight comprehensive economic zones from 2005 to 2015 is in a stable state. However, the change of green development level of manufacturing industry in different regions is different. Among them, the regions with the most obvious upward trend include the middle reaches of the Yangtze River, the middle reaches of the Yellow River and the southwest, and the green development

Table 9
Spatial spillover effect under different matrices.

Variable	*W1*	*W2*	Variable	*W1*	*W2*
SI	0.2987** (0.1386)	0.2836*** (0.0700)	*SH*	0.3125** (0.1543)	0.2889*** (0.1103)
W SI*	0.4278* (0.2229)	0.3374* (0.2050)	*W* SH*	0.0818*** (0.0130)	0.4077* (0.2236)
control variables	Yes	Yes	control variables	Yes	Yes
ρ	−0.2292*** (0.0257)	−0.2004*** (0.0306)	ρ	−0.3023*** (0.0472)	−0.2282*** (0.0260)
Variance	0.3983*** (0.0603)	0.3880*** (0.0560)	Variance	0.4474*** (0.0652)	0.3992*** (0.0607)
N	480	480	*N*	480	480
R^2	0.2241	0.3012	R^2	0.2309	0.2233

Note: *W1* Represents the geographic distance matrix. *W2* Represents the economic distance matrix.

level of the manufacturing industry in the eastern and other developed regions lags behind the central region. The green development level of the manufacturing industry shows a gradual increase, but the differences in the green development level of the manufacturing industry in each province gradually become larger, and there is an imbalance between the green development level of the manufacturing industry. The imbalance phenomenon is expanding, the polarization phenomenon, and the difference in the level of green development of the manufacturing industry mainly comes from the inter-regional differences.

(3) From the point of view of the influencing factors of the green development level of the manufacturing industry. The adjustment and optimization of the industrial structure of the manufacturing industry has a significant positive impact on the green development level of the manufacturing industry, and the promotion effect of the advanced manufacturing structure relative to the rationalization of the manufacturing industry structure is more obvious. The green development level of the manufacturing industry has a spatial correlation, there is a spatial spillover effect, and the enhancement of the green development level of the local manufacturing industry will inhibit the enhancement of the green development level of the manufacturing industry in the surrounding areas. The rationalization and advancement of manufacturing structure have positive spatial spillover effects on the green development level of the manufacturing industry in the surrounding areas.

5.2. Policy recommendations

Based on the above research findings, the following policy recommendations are made:

(1) Increase the development and utilization of clean energy, control traditional energy consumption, and enhance the green development level of the manufacturing industry. Energy is an important input element of green total factor productivity, if the type and structure of energy consumption, can fundamentally promote the green development level of the manufacturing industry. On the one hand, strengthen constraints on energy consumption in the manufacturing industry, establish and strictly implement green manufacturing standards, promote enterprises to increase investment in cleaner production technology, reduce environmental pollution and waste of resources. In particular, it is necessary to control the proportion of coal consumption, to control energy consumption intensity, but also to control the total amount of energy consumption, actively respond to the national dual control requirements, and guide the industry to shift energy demand to clean energy. Improve the energy management system, encourage enterprises to implement energy conservation and cleaner production measures, improve energy efficiency, and reduce energy consumption. On the other hand, it should help the development of clean energy accelerate the popularization of clean energy through relevant policies such as tax and fee reduction, technical guidance, and first pilot.Create incentives and subsidies to encourage businesses and individuals to increase investment and use of clean energy, such as solar and wind power.

(2) Take full account of regional heterogeneity and promote the green development of the manufacturing industry according to local conditions. The economic foundation, resource endowment, stage of the manufacturing industry, and its carbon emission situation are different in each region, and the realization path of green development of the manufacturing industry is also characterized by differentiation. The eastern and southern coastal regions can rely on their heritage to focus on the layout of advanced manufacturing industries and upgrade specialized, special, and new enterprises in the service sector. The northern coast, with Beijing as its core, will take advantage of its position as a source of innovation and, by driving the upgrading of the industrial structure of the neighboring regions, focus on alleviating the disparity within the region and promoting integrated regional development. The central and western regions should raise environmental standards, strictly control the blind expansion of traditional manufacturing industries, deepen technical cooperation between the East and the West in combination with regional characteristics, continue to implement the task of transforming green innovation results.

(3) Optimize the industrial structure with the market-leading, and build a long-term synergistic mechanism for regional integration and green development of the manufacturing industry. The industrial structure is a key factor affecting the level of green development of the manufacturing industry, and the optimization and adjustment of the manufacturing structure have a significant spatial spillover effect on the level of green development of the regional manufacturing industry. It is necessary to play a decisive role in the market, accelerate the adjustment of the industrial structure, and actively cultivate the green and low-carbon emerging industries with less pollution and higher demand, to gradually Promote the high-end transformation of industries. We will guide enterprises to optimize the industrial structure through market mechanisms and encourage industrial restructuring and upgrading. Establish a unified green manufacturing standard and certification system to promote regional enterprises to implement green production. We will encourage enterprises to increase investment in technological innovation, promote the development of high-end, intelligent and green manufacturing, and promote the development of green manufacturing. Empirical testing of the level of green development of the manufacturing industry will inhibit the level of green development of the manufacturing industry in neighboring regions, so we should take reasonable measures to prevent regional integration may bringing negative effects to the green development of manufacturing industry in neighboring regions, and promote the synergistic improvement of the level of green development of regional manufacturing industry.

5.3. Limitations and future research directions

The research limitations of this paper are mainly reflected in two aspects: First, due to the availability of data, the selection of input and output indicators and influencing factor indicators when measuring the green development level of the manufacturing industry is not comprehensive enough. Future studies can further measure the green development level of the manufacturing industry when more comprehensive data can be obtained. Second, in the study on the spatial effect of the green development level of manufacturing industry, this paper only uses the spatial Durbin model for empirical analysis. At present, there are many models on spatial influencing factors, such as GWR, GTWR, MGWR and other spatial models, which can well reflect the spatio-temporal heterogeneity of influencing factors, and can be used as a reference in future research. To improve the comprehensiveness of the study, different models were selected to comprehensively analyze the spatial effects of spatial influencing factors in manufacturing industry.

Ethical statement

Ethics approval for this research was not required as per institutional and national guidelines.

Data availability statement

Data will be made available on request, further inquiries can be directed to the corresponding author.

Informed consent

No animal studies are presented in this manuscript.
No human studies are presented in this manuscript.
No potentially identifiable human images or data is presented in this study.

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CRediT authorship contribution statement

Weiwei Zhu: Writing – review & editing, Visualization, Supervision, Resources, Methodology, Funding acquisition, Data curation. **Guozhuo Yang:** Writing – original draft, Validation, Software, Project administration, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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