Chin. Geogra. Sci. 2020 Vol. 30 No. 2 pp. 352–365
https://doi.org/10.1007/s11769-020-1114-3

Springer Science Press
www.springerlink.com/content/1002-0063

Spatial-temporal Heterogeneity of Green Development Efficiency and Its Influencing Factors in Growing Metropolitan Area: A Case Study for the Xuzhou Metropolitan Area

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Abstract: This study analyzed the spatial-temporal heterogeneity of green development efficiency and its influencing factors in the growing Xuzhou Metropolitan Area for the period 2000–2015. The slacks-based measure (SBM) model, spatial autocorrelation, and the geographically weighted regression (GWR) model were used to conduct the analysis. The conclusions were as follows: first, the overall efficiency of green development of the Xuzhou Metropolitan Area decreased, the regional differences and spatial agglomeration shrunk and differences within the region were the main contributors to the regional differences of green development efficiency. Second, the counties with high-efficiency green development were distributed along the coast, and along the routes of the Beijing-Shanghai and the Eastern Longhai railways. A developing axis of the high-efficiency counties was the main feature of the spatial pattern for green development efficiency. Third, regarding spatial correlation and green development efficiency, the High-High type counties in the Xuzhou Metropolitan Area formed a centralized distribution corridor along the inter-provincial border areas of Henan and Jiangsu, whereas the Low-Low type counties were concentrated in the external, marginal parts of the metropolitan area. Fourth, the major factors (ranked in decreasing order of impact) influencing green development efficiency were innovation, government regulations, the economic development level, energy consumption, and industrial structure. These factors exerted their influence to varying extents; the influence of the same factor had different effects in different regions and obvious spatial differences were observed for the different regions.

Keywords: growing metropolitan area; green development efficiency; spatial and temporal heterogeneity; influential factors; Xuzhou Metropolitan Area, China

Citation: QIU Fangdao, CHEN Yang, TAN Juntao, LIU Jibin, ZHENG Ziyan, ZHANG Xinlin, 2020. Spatial-temporal Heterogeneity of Green Development Efficiency and Its Influencing Factors in Growing Metropolitan Area: A Case Study for the Xuzhou Metropolitan Area. *Chinese Geographical Science*, 30(2): 352–365. https://doi.org/10.1007/s11769-020-1114-3

1 Introduction

The *Guiding Opinions on the Cultivation and Development of Modernized Metropolitan Area*, issued by the National Development and Reform Commission in 2019, states that modernized metropolitan areas will be cultivated and developed to support high-quality urban agglomeration and economic transformation. As an important form for spatial organization of new urbanization in China, metropolitan areas are characterized by a rapid economic growth, changes in industrial structure, changes in spatial patterns and urbanization. However, for a typical area where industrial agglomeration and the environment become prominent, a contradiction to the

Received date: 2019-08-14; accepted date: 2019-12-17

Foundation item: Under the auspices of the National Natural Science Foundation of China (No. 41671123, 41971158, 41671122), Major Project of Philosophy and Social Science Research of Jiangsu Universities (No. 2018SJZDA010)

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aforementioned model may exist. Therefore, it is necessary to promote green development in China's metropolitan areas. Green development, with an emphasis on the coordinated development of the economy and the environment, is a main manifestation of regional sustainable development and, the strategic choice for China's economic and social development (Fay et al., 2012; Hu and Zhou, 2014; Yang and Liu, 2016; Che et al., 2018; Li et al., 2019). Green development is essential for implementing the requirement to build a 'beautiful China' as proposed by the 19th National Congress. Improving green development efficiency is the key to achieving green development and a coordinated development of economic growth, resource reduction, and minimizing environmental impact. Green efficiency can also help transform the existing development pattern into a high-efficiency, low-material consumption, and low contamination pattern (Yang and Wen, 2017). Therefore, conducting research on green development efficiency and the driving mechanisms underpinning a rapidly urbanizing metropolitan area has become the key to addressing and potentially solving the contradiction between China's growing economy and its environment.

Currently, studies on green development efficiency have focused on the following aspects: First, *a definition of green development efficiency*. Researchers define green development as a brand-new development philosophy that emphasizes balancing various conflicts of interest, optimizing various resources, and pursuing the harmonious coexistence and sustainable development of economics, society, humans, and nature (Zhang et al., 2019). Second, a *comprehensive evaluation system for green development*. Scholars have established economic and environmental accounts, and integrated economic and environment accounts, green national economic accounting systems, green growth monitoring frameworks, green economy measurement evaluation models, and ecological efficiency indicators systems to devise a comprehensive system for evaluating green development (Moutinho et al., 2017; Lyytimäki et al., 2018; Xing et al., 2018). With regard to green development efficiency in different industries, this issue has been studied in the context of green economy efficiency, green innovation efficiency, and water resources green efficiency (Luo and Liang, 2016; Tao et al., 2016; Liu, 2017; Ma et al., 2017; Mu et al., 2017; Sun et al., 2017). In addition, green development efficiency has been analyzed in terms of its spatial and temporal patterns (Nie and Wen, 2015; Lin et al., 2017; Che et al., 2018). Third, *green development path*. Researchers have proposed the introduction of low-carbon policies (Wang and Wang, 2017; Zhang and Zhao, 2018), and the development of green energy (Hosseini and Wahid, 2016; Hennig and Harlan, 2018) and green cities (Affolderbach and Schulz, 2017; Richter and Behnisch, 2019), to realize green development. Fourth, the *Research Methods for Studying green development efficiency*. Scholars have applied eco-efficiency methods, the comprehensive index method, the stochastic frontier analysis method, and the life cycle method to measure green development efficiency (Yang et al., 2015; Hu et al., 2017; You et al., 2017; Peng and Xiong, 2018).

In general, current studies on green development efficiency have focused mainly at the urban, provincial, and national level; however, research, conducting on growing metropolitan areas, is scarce. Although quantitative analysis has been widely used to study metropolitan areas (Liu et al., 2009; Yan, 2016; Zhu et al., 2017; Ren et al., 2019; Wang and Huang, 2018) and green development efficiency, the role of spatial location has not received the attention it deserves. Therefore, it is believed that an exploration of the spatial interdependence of green development will represent a valuable contribution to the literature on spatial heterogeneity. Particularly, most studies have not captured adequately the local diferences between the different influencing factors. This paper selected the county level as a research unit and quantitatively measured the green development efficiency of the industrial system in a growing metropolitan area from 2000 to 2015 and studied the spatial-temporal heterogeneity of green development efficiency and its influencing factors. The slacks-based measure (SBM) model, spatial autocorrelation, and the geographically weighted regression (GWR) model were used. Finally, tentative recommendations for green development transition and sustainable development of the industrial system in the Xuzhou Metropolitan Area and similar growing metropolitan areas have been proposed.

2 Materials and Methods

2.1 Study area

The Xuzhou Metropolitan Area is located in the border areas of Jiangsu, Shandong, Anhui, and Henan provinces, and includes Xuzhou and seven other cities (Fig. 1). It was highlighted as one of the major development zones in *The Outline of the National Territory Planning* (2017) and *National Major Functional Zone Planning* (2010) and a strategic spatial fulcrum area proposed under the Belt and Road Initiative (BRI). In 2015, the metropolitan area of Xuzhou was 66.882 km^2 with a population of 51.3874 million, and accounting for 0.69% and 3.74% of the national totals, respectively. The regional GDP reached 1945.099 billion yuan, accounting for 2.83% of the national GDP. The per capita GDP was 37 851.67 yuan (RMB), which was 0.76 times the national average. The three industrial output ratios over the period 2000–2015 changed from 26.32:40.51:33.17 to 12.13:46.48:41.39. The total energy consumption during the same period increased from 50.9097 million t of standard coal equivalent to 182.1435 million tce, with an average annual growth rate of 8.87%. The amount of industrial SO_2 emissions increased from 367 600 t to 471 400 t, with an average annual growth rate of 1.67%. The aforementioned industrial output data show that resource consumption, environmental pollution, and economic growth were trending in the same development direction—an indication that economic growth was being driven by resource consumption. Therefore, reducing resource consumption and environmental pollution (the byproducts of economic growth), improving

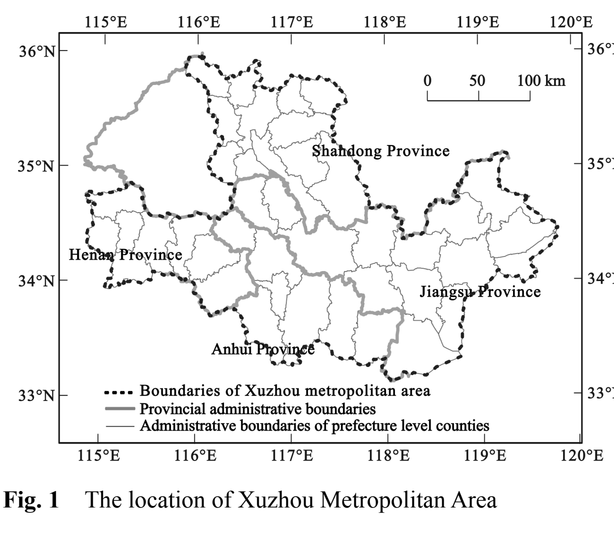

Fig. 1 The location of Xuzhou Metropolitan Area

green development efficiency, and promoting the green transformation of the economy are essential for constructing an ecologically responsible society in the Xuzhou Metropolitan Area.

2.2 Methods

2.2.1 SBM model

The SBM model deals with undesirable outputs. This study selected the SBM model to deal with the undesirable outputs. Next, we considered a production system with n decision making units (DMUs), where each unit has three factors: inputs, desirable outputs, and undesirable outputs (e.g., environmental pollution such as CO_2, SO_2) as represented by three vectors $x \in R^m$, $y^g \in R^{s_1}$, $y^b \in R^{s_2}$. We define the matrices X, Y^g, Y^b as $X = (x_{i,j}) \in R^{m \times n}$, $Y^g = (y^g{}_{ij}) \in R^{s_1 \times n}$, $Y^b = (y^b{}_{ij}) \in R^{s_2 \times n}$ and assume that $X > 0$, $Y^g > 0$, $Y^b > 0$. The production possibility set (P) is defined by assuming that Equation (1) (Tone, 2007)

$$P = \left\{ (x, y^g, y^b) \middle| x \geq X\lambda, y^g \leq Y^g \lambda, y^b \geq Y^b \lambda, \lambda \geq 0 \right\} \quad (1)$$

where λ is the intensity vector. According to the SBM model, the improved SBM model dealing with undesirable outputs for evaluating DMU (x_0, y_0^g, y_0^b) is as Equations (2) and (3).

$$\rho^* = \min \frac{1 - \dfrac{1}{m} \sum_{i=1}^{m} \dfrac{S_i^-}{X_{i_0}}}{1 + \dfrac{1}{S_1 + S_2} \left(\sum_{r=1}^{s_1} \dfrac{S_r^g}{y_{r0}^g} + \sum_{r=1}^{s_2} \dfrac{S_r^b}{y_{r0}^b} \right)} \quad (2)$$

$$\text{s.t.} \begin{cases} x_0 = X\lambda + S^- \\ y_0^g = Y^g \lambda - S^g \\ y_0^b = Y^b \lambda + S^b \\ S^- \geq 0, S^g \geq 0, S^b \geq 0, \lambda \geq 0 \end{cases} \quad (3)$$

where S^-, S^g, S^b are slacks corresponding to the inputs, desirable outputs, and undesirable outputs, respectively, of the DMUs. The objective function ρ^* is strictly decremented with respect to S^-, S^g, S^b, and $0 \leq \rho^* \leq 1$. When $\rho^*=1$, that is, $S^-=S^g=S^b=0$, this indicates that the decision unit is fully effective. When $\rho^*<1$, that is, at least one of the three variables S^-, S^g, and S^b is not equal to 0, and is an indication that the measured unit is invalid.

2.2.2 Spatial autocorrelation analysis

(1) Global spatial autocorrelation

Global spatial autocorrelation was conducted using Moran's *I* index to reveal the spatial correlation characteristics among the different regions. The formula for calculating the global Moran's *I* index can be expressed as Equation (4) (Long et al., 2016).

$$I = \frac{N}{S_0} \cdot \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} W_{ij}\left(X_i - \bar{x}\right)\left(X_j - \bar{x}\right)}{\sum_{i=1}^{N}\left(X_i - \bar{x}\right)^2} \tag{4}$$

In this formula X_i and X_j represent the green development efficiency of counties *i* and *j* respectively; $\bar{x}$ is the average value of the green development efficiency of the industrial system; *N* represents the number of counties in the Xuzhou Metropolitan Area; W_{ij} is the spatial weight of counties *i* and *j*; and the value range of Moran's *I* index is [–1, 1]. The closer the value is to 1, the greater the clustering in the pattern; the closer the value is to –1, the greater is the dispersion in the pattern; if the value equals 0, there is no spatial dependence and the green development efficiency will exhibit a random spatial distribution.

(2) Local spatial autocorrelation

The global Moran's *I* value reveals the overall spatial associations but does not illustrate the spatial association of individual units. To address this issue, we applied local spatial autocorrelation to conduct a disaggregated analysis of green development efficiency. The Moran's *I* scatter plot and the LISA cluster plot were combined to reveal the spatial heterogeneity of the study area (Long et al., 2016). The Equation (5) can be expressed for calculating the local spatial autocorrelation.

$$I_i = Z_i \sum_j W_{ij} Z_j \tag{5}$$

where Z_i, Z_j are the standardized values of green development efficiency of counties *i* and *j*, and W_{ij} is the spatial weight. If the *I*–value is positive, it indicates that there is a positive local spatial autocorrelation. If the *I*–value is negative, it indicates that there is a negative local spatial autocorrelation. In addition, we can find the spatial correlation characteristics based on the value of Z_i and $\sum_j W_{ij} Z_j$.

2.2.3 Geographically weighted regression model

The GWR model puts the spatial location of the observed sample into a parametric equation, which shows both the spatial interdependence and the spatial heterogeneity of the observed variables (Anselin, 1999; Hu et al., 2012; Xiao and Yi, 2014; Xu and Lin, 2017). Therefore, we used the GWR model to explore the factors that influence green development efficiency. The calculation formula can be expressed as follows (Fang et al., 2015; Hu et al., 2016):

$$Y_i = \beta_0(u_i, v_i) + \sum_{k=1}^{p} \beta_k(u_i, v_i) x_{ik} + \varepsilon \tag{6}$$

where Y_i represents the green development efficiency of the industrial system and (u_i, v_i) indicates the latitude and longitude of the *i*th point in space. $\beta_k(u_i, v_i)$ denotes the *k*th regression parameter at the *i*th sampling point. ε is the random error.

The analysis steps used in the study were as follows:

(1) We examined the differences in green development efficiency among all spatial units in the Xuzhou Metropolitan Area to eliminate any instability in the spatial data.

(2) We clarified whether the kernel function was an adaptive type, in the case of GWR analysis, since this is the key to establishing the kernel function to determine the optimal bandwidth.

(3) We determined the kernel function with the use of the Akaike Information Criterion (AIC).

(4) We constructed a GWR model of the green development efficiency of the Xuzhou Metropolitan Area's industrial system and conducted an empirical simulation analysis.

2.3 Data source and indicator selection

2.3.1 Data source

The research period was from 2000 to 2015. The unit of research was at the county level (including county, county-level city, and the urban area of prefecture-city), and 41 counties were selected. All the primary data in the study came from the 2001–2016 statistical yearbooks of the various cities for the Xuzhou Metropolitan Area and from the *Jiangsu Statistical Yearbook* (NBSC, 2000–2016), the *Anhui Statistical Yearbook* (NBSC, 2000–2016), the *Shandong Statistical Yearbook* (NBSC, 2000–2016), the *Henan Statistical Yearbook* (NBSC, 2000–2016), the *China Statistical Yearbook* (NBSC, 2000–2016), and the *China City Statistical Yearbook* (NBSC, 2000–2016).

2.3.2 Input-output indicator selection

Based on available data and previous studies (Yang et al., 2014; Di and Meng, 2017), the fixed assets investment, the number of whole society employees, and the total energy consumption were selected as input indicators from the capital, labor, and resources aspect. These indicators can reflect the capital input, the labor input, and the consumption of resources in the process of green development. The output indicators included desirable and non-desirable output indicators. The regional GDP was selected as a desirable output indicator, and industrial SO_2 emissions was selected as a non-desirable output indicator.

2.3.3 Selection of influencing factors

Indicators such as population, economy, energy, and industry were selected as influencing factors in an attempt to identify the main reasons for the spatial differences of green development efficiency. Considering the collinearity test of the GWR model, only five influencing factors, namely the economic level, the industrial structure, energy consumption, government regulation, and innovation were re-defined as independent variables, and the index of green development efficiency was defined as the dependent variable. According to the Environmental Kuznets Curve (EKC) theory, environmental quality improves simultaneously with growing economic development. Therefore, *the per capita GDP* (yuan/person) was selected to represent the level of economic activity. Thus, the ratio of the tertiary industry's output value to GDP (%) was selected to represent industrial structure. There is a close relationship between energy consumption and the ecological environment, so per capita energy consumption (tce/person) was selected to reflect the energy efficiency. Government regulation is considered as an effective environmental protection measure, so the per capita local fiscal expenditure (yuan/person) was selected to reflect the effectiveness of government regulations in protecting the environment. Innovation is considered as a driver of green energy technology, so the per capita technology expenditure (yuan/person) was selected to represent innovation as a driver of green energy technology.

3 Results

3.1 Spatial-temporal heterogeneity of green development efficiency

3.1.1 Overall difference characteristics

Overall, the green development efficiency of the Xuzhou Metropolitan Area fluctuated, declining from 0.75 to 0.65, with an annual average growth rate of –0.95% over the period 2000–2015 (Fig. 2). The green development efficiency index can be divided roughly into four stages. A gradual ascent (2000–2003): the index increased from 0.75 to 0.79 and with an average annual growth rate of 1.75%. An annual decline (2003–2006): the index decreased from 0.79 to 0.58, with an average annual growth rate of –9.79%. A fluctuating rising stage (2006–2011): the index rose from 0.58 to 0.85, with an average annual growth rate of 7.94%. A rapid decline (2011–2015): the index dropped from 0.85 to 0.65, with an average annual growth rate of –6.49%. During the same period, the standard deviation for the green economic efficiency decreased from 0.371 to 0.284, and the coefficient of variation decreased from 0.496 to 0.436, indicating that the absolute and relative differences in green development efficiency for the Xuzhou Metropolitan Area were in decline. The Moran's *I* index decreased from 0.207 to 0.024, indicating that the spatial agglomeration of green economic efficiency in the Xuzhou Metropolitan Area had become homogenized (Fig. 3).

3.1.2 Characteristics of inter-region and intra-region differences

Basing our methodology on the decomposable characteristics of the Theil index, the differences in green development efficiency in the Xuzhou Metropolitan Area

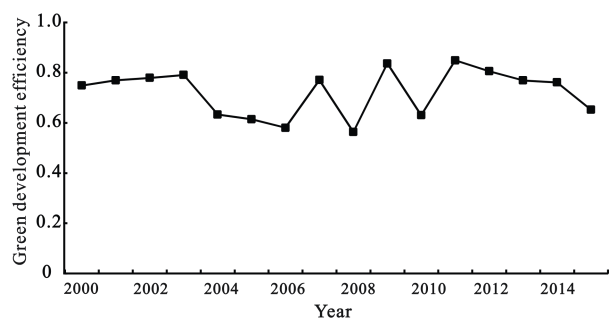

Fig. 2 Evolution of the green development efficiency index for the Xuzhou Metropolitan Area from 2000 to 2015

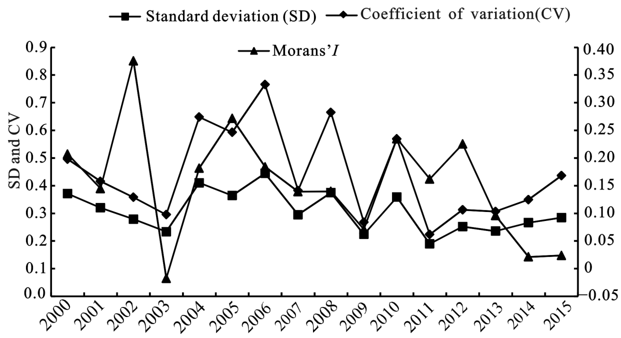

Fig. 3 Regional differences of green development efficiency for the Xuzhou Metropolitan Area from 2000 to 2015

(including Northern Jiangsu, Southern Shandong, Northern Anhui, Eastern Henan, and Northern Jiangsu) were divided into inter-region differences/variations, and intra-region differences/variations, in order to analyze the influences of each region. Specifically, the average values of the Theil index for the four regions were 0.0495, 0.0268, 0.0243, and 0.0120, respectively, indicating that the intra-regional differences in Northern Jiangsu were highest, followed by Southern Shandong, Northern Anhui, and Eastern Henan (Table 1). For the time series, the volatility trend in Northern Jiangsu was relatively obvious, and intra-regional differences in Southern Shandong, Northern Anhui, and Eastern Henan decreased and then increased, indicating a distinct trend in green development efficiency in the four regions of the Xuzhou Metropolitan Area. With regard to inter-regional differences, the average value of the Theil index for the four regions was 0.0281 (2001–2015), and the contribution rate of the overall difference of the metropolitan area was 16.87%. This was far less than the contribution of intra-regional differences (83.13%) to the overall difference. Thus, it can be inferred that the intra-regional differences were the main contributors to the overall difference of the green development efficiency of the industrial system in the Xuzhou Metropolitan Area.

3.1.3 Characteristics of spatial evolution

In 2015, there were 24 counties, accounting for 58.5% of the total number of counties (Fig. 4), that had a green development efficiency level that was lower than the average value, indicating that only a few counties in the Xuzhou Metropolitan Area had achieved a high level of green development efficiency. Thus, it can be inferred that green development efficiency in the Xuzhou Metropolitan Area had large spatial differences in 2015, and that the green development efficiency exhibited features characteristic of a multi-scale pattern.

Table 1 Decomposition of green development efficiency inequalities from 2000 to 2015

Year	Intra-region								Inter-region	
	Northern Jiangsu		Southern Shandong		Northern Anhui		Eastern Henan			
	Theil index	Contribution rate (%)	Theil index	Contribution rate (%)	Theil index	Contribution rate (%)	Theil index	Contribution rate (%)	Theil index	Contribution rate (%)
2000	0.0020	1.20	0.0377	22.38	0.0359	21.30	0.0204	12.08	0.0726	43.04
2001	0.0559	50.14	0.0023	2.03	0.0326	29.29	0.0087	7.83	0.0119	10.71
2002	0.0088	11.38	0.0126	16.19	0.0241	31.00	0.0239	30.76	0.0083	10.67
2003	0.0248	51.94	0.0045	9.43	0.0054	11.26	0.0072	15.04	0.0059	12.33
2004	0.1045	40.82	0.0612	23.91	0.0331	12.94	0.0001	0.04	0.0571	22.29
2005	0.0814	40.19	0.0624	30.80	0.0223	11.02	0.0091	4.52	0.0273	13.47
2006	0.1874	49.20	0.1003	26.35	0.1040	2.74	0.0377	9.90	0.0450	11.81
2007	0.0508	58.49	0.0029	3.31	0.0129	14.84	0.0026	3.00	0.0177	20.36
2008	0.0892	36.86	0.0572	23.64	0.0284	11.74	0.0001	0.04	0.0671	27.72
2009	0.0263	64.13	0.0023	5.72	0.0028	6.70	0.0045	10.87	0.0052	12.58
2010	0.0666	35.51	0.0241	12.86	0.0295	15.74	0.0172	9.19	0.0501	26.70
2011	0.0147	53.45	0.0053	19.13	0.0047	17.07	0.0011	4.00	0.0017	6.35
2012	0.0159	25.43	0.0048	7.65	0.0060	9.59	0.0216	34.63	0.0142	22.70
2013	0.0205	39.64	0.0077	14.91	0.0128	24.78	0.0056	10.86	0.0051	9.81
2014	0.0160	23.67	0.0131	19.47	0.0165	24.46	0.0134	19.85	0.0085	12.55
2015	0.0270	27.05	0.0297	29.68	0.0170	17.04	0.0194	19.45	0.0068	6.78

In 2000, 29 counties in the Xuzhou Metropolitan Area achieved a high level of green development efficiency. Most of these counties were distributed along the coast, and along the routes of the Beijing-Shanghai and the Eastern Longhai railways. 20 conties in 2005 and 21 counties in 2010, achieved a high level of green development efficiency respectively. In 2015, the counties with a high level of green development efficiency expanded along both sides of the Beijing-Shanghai railway. Many of these counties are located in counties of the Xuzhou and the Jining urban areas where pockets of high-level green development efficiency were concentrated. During the same period, the number of counties with a high level of green development efficiency increased from 10 in 2000 to 15 in 2010, and then decreased to 9 in 2015. The distribution of the counties having areas with a low level of green development efficiency spread from Eastern Henan, Northern Anhui, and Southern Shandong to Northern Anhui and Northern Jiangsu. By 2015, nine counties with a low level of green development efficiency were distributed in the periphery of the Xuzhou Metropolitan Area, indicating that counties with areas of low-level green development were shrinking.

Concerning the scale of provincial boundaries, from 2000 to 2015, the average value of green development efficiency in Northern Jiangsu, Southern Shandong, Northern Anhui, and Eastern Henan evolved from 0.94, 0.76, 0.21 and 0.83 to 0.74, 0.56, 0.68, and 0.60, respectively. A corridor of counties with high efficiency developed in the border areas of Jiangsu and Anhui as well as in Henan and Anhui. This development can be ascribed to the relatively low industrialization of border areas, which produce relatively low levels of air and water pollution. Concerning the aspect of urban and rural scales, the average value of green development efficiency in the urban areas of the Xuzhou Metropolitan Area was 0.68, and the average value in the peripheral counties was 0.65, indicating that green development efficiency in the Xuzhou Metropolitan Area was characterized by a high-centered and low-peripheral pattern. Broadly speaking, the regions with high green development efficiency were laid out on an extended axis along specific corridors. That is, the distribution of the counties with high-efficiency green development spread along the coast and along the routes of the Beijing-Shanghai and the Eastern Longhai railways.

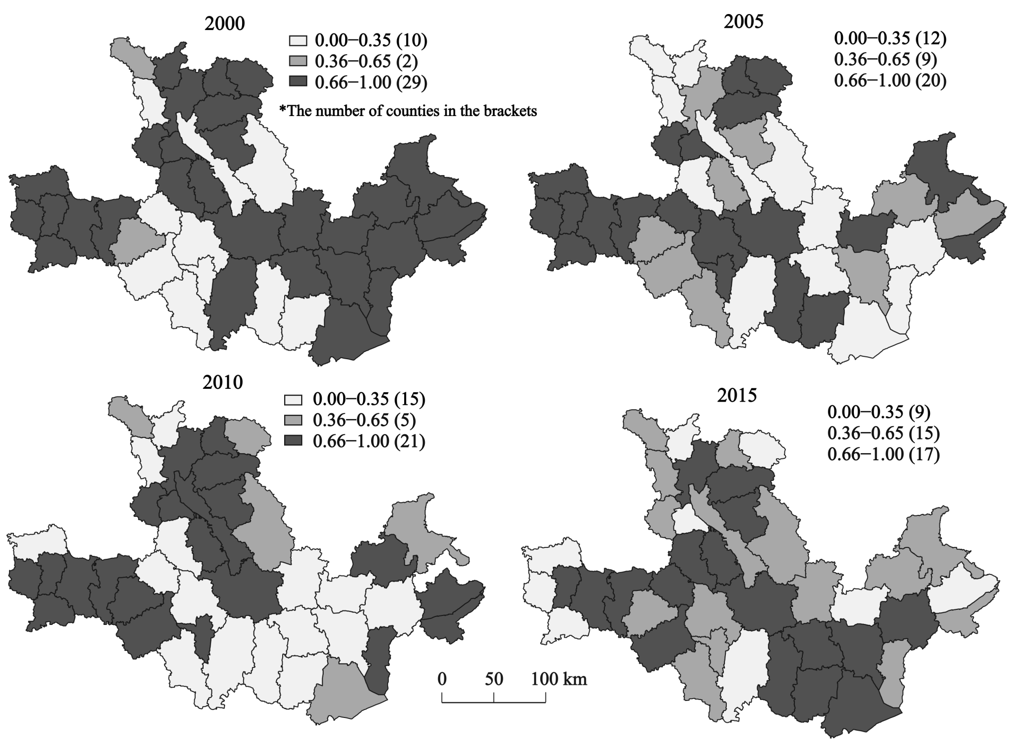

Fig. 4 Spatial distribution patterns of green development efficiency from 2000 to 2015

3.1.4 Characteristics of spatial correlation

To identify the spatial correlation characteristics of green development efficiency in the industrial system of the Xuzhou Metropolitan Area, GeoDa software was used to calculate the local spatial autocorrelation coefficient for green development efficiency during 2000–2015. The counties were divided into four categories as follows (Fig. 5):

High-High (H-H) type. In 2000, 17 counties were of the H-H type, of which eight were in Northern Jiangsu, four in Southern Shandong, and five in Eastern Henan. The locations indicated the characteristic of a three-pillar spatial pattern found in Shangqiu, Lianyungang, and Jining. In 2015, the number of H-H type counties was 13. These types of counties were concentrated mainly in the provincial boundary areas of Jiangsu and Anhui, and Henan and Anhui. High-Low (H-L) type. In 2000, there were 11 H-L type counties, including five each in Northern Jiangsu and Southern Shandong, and one in Northern Anhui. In 2015, there were only four H-L type counties in the study area. Low-High (L-H) type. In 2000, there were four L-H type counties located in the urban areas of Zaozhuang, Jiaxiang, Liangshan, and Weishan. In 2015, the number of L-H type counties increased to 16; these were distributed along the periphery of the H-H-type counties and concentrated around the urban areas of Xuzhou and Suqian. Low-low (L-L) type. In 2015, there were eight L-L type counties. In 2000, there were nine. The pattern of the L-L type counties changed from agglomeration to dispersion with a distribution in the northeast and south of the Xuzhou Metropolitan Area.

Overall, since 2000, the spatial correlation of the green development efficiency of the industrial system in Xuzhou Metropolitan Area showed that the H-H type counties changed from a three-pillar pattern to a concentrated pattern in the border areas of Jiangsu and Anhui, and Henan and Anhui. The L-L type counties remained concentrated in the areas of Eastern Henan and Northern Anhui. These results indicated that the differences in green development efficiency between the northern and southern areas in the Xuzhou Metropolitan Area were the key features.

3.2 Factors Influencing Green Development Efficiency

3.2.1 Model test

The results of the tests using GWR4.0 software are shown in Table 2. The results indicate that the determinants of coefficient R^2 increased and then decreased from 2000 to 2015. The local R^2 values were 0.2098–0.3251, 0.1589–0.3867, and 0.1379–0.3012 in 2000, 2008, and 2015, respectively, indicating an increased explanatory power of the GWR model.

The results, obtained by calculating the average regression coefficient for the different factors (Table 3), show that innovation had the strongest effect on green economic efficiency, followed by government regulations, economic level, energy consumption, and industrial structure. Concerning the time series, the influence of the level of economic development, government regulations, and innovation on green development efficiency were weak; the influence of energy consumption increased, then decreased; and the influence of industrial structure decreased, then increased. It may be inferred that the 11th Five-Year Plan facilitated a rapid development of the industrial system, so that traditional industries with high energy consumption and pollution levels were responsible for the low efficiency of green development. During the 12th Five-Year Plan phase, a

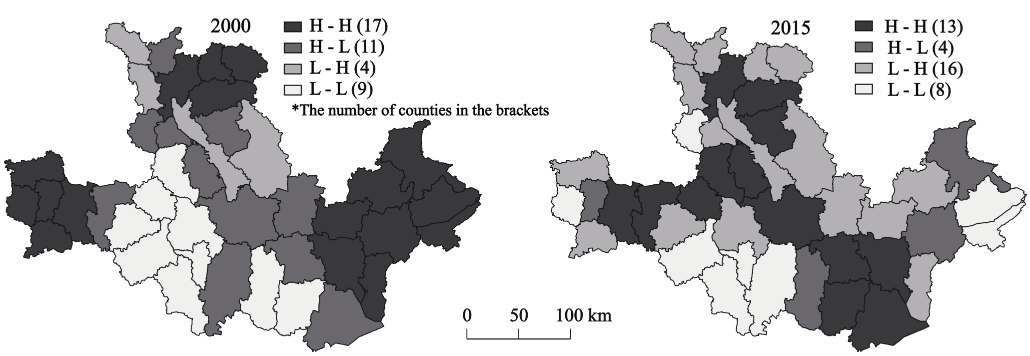

Fig. 5 Spatial correlation types of green development efficiency from 2000 to 2015

Table 2 Estimation results for geographically weighted regression

Indicator	2000	2008	2015
Local R^2	0.2098–0.3251	0.1589–0.3867	0.1379–0.3012
Sigma	0.3621	0.3526	0.2777
R^2	0.2978	0.3359	0.2883
Adjusted R^2	0.0699	0.1355	0.0695
AICc	48.2998	45.5308	25.9569

Table 3 Average regression coefficient for the different influencing factors

Year	Economic development level	Industrial structure	Energy consumption	Government regulations	Innovation
2000	0.000039	–0.118647	–0.023717	0.000230	0.027268
2008	0.000010	–0.142544	0.004462	0.000090	0.003891
2015	0.000008	0.280492	–0.003391	0.000013	0.000461

series of industrial reforms such as the upgrading of traditional production technology and industrial equipment and the transformation of the industrial structure had a positive effect on green development efficiency in the Xuzhou Metropolitan Area.

3.2.2 Main influential factors

Concerning the level of economic activity (Fig. 6), the effect of economic activity on the green development efficiency in the industrial system had regional differences during the period 2000–2015. In 2000, economic activity had a positive effect on the green development efficiency of four urban counties—Suqian, Wenshang, Peixian, and Yucheng; the level of economic activity did not have a positive effect on 14 counties—Liangshan, Jiaxiang, and 12 other counties which were in the central part of the Xuzhou Metropolitan Area. The regression coefficient for the level of economic activity and green development efficiency in the Xuzhou Metropolitan Area decreased in 2008 and 2015. In general, the influence of the level of economic activity on green development efficiency was larger in the peripheral regions than that in the interior regions. It could be inferred that the greater emphasis of modern manufacturing and services in the center of the Xuzhou Metropolitan Area was the reason that the efficiency level of green development was relatively low in these interior regions. In the peripheral eastern and western regions of the Xuzhou Metropolitan Area, economic development remained slow, which could explain why the environmental impact of economic development was relatively high.

Concerning industrial structure (Fig. 7), in 2000 industrial structure had a positive effect on the green development efficiency of five urban area counties—Xuzhou, Suzhou, Shangqiu, Peixian, and Tengzhou—and a negative effect on the green development efficiency of 10 counties—Zaozhuang, Huaibei, Sixian, Jiaxing, Xiaoxian, Weishan, Dangshan, Suixi, Yongcheng, and Lingbi—that were distributed in Southern Shandong and Northern Anhui. Overall, the effect of industrial structure showed a core-edge type pattern with a high value area centered in the urban area of Xuzhou and a low value area located near the periphery of the counties. The regression coefficient for industrial structure and green development efficiency increased in 2015 and showed a corridor-type pattern in which high value areas were distributed along the border areas of Jiangsu and Anhui, and Henan and Anhui.

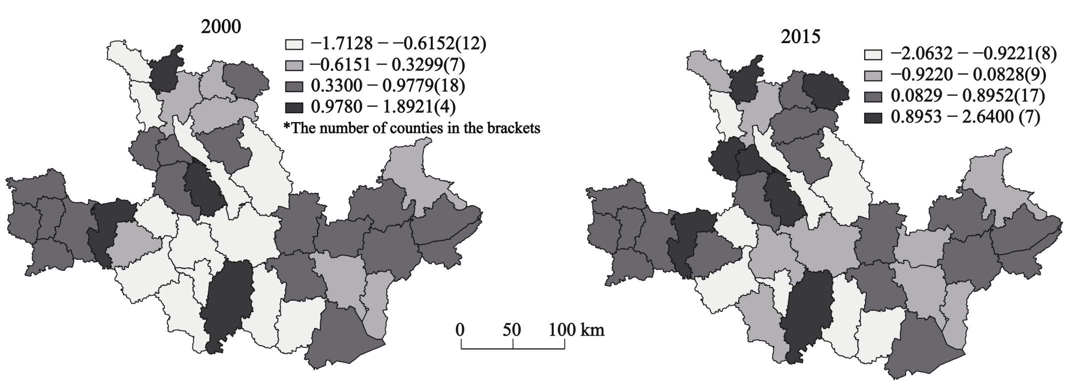

Fig. 6 Regression coefficients for the level of economic activity

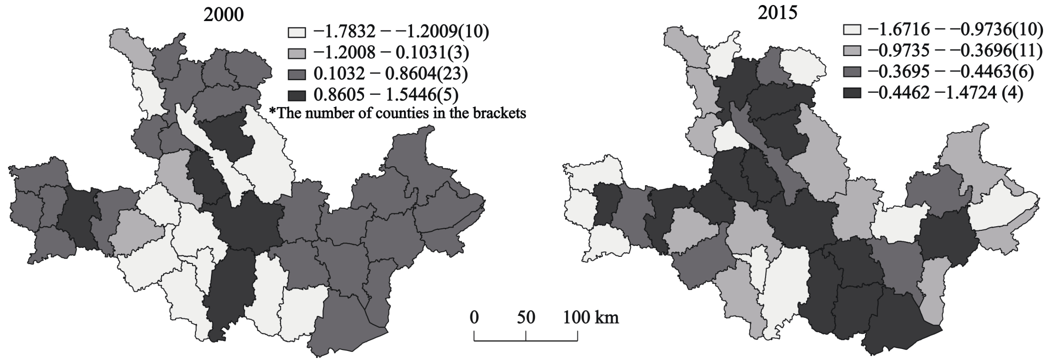

Fig. 7 Regression coefficients for industrial structure

Concerning energy (Fig. 8), in 2000 the energy consumption for 12 counties exerted strong effect on green development efficiency in urban areas of Xuzhou, Suzhou, and Lianyungang. It revealed a spatial distribution pattern of one belt and three cores, of which one belt was centered on the area along Xuzhou and Jining, and where the three cores referred to the urban areas of Lianyungang, Shangqiu, and Suzhou. There were 10 counties where the energy consumption was relatively unaffected, these being the urban areas of Zaozhuang, Huaibei, Jiaxiang, Yongcheng, Weishan, Dangshan, Suixi, Xiaoxian, Lingbi, and Sixian, the cities being distributed in the south and north of the Xuzhou Metropolitan Area. In 2015, the counties where energy consumption exerted a strong effect on green development efficiency showed a ribbon-type corridor pattern which was concentrated on the border of Henan and Anhui, and Jiangsu and Anhui. It can be concluded that energy consumption was the main contributor to improving the green development efficiency. Hence, reducing energy consumption is a key to improving the green development efficiency of the regional economy in provincial border areas.

From the perspective of government regulations (Fig. 9), the counties where government regulations had

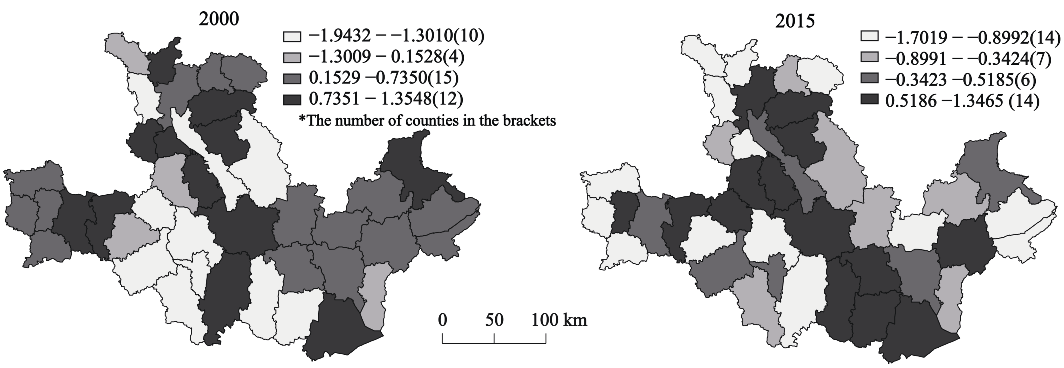

Fig. 8 Regression coefficients for energy consumption

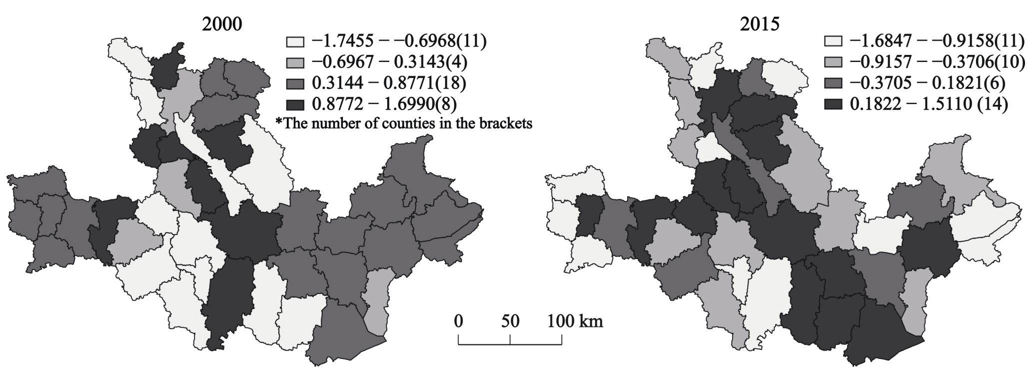

Fig. 9 Regression coefficients for government regulations

strong effect on the green development efficiency, a dual-core pattern was the main feature, the pattern being concentrated in the urban areas of Xuzhou and Yucheng. This pattern indicated that the government's fiscal expenditure in Northern Jiangsu and Eastern Henan had a strong impact on green development efficiency, while a relatively low fiscal expenditure in Northern Anhui and Southern Shandong (Zoucheng only accounted for 8.03% of the GDP), had minimal impact on the promotion of green development efficiency. In 2015, the counties in which government regulations had a strong influence on green development efficiency, were distributed mainly along the urban areas of Jining, the urban areas of Jining Xuzhou and Sihong; beyond these zones a declining trend was observed.

Concerning innovation (Fig. 10), in 2000 there were eight counties, including the urban areas of Suzhou, Minquan, Zhecheng, and Yucheng where innovation had a strong impact on green development efficiency. In 2015, the counties with high regression coefficients formed a three cores pattern centering on Zoucheng, Sixian, and Yucheng; the counties with low regression coefficients were distributed in the central and eastern regions of the Xuzhou Metropolitan Area. Overall, innovation had a higher effect on green development efficiency in the urban area of Xuzhou and its surrounding counties, which form the core areas of the Xuzhou Metropolitan Area. This may have been because many colleges, universities, and research institutions are present in these areas. Therefore, an acceleration of technology transfer into manufacturing and commercial activities should play a strategic role in improving green development efficiency.

4 Conclusions and Recommendations

4.1 Conclusions

(1) For the Xuzhou Metropolitan Area, over the period 2000–2015, regional differences in green development efficiency shrank, with a relatively low and weakening spatial agglomeration. Intra-regional differences were the major contributors to spatial heterogeneity, indicating that significant differences in green development efficiency existed at the county level. Due to the rapid urbanization and industrialization of growing metropolitan areas, the level of green development efficiency varied significantly within the counties. Therefore, local conditions should serve as a key guideline when planning for green development transformation.

(2) The green development efficiency in the Xuzhou Metropolitan Area exhibited characteristics of a multiscale pattern. Considering the overall metropolitan scale, green development efficiency was relatively low, but counties with high green development efficiency began to form along specific corridors. At the provincial boundary scale, economically developed areas like Northern Jiangsu, Northern Anhui, East Henan, and South Shandong had the highest level of green development efficiency. This indicated that a high level of economic development in growing metropolitan areas was usually accompanied by a high level of green development efficiency. Growing metropolitan areas also exhibited consistent distribution characteristics.

(3) There was a trend for counties with high levels of green development efficiency to be distributed along the coast, and along the routes of the Beijing-Shanghai and the Eastern Longhai railways. The distribution of

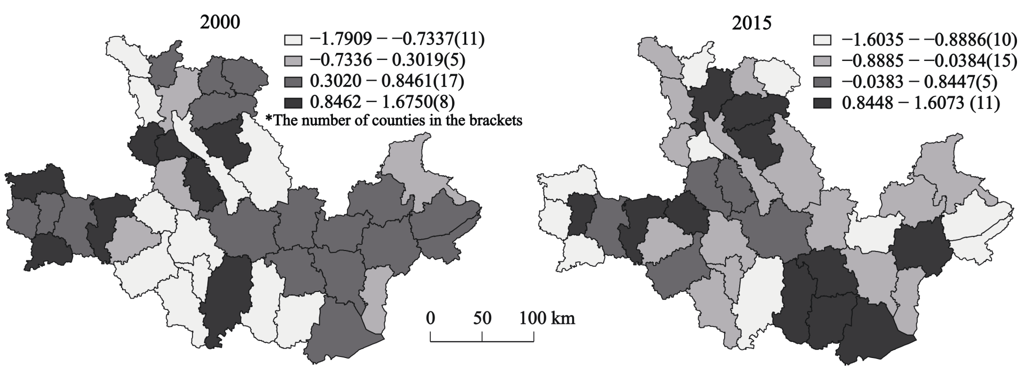

Fig. 10 Regression coefficients for innovation

counties with low levels of green development efficiency evolved from an agglomeration-type pattern to a decentralized one. Therefore, it can be inferred that the Xuzhou Metropolitan Area is located at the center of a point-axis and the expansion of this axis has been shaped with a high level of green development efficiency.

(4) The analysis concerning spatial autocorrelation showed that the H-H type counties were distributed along the provincial boundary areas of Jiangsu and Anhui, and Henan and Anhui. The number of H-L type counties showed a decreasing trend, with a diverging spatial distribution. The L-L type counties were transformed from agglomeration to dispersion and were distributed in the northeast and south of the Xuzhou Metropolitan Area. The number of L-H type counties increased rapidly and were distributed in the periphery of the H-H type counties, forming a concentration of L-H counties around the urban areas of Xuzhou and Suqian. These findings indicated that the north-south differences were representative of the spatial differences in green development efficiency in the Xuzhou Metropolitan Area. Of note was that the border areas of Jiangsu and Anhui, and Henan and Anhui had a high level of green development efficiency but low levels of economic development. This problematic paradox will require the attention of the relevant government departments.

(5) In the Xuzhou Metropolitan Area, innovation had the strongest impact on green development efficiency, followed by government regulations, the level of economic development, energy consumption, and industrial structure. However, the influence of all these factors showed a decreasing trend. The influence of the level of economic development on green development efficiency was larger in the peripheral regions than that in the interior regions. The counties whose green development efficiency was positively affected by industrial structure and energy consumption showed a ribbon-type corridor pattern that was concentrated on the borders of Henan and Anhui, and Jiangsu and Anhui, and then became dispersed towards the outer edges of the borders. The counties whose green development efficiency was positively affected by government regulations were located in a ribbon corridor pattern along the urban areas of Jining, Jining Xuzhou, and Sihong. The counties with high regression coefficients for innovation formed three-core patterns which were centered on Zoucheng, Sixian, and Yucheng.

To sum up, the influence of different factors on green development efficiency had varying effect on the growth of the Xuzhou Metropolitan Area. Additionally, the effect of the same factor (e.g., the level of economic development) did not always have the same effect in all the counties and clear spatial differences were exhibited.

4.2 Recommendations

Based on the above conclusions, several recommendations are proposed to help promote the green development efficiency of the industrial system in the Xuzhou Metropolitan Area. First, guided by the concept of green development, the construction of metropolitan areas should focus on resource sharing, transportation intercommunication, and information interconnection to build a regional, green development network system. Second, a center of green energy technology and an R&D infrastructure system should be established to enhance the technological innovation capability of green development, create innovative service exchange platforms, and introduce and encourage innovative green energy technology solutions. Finally, green development strategies should be adapted to local conditions to promote regional green development. For areas with high levels of green development efficiency, green industries should be established. Further, strengthening of the harmonious development of green industries and green services should be encouraged. For the areas with a medium level of green development efficiency, government should construct industrial and high-tech parks to extend the green industry chain and promote green industry agglomeration. For areas with low levels of green development efficiency, labor-intensive industries and resource-processing industries should be encouraged to use green development strategies that will rapidly transform traditional industries into green industries and to establish low pollution and low-consumption green industrial systems.

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