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The Administrative Center or Economic Center: Which Dominates the Regional Green Development Pattern? A Case Study of Shandong Peninsula Urban Agglomeration, China

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Abstract: Central cities play a critical role as beneficial areas for regional development and lead the high-quality development of an entire region and surrounding cities. As social and economic activities expand, the regional development pattern becomes more complex. This is typically manifested in the separation of administrative and economic centers. In this context, there is high research value in identifying the roles of different types of central cities in the regional green development pattern. This paper analyzes the urban linkage pattern and evolving characteristics of green development in the Shandong Peninsula, China, from 2016 to 2020. The study adopts the methods of bootstrap data development analysis, modified gravity model, and social network analysis. The results show the following. (1) Both the administrative center and economic center have positive driving effects on the spatial connection of surrounding cities in the urban agglomeration. There is a multi-point, multi-core, and multi-path spatial correlation in the Shandong Peninsula urban agglomeration. (2) The joint strength of the administrative center is higher compared to the economic center, and most of the green development partnerships are centered on the provincial capital. (3) The gravitational force of cities close to the administrative center is generally higher than seen with the economic center cities, but there is a gradual emergence of a substantial gravitational effect of the economic center.

Keywords: green development, urban linkage, city interaction, spatial pattern

1. Introduction

Economic development is an eternal theme in regional development and has evolved into green development as sustainability has spread worldwide. In this context, resource and environmental problems are considered the cost of economic growth, reflecting a consideration of the balance between economic growth and the environment. China has defined green, low-carbon development and efficient resource use as critical tasks in strengthening ecological progress and encouraging green and high-quality development. China has deployed a series of solutions since the proposal of green development. For example, it launched policies, such as the *Green Development Index System*; *Guiding Opinions on Accelerating the Establishment and Improvement of a Green, Low-Carbon, and Circular Development Economic System*; and *Opinions on Carbon Peak and Carbon Neutralization based on the New Development Concept*. China has also implemented green city pilot projects, achieving signs of progress. In 2021, China's carbon dioxide (CO_2) emissions per unit of gross domestic product (GDP) decreased by 52.2% compared with 2005. For the first time in Olympic history, all venues in the 2022 Beijing Winter Olympics are powered by 100% green electricity.

As a core force of regional development, central cities tend to have a strong attraction and driving effect on surrounding cities in regional development (Huang et al., 2020; Yue et al., 2010). The administrative centers and the economic centers are two typical examples of these cities. However, the separation of administrative centers and economic centers is a common occurrence among global powers during regional development. For example, Washington D.C. and New York in the United States, Toronto and Ottawa in Canada, and New Delhi and Mumbai in India are all typical cases where the administrative and economic centers are in different cities. China has a vast land area and complex administrative regions. Different regions have different development states and methods, with examples of separations of administrative centers and economic centers. For example, Shanghai's economic aggregate and total fiscal revenue are higher than in Beijing, which is the capital of China.

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This separation has occurred in China's top three provinces with respect to GDP. In 2022, Guangdong Province was the province with the largest GDP; Guangzhou is its administrative center, while Shenzhen is the city with the largest economic aggregate. Jiangsu Province has the second largest GDP, and its administrative center and economic center are Nanjing and Suzhou, respectively. Shandong Province has the third largest GDP, with its administrative center in Jinan and the economic center in Qingdao. In these three provinces, the administrative centers' GDP ranks second in the province, while the higher economic aggregates are reported for other cities.

Green development is an important topic with practical applications and is also a topic of significant academic research. Methods for measuring green development level can be divided into the index evaluation method and efficiency evaluation method. The index evaluation method involves either a single index, such as the pollutant discharge per unit of regional GDP, or a multi-index evaluation method, based on creating a green development index system. This index approach has been widely used due to its simple operation and comprehensive coverage (Zhang et al., 2022). As research has deepened, the efficiency evaluation represented by data envelopment analysis (DEA) began to emerge. This method overcomes the problem inherent in the index evaluation method, which only reflects the status of the evaluated object. Calculation results based on multiple inputs and outputs are more aligned with actual production processes. Consistent with actual production processes, the DEA method is a mainstream method for evaluating the green development level. Scholars have used this method to measure and conduct spatial pattern analyses of green development levels at different geographical scales, such as countries, provinces (autonomous regions, municipalities), and cities (Huang & Hua 2019; Moutinho et al., 2017).

Many studies have focused on urban agglomerations when researching the green development level of multi-sample cities (Jiang et al., 2022). Studies begin by measuring and calculating the green development level and conduct an analyses from the perspectives of the factors driving green development and the dynamic relationship with economic growth. Analyzing regional differences in green development from a spatial perspective helps support precise, location-based policy implementation. Therefore, studies on the green development have also integrated spatial analyses. Many studies have researched polycentric cities and their role in regional development. Depending on a regional scope, the regional center corresponds to different levels of administrative regions (Liu & Wang, 2016). For example, in micro-city-scale studies, regional centers are often central business districts and residential districts. In meso-megaregion-scale studies, regional centers are often cities, and in macro-national-scale studies, they are often the province (Feng et al., 2018). Measuring the attraction of the regional center to the surrounding area is a key point when studying a central city and its role in regional development. Studies measure regional centrality using the following methods: threshold measurement (Hajrasouliha & Hamidi, 2017), rank-size regression line (Burger et al., 2014; Vasanen, 2013), and the degree of deviation from monocentric status (Green, 2007; Wen & Thill 2016).

Determining the connection strength between regions is key to analyzing their spatial correlations. With increased research and as the complexity of regional centers has increased, studies have introduced the gravity model and centrality indices in this research field, such as degree centrality and betweenness centrality. These have been applied to analyze such topics as city-scale levels, the intensity of economic relationships, and the strength of economic relationships (Jiao et al., 2017; Shi et al., 2021; Wang et al., 2019; Ye & Qian, 2021). In this field, the city network concept provides a new way of understanding the division of labor between cities (Taylor et al., 2010). The spatial analysis provides a quantitative reference for encouraging coordinated development and optimizing spatial layout. Studies on the specific mode of function have found that the central city acts on its surrounding cities in different ways, mainly represented by key regional development factors, such as economy, infrastructure, population, and culture. These factors connect the surrounding cities together and promote regional economic development (Feng et al., 2018).

Studies have clarified the roles and functions of central cities in regional development by studying regional development centers from the perspectives of division, measurement, and mode of action. However, there is still room for further study. First, spatial analyses have mostly been conducted by analyzing overall patterns; more studies are needed to analyze the linkage effect of the cities, the spatial structure of the urban circle, and the leading role of the central city. Second, the nature of central cities needs further differentiation. Quantitative methods have been used to identify the central cities of regional development, but few studies have focused on different types of central cities, such as administrative centers and economic centers. Third, few studies have applied a time series analysis approach. Many studies have focused on interface analysis. This provides an opportunity to explore the status and evolution of roles with respect to central cities in regional development.

Given this background, this study takes the Shandong Peninsula urban agglomeration (SPUA) in China as a sample to examine the roles and changes in different types of central cities with respect to the regional economic green development of the regional economy from 2016 to 2020 (i.e., during China's "13th Five-Year Plan period"). This study evaluates the regional green development level, the role of different types of central cities, and urban linkage patterns during regional green development. The roles of different types of central cities in regional development are carefully evaluated, providing a reference for other large regions for enhancing the quality of green growth.

The rest of this paper is organized as follows. Section 2 provides an overview of the sample area. Section 3 presents the methods and datasets used in this study. Section 4 analyzes the spatial and temporal evolutionary process and its regional pattern; it also evaluates the administrative center and the changing role of the economic center during regional green development. Section 5 discusses the results and summarizes the conclusions.

2. Overview of the Study Area

The SPUA covers the entire area of Shandong Province (34°22.9'N-38°24.01'N, 114°47.5'E-122°42.3'E), a provincial-level administrative region in China. This province is located on the east coast of China and at the lower reaches of the Yellow River. The Shandong Peninsula protrudes into the Bohai Sea and the Yellow Sea and faces Japan and Korea to the east.

Shandong Province has a unique and crucial strategic position in China. The province is an important industrial base in China, with a solid foundation of 41 major industrial categories. The region is also the strategic fulcrum for economic development in northern China. The GDP of Shandong Province ranks third in the country and has ranked first in northern China for more than 30 years. As a traditional economic province, Shandong Province ranked first with respect to the country's economic aggregate in the 1980s; it was later passed by Jiangsu Province and Guangdong Province in the south. While there remains a large economic volume, Shandong Province faces large challenges in transforming and upgrading its economic mode of development.

Shandong Province has long planned its development around the concept of urban agglomeration, first formulating *The Overall Plan for the Shandong Peninsula Urban Agglomeration (2006–2020)* in 2006. In this plan, the SPUA consisted of eight prefecture-level cities: Jinan, Qingdao, Yantai, Zibo, Weihai, Weifang, Dongying, and Rizhao. Most of these cities are coastal and provincial capital cities. In 2021, Shandong Province issued *The Shandong Peninsula Urban Agglomeration Development Plan (2021–2035)*. This plan expanded the scale of the SPUA from the original 8 cities to all the 16[1] prefecture-level cities, reflecting the progress and optimization of spatial linkage development in the province. It is also the first urban agglomeration in China including all prefecture-level cities in a provincial administrative region.

In *The 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and the Outline of the Long-range Goals for 2035* (launched in 2021), the Chinese government proposed a development plan of 20 mega regions. This plan included 5 national-level mega regions needing optimization and improvement, 5 national secondary-level mega regions needing stronger growth and development, and 9 regional-level mega regions needing nurturing. Of these, the SPUA was ranked as the first mega region needing to be developed and strengthened. This highlighted its key role in leading the ecological protection and high-quality development of the Yellow River Basin and in building a strong ecological security barrier in the northern region. The level and quality of green development in the SPUA directly relate to the overall state of green, low-carbon, and high-quality development in northern China.

The green development level in Shandong Province has recently and significantly improved. The energy consumption per 10,000-yuan GDP decreased by 19.60% in 2016–2020. The PM2.5 concentration decreased by 37% and the number of days with good air quality increased by 14.2%[2]. In 2021, Qingdao was approved as the China's first "green city" pilot. The goal of a pilot city is to accelerate the exploration of new paths for urban green and high-quality development and eliminate the traditional development approaches of mass construction, mass consumption, and mass emissions.

The trend of separate administrative and economic centers emerged during the economic development of Shandong Province. According to the *Shandong Statistical Yearbook (2001–2022)*, the economic gap between the economic center Qingdao and the administrative center Jinan increased after 2000, from 24.99 billion yuan in 2000 to 270.42 billion yuan in 2021. In the past 20 years, the proportion of Qingdao's GDP as a part of Shandong's GDP increased from 13.69% to 17.01%; in contrast, Jinan's GDP accounted for only 11.09% to 13.76%, despite being merged with Laiwu, a traditional iron and steel city in 2019.

The SPUA has and continues to face challenges during its green development. Specifically, there is unbalanced and insufficient development, and the ability of the central city to drive its radiation needs to be increased. Therefore, using the SPUA as a case study to scientifically evaluate the green development level and the urban spatial linkage pattern and to further explore the role of different types of central cities is valuable for improving green development overall. This can serve as a useful example for similar regions seeking to invest in green development.

[1]According to *the Reply of the State Council Concerning the Approval of Shandong Province to Adjust the Administrative Division of Laiwu*, Laiwu was revoked on December 26, 2018. The area under its jurisdiction was placed under the jurisdiction of Jinan as Laiwu District and Gangcheng District. Therefore, in this study, the Laiwu city is incorporated into Jinan city during analysis.

[2]Data source: The People's Government of Shandong. http://www.shandong.gov.cn/art/2021/1/1/art_97564_392746.html

3. Methodologies and Datasets

3.1. Measurement model of green development level

As noted above, the efficiency evaluation method is commonly used when evaluating the green development level. Efficiency measures the relationship between input–output utilization in production or development, which is also an important indicator for measuring development quality (Sun et al., 2020). Formally proposed by Charnes et al. (1978), the DEA method is a non-parametric analysis method that measures the relative effectiveness of the production process of a set of decision-making units (DMUs) with multiple input–output indicators through a mathematical programming model. It has been widely used in efficiency performance evaluation in various fields such as industry, agriculture, banking, supply chain, transportation, education, public policy, and ecological environment.

When addressing undesirable outputs, the directional distance function (DDF) is frequently applied for measurement. However, DDF is mostly based on radial efficiency measurement, so the inputs and outputs must increase or decrease proportionally, and slacks are not considered. Consequently, this may overestimate the efficiency when there is excessive input or insufficient output (Cooper et al., 2007). In this case, the slacks-based measure model (SBM), considering relaxation variables, better measures the efficiency of DMUs, by eliminating the bias caused by radial efficiency measures.

For n DMUs in the SPUA, $DMU_j (j = 1, \ldots, n)$ uses m inputs $x_{ij} (i = 1, \ldots, m;\ j = 1, \ldots, n)$ to produce p desirable outputs $y_{rj} (r = 1, \ldots, p;\ j = 1, \ldots, n)$ and q undesirable outputs $u_{lj} (l = 1, \ldots, q;\ j = 1, \ldots, n)$. This set of DMUs constitutes a production possibility set (PPS) as $PPS = \{(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{u}) | \boldsymbol{x} \text{ can produce } (\boldsymbol{y}, \boldsymbol{u})\}$. The efficiency of $DMU_j (j = 1, \ldots, n)$ is then calculated as follows:

$$
\begin{aligned}
\theta_j^* = \min & \frac{1 - \frac{1}{m} \sum_{i=1}^{m} \frac{s_{ij}^x}{x_{ij}}}{1 + \frac{1}{p+q} \left(\sum_{r=1}^{p} \frac{s_{rj}^y}{y_{rj}} + \sum_{l=1}^{q} \frac{s_{lj}^u}{u_{lj}} \right)} \\
s.t. & \sum_{j=1}^{n} \lambda_j x_{ij} \le x_{ij} - s_{ij}^x,\ i = 1, \ldots, m \\
& \sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{rj} + s_{rj}^y,\ r = 1, \ldots, p \\
& \sum_{j=1}^{n} \lambda_j u_{lj} = u_{lj} - s_{lj}^u,\ l = 1, \ldots, q \\
& \sum_{j=1}^{n} \lambda_j = 1,\ \lambda_j \ge 0,\ j = 1, \ldots, n \\
& s_i^x,\ s_r^y,\ s_l^u \ge 0
\end{aligned}
\tag{1}
$$

where s_i^x, s_r^y, and s_l^u are the slacks variables corresponding to the inputs, desirable outputs, and undesirable outputs, respectively. The term λ_j is the intensity vector. Model (1) indicates that the efficiency value of $DMU_j (j = 1, \ldots, n)$ ranges from 0 to 1. A value of $\theta_j^* = 1$ means the green development process of $DMU_j (j = 1, \ldots, n)$ achieves efficiency. When $\theta_j^* < 1$, $DMU_j (j = 1, \ldots, n)$ needs to increase the quality of its green development.

Using multiple inputs and outputs, without a need for a function form are the two benefits of the approach in this paper; however, it may lead to evaluation bias compared with the parameter estimation method, because it does not involve a statistical test. To address this problem, this study adopts the bootstrap method to improve upon the results of green development efficiency measured using SBM-DEA, through a repeated sampling simulation data generation process.

For the SMB-efficiency values $\theta_j^*(j = 1, \ldots, n)$ of the n DMUs, the naive bootstrap samples $\theta_{jb}^*(j = 1, \ldots, n)$ are obtained using b random replacement sampling. Furthermore, smoothing the above samples enables smoothing the bootstrap samples $\hat{\theta}_{jb}^{*}(j = 1, \ldots, n)$. The smoothing bootstrap samples are used to adjust the original input sample $x_j(j = 1, \ldots, n)$ based on the principle of $x_{jb}^*(j = 1, \ldots, n)$. The bootstrap estimated efficiency values $\hat{\theta}_{jb}^{**}(j = 1, \ldots, n)$ are further assessed using adjusted sample data. Repeating the above steps for B times produces B estimated bootstrap efficiency values. The final corrected efficiency values are calculated using $\tilde{\theta}_j = 2\theta_j^* - \frac{1}{B}\sum_{b=1}^{B}\hat{\theta}_{jb}^{**}$. The bootstrap efficiency values range from [0, 2]. To maintain consistency with the range of SBM-efficiency values, the rectified efficiency values are divided by 2, so the final efficiency values $\tilde{\theta}_j$ range within [0, 1].

Based on previous studies (Jiang et al., 2022; Qin et al., 2017; Zhou et al., 2020) and policy documents, such as the *Green Development Index System of China* and the *Development Plan of Shandong Peninsula Urban Agglomeration*, this study constructs an indicator system to assess the efficiency (Table 1).

The data of the indicators are derived from the *Shandong Statistical Yearbook (2017–2021)* launched by the Shandong Provincial Bureau of Statistics. To eliminate the impact of price fluctuations, all the data of economic-related indicators are deflated based on the constant prices in 2016. Moreover, since Jinan acquired Laiwu in 2019, data for Laiwu in 2018 and before were merged into Jinan during the measurement.

3.2. Analysis model of urban association pattern

This study applies the gravity model to describe the strength of green development links among cities in the SPUA. The gravity model is a widely applied model to analyze and predict the spatial interaction of a certain area. The gravity model originates from the law of gravity, which states that the gravitational force between two objects is proportional to their respective masses and inversely proportional to their distance. Tinbergen (1963) and Pöyhönen (1963) first introduced this model into economic study.

The traditional gravity model uses the distance and quality (urban population or economic aggregate) between regions as the key indicators. It is expressed as follows:

$$F_{ij} = G\frac{P_iP_j}{r_{ij}^2} \tag{2}$$

where P is the city size measured by population or economic aggregate; r is the distance between two cities; and G is the empirical constant.

To more effectively analyze the degree of connection associated with urban green development, this study introduces the green development level to adjust the gravity model. Specifically, the attractiveness of urban green development in one area to urban green development in another is as follows:

$$F_{ij} = G\frac{P_iP_j}{r_{ij}^2},\ G = \frac{P_i}{P_i + P_j}, \tag{3}$$

where P_i and P_j are the green development levels of city i and city j, respectively.

3.3. Analysis model of urban network characteristics

Social network analysis is a method used to study the relationship between members of the network structure; it has been widely used in the fields of sociology, management, economics, and geography. The characteristics of the central cities in the green development network provide key data for this study. Therefore, the social network analysis method is used to analyze the characteristics of the associated network structure of green development in the SPUA, focusing on the network's overall and individual characteristics, and the roles and positions of different cities in the network. Based on previous studies (Wang et al., 2017; Restrepo et al., 2021), Table 2 shows the selected descriptive indicators and their representative meanings. All indicators are positive indicators except for the average shortest path and closeness centrality.

3.4. Data descriptive analysis

Before calculating the green development level, descriptive statistical analysis can help gain a comprehensive understanding of the overall status of the research objects. Furthermore, this analysis reveals the research objects' internal gaps, developmental advantages, and disadvantages. Here, five variables in data descriptive statistical analysis (i.e., mean, standard deviation, median, maximum value, and minimum value) are selected to analyze the characteristics of input and output indicators in the green development process of the SPUA (Table 3).

From 2016 to 2020, the capital stock, electricity consumption, and built-up area in the SPUA continued to grow (Figure 1).

Table 1
Indicator system of green development efficiency for the SPUA

Indicator type	Description dimension	Indicators	Unit
Input	Capital utilization	Capital stock	Trillion yuan
	Labor utilization	The number of employed persons	10 thousand people
	Resource utilization	The amount of electricity consumption	Trillion kilowatt hours (kwh)
	Space utilization	Built-up area	Square kilometer
Desirable output	Economic growth	Gross regional product	Trillion yuan
Undesirable output	Air pollution	The amount of SO_2 (Sulfur Dioxide) emissions	Million tons
	Water pollution	The amount of COD (Chemical Oxygen Demand) discharges	Million tons

Table 2
Indicators characterizing the green development network

	Indicators	Meaning
Overall spatial network structure characteristics	Network correlation	The degree of connection between nodes
	Network density	The closeness of connections between nodes
	Network efficiency	The cohesion of the entire network
Individual spatial network structure characteristics	Degree centrality	The number of other nodes directly connected to a node
	Closeness centrality	The sum of the shortest paths between a node and other nodes
	Betweenness centrality	The ability of a node to control the relationship between other point pairs

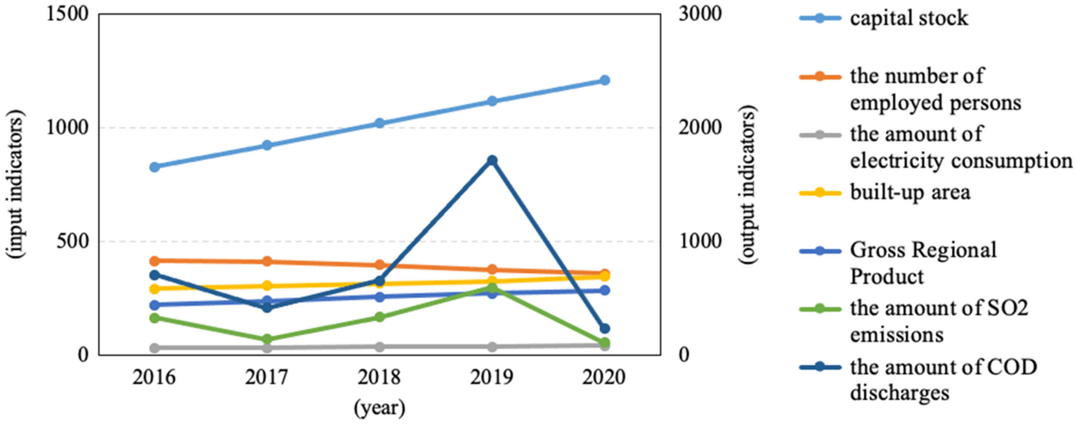
Table 3
Descriptive statistical analysis of the data

Year	Indicator	Mean	Std.	Median	Max	Min
2016	Capital stock	828.44	517.76	741.83	2136.44	205.88
	The number of employed persons	415.08	159.93	410.45	721.75	150.90
	The amount of electricity consumption	334.82	231.20	290.35	1126.20	108.70
	Built-up area	293.90	193.40	218.43	790.51	102.25
	Gross regional product	444.49	219.99	433.69	978.84	167.34
	The amount of SO_2 emissions	331.57	140.13	333.86	598.00	112.41
	The amount of COD discharges	709.08	417.79	657.18	1717.35	233.20
	Capital stock	924.02	576.74	826.81	2381.76	230.81
	The number of employed persons	412.83	157.27	411.95	705.55	146.90
	The amount of electricity consumption	338.14	214.65	279.34	1035.39	117.03
	Built-up area	305.22	197.68	246.14	833.66	105.40
	Gross regional product	478.66	237.62	467.49	1055.80	180.83
	The amount of SO_2 emissions	325.50	151.27	311.80	613.88	85.34
	The amount of COD discharges	461.95	218.54	452.67	977.36	155.41
	Capital stock	1021.02	637.37	912.71	2636.45	256.55
	The number of employed persons	398.16	155.57	392.32	673.65	137.90
	The amount of electricity consumption	368.34	225.84	308.14	1100.42	126.43
	Built-up area	316.74	197.49	253.36	791.23	108.90
	Gross regional product	513.60	254.95	504.87	1135.28	197.10
	The amount of SO_2 emissions	331.53	137.06	336.35	582.12	99.57
	The amount of COD discharges	384.35	177.27	377.79	795.09	131.61
	Capital stock	1115.88	698.15	996.20	2897.70	283.23
	The number of employed persons	377.62	154.29	361.25	647.90	131.30
	The amount of electricity consumption	387.11	242.09	319.06	1179.90	132.81
	Built-up area	326.78	207.18	259.63	908.23	113.20
	Gross regional product	545.84	274.56	539.66	1219.11	211.41
	The amount of SO_2 emissions	343.60	115.00	341.79	530.17	128.03
	The amount of COD discharges	229.16	97.71	215.41	430.55	84.01
	Capital stock	1208.31	757.61	1076.61	3151.99	309.21
	The number of employed persons	359.31	152.82	329.73	629.15	126.73
	The amount of electricity consumption	432.07	258.11	380.43	1235.37	137.82
	Built-up area	345.59	226.81	266.26	945.35	120.20
	Gross regional product	573.15	292.51	558.01	1298.35	226.63
	The amount of SO_2 emissions	355.63	109.93	339.51	525.66	149.38
	The amount of COD discharges	120.80	47.25	115.20	205.96	45.85

Meanwhile, the average annual number of employed persons experienced a slight decline. Among the input indicators, the average value of the capital stock increased from 828.44 trillion yuan to 1208.31 trillion yuan, with an increase of 45.85%. The most considerable value of the capital stock over the years has occurred in Qingdao, exceeding 2000 trillion yuan and increasing yearly. And the smallest value has happened in Rizhao, the city adjacent to Qingdao, of which the capital stock has grown steadily between 200 and 300 trillion yuan. The total electricity consumption in the 16 cities is also increasing, with an average increase from 33.48 KWH in 2016 to 43.21 KWH in 2020. The growth rate in 2019–2020 is significantly higher than in 2016–2018. The maximum amount of electricity consumption among the 16 cities occurred in Binzhou, more than three times the annual average.

Meanwhile, the gross regional product (GRP) level of each city showed a continuous growth trend, but the growth rate continued to

Figure 1
The average values of input and output indicators from 2016 to 2020



decrease. The average value increased from 444.49 trillion yuan to 573.15 trillion yuan, while the average growth rate dropped from 7.64% in 2016–2017 to 4.88% in 2019–2020. The economic development gap among cities has increased from 2016 to 2020, with the standard deviation of GRP climbing from 219.99 trillion yuan to 292.51 trillion yuan. Affected by the impact of COVID-19 on economic development, the increase in standard deviation has decreased in 2020 compared to 2019.

Undesirable outputs reflect the loss of the environment caused by economic development. In the SPUA, the COD emissions of each city were relatively stable from 2016 to 2020, and the average annual COD emissions fluctuated around 300 million tons. Specifically, Weifang had the largest COD pollution emissions in the early stage and was later replaced by Heze. Since 2019, Linyi's COD emissions have risen from second to first place, replacing Heze as the city with the largest emissions. In contrast, the SO_2 emissions of each city had an evident decline from 2016 to 2020, with the average value dropping from 709.08 million tons to 120.80 million tons. Except for 2020, the maximum values appear in Zibo, and the minimum values appear in Qingdao.

4. Empirical Results

4.1 Temporal evolution of green development level

Using the bootstrap-DEA model, the green development efficiency of 16 cities in the SPUA during the "13th Five-Year Plan" period from 2016 to 2020 was calculated. Figure 1 shows the overall green development efficiency of the full region in the study period. The average green development efficiency value for each city represents the overall green development efficiency value of the SPUA. The figure shows that the overall green development level of the agglomeration was relatively stable at an upper-middle level during the "13th Five-Year Plan" period. The green development efficiency value fluctuated slightly, around 0.700. The maximum value was in 2016 at 0.709, and the minimum value was in 2019 at 0.683.

From a city perspective, coastal cities represent the largest use of efficient green development process; these include Qingdao, Zaozhuang, Dongying, Weihai, and Rizhao. These five cities are further divided into two types. The first type is represented by Qingdao, Dongying, and Weihai. The economic aggregates of these cities are above the middle level in the overall agglomeration. Meanwhile, the intensity of input consumption and environmental pollution of these cities are also relatively low, resulting in a higher green development efficiency level. The second type of cities includes Zaozhuang and Rizhao. They have a lower economic development level compared to the first type. However, due to smaller levels of input consumption and environmental pollution, these cities have achieved a high level of green development efficiency.

The development plan of the SPUA divides the 16 cities in Shandong into three economic circles: the Capital Economic Circle, the Jiaodong Economic Circle, and the Southern Economic Circle[3]. The Capital and Jiaodong Economic Circles both have central cities. The Capital Economic Circle includes the administrative center Jinan, and the Jiaodong Economic Circle includes the economic center Qingdao. The economic development levels of most cities in the Southern Economic Circle are relatively close, except for Zaozhuang. The GDP values of Linyi, Jining, and Heze rank 5th, 6th, and 8th, respectively, among the 16 cities.

Among the three economic circles, the green development level of the Jiaodong Economic Circle was significantly higher compared to Capital Economic Circle and Southern Economic Circle. The total economic output of the five cities in Jiaodong Economic Circle made up the largest proportion within the overall urban agglomeration, increasing from 41.00% in 2016 to 42.55% in 2020. Concurrently, the environmental pollution intensity of the cities in Jiaodong Economic Circle was lowest within the three economic circles. In 2020, the proportions of COD discharges and SO_2 emissions from the Jiaodong Economic Circle were both less than 30%. This indicates that the economic circle where the central city is located had a higher green development level, while the economic circle without the central city showed more room for progress. With respect to the overall green development level, the level of the economic circle where the economic center is located was higher compared to the level of the economic circle where the administrative center is located. However, the specific mode of action requires verification using a spatial pattern analysis. This analysis is the subject of the following sections.

4.2. Spatial gravity analysis of urban linkage

The modified gravity model (Model 3) is applied to calculate the spatial correlation strength of green development among 16 cities in the SPUA from 2016 to 2020. Overall, the spatial connection intensity of green development in the agglomeration

[3]The Capital Economic Circle includes 7 cities: Jinan, Zibo, Tai'an, Liaocheng, Dezhou, Binzhou, and Dongying. The Jiaodong Economic Circle includes 5 cities: Qingdao, Yantai, Weifang, Weihai, and Rizhao. The Southern Economic Circle includes four cities: Linyi, Zaozhuang, Jining, and Heze.

Figure 2
Green development efficiency values from 2016 to 2020

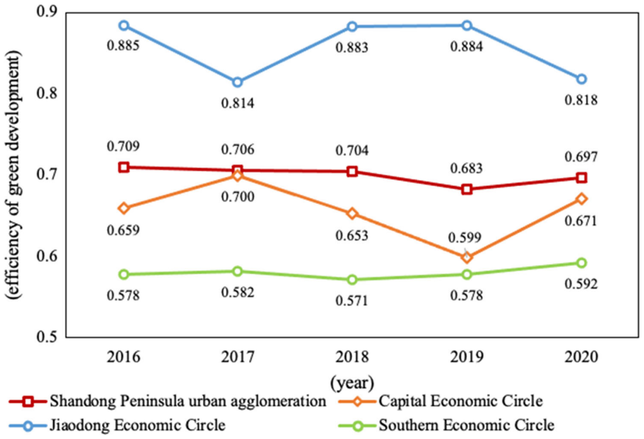
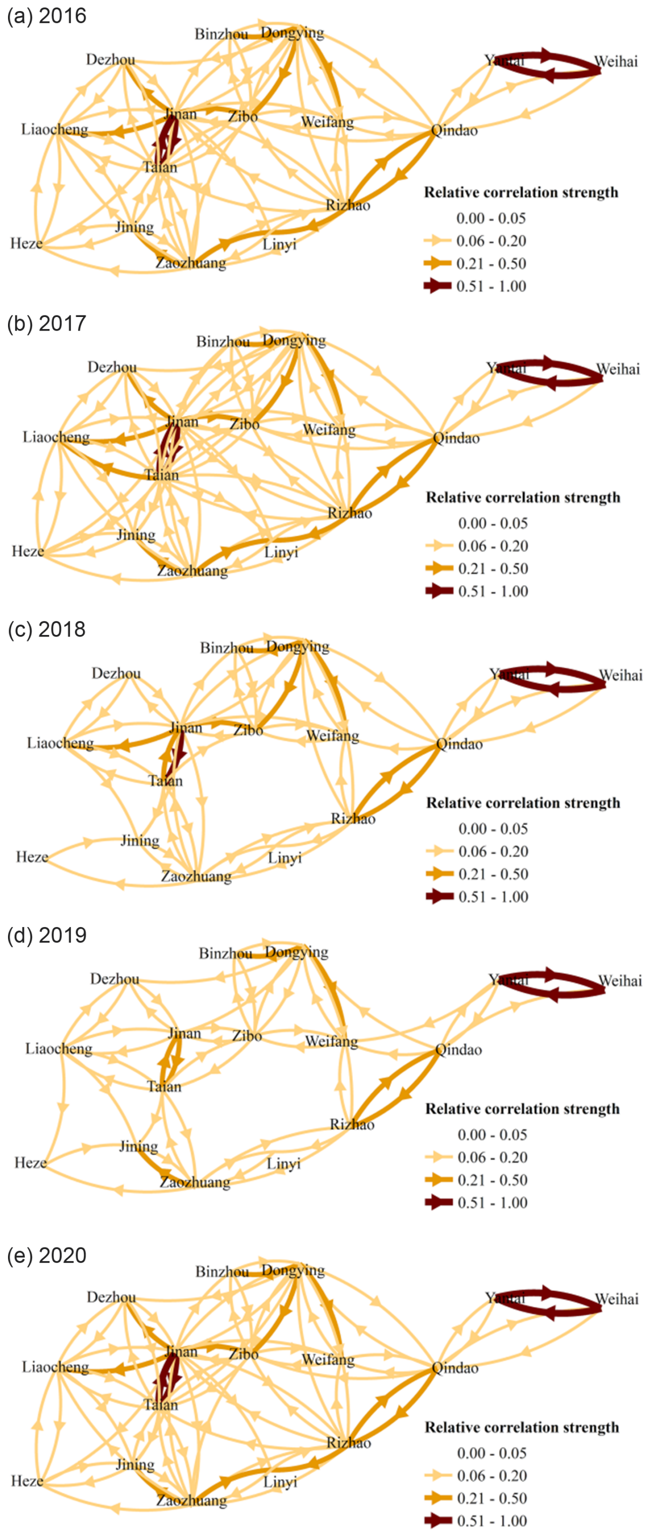


Figure 3
Spatial linkage intensity of green development from 2016 to 2020



somewhat improved over the study period, and the mean and median of the relative spatial connection intensity increased, reaching the highest level in 2020. Figure 2 shows that the spatial connection density of green development in 2020 significantly improved compared with previous periods, and cities with high connection intensity achieved growth. Specifically, in 2016, the relative connection intensity of green development in 75.42% of cities was lower than 0.05, indicating a low spatial correlation with respect to green development. In 2020, this proportion dropped to 67.92%, while the proportion of cities with medium and high connection intensity increased significantly. The total proportion increased from 23.33% in 2016 to 30.42% in 2020.

At the city level, the green development space of the SPUA is dominated by cities in the Capital Economic Circle. The three cities with the strongest relative connection strength in that circle are Jinan, Dongying, and Tai'an. Of these, Jinan, the administrative center Shandong, has the highest connection with other cities and maintains a moderate or above connection strength with three quarters of all the cities. In contrast, the cities in the Southern Economic Center, including Heze, Linyi, and Jining, have low connection strengths. Compared with the other two economic circles, their attraction to other cities and the degree of influence from other cities are both low in the overall agglomeration.

The calculation results from the gravity model show two main paths in the spatial pattern of green development: the Jinan-Tai'an path and Yantai-Weihai path. The two pairs of cities have a high degree of mutual influence and are closely interdependent with respect to green development. However, the two paths have nuances. From 2016 to 2020, Yantai and Weihai maintained a strong interaction, while the interaction between Jinan and Tai'an decreased after 2019. In addition, Qingdao-Rizhao was a major path for the green development of the SPUA. As an important city in the Yellow River Delta, Dongying has a strong influence on the green development of its surrounding Binzhou, Zibo, and Weifang.

Figure 3 shows the strength of the cities' outward and inward attraction levels. None of the 16 cities in the SPUA had a high degree of external attraction and a low degree of attraction. These results indicate that during green development in the agglomeration, the central city significantly impacted its surrounding cities. The administrative center Jinan had the highest outward attraction and inward attraction intensity among all 16 cities. During regional development, it had a relatively high intensity of external attraction and was highly attracted by other neighboring cities.

Qingdao, the economic center, was at an intermediate level with respect to the outward and inward attraction intensity (Figure 4). Qingdao had a significantly lower attraction ability compared to Jinan. In addition, regardless of the kind of central city, there is a neighboring city with similar attractive properties. For example,

Figure 4
Urban classification of spatial connection intensity of green development from 2016 to 2020

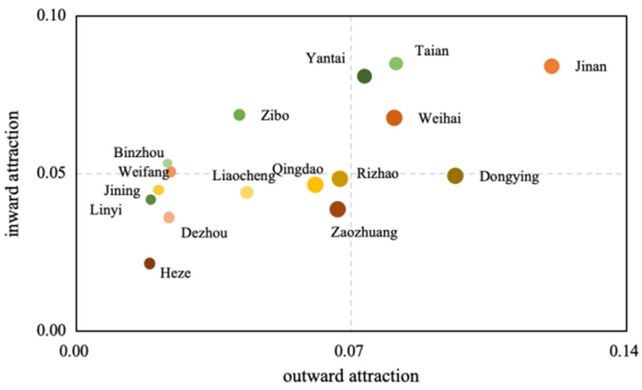
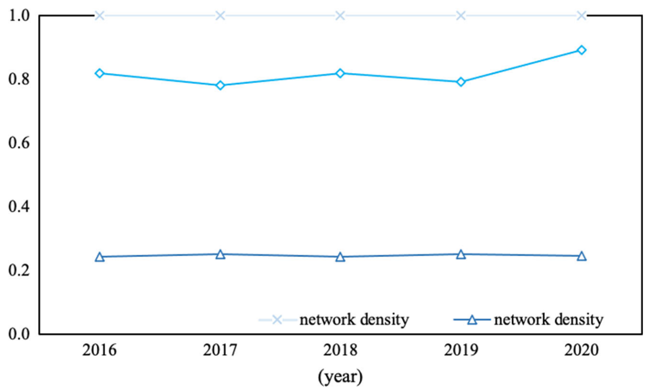


Figure 5
The overall characteristics of green development network from 2016 to 2020



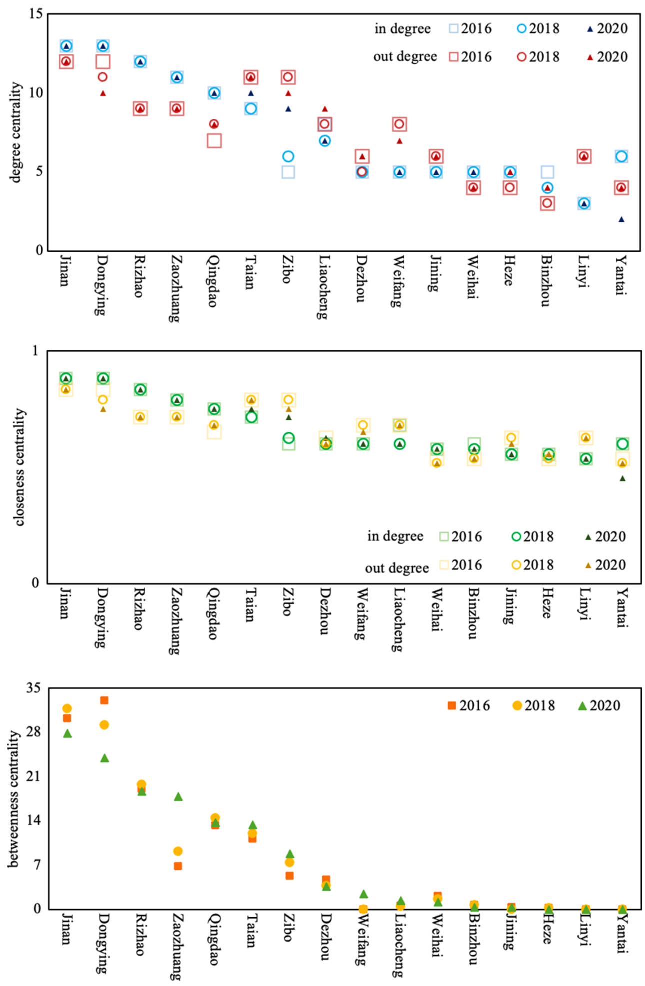
Tai'an, only 75 km away from Jinan, shows the same high intensity of outward and inward attraction as Jinan. Rizhao, 150 km away from Qingdao, also shows the same medium intensity as Qingdao. Similar to the performance of regions with low green development levels, cities in the economic circle without a central city have a low external attraction intensity and low influence from other cities, represented by Heze and Dezhou.

4.3. Network structure analysis of urban linkage

In terms of overall network characteristics, the SPUA has a good overall urban connectivity effect. The correlation degree of the overall network was consistently 1 from 2016 to 2020. There were direct or indirect correlations between all 16 cities. The green development within the SPUA had a good spatial correlation effect, with cities having good accessibility. At the same time, the density in the cities of the SPUA is relatively stable. The overall network density remained at around 0.246 during the five study years; the highest level appeared in 2017 and 2019. The correlation density of the green development network in the agglomeration reached 0.250, and one quarter of the cities had relatively close connections and accessibility. The lowest level appeared in 2016 and 2018, at a network density of 0.242. Despite the relatively stable degree of connection, the absolute value of the green development network density of the SPUA remained low, with significant room to improve the stability of the green development network structure. In addition, the network efficiency of the green development network of the agglomeration increased in fluctuations, from the initial 0.819 to 0.892.

The status of each city in the SPUA during 2016–2020 is measured using degrees of centrality, proximity centrality, and intermediate centrality (Figure 6). Using 2016, 2018, and 2020 as cross sections, Figure 5 shows the evolution of the role-related characteristics of each city in the green development network of the SPUA. The centrality degree of each city reflects its ability to communicate with other cities. Among the 16 cities in the SPUA, Jinan has the highest centrality degree and thus the strongest ability to communicate with other cities. In 2016–2020, the out-degree of Jinan was consistently 13, reflecting a closely connection with the cities in the Capital Economic Circle and with the cities outside the economic circle. Jinan had an in-degree of 12 in the same period, also the highest level in the Shandong Peninsula. Therefore, Jinan, as the administrative center, has a high spillover effect with respect to green development, forming a more extensive connection and influence in the whole province.

Figure 6
The centrality characteristics of green development network from 2016 to 2020



The proximity degree describes the reciprocal of the sum of the shortest paths between each city and other cities during green development. A higher closeness centrality of a city is associated with a lower level of the city's dependence on other cities in the green development network and a greater speed with which it can connect with other cities in green development. This increases the chance it becomes the core node in the green development network of the SPUA.

From 2016 to 2020, the intercity influence of green development in the SPUA showed a slightly decreasing trend. The average value of out-closeness centrality decreased from 0.672 in 2016 to 0.667 in 2018, and was essentially consistent with the 2018 level in 2020, at 0.668. The decreasing trend in closeness centrality was more significant, dropping from 0.669 in 2016 to 0.657 in 2020. In terms of central cities, the calculation results of closeness centrality reflected the characteristics similar to the degree centrality. Among the 16 cities in the SPUA, Jinan was at the highest level of closeness centrality, in addition to its high level of degree centrality.

During the 13th Five-Year Plan period, the central node of the green development network of SPUA significantly increased, with the average increasing from 7.937 to 8.313. The leading role of the central node correspondingly continuously increased. The betweenness centrality levels were highest for Jinan, Rizhao, and Dongying in the green development network of the overall agglomeration. The ranking was consistent with the ranking of the degree centrality and closeness centrality, with the average of these three cities approaching or exceeding 20, more than twice the average level. In contrast to degree centrality and closeness centrality, the betweenness centrality of Qingdao exceeded that of Zaozhuang, playing a more important role as a bridge. This indicates that in the green development cooperation network of SPUA, Jinan, Rizhao, Dongying, Qingdao, and Zaozhuang dominated most of the green development cooperation relationships.

5. Conclusions, Policy Implications, and Discussions

5.1. Conclusions

This study takes the green development level of the SPUA as the research object, calculates the green development level, describes the spatial pattern of green development of urban agglomeration, and analyzes the spatiotemporal evolution of urban linkage pattern of green development of urban agglomeration and the role of central cities in this process. This study provides a reference for further promoting regional green development level and giving play to the leading role of central cities from the perspective of regional coordinated development.

This study draws three main conclusions. Firstly, the central city can drive the local economic green development. For the different sub-regions of Shandong Peninsula, that is, the Capital Economic Circle, the Jiaodong Economic Circle, and the Southern Economic Circle, there are obvious differences in the performance of green development level of sub-regions with or without central cities. The overall green development level of the region is higher than that of south Shandong economic circle, no matter the Capital Economic Circle where the administrative center Jinan is located, or Jiaodong Economic Circle where the economic center Qingdao is located.

Secondly, compared with the administrative center, the economic center has a better level of development, but it is weaker than the administrative center in terms of its ability to radiate and drive the surrounding cities. The green development level of the economic center Qingdao is significantly better than that of the administrative center Jinan during 2016–2020, but Jinan is obviously stronger than Qingdao in terms of external attraction intensity and spatial correlation intensity. The driving and radiating effect of the administrative center on the region is not only limited to its economic circle but also influences other cities in the province outside the economic circle.

Thirdly, the promotion of the development level of administrative center and the promotion of the driving ability of economic center are the key directions in the development process of similar regions. During the "13th Five-Year Plan" period, the overall green development level of the SPUA is relatively stable and at an above medium level. In terms of green development, it has a good urban connectivity effect. However, the influence of cities with high green development level on surrounding cities needs to be further improved. In this context, it is a feasible way to further enhance the overall level of green development in Shandong Province to enhance the driving ability of economic centers with high green development level and improve the green development level of administrative centers.

5.2. Policy implications

Policy implications for improving the overall green development level of the SPUA arise from the findings of this study.

Firstly, the central cities should further play their leading role in green development. On the one hand, Jinan and Qingdao should maintain their position in promoting the green development of the Capital Economic Circle and the Jiaodong Economic Circle. While improving the green development level in the central cities, they should also promote the improvement of ecological protection and high-quality development of surrounding cities through measures such as resource optimization, technological innovation, talent attraction, and opening up. On the other hand, the authorities need to enhance the city's primacy of Jinan and further strengthen the linkage between Jinan and Qingdao. The resource sharing, functional complementarily, and cooperation deepening between the political center city Jinan and the economic center city Qingdao should become a powerful driving force for the SPUA to build a national innovative and competitive regional coordinated development axis.

Secondly, the three economic circles' integrated development should be accelerated. The Capital Economic Circle, the Jiaodong Economic Circle, and the Southern Economic Circle should establish a synergy mechanism in line with the trend of industrial upgrading, population flow, and spatial evolution. Specifically, Jinan and Qingdao should focus on constructing scientific and technological innovation cooperation mechanisms, develop critical areas such as clean energy and industrial Internet, and build a world-class advanced manufacturing cluster. Southern cities should focus on improving the speed of green development by strengthening logistics cooperation with other economic circles. The advantages of ports, railways, airports, and the innovation of resource allocation models are essential directions that will serve.

5.3. Discussions

There are still research limitations and room for improvement in this paper. Future research can be considered from the following aspects to improve. Firstly, the driving effect of different types of central cities on the surrounding areas and the influencing factors of the evolution of the linkage pattern of local cities could be explored, the influencing mechanism of key factors on the regional green coordinated development could also be identified, and countermeasures and suggestions to promote the green development level of the SPUA from the perspective of regional coordinated development could be further put forward. Secondly, research on the level of green development in different fields and the linkage pattern of cities could be detailed, and in-depth research could be carried out from multiple dimensions, such as green energy system, green industrial transformation, and green urbanization development. The influencing factors behind green development of similar urban agglomerations or regions are also worth exploring.

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Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

References

Burger, M. J., Van der Knaap, B., & Wall, R. S. (2014). Polycentricity and the multiplexity of urban networks. *European Planning Studies*, *22*(4), 816–840. https://doi.org/10.1080/09654313.2013.771619

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European journal of operational research*, *2*(6), 429–444. https://doi.org/10.1016/0377-2217(78)90138-8

Cooper, W. W., Seiford, L. M., & Tone, K. (2007). *Data envelopment analysis: A comprehensive text with models, applications, references and DEA-solver software*. USA: Springer.

Feng, Y., Wu, S., Wu, P., Su, S., Weng, M., & Bian, M. (2018). Spatiotemporal characterization of megaregional poly-centrality: Evidence for new urban hypotheses and implications for polycentric policies. *Land Use Policy*, *77*, 712–731. https://doi.org/10.1016/j.landusepol.2018.06.022

Green, N. (2007). Functional polycentricity: A formal definition in terms of social network analysis. *Urban Studies*, *44*(11), 2077–2103. https://doi.org/10.1080/00420980701518941

Hajrasouliha, A. H., & Hamidi, S. (2017). The typology of the American metropolis: Monocentricity, polycentricity, or generalized dispersion? *Urban Geography*, *38*(3), 420–444. https://doi.org/10.1080/02723638.2016.1165386

Huang, D. M., Liu, X. Y., Zheng, Q. C., & Liu, J. (2020). Effects of polycentric mode on the coupling and coordinated development between urbanization and ecological environment: A case study of two metropolitan areas in Fujian Province. *Acta Ecologica Sinica*, *40*, 7886–7896.

Huang, J., & Hua, Y. (2019). Eco-efficiency convergence and green urban growth in China. *International Regional Science Review*, *42*(3–4), 307–334. https://doi.org/10.1177/0160017618790032

Jiang, S., Yu, H., Li, Z., Geng, B., & Li, T. (2022). Study on the evolution of the spatial-temporal pattern and the influencing mechanism of the green development level of the Shandong Peninsula urban agglomeration. *Sustainability*, *14*(15), 9549. https://doi.org/10.3390/su14159549

Jiao, J., Wang, J., & Jin, F. (2017). Impacts of high-speed rail lines on the city network in China. *Journal of Transport Geography*, *60*, 257–266. https://doi.org/10.1016/j.jtrangeo.2017.03.010

Liu, X., & Wang, M. (2016). How polycentric is urban China and why? A case study of 318 cities. *Landscape and Urban Planning*, *151*, 10–20. https://doi.org/10.1016/j.landurbplan.2016.03.007

Moutinho, V., Madaleno, M., & Robaina, M. (2017). The economic and environmental efficiency assessment in EU cross-country: Evidence from DEA and quantile regression approach. *Ecological Indicators*, *78*, 85–97. https://doi.org/10.1016/j.ecolind.2017.02.042

Pöyhönen, P. (1963). A Tentative Model for the Volume of Trade between Countries. *Weltwirtschaftliches Archiv*, *90*, 93–100. http://www.jstor.org/stable/40436776

Qin, Q., Li, X., Li, L., Zhen, W., & Wei, Y. M. (2017). Air emissions perspective on energy efficiency: An empirical analysis of China's coastal areas. *Applied Energy*, *185*, 604–614. https://doi.org/10.1016/j.apenergy.2016.10.127

Restrepo, N., Lozano, S., & Clavé, S. A. (2021). Measuring institutional thickness in tourism: An empirical application based on social network analysis. *Tourism Management Perspectives*, *37*, 100770. https://doi.org/10.1016/j.tmp.2020.100770

Shi, T., Qiao, Y., & Zhou, Q. (2021). Spatiotemporal evolution and spatial relevance of urban resilience: Evidence from cities of China. *Growth and Change*, *52*(4), 2364–2390. https://doi.org/10.1111/grow.12554

Sun, Y., Du, J., & Wang, S. (2020). Environmental regulations, enterprise productivity, and green technological progress: large-scale data analysis in China. *Annals of Operations Research*, *290*, 369–384. https://doi.org/10.1007/s10479-019-03249-4

Tinbergen, J. (1963). Shaping the world economy. *The International Executive*, *5*(1), 27–30. https://doi.org/10.1002/tie.5060050113

Taylor, P. J., Hoyler, M., & Verbruggen, R. (2010). External urban relational process: introducing central flow theory to complement central place theory. *Urban Studies*, *47*(13), 2803–2818. https://doi.org/10.1177/0042098010377367

Vasanen, A. (2013). Spatial integration and functional balance in polycentric urban systems: A multi-scalar approach. *Tijdschrift Voor Economische En Sociale Geografie*, *104*(4), 410–425. https://doi.org/10.1111/tesg.12029

Wang, X., Wang, X., Wu, J., & Zhao, G. (2017). Social network analysis of actors in rural development: A case study of Yanhe village, Hubei Province, China. *Growth and Change*, *48*(4), 869–882. https://doi.org/10.1111/grow.12195

Wang, S., Wang, J., & Liu, X. (2019). How do urban spatial structures evolution in the high-speed rail era? Case study of Yangtze River Delta, China. *Habitat International*, *93*, 102051. https://doi.org/10.1016/j.habitatint.2019.102051

Wen, Y., & Thill, J. C. (2016). Identification, structure and dynamic characteristics of the Beijing–Tianjin–Hebei mega-city region. *Cambridge Journal of Regions, Economy and Society*, *9*(3), 589–611. https://doi.org/10.1093/cjres/rsw023

Ye, S., & Qian, Z. (2021). The economic network resilience of the Guanzhong plain city cluster, China: a network analysis from the evolutionary perspective. *Growth and Change*, *52*(4), 2391–2411. https://doi.org/10.1111/grow.12530

Yue, W., Liu, Y., & Fan, P. (2010). Polycentric urban development: The case of Hangzhou. *Environment and Planning A*, *42*(3), 563–577. https://doi.org/10.1068/a42116

Zhang, L., Wang, H., Zhang, W., Wang, C., Bao, M., & Liang, T. (2022). Study on the development patterns of ecological civilization construction in China: An empirical analysis of 324 prefectural cities. *Journal of Cleaner Production*, *367*, 132975. https://doi.org/10.1016/j.jclepro.2022.132975

Zhou, L., Zhou, C., Che, L., & Wang, B. (2020). Spatio-temporal evolution and influencing factors of urban green development efficiency in China. *Journal of Geographical Sciences*, *30*, 724–742. https://doi.org/10.1007/s11442-020-1752-5

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