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BREAKTHROUGH UNDER TRANSFORMATION AND REGULATION: EXPLORING THE DEVELOPMENT OF ENERGY INTERNET INDUSTRY IN JIANGSU PROVINCE

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Energy Internet, an energy supply system that integrates electronic, information, and intelligent management technology, is important for future development. Considering the current regulation of energy consumption, multi-stakeholders expect an accelerated development of the energy Internet industry. With the successful development of 5G technology, energy Internet technology is regarded as one of the topics most likely to experience great success in the sustainable field. Previous research on Energy Internet has mainly focused on architectural innovation and utility evaluation, whereas not much focus has been put on the evolution and development of energy Internet enterprises. This paper analyzed enterprise data with ArcGIS and other geoscience software. Taking Jiangsu Province as an example, the present study explored the evolution of the spatial distribution pattern of the energy Internet over time. The results showed that from 2017 to 2021, the average nearest neighbor index of energy Internet enterprises in Jiangsu Province was 0.3494, indicating the significant presence of spatial agglomeration in the area.

Furthermore, the degree of agglomeration has been increasing year by year. There was a large gap between cities in Jiangsu Province. In 2021, the number of energy Internet enterprises in Yangzhou was only a bit over one-eighth of Nanjing, and the gap was growing. The enterprise development center appeared in the southern part of Yangzhou City and tended to move to the northwest.

1. INTRODUCTION

Under the dual pressure of energy consumption regulations and climate governance, achieving a breakthrough in developing the Energy Internet has become a crucial objective of energy transformation in China. In July 2015, the State Council issued the "Guiding Opinions on Actively Promoting the 'Internet+' Action," which contained a dedicated chapter on "Internet + Smart Energy" and outlined the roadmap for Energy Internet development.

As a result of the ongoing implementation of policies such as "Energy Revolution," "Internet +," and smart energy, the Energy Internet industry has rapidly expanded and gained considerable momentum in China. Provincial and municipal governments nationwide have successively launched or formulated relevant policies, striving to catch up with the express train of the energy Internet industry. Except for the Tibet Autonomous Region, all other 30 provinces and cities have promoted Energy Internet development in their energy development plans and "Internet +" implementation opinions. Among them, 21 provinces and cities have encouraged the development of "Internet + smart energy" in their "13th Five-Year" energy development plans. For instance, Chongqing has explicitly emphasized promoting "Internet + Smart Energy" development in its "13th Five-Year" Information Plan. Shaanxi Province, Qinghai Province, and Xinjiang Province have all indicated in their "Internet +" implementation opinions that the Internet can enhance energy efficiency.

The Energy Internet is an innovative concept that has gained significant attention from the global academic and industrial communities. It is considered an important direction for the development of the energy industry following the development of the smart grid. Mohammadi et al. [1] defined the Energy Internet as a deep integration of energy and the Internet, which aims to enhance the energy system's efficiency, reliability, and sustainability. Energy Internet enterprises are companies that operate in the field of Energy Internet technology, which involves integrating the energy and Internet sectors to connect all energy-consuming units and enable the tracking, transacting, and supplying of energy [2]. As a result, research on Energy Internet enterprises has been increasing rapidly in recent years. Teske [3] conducted an industry survey on Energy Internet enterprises globally and argued that using clean energy would become the future development trend of Energy Internet power. Meanwhile, Zhao et al. [4] scientifically evaluated the comprehensive benefits of Energy Internet enterprises in China using the G1-DEMATEL-CV method. The results suggested that establishing a comprehensive biomass energy utilization system by Energy Internet enterprises can effectively improve their energy self-sufficiency rate.

The Energy Internet industry has gained increasing attention from researchers due to its potential to connect all power-consuming units and supply energy efficiently [5]. However, despite the numerous studies on Energy Internet technology, there is still no consensus on its industrial studies. Although many scholars have emphasized the impact of technology on enterprises, they have tended to neglect the industry's overall development. This lack of attention can impede our understanding of the heterogeneity of research and development in the Energy Internet across different cities. For example, scholars like Çetinbaş et al. [6] have only focused on how to use algorithms to optimize enterprise performance in multi-energy flow microgrids based on the functional structure of biogas cold and hot-spot multi-energy rural microgrids without examining the industry's broader development. Therefore, to gain a comprehensive understanding of Energy Internet research and development, it is crucial to shift some focus to the industry's development. This will be the objective of our study.

Before the explosive development of information technology and the rapid upgrade of computer hardware, research on enterprise outlets relied heavily on qualitative analysis, particularly in the formation mechanism, spatial structure, changing trend of urban commercial outlets, and location selection of commercial outlets at the mesoscale [7]. However, the advancement in information technology has allowed for the use of big data to investigate the evolution of the spatial distribution of enterprises [8]. This has shifted towards quantitative and visual analysis of business formats

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using mathematical models, POI data, and GIS methods. For instance, Lan et al. [9] utilized geoscience tools to examine the evolution of the spatial distribution of large-scale public cultural facilities in Xi'an. They identified three stages in the evolution of Xi'an's cultural function pattern. They used a questionnaire to identify non-spatial factors that affect the utilization of large-scale public cultural facilities. Reyna-Bowen [10] analyzed the spatial distribution and potential factors influencing soil organic carbon pools, including geographical location, soil depth, organic matter content, bulk density, area, main characteristics, typical profiles, and production performance of soil profiles as predictors. Wu et al. [11] employed a Gaussian function to simulate the geographic impedance decay model and improved the two-part mobile search method. They also utilized gravity-shaped 2SFCA and enhanced 2SFCA optimization schemes to examine the distributional characteristics and accessibility of green facilities to residents in the Wuhan area. Additionally, a comparison of mathematical models was conducted.

In recent years, China's rapid economic development and frequent extreme weather occurrences have increased the demand for development and residential energy. Despite the emergence of various new energy supply technologies, the overall energy shortage situation remains concerning. This study focuses on Jiangsu Province as a representative area to analyze the spatial evolution of Energy Internet enterprises from 2017 to 2022 and select several representative cities for individual analysis. The objective is to explore the developmental trends of Energy Internet enterprises, examine whether the development is balanced across different regions, and investigate the situation of agglomeration. This study provides insights into the future of new energy technology by analyzing and finding results.

2. METHODOLOGY

2.1 AVERAGE NEAREST NEIGHBOR ANALYSIS

The concentration of study objects is an important indicator in geoscience research, as Tobler's first law of geography explains that things that are close by are more closely related than things that are far away. The average nearest-neighbor analysis is the most widely used method to assess the degree of agglomeration. This method is sensitive to measuring agglomeration because it compares the actual nearest neighbor distance to the theoretical nearest neighbor distance [12]. When the index value is less than 1, the study objects tend to be clustered, while when it is greater than 1, they tend to be dispersed or uniformly distributed. In situations of agglomeration, the actual nearest neighbor distance is likely to be smaller than the theoretical nearest neighbor distance, as study objects tend to cluster together. Conversely, in cases of uniform distribution, the actual nearest neighbor distance is likely to be close to the theoretical nearest neighbor distance [13]. The sensitivity of the average nearest neighbor analysis method makes it one of the most widely used agglomeration analysis methods in geoscience.

$$k_i = 1/2\sqrt{n/a}. \quad (1)$$

In the eq. (1), k_i is the theoretical nearest distance; n refers to the total number of enterprises; a represents the neighborhood area.

2.2 THE STANDARD DEVIATIONAL ELLIPSE

The standard deviational ellipse (SDE) method is a widely used technique in geoscience that summarizes the spatial distributional characteristics of point elements. It visualizes these characteristics as an ellipse center of gravity, major and minor axes, and azimuth angles [12]. The SDE method is often used to evaluate the overall distributional characteristics of a spatial distribution. The SDE method is based on the standard deviation of a set of points x- and y-coordinates. The standard deviation ellipse is then drawn with its center at the mean x- and y-coordinates of the set of points. The major and minor axes of the ellipse are defined by the covariance matrix's first and second principal components of the x- and y-coordinates. The azimuth angle of the major axis is defined as the angle between the x-axis and the direction of the first principal component. The SDE method is sensitive to the shape and orientation of the spatial distribution of the point elements [14]. For example, a circular distribution will result in an SDE with equal major and minor axes.

In contrast, an elongated distribution will result in an SDE with a long major axis and a short minor axis. Therefore, in the context of our study, the SDE method is sensitive to the overall spatial distribution of the point elements and provides a useful tool to evaluate the clustering or dispersion characteristics. The main parameters of SDE are calculated as follows:

The center of gravity:

$$\bar{X}_w = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i},\ \bar{Y}_w = \frac{\sum_{i=1}^{n} w_i y_i}{\sum_{i=1}^{n} w_i}\ , \quad (2)$$

Azimuth:

$$\tan\theta = \frac{\left(\sum_{i=1}^{n} w_i^2 \tilde{x}_i^2 - \sum_{i=1}^{n} w_i^2 \tilde{y}_i^2\right) + \sqrt{\left(\sum_{i=1}^{n} w_i^2 \tilde{x}_i^2 - \sum_{i=1}^{n} w_i^2 \tilde{y}_i^2\right)^2 + 4\sum_{i=1}^{n} w_i^2 \tilde{x}_i^2 \tilde{y}_i^2}}{2\sum_{i=1}^{n} w_i^2 \widetilde{x_i}\widetilde{y_i}}\ , \quad (3)$$

Standard deviation in x axis :

$$\sigma_x = \sqrt{\frac{\sum_{i=1}^{n} (w_i\widetilde{x_i}\cos\theta - w_i\widetilde{y_i}\sin\theta)^2}{\sum_{i=1}^{n} w_i^2}}, \quad (4)$$

Standard deviation in y axis:

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^{n} (w_i\widetilde{x_i}\sin\theta - w_i\widetilde{y_i}\cos\theta)^2}{\sum_{i=1}^{n} w_i^2}}. \quad (5)$$

In the eq. (2) to (5), (x_i, y_i) represents the position of the research object, w_i represents the weight, $(\bar{X}_w, \bar{Y}_w)$ represents the weighted centroid; θ is the azimuth angle of the ellipse, indicating the angle formed by rotating clockwise from true north to the major axis of the ellipse, ~xi and ~yi represent the deviations of each object's position to the centroid, and σ_x and σ_y represent the standard deviations along the x-axis and y-axis, respectively.

2.3 CIRCLE ANALYSIS

To analyze the distributional characteristics of the study area, circle analysis was applied. This geostatistical method uses the residential area as a base to divide different areas into circles based on their distance from the base and the number of research objects included in the circles. In this study, four representative cities in Jiangsu Province were selected, and the study areas were divided into three types for statistical analysis: central urban area, suburban area, and outer suburban area. By analyzing the distributional characteristics of different circles, the spatial distribution of the research objects in the study area can be better understood. Circle analysis is a widely used method in geostatistics because it captures the spatial distribution of research objects in a specific area [9].

2.4 HOT SPOT ANALYSIS

Hot spot analysis involves calculating Getis-Ord Gi* for each element in the research object data set, which can reveal where the high and low values are clustered in space and estimate the strength of the correlation between the regional element values and the adjacent regional element values. This method can be susceptible to local variations and spatial clustering. By identifying statistically significant hot spots (areas with high element values and high spatial autocorrelation) or cold spots (areas with low element values and high spatial autocorrelation), the analysis can provide insights into the spatial distribution of the element values and help identify areas that may require targeted interventions or further investigation [15]. The Getis-Ord Gi* formula is:

$$G_i^*(a) = \frac{\sum_j^n t_{ij}(a)x_j}{\sum_j^n x_j} \,. \tag{6}$$

where standardization of $G_i^*(a)$ is performed to get $Z(\mathrm{x})$

$$Z(\mathrm{x}) = \frac{x-E(x)}{\sqrt{\mathrm{Var}(\mathrm{x})}} \,. \tag{7}$$

Here, $E(x)$ is the expected value of the statistic; $\mathrm{Var}\,(x)$ is the variance; a positive and significant Z value represents the formation of a hot spot area; a negative and significant Z value represents the formation of a cold spot area; t_{ij} is the spatial weight matrix; x_j is the spatial variable value of the region j, representing the number of units in region j.

3. **RESULTS**

3.1 AGGLOMERATIONAL CHARACTERISTICS

The collected POI data was initially integrated and sorted, with duplicate and incorrect information removed. To further analyze the spatial distribution characteristics of Energy Internet enterprises in Jiangsu Province, the ArcGIS geoscience data analysis software was employed to conduct an average nearest neighbor analysis. The results in Table 1 reveal that Energy Internet enterprises in Jiangsu Province have a strong spatial agglomeration tendency. The nearest neighbor indices from 2017 to 2022 were less than 1, indicating that Energy Internet enterprises were highly concentrated in some regions of the province. The statistical significance indicators, namely Z-Score and P value, support this finding.

Table 1

Results of average nearest neighbor analysis

Year	Average actual nearest neighbor distance (m)	Nearest Neighbor Index	Z score	P value	Distribution
2021	987.113334	0.287762	-79.1576	0	*Significant agglomeration*
2020	1415.944985	0.314503	-58.2653	0	*Significant agglomeration*
2019	2699.8052	0.394533	-31.2312	0	*Significant agglomeration*
2018	3146.653238	0.408323	-28.1618	0	*Significant agglomeration*
2017	1512.784273	0.344409	-56.4525	0	*Significant agglomeration*

The average nearest neighbor distances from 2017 to 2021 were 1512 km, 3146 km, 2699 km, 1415 km, and 987 km. After a sharp rise in 2018, the distance has decreased annually, suggesting that the concentration of Energy Internet enterprises in Jiangsu Province has continued to increase since 2018, with regionalism becoming more prominent. This trend is expected to continue, as more significant agglomeration can facilitate enterprise subdivision and specialization, which can help to avoid unnecessary and repetitive expenses while improving product quality. This concentration can also help meet the energy needs of urban development institutes and residents' daily energy expenses, promoting the development of scale economies and enhancing enterprise efficiency. Notably, the sudden increase in 2018 may be attributed to the government's heightened emphasis on the Energy Internet, leading to delisting energy enterprises that were not initially part of it. Overall, the findings suggest that the development of the Energy Internet in Jiangsu Province has significantly impacted the enterprise's spatial distribution and efficiency.

3.2 OVERALL DISTRIBUTION CHARACTERISTICS

Using ArcGIS software and POI data, we generated a standard deviational ellipse to visualize the distribution of Jiangsu Energy Internet enterprises annually (refer to Figure 1). The center of the Energy Internet enterprises in Jiangsu Province was mainly located in the southern part of Yangzhou Province, and the standard deviational ellipse's long axis extending in the northwest-southeast direction. This suggests that the Energy Internet enterprises in Jiangsu Province are primarily concentrated in the south of Yangzhou Province and expanding towards the northwest-southeast direction. The high ratio of the long to short axes indicates a strong directional characteristic and less randomness in the distribution of Energy Internet enterprises. This observation is consistent with the previous analysis, which showed strong agglomeration distribution characteristics.

A comparison of the standard deviational ellipses for each year reveals that the ellipses for 2017 and 2018 were essentially the same, indicating no significant changes in the distribution of enterprises. From 2018 to 2020, the center of gravity of the standard deviational ellipse of Yangzhou Energy Internet enterprises gradually moved to the northwest, increasing directionality and the long-axis growth concentrated in the northwest-southeast direction. The short-axis length remained unchanged, and the long-axis length peaked in 2020 before slightly decreasing in 2021.

These results indicate that from 2018 to 2020, the Energy Internet construction in Jiangsu Province was mainly concentrated in the south of Yangzhou, with the construction center of gravity gradually shifting towards the northwest. In 2021, construction mainly focused on supplementing the original agglomeration area, leading to a decrease in directionality and a partial reversal of the center of gravity of the standard deviational ellipse.

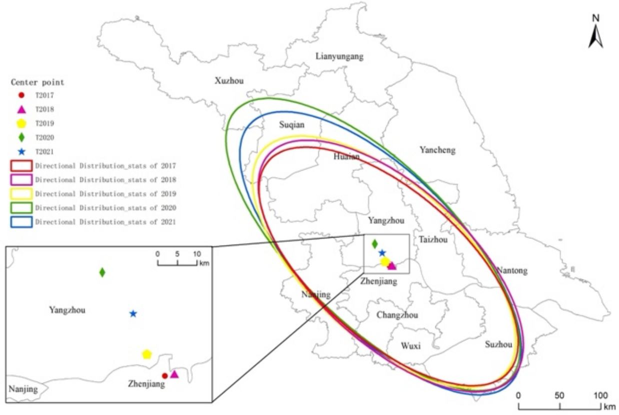


Fig. 1 – Standard deviational ellipse of Energy Internet Enterprises in Jiangsu Province

The distribution of Energy Internet enterprises in Jiangsu Province has shifted from highly concentrated to relatively dispersed before gradually reconverging. This has resulted in an increase in agglomeration and a decrease in directionality over time. Based on these findings, it is recommended that emerging Energy Internet Enterprises focus on developing areas when selecting sites to take advantage of the low cost and high efficiency provided by policies and industrial development.

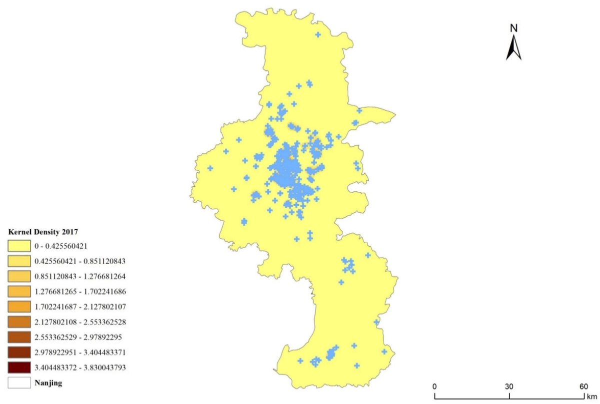
3.3 HOTSPOT ANALYSIS

To begin the analysis, we divided Jiangsu Province into 1km × 1km grids. Using ArcGIS software, we examined the distribution of energy Internet enterprise hotspots in Nanjing, Suzhou, Xuzhou, and Yangzhou in 2017, 2019, and 2021. A cold and hotspot map was created to visualize the results (Fig. 3). The main findings are as follows: In Nanjing, energy Internet enterprises were mainly concentrated in the central region and along the primary traffic routes. Small clusters were present in the southernmost part of the city, while the northern area had fewer enterprises.

There was little change in the agglomeration of energy Internet enterprises in Nanjing between 2017 and 2021. The hotspot areas slightly expanded, but the core density values sharply increased, indicating an increase in agglomeration. New enterprises were primarily located in the original gathering point. In Suzhou, energy Internet enterprises were mainly concentrated in the central region, with a trend towards spreading eastwards, while the southern part of the city had few such enterprises. From 2017 to 2022, the distribution of energy Internet enterprises in Suzhou City spread from the original gathering point, with more intensive construction in the northeast.

The distribution characteristics of energy Internet enterprises in Xuzhou City varied greatly. In 2017, energy Internet enterprises in Xuzhou were primarily concentrated in the western and westernmost parts of the central region, with only sporadic distribution in the east. In 2021, the distribution in the western region remained largely unchanged, while a smaller clustering point appeared in the east. Energy Internet enterprises in Yangzhou were mainly concentrated in the south and southwest regions.

From 2017 to 2021, the distribution and agglomeration of energy Internet enterprises in Yangzhou gradually increased. The agglomeration point in the southwest, present in 2017, began to spread in 2019, and by 2021, there was only one large-scale agglomeration point in the south. Overall, the findings suggest that the distribution and agglomeration of energy enterprises in these four cities have changed, with varying patterns in each city.



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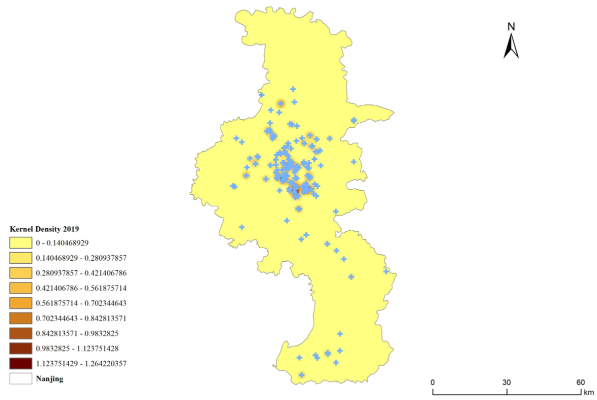

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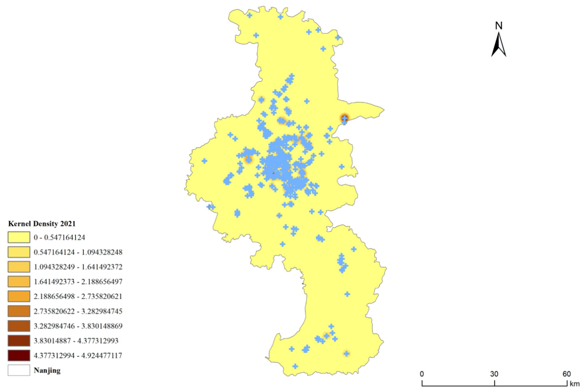

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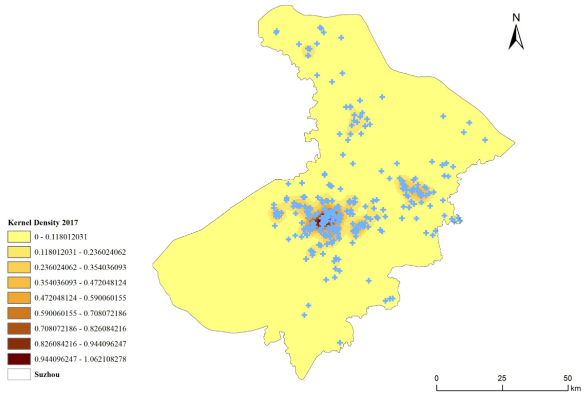
Fig. 3 – Hotspots of Energy Internet Enterprises in Nanjing (Southern Jiangsu); (a) 2017; (b) 2019; (c) 2021.



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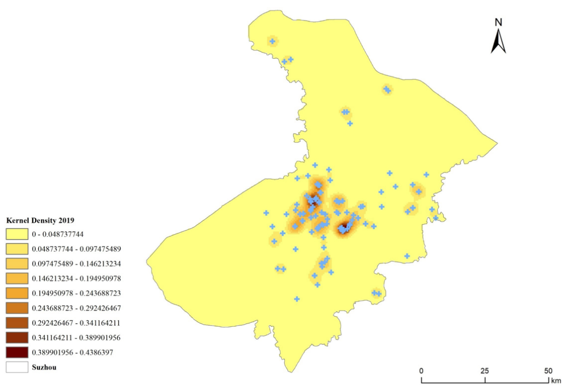

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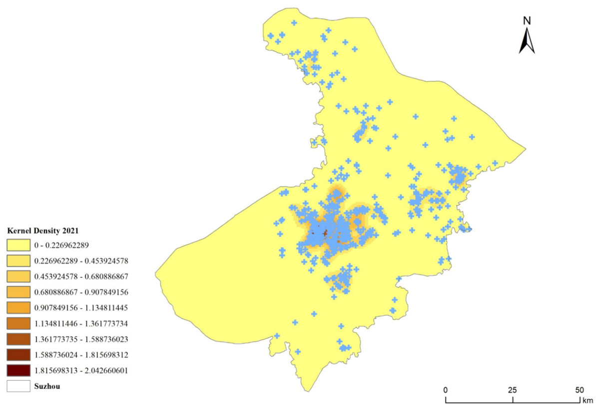

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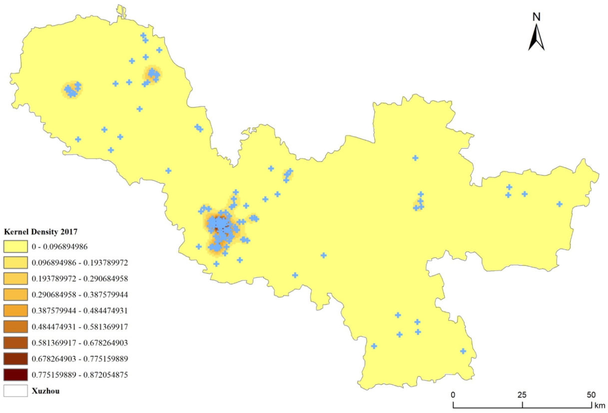
Fig. 4 – Hotspots of Energy Internet Enterprises in Suzhou (Southern Jiangsu); (a) 2017; (b) 2019; (c) 2021.



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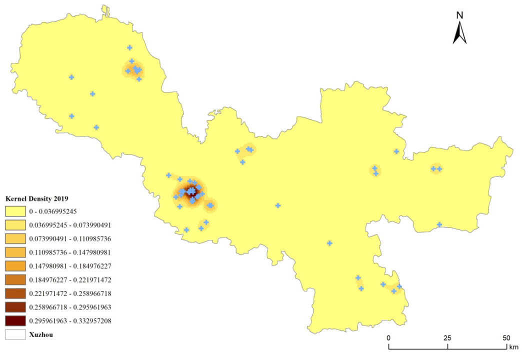

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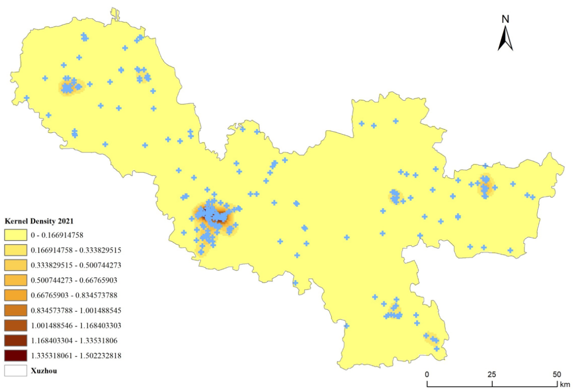

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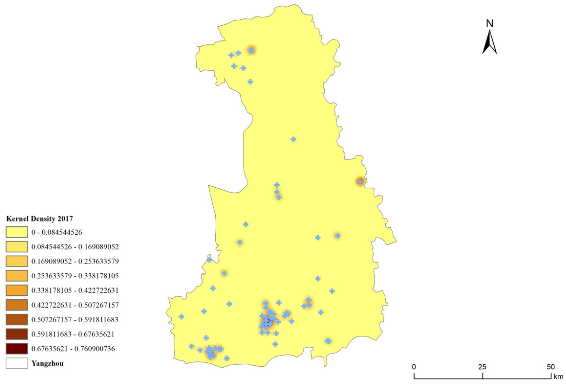
Fig. 5 – Hotspots of Energy Internet Enterprises in Xuzhou (Northern Jiangsu); (a) 2017; (b) 2019; (c) 2021.



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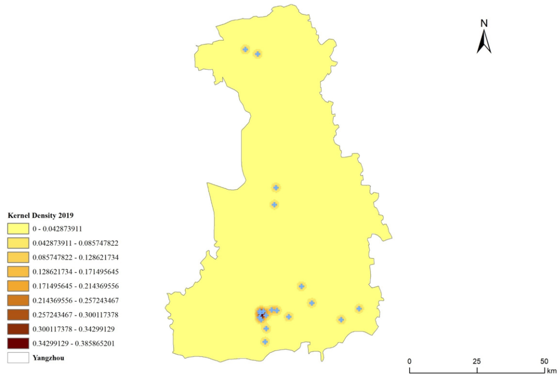

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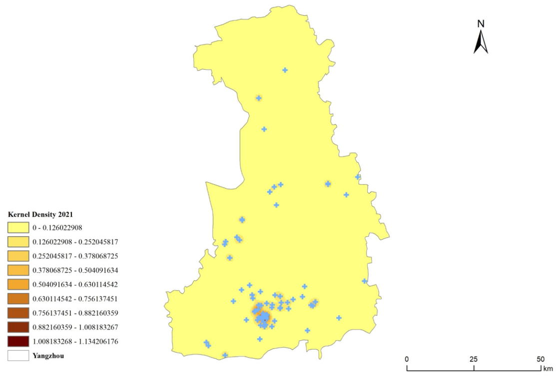

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Fig. 6 – Hotspots of Energy Internet Enterprises in Yangzhou (Middle Jiangsu); (a) 2017; (b) 2019; (c) 2021.

4. CONCLUSIONS

In the context of current climate governance and energy regulation, the development of the Energy Internet industry plays an important role. To study the changing process and pattern characteristics of the spatial distribution of energy Internet enterprises in Jiangsu Province, POI information of enterprises from 2017 to 2021 was collected. Average nearest neighbor analysis and standard deviational ellipse analysis were used with ArcGIS software to analyze the overall pattern of Jiangsu Province. According to preliminary analysis, four cities were selected for further analysis: Yangzhou, Suzhou, Nanjing, and Xuzhou, from the southeast and northwest of Jiangsu. For each city, 10-30 km from the central area was defined as the suburban area, and 20-30 km away was defined as the outer suburban area. Enterprise circle analysis and analysis of cold and hotspots were conducted. The main conclusions are as follows:

(1) Energy Internet enterprises in Jiangsu are increasingly agglomerating in Yangzhou City, with stronger development in the northwest. The 2021 nearest neighbor index was 0.287, down 17 % from 2017. Although the gap between regions grew in 2017-2020, it reversed in 2021.

(2) Nanjing's Energy Internet enterprises develop most conventionally, followed by Suzhou. Xuzhou and Yangzhou are slower, with only one-eighth and one-fourth of Nanjing's scale. Enterprises cluster in the city centers of Nanjing and Suzhou, while Xuzhou's primary concentration is in the west. Yangzhou lacks a large-scale industrial chain, with scattered distribution and small-scale agglomerations in the south. Industrial location selection should consider regional factors to prevent diseconomies of scale.

The number of energy Internet enterprises in Jiangsu Province has increased while the industry is gradually moving closer, and agglomeration is becoming more salient. However, this development varies significantly from city to city. As the energy industry is highly dependent on regional factors such as smooth traffic and the richness of regional resources, the government is suggested to make reasonable plans for industrial location selection based on location advantages to prevent diseconomies of scale caused by agglomeration and wrong locations.

Despite the insightful findings, this study has some limitations that must be addressed. Firstly, the data used in this study only covers 2017 to 2021. Therefore, it may not fully reflect the long-term development trend of Energy Internet enterprises in Jiangsu Province. Secondly, this study only focuses on the spatial distribution pattern of Energy Internet enterprises in Jiangsu Province. It does not consider other factors that may influence the development of the industry, such as policy support, technological innovation, and social demand [16]. Thirdly, this study mainly uses quantitative methods to analyze the data, and qualitative research methods, such as interviews and case studies, were not applied, which may limit the depth of analysis. Finally, the definition of suburban areas may vary depending on each city's urban and rural characteristics, which may affect the accuracy of the analysis results. Therefore, further research is needed to overcome these limitations and provide a more comprehensive understanding of the development of the Energy Internet industry in Jiangsu Province.

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