Evaluation of renewable energy resources abundance and spatial correlation analysis in Beijing

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Abstract. Beijing is actively exploring the development and utilization potential of local renewable energy resources in order to speed up the adjustment of energy structure, implement clean energy substitution and build a modern green energy system in the capital. In this context, it is urgent to systematically analyze the status and characteristics of renewable energy resources in Beijing. Taking Beijing as the research area, this paper calculates the abundance indexes of solar energy, wind energy and biomass resources respectively, and establishes the renewable energy abundance evaluation model. Based on the spatial distribution characteristics of renewable energy resources in Beijing, the spatial correlation of renewable energy resources was tested. The results show that renewable energy resources in Beijing are generally characterized by “rich in the north and poor in the South” and “rich in the surrounding areas and poor in the center”. Among them, solar energy resources are relatively rich, wind energy resources are scarce with random distribution characteristics, and biomass resources are decreasing year by year. The research results can provide important reference for the development and utilization of renewable energy resources in different regions of Beijing.

1. Introduction
Beijing energy development plan clearly proposes that the energy development of the capital will adhere to the principle of green and low-carbon, accelerate the implementation of ecological civilization construction and air pollution control tasks. Beijing municipal government is determined to further accelerate the adjustment of energy structure with greater efforts and unconventional measures, implement clean energy substitution, and strive to shift from the supply guarantee of traditional fossil energy to solar energy, wind energy, biomass energy, etc. The development and utilization of renewable energy will be transformed to achieve a new leap in the scale and development level of renewable energy utilization in Beijing. Beijing should speed up the construction of a multi-source, multi-directional and multi-point energy facility supply system, fully tap the development and utilization potential of local renewable energy resources, implement the green energy action plan, and fully and orderly develop solar energy, wind energy, biomass energy and geothermal energy, so as to realize the rapid improvement of the scale of renewable energy utilization in Beijing and the transformation from pilot demonstration to regulation of renewable energy utilizationModel application transformation, better and faster to build a modern green energy system in the capital, and give play to the role of clean utilization demonstration in the capital.

2. Literature review
Based on the existing researches on renewable energy resources in Beijing, Zhou Zhongren et al. proposed the development strategy of renewable energy in rural areas of Beijing by analyzing the
conditions and development status of renewable energy resources in Beijing and analyzing solar thermal utilization, biomass gas and building energy conservation transformation from the perspectives of development and energy conservation[1]. Lin Yanmei et al. proposed the regional integrated development strategy of Renewable energy in Beijing-Tianjin-Hebei region from the aspects of planning, mechanism, energy and service[2]. Ye Tanglin et al. analyzed the development potential, technical status and market demand of renewable energy in Beijing and put forward the key strategic points of renewable energy development[3]. Li Chunhua established an annual energy basis reference model based on historical data to calculate the grid connection space of renewable energy to achieve Beijing’s 2030 emission reduction target[4]. Gao Xinyu constructed a comprehensive renewable energy planning model of Beijing by constructing the new energy dynamic optimization objective function with the minimum cost as the target, combined LEAP model and MESSAGE model, and used the model to analyze the renewable energy development situation and government response cost of Beijing under three scenarios and put forward policy Suggestions [5].

3. Model building

3.1 Evaluation model of renewable energy resource abundance

There are many types of renewable energy resources. Because the data sources and data units of various renewable energy abundances are not uniform, it is necessary to normalize the data and remove the dimensions, as shown in formula (1):

$$x_i^* = \frac{x_i - x_m}{x_M - x_m}$$  \hspace{1cm} (1)

Where: $x_i^*$ is the normalized data value; $x_i$ is the value of the original data; $x_M$ and $x_m$ are the maximum and minimum values of the data in the study sample, respectively. After normalization, the evaluation model of renewable energy resource abundance is as follows (2):

$$Y = \sum_{i=1}^{n} a_i x_i^*$$  \hspace{1cm} (2)

Where: $Y$ is the evaluation result of renewable energy resource abundance; $n$ is the total $n$ renewable energy resources; $a_i$ is the ith renewable energy resource abundance the weight of degree, $\sum_{i=1}^{n} a_i$.

3.2 Spatial correlation model of renewable energy

Spatial correlation is a concept used to describe the degree of spatial interdependence between things in different regions. There are spatial distribution characteristics of renewable energy. In order to better reveal the characteristics and laws, the global Moran’s I index model is selected for calculation in this study. The index can test whether the adjacent areas in the whole study area are similar, different or independent. The calculation is as follows (3):

$$I = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \omega_{ij} (x_i - \bar{x})(x_j - \bar{x})}{s^2 \sum_{i=1}^{n} \sum_{j=1}^{n} \omega_{ij}}$$  \hspace{1cm} (3)
Type: \( n \) number area as the research area, \( \omega_{ij} \) as weights for the space, \( x_i \) and \( x_j \) region i and j properties, respectively, \( \bar{x} \) is an attribute within a region the average, the mean value, \( s^2 \), is the variance of the attributes in the region. The value range of the global Moran's I index is \([-1,1]\). A value greater than 0 indicates a positive correlation, and a value closer to 1 indicates a clustering feature with similar attributes. A value less than 0 indicates a negative correlation, while a value closer to -1 indicates a discrete feature with similar attributes; equal to 0 means that the values of the attributes are independent of each other.

Although the global Moran's I index can test the correlation degree of the study area, it cannot test the correlation degree of the regions within the region measurements. Therefore, this study introduces the local Moran's I index model to test whether the observed values in local areas are similar or phase (4):

\[
I_1 = \left( x_i - \bar{x} \right) \sum_{j=1}^{n} \omega_{ij} \left( x_j - \bar{x} \right) / s^2
\]  

(4)

4. Evaluation of renewable energy resources abundance and spatial correlation analysis in Beijing

4.1 Evaluation on the abundance of renewable energy resources in Beijing

In the renewable energy resource abundance evaluation model, the weight of each type of renewable energy should be equal, that is, there are \( n \) types of renewable energy and the weight of each type of renewable energy is \( 1/n \). Formula (2) is used to evaluate the renewable energy resource abundance in Beijing. The evaluation results are shown in Table 1. The evaluation results were divided into four grades: 0~0.25 was resource poverty, 0.25~0.5 was general resource poverty, 0.5~0.75 was abundant resource, and 0.75~1 was abundant resource. It can be seen that the abundance of renewable energy resources in Beijing is characterized by “more north and less south”. Yanqing District has the most abundant renewable energy resources, and its solar energy, wind energy and biomass resource abundance are in the leading position in Beijing, which has been appraised. It is the only resource-rich administrative region in Beijing. There are many administrative regions with poor renewable energy resources, among which, Dongcheng District, Xicheng District, Shijingshan District and Fengtai District are deficient in biomass resources, and their evaluation scores are at a low level.

| Administrative region | Score  | Administrative region | Score  |
|-----------------------|--------|-----------------------|--------|
| Dongcheng district    | 0.0408 | Tongzhou district     | 0.2352 |
| Xicheng district      | 0.0450 | Shunyi district       | 0.2055 |
| Chaoyang district     | 0.1671 | Changping district    | 0.2842 |
| Fengtai district      | 0.0941 | Daxing district       | 0.1958 |
| Shijingshan district  | 0.0492 | Huairou district      | 0.5952 |
| Haidian district      | 0.1538 | Pinggu district       | 0.2009 |
| Mentougou district    | 0.3532 | Miyun district        | 0.5835 |
| Fangshan district     | 0.1882 | Yanqing district      | 0.9698 |

4.2 Evaluation on the abundance of renewable energy resources in Beijing

The abundance of solar energy resources, wind energy resources, biomass resources and renewable energy resources in Beijing was calculated by the global Moran's I index. The results are shown in Table 2. The Moran's I index of the abundance of solar energy resources, biomass resources and renewable energy resources is 0.46, 0.61 and 0.46, which have a certain positive correlation in space. P value <0.05 indicated that the test results were highly significant. Z score > 1.96, indicating that the observed values are spatially clustered. However, the Moran's I index test results of wind energy
resource abundance are not significant, and the wind energy resource abundance index presents the characteristics of random distribution in space.

| Table 2. Evaluation results of renewable energy resources abundance in Beijing |
|--------------------------------------------------|
| Inspection items | Moran's I index | Z score | P values |
|--------------------|-----------------|---------|----------|
| Solar energy resources | 0.4564 | 3.3991 | 0.000676 |
| Wind energy resources | 0.0754 | 0.9980 | 0.318269 |
| Biomass resources | 0.6120 | 4.2362 | 0.000023 |
| Renewable energy resources | 0.4592 | 3.4488 | 0.000563 |

The spatial clustering relationship of renewable energy resources among administrative regions is further explored and solve the local Moran's I index for the abundance of solar energy resources, biomass resources and renewable energy resources in Beijing. In terms of solar energy resources, Dongcheng, Xicheng, Haidian, Chaoyang, Shijingshan and Fengtai District show the spatial characteristics of low and low concentration, while the other administrative regions are not significant. The abundance of solar energy resources in the central urban area of Beijing is relatively weak, showing the phenomenon of poor solar energy resources gathering in six administrative regions. In terms of biomass resources, Dongcheng, Xicheng, Haidian, Shijingshan, Fengtai, Chaoyang, Tongzhou and Daxing District have the spatial characteristics of low and low concentration, while the other administrative regions are not significant. Biomass resources show the obvious dual distribution characteristics of urban and rural areas. In terms of renewable energy resources, Dongcheng, Xicheng, Haidian, Shijingshan, Fengtai, Chaoyang, Tongzhou and Daxing districts show the spatial characteristics of low-level agglomeration, while the rest administrative districts are not significant, showing the characteristics of "rich around and poor in the middle".

5. Conclusion

Based on the basic data, the abundance of renewable energy resources in Beijing is measured and evaluated, and its spatial distribution and correlation characteristics are analyzed. The conclusions are as follows.

The abundance of renewable energy resources in Beijing is relatively poor. Among them, solar energy resources are relatively rich, wind energy resources are scarce, and biomass resources have an obvious decreasing trend year by year. In terms of spatial distribution, it is characterized by "rich in the north and poor in the South". Yanqing District has the largest amount of renewable energy resources, solar energy, wind energy and biomass energy resources are relatively rich, and it is the region with the largest potential for renewable energy resources development. Dongcheng District and Xicheng District are the poorest in terms of renewable energy resources and have little development potential.

The abundance of solar energy resources and biomass resources in Beijing shows a positive spatial correlation. The six administrative regions near the city center, such as Dongcheng, Xicheng, Haidian, Shijingshan, Fengtai and Chaoyang, are the representatives. The administrative regions with poor resources show a low spatial concentration phenomenon, which is characterized by "rich surrounding and poor center" of renewable energy resources in Beijing. However, the abundance of wind energy resources presents the characteristics of random distribution.

The renewable energy evaluation method proposed in this paper can evaluate the resource abundance and spatial distribution pattern scientifically and effectively based on the measurement of renewable energy resources. However, this study only evaluates the three major renewable energy resources in Beijing. In the future, more types of energy, such as geothermal energy, can be included to improve the integrity of the evaluation of renewable energy resources.

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