Research on Suitability of Solar Energy Utilization in Public Institutions Across the Country

Yu Shui, Bai Lu and Feng Guohui

Abstract This paper studies the suitability of solar energy utilization in public institutions across the country. The energy consumption of typical building is simulated by DeST, and the energy consumption per unit area of three public institutions in 32 provincial capitals and major cities nationwide are obtained. The energy consumption data is combined with the resources, climate, and economic data obtained from the survey. Principal component analysis and fuzzy cluster analysis are used successively. The MATLAB programming simulation is used to divide the country into ten regions of different appropriate degrees. Forming a map of suitability for solar energy utilization in four different types of public institutions and developing suitability software for solar energy utilization in public institutions across the country as a renewable and clean energy source, solar energy is of great significance to China's economic development and environmental protection. This research provides a theoretical basis for the rational use of solar energy in public institutions across the country.

Keywords Public institution · Solar energy · Suitability partition · MATLAB

1 Introduction

Renewable energy refers to the primary energy that can be continuously regenerated and used continuously from nature. It includes passive energy sources such as solar energy and shallow geothermal energy. They can replace conventional energy sources to a certain extent and become an important way to adjust energy structure [1] (Fig. 1).

To study the suitability of solar energy utilization in public institutions across the country, it is necessary to take into account the national conditions of large land areas, different solar resource richness, significant climate differences, and different

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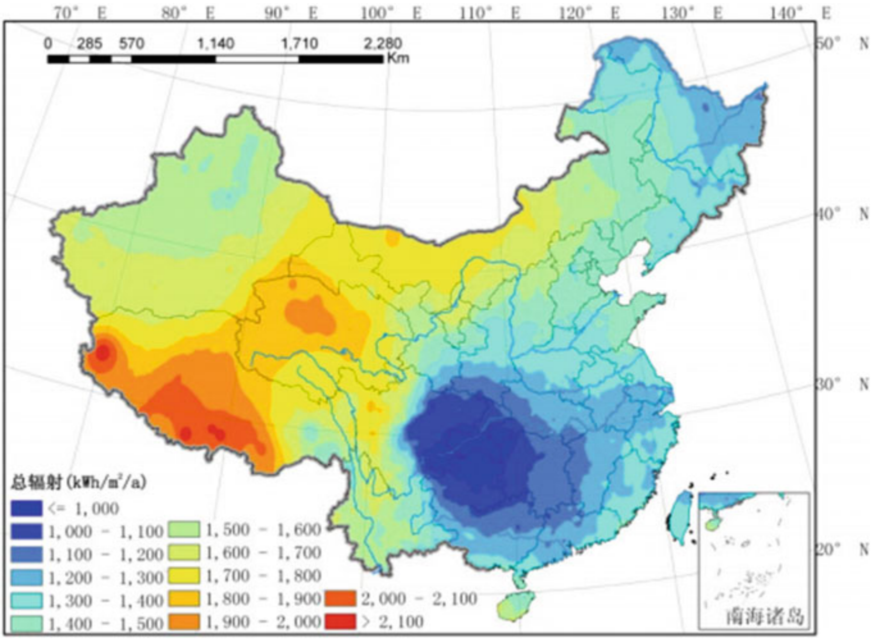

Fig. 1 Solar resource distribution map

levels of economic development in various regions, combined with the energy consumption per unit area of different types of public institutions in different regions. To determine the suitability of solar energy utilization in public institutions, to draw a suitability map of solar energy utilization in public institutions, and to develop appropriate suitability software to provide a theoretical basis for the rational use of solar energy in public institutions across the country.

2 Principal Component Analysis

Above all, the selection of evaluation indicators is carried out. The evaluation index system consists of a series of indicators, which can comprehensively reflect the comprehensive situation of all aspects of the research object. According to the status quo and characteristics of solar energy application in China, we select the evaluation factors that can significantly affect the suitability of solar energy utilization in public institutions in various regions: (1) Solar energy resources: year total solar radiation; (2) Climatic conditions: the coldest month, the hottest month average temperature; (3) Economic situation: fixed assets investment in various regions; (4) Energy consumption: energy consumption per unit area of different types of public institutions across the country [2].

Principal component analysis can try to recombine the original indicators into a new set of relatively independent indicators that reflect the original indicators on the basis of maximally retaining the original data information [3]. Its mathematical model is as follows:

(1) The standardized calculation formula for indicator data is

$$x_{ij}^{*} = \frac{x_{ij} - \overline{x_j}}{s_j}, \quad (i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, p) \tag{1}$$

(2) Calculate the correlation coefficient matrix R of the indicator.

$$R = (r_{ij}), r_{ij} = \frac{1}{n}\sum_{k=1}^{n} x_{ki}^{*} x_{kj}^{*}, \quad (i = 1, 2, \ldots, p) \tag{2}$$

In the middle, $r_{ii} = 1$, $r_{ij} = r_{ji}$, $(i, j = 1, 2, 3\ldots, p)$

(3) Calculate feature values and feature vectors.

(4) Calculate the contribution rate and the cumulative contribution rate.

$$d_i = \frac{\lambda_i}{\sum_{i=1}^{p} \lambda_i}, \quad D_m = \frac{\sum_{i=1}^{m} \lambda_i}{\sum_{i=1}^{p} \lambda_i} \tag{3}$$

(5) Determine the number of principal components.

(6) Calculate the principal component score and the composite score.

$$F = \sum_{i=1}^{m} a_i y_i, \quad (i = 1, 2, \ldots, m) \tag{4}$$

In the middle, a_i is the variance contribution rate of the i-th principal component, and y_i is the i-th principal component score.

Therefore, the principal component analysis method is used to comprehensively analyze the suitability of solar energy utilization in public institutions across the country, the main components of the evaluation index system are screened out, the comprehensive score is obtained, and the degree of suitability is distinguished by the comprehensive level.

3 Fuzzy Clustering Analysis

Fuzzy clustering analysis is a kind of analysis of the fuzzy relationship between things or phenomena affected by many or more factors, and based on this, the similarity between samples is determined according to a certain degree of membership, and the similarity is high [3]. The fuzzy mathematics of the respective clusters of objects. After selecting the principal components by principal component analysis, the comprehensive scores of the principal components are classified according to the fuzzy clustering analysis method. Its mathematical model is as follows [4–6]:

(1) In order to eliminate the influence of dimension on cluster analysis, it is necessary to standardize the data before using cluster analysis, so that each index value is unified in a certain range of common data characteristics.

$$x_{ij}^{*} = \frac{x_{ij} - \bar{x}_j}{s_j}, \quad (i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, m) \tag{5}$$

$$\overline{x_j} = \frac{1}{n}\sum_{i=1}^{n} X_{ij}, \quad s_j = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_{ij} - \overline{x_{ij}}\right)^2} \tag{6}$$

In the middle, X_{ij} and s_j are the mean and standard deviation of the *j*-th variable, respectively.

(2) For the above-mentioned normalization matrix, calculate the similarity degree between each classification object and establish the fuzzy similarity matrix $R = (r_{ij})$. This process is also called calibration. Here, we choose the absolute value subtraction method calibration.

$$r_{ij} = \begin{cases} 1 & \text{when } i = j \\ 1 - c\sum\limits_{k=1}^{m}\left|x_{ik} - x_{jk}\right| & \text{when } i \neq j \end{cases} \tag{7}$$

where c is appropriately selected, the parameters may be 0.1, 0.2, …, and the fuzzy similar matrix $R = (r_{ij})$ may be obtained.

(3) The matrix R obtained from the established fuzzy similarity relationship is only a fuzzy similar matrix, and it is not necessarily transitive. In order to classify, it needs to be transformed into an equivalent matrix. Therefore, the transitive closure $t(B)$ of R is obtained by the flat method, and $t(B)$ is the equivalent matrix obtained.

$$t(B) : R \rightarrow R^2 \rightarrow R^4 \ldots, \text{when } R^p * R^P = R^P, t(B) = R^P \tag{8}$$

(4) After processing the original matrix into a fuzzy equivalence matrix through the above steps, select the appropriate $k \in [0,1]$ and select the best partition result from the different partitioning results obtained by clustering different k values.

4 Research Process

4.1 Principal Component Analysis

Enter the initial evaluation index data matrix x to simulate in the software of Matlab, taking the solar energy suitability of colleges and universities as an example, the process is as follows:

```
x =

1.5850  -11.0000  25.0000  0.6445  37.1300    1.4760    6.0000  30.0000  2.1770  20.1600
1.5690   -3.0000  27.0000  1.1275  15.9300    1.3350    1.0000  27.5000  4.3890  28.7800
1.6770   -3.5000  26.5000  0.8307  27.9700    1.2670    3.0000  28.5000  2.8816  23.9800
1.3140    4.5000  28.5000  0.7247  12.8100    1.3930   11.5000  29.5000  2.6110  14.0900
1.0750    8.0000  29.0000  1.7440  19.6700    1.4340  -13.5000  23.0000  1.1080  50.2400
1.4670   13.5000  28.5000  2.6110   9.7700    1.5660   -2.0000  27.5000  3.3012  27.0100
1.3990   14.0000  29.0000  3.7403  10.4700    1.3930    9.0000  20.5000  1.8474  10.8500
1.3480    4.0000  29.5000  3.1873  16.0300    1.6780   13.5000  29.0000  1.9908  14.2200
1.5410  -15.0000  23.5000  1.3131  46.4600    1.1620    5.5000  24.5000  1.5288  19.4900
1.1980    0.5000  27.0000  2.3468  19.2800    1.5230   -5.5000  24.0000  0.5722  29.3900
1.2180    4.5000  29.0000  3.1126  20.1600    1.6430  -13.0000  24.5000  1.1796  48.8500
1.5090   -0.5000  27.5000  5.4236  27.7300    1.4580   -5.0000  23.0000  0.5696  30.4600
1.3590    5.5000  30.0000  3.1328  22.4100    1.5250   18.5000  29.5000  0.4125  11.7800
1.6300  -11.0000  22.0000  1.3828  40.6300    1.6080   -6.5000  18.0000  0.3820  34.0500
1.3570    3.0000  28.8000  5.3000  22.5400    1.5840   -7.5000  24.0000  0.3640  32.2700
1.0250    6.5000  26.0000  3.1236  19.0300    1.6180   -1.0000  16.5000  0.1976  19.5900
```

The MATLAB programming simulation of principal component analysis was performed, and the simulation results were as follows:

```
result_report =

 2.7993   0.9354   0.5926   4.3274  27.0000   -1.3125   0.6046   0.3228  -0.3851  13.0000
 2.6909   1.0712  -0.0368   3.7253   9.0000    2.0417  -1.9767  -0.6341  -0.5690  32.0000
 2.6553   1.2223  -0.6523   3.2254  21.0000   -1.0372  -1.2624   1.6511  -0.6485  24.0000
 2.5636   0.3899   0.2554   3.2089  14.0000   -1.0297   0.7196  -0.3849  -0.6950  19.0000
 2.1151   0.1864   0.2843   2.5859   1.0000   -1.4748   0.3837   0.1973  -0.8939   8.0000
-0.6692   1.7417   1.0929   2.1655  12.0000   -1.5186   0.6944  -0.5185  -1.3427  11.0000
 0.0676   0.7203   1.0108   1.7987  22.0000   -0.8982   0.3767  -1.0302  -1.5517  10.0000
 1.2158  -0.5432   1.0146   1.6871   3.0000   -1.7632  -0.3904   0.3826  -1.7711  20.0000
 1.8933  -0.4015   0.1301   1.6218  31.0000   -2.2898  -0.2084   0.5543  -1.9438   7.0000
 2.7411  -0.8384  -0.4957   1.4070  30.0000   -1.7833  -0.8789   0.6372  -2.0251   6.0000
 1.4610  -0.4339  -0.1255   0.9016  26.0000   -0.9441  -0.9262  -0.5072  -2.3775   4.0000
-0.8168   1.5356   0.0667   0.7855  18.0000   -0.7267  -0.3427  -1.6220  -2.6915  25.0000
-1.5715   1.6263   0.5030   0.5578  15.0000   -0.3807  -1.4349  -0.9029  -2.7185  23.0000
 1.4692  -0.3758  -0.5711   0.5223  28.0000   -1.4261  -2.0380   0.7266  -2.7374  29.0000
 0.2824  -0.7776   0.5840   0.0888   2.0000   -1.7149   0.6488  -1.8416  -2.9077  16.0000
-0.9394  -0.1490   0.7483  -0.3401  17.0000   -1.6998   0.1212  -1.4316  -3.0102   5.0000
```

The first three columns of the matrix represent the scores of the first three principal components of the original evaluation index, the fourth column represents the composite score of the principal component, and the last column represents the city code. The comprehensive score is positive, indicating that the city's solar energy suitability is higher than the average level; the comprehensive score is negative, indicating that the city's solar energy suitability is lower than the average. The higher the score, the more appropriate, the lower the corresponding score, the less appropriate.

4.2 Fuzzy Clustering Analysis

The scores of the first three principal components in the matrix of the above graph, which are the initial matrix *x* of MATLAB in the fuzzy clustering analysis method, are simulated as follows [7, 8]:

x =

2.7993	0.9354	0.5926	-1.3125	0.6046	0.3228
2.6909	1.0712	-0.0368	2.0417	-1.9767	-0.6341
2.6553	1.2223	-0.6523	-1.0372	-1.2624	1.6511
2.5636	0.3899	0.2554	-1.0297	0.7196	-0.3849
2.1151	0.1864	0.2843	-1.4748	0.3837	0.1973
-0.6692	1.7417	1.0929	-1.5186	0.6944	-0.5185
0.0676	0.7203	1.0108	-0.8982	0.3767	-1.0302
1.2158	-0.5432	1.0146	-1.7632	-0.3904	0.3826
1.8933	-0.4015	0.1301	-2.2898	-0.2084	0.5543
2.7411	-0.8384	-0.4957	-1.7833	-0.8789	0.6372
1.4610	-0.4339	-0.1255	-0.9441	-0.9262	-0.5072
-0.8168	1.5356	0.0667	-0.7267	-0.3427	-1.6220
-1.5715	1.6263	0.5030	-0.3807	-1.4349	-0.9029
1.4692	-0.3758	-0.5711	-1.4261	-2.0380	0.7266
0.2824	-0.7776	0.5840	-1.7149	0.6488	-1.8416
-0.9394	-0.1490	0.7483	-1.6998	0.1212	-1.4316

After the fuzzy clustering analysis MATLAB programming simulation, a 32 * 32 [0,1] distribution matrix can be obtained, the cities corresponding to the same distribution are divided into one region, and ten regions with different degrees of appropriateness can be obtained. Combined with the comprehensive scores of the principal components of each city obtained by principal component analysis, the average score of the principal components of each region is calculated, the solar energy suitability zoning is obtained, and the solar utilization suitability distribution map of the public institutions in the country is formed.

5 Research Results

University solar energy suitability (Fig. 2; Table 1).

6 Result Analysis

It can be seen from the above research results that because the energy consumption per unit area of different types of public institutions is different, the corresponding

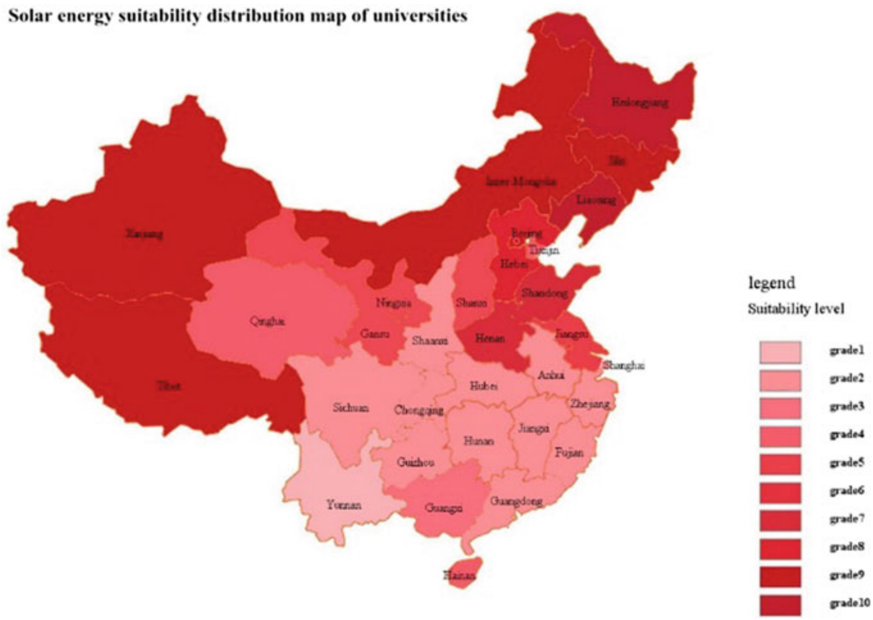

Fig. 2 Solar energy suitability distribution map of universities

Table 1 Average scores of university solar energy districts

Region	Average score
Shenyang (Liaoning), Harbin (Heilongjiang)	2.906
Changchun (Jilin), Urumqi (Xinjiang), Hohhot (Inner Mongolia), Lhasa (Tibet)	2.673
Shijiazhuang (Hebei)	1.799
Jinan (Shandong), Zhengzhou (Henan)	1.476
Beijing, Taiyuan (Shanxi), Lanzhou (Gansu Province), Yinchuan (Ningxia)	1.183
Nanjing (Jiangsu)	0.558
Xining (Qinghai), Tianjin, Haikou (Hainan)	−0.414
Shanghai, Nanning (Guangxi)	−1.513
Nanchang (Jiangxi), Changsha (Hunan), Hefei (Anhui), Wuhan (Hubei), Hangzhou (Zhejiang), Xi'an (Shaanxi), Fuzhou, Xiamen (Fujian), Guangzhou (Guangdong), Guiyang (Guizhou), Chengdu (Sichuan), Chongqing	−1.630
Kunming (Yunnan)	−2.719

suitability distribution map is also different. The research on the suitability of solar energy utilization in public institutions across the country provides a theoretical basis for the rational use of solar energy in public institutions across the country.

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References

1. Yi, S.: The Spatial Distribution of Solar Energy in China and the Comprehensive Potential Evaluation of Regional Development and Utilization. Lanzhou University (2014)
2. Qiang, Gong, et al.: Solar energy resource assessment and applicability analysis of NASA data in Liaoning Province. China Electr. Power **51**(02), 105–111 (2018)
3. Xie, H., et al.: Comprehensive evaluation of suitability of solar forced installation areas. J. Chongqing Univ. **34**(S1), 93–99 (2011)
4. Beaula, T.J.P.: Risk assessment of natural hazards in Nagapattinam District using fuzzy logic model. Int. J. Fuzzy Logic Syst. **3**(3), 27–37 (2013)
5. Leonardi, G., Palamara, R., Cirianni, F.: Landslide susceptibility mapping using a fuzzy approach. Procedia Eng. **161** (2016)
6. Barrile, V., Cirianni, F., Leonardi, G., et al.: A fuzzy-based methodology for landslide susceptibility mapping. Procedia—Soc. Behav. Sci. **223** (2016)
7. Rahmati, O., Zeinivand, H., Besharat, M.: Flood hazard zoning in Yasooj region, Iran, using GIS and multi-criteria decision analysis. Geomatics, natural hazards and risk, 2016, 73: Author, F.: Contribution title. In: 9th International Proceedings on Proceedings, pp. 1–2. Publisher, Location (2010)
8. Pradhan, B.: Use of GIS-based fuzzy logic relations and its cross application to produce landslide susceptibility maps in three test areas in Malaysia. Environ. Earth Sci. **63**, 329–349 (2011)

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