Research on Distributed Photovoltaic Construction Using Entropy-Weighted TOPSIS Analysis

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Abstract. The promotion of photovoltaic construction is an important link affecting the development of the photovoltaic supply chain. The whole-county promotion of distributed photovoltaic can effectively alleviate the socio-ecological problems of environmental pollution and power tension, but given the late start of the distributed photovoltaic industry, most areas in China are currently not building regional distributed photovoltaic, so the whole-county promotion of distributed photovoltaic is imminent. In this paper, the list of whole-county photovoltaic regions announced by the National Energy Administration, 16 counties were selected as research objects according to spatial geographic location, economic development and natural environment, and the entropy-weight-TOPSIS model was used to evaluate the priority level of whole-county distributed photovoltaic promotion. The results show that: areas with high industrial power demand, sufficient light and good development of local photovoltaic enterprise industry chain can be prioritized for whole-county distributed photovoltaic construction.

Key words: Distributed photovoltaic construction ; TOPSIS analysis ; The photovoltaic supply chain; Entropy power-TOPSIS model

1. Introduction

With the improvement of China's economic level, the scale of industrial enterprises continues to expand, and the demand for electricity from the rapid development of enterprises is also growing rapidly. Although traditional thermal power generation can solve the problem of power supply, it also brings more serious problems such as resource loss, environmental pollution and climate change.

In 2021, many places in the country will have power supply restrictions due to the shortage of coal supply and "energy consumption double control" and other factors, and the pressure on power supply is increasing. Solar energy is widely distributed, and the annual solar radiation is equivalent to 130 trillion tons of standard coal. If we can make good use of renewable resources, we can greatly reduce energy tension and improve environmental pollution. In December 2020, General Secretary Xi Jinping mentioned in his speech at the Climate Ambition Summit that China strives to achieve the carbon neutrality target by 2060, and the total installed capacity of solar power reaches more than 1.2 billion kW. Photovoltaic as an important carrier of effective use of solar energy resources, has the advantages of environmental cleanliness, easy to be consumed, and distributed photovoltaic does not require the establishment of distribution stations, lower transmission and installation costs, better economic benefits, is an important area

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of future domestic photovoltaic market applications [1]. In view of the need to develop distributed photovoltaic, the national level has also given high attention and introduced relevant policies. In 2013, China clarified the principle that the government should strongly support the photovoltaic industry and promote the development of new energy sources. Therefore, it becomes particularly important to judge the priority of the whole county to promote distributed photovoltaic construction.

In recent years, scholars' research on distributed photovoltaic has focused on the following perspectives. From the perspective of economic efficiency, scholars have studied 331 cities in China and used methods such as cost-benefit to establish an economic analysis model for distributed photovoltaic. Based on the calculation results, it is concluded that the economic development of photovoltaic is influenced by geographical differences, and the national regions can be targeted into four classes for the development of distributed photovoltaic. In addition, we also establish a model for evaluating the economics of grid-parity photovoltaic projects in terms of internal rate of return, analyse several factors affecting the evaluation of the economics of photovoltaic power projects, and give countermeasures and suggestions from both government and enterprises. From the perspective of distributed photovoltaic site-setting research, comprehensive planning in terms of economy, environment and safety and reliability is needed. For distributed photovoltaic spatial geography to promote construction, the establishment of a dynamic monitoring mechanism based on satellite remote sensing of national distributed photovoltaic construction, that hierarchical classification to promote the construction of photovoltaic, should start construction from the more densely populated eastern regions.

Ding et al. proposed the concept and method of distributed power cluster planning, established a coordinated siting and capacity planning model for distributed photovoltaic and energy storage in two layers, and verified the feasibility of the siting planning model. From the perspective of distributed photovoltaic construction potential, different scholars have conducted targeted studies on the factors affecting distributed photovoltaic construction. Yuan Jindou et al. concluded that distributed photovoltaic development is mainly influenced by factors such as technology cost, resource abundance, power capacity demand, and policy subsidies [2]. Cai Yongzhi et al. analyzed the factors influencing residents' willingness to install photovoltaic equipment on rooftops through the DEMATEL-ISM model, and the results showed that the most fundamental factors for residents' willingness to install are photovoltaic regulations and subsidies [3]. Yanan Liu et al. used the peak sunshine hours method and the modeling method of sunshine hours and power generation to estimate the rooftop solar power generation in Inner Mongolia and concluded that there is a good linear relationship between sunshine hours and power generation [4]. Lv Tao et al. used fuzzy comprehensive evaluation and entropy power method to evaluate the photovoltaic resource utilization level of 31 provinces in China in 2015, and divided four development areas, namely, optimized adjustment area, key development area, potential development area and orderly development area, based on the actual situation of photovoltaic resource utilization [5].

The above studies have analyzed distributed photovoltaic from different perspectives, but the existing literature is more focused on the mechanism of distributed photovoltaic and the prospect of macro distributed photovoltaic development, while few studies have been conducted on regional promotion and construction, and the literature on the promotion of distributed photovoltaic in whole counties is even scarcer. Therefore, in this paper, we analyze the factors affecting the whole-county promotion of distributed photovoltaic, establish an evaluation index

system for the promotion of distributed photovoltaic, and construct an entropy-weight-TOPSIS model to analyze the whole-county promotion of distributed photovoltaic. This will provide a reference for other regions to promote photovoltaic planning and construction in the whole county.

2. Evaluation index system construction

There are numerous factors affecting the priority of distributed PV whole county promotion, which are reflected in natural resource conditions, regional economic development level, equipment enterprise development level, social industrial electricity consumption and roof available area. Wang Guanghui et al. concluded through their study that the roof area is positively correlated with the number of population, with a correlation coefficient greater than 0.84, so the examination of the roof area can be analyzed in terms of the regional population. From the viewpoint of the convenience of acquiring the necessary equipment components for PV construction, it is necessary to examine the number of PV enterprises that can provide PV modules within the region, the more the number of local enterprises, the simpler the process of purchasing and installing distributed PV, the more conducive to fully promote the development of PV construction, by the development of the PV supply chain, the production, transportation, and sales of PV modules will also generate a large amount of carbon dioxide, making the distributed PV construction The environmental performance of the distributed PV construction decreases, so when considering the development of the PV industry, it is more favorable to adopt the concept of local construction and local use. The constructed index system is shown in Table 1.

Table 1 Distributed photovoltaic whole county promotion construction index system

Primary Indicator	Secondary Indicator	Explanation of Indicator	Data source
Regional economic development level	Total regional GDP (billion yuan)	Reflecting the level of regional economic development	Statistical Yearbook of each region
	GDP per capita (Yuan)	Reflects per capita disposable income	
	Gross industrial product (billion yuan)	Gross industrial product reflects industrial development capacity, industrial production and electricity consumption are closely related	
Photovoltaic enterprise development	Number of photovoltaic enterprises (pcs)	When examining the development of the photovoltaic industry, the concept of local construction and local	Network census data

Social industrial electricity consumption	Industrial electricity consumption (billion kWh)	use is preferred, and priority is given to counties or cities with photovoltaic industries within the city to promote distributed photovoltaic construction Electricity consumption for industrial development, reflecting regional electricity demand	Statistical Yearbook of each region
Natural resource conditions	Annual effective utilization time of sunlight (h)	The longer the annual effective utilization time of light, the more suitable for the promotion of distributed photovoltaic construction	Network census data / Meteorological Bureau related statistics
Regional population	Total population of the region (persons)	The number of people living in the region, the more the population, the greater the demand for electricity.	Announcement of the 7th National Population Census

3. Entropy-TOPSIS model construction

In this paper, we establish an evaluation index system for promoting the priority of distributed PV development, using the entropy-weighted-TOPSIS model, and firstly construct the original data matrix $R=(r_{ij})_{mn}$ consisting of city node m and evaluation index n, where r_{ij} is the original value of the data.

$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{1}$$

Normalize the original data:

$$R_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \tag{2}$$

The normalized matrix $\overline{R}$. is obtained after the processing is completed:

$$\overline{R} = \left(R_{ij}\right)_{mn} = \begin{bmatrix} R_{11} & R_{21} & \cdots & R_{m1} \\ R_{12} & R_{22} & \cdots & R_{m2} \\ \vdots & \vdots & & \vdots \\ R_{1n} & R_{2n} & \cdots & R_{mn} \end{bmatrix} \tag{3}$$

Calculation of the entropy value:

Note: P_{ij} is the weight of the j th indicator of the i th city.

$$P_{ij} = \frac{R_{ij}}{\sum_{j=1}^{n} R_{ij}} (i = 1, 2, \cdots, m; j = 1, 2, \cdots, n) \tag{4}$$

Entropy value:

$$e_j = -k \sum_{j=1}^{n} P_{ij} \ln P_{ij} \left(i = 1, 2, \cdots, m; k = \frac{1}{\ln m} \right) \tag{5}$$

e_j is the entropy value of the j th index, e_j is not greater than 1 and k is greater than 0.

Calculation of weights:

$$g_j = 1 - e_j \tag{6}$$

$$w_j = \frac{g_j}{\sum_{j=1}^{n} g_j} (j = 1, 2, \cdots, n) \tag{7}$$

w_j is the weight of the j th indicator, g_j is the coefficient of variability of the j th indicator, the greater the entropy value of the indicator, the smaller the coefficient of variability, the greater its weight, and the greater the impact on the distributed PV development produced. The weight matrix A is shown in equation (8).

$$A=\begin{bmatrix} w_1 & 0 & \cdots & 0 \\ 0 & w_2 & \cdots & 0 \\ \vdots & \vdots & & \vdots \\ 0 & 0 & \cdots & w_n \end{bmatrix} \tag{8}$$

Construct the normalized weighting matrix V :

$$V=A\cdot\overline{R}\begin{bmatrix} w_1R_{11} & w_1R_{21} & \cdots & w_1R_{m1} \\ w_2R_{12} & w_2R_{22} & \cdots & w_2R_{m2} \\ \vdots & \vdots & & \vdots \\ w_nR_{1n} & w_nR_{2n} & \cdots & w_nR_{mn} \end{bmatrix} \tag{9}$$

Let the positive ideal solution V^+ denote the most preferred solution and the negative ideal solution V^- denote the least preferred solution.

Positive indicator :

Positive ideal solution

$$V^+=\left\{\max V_{ij}\mid i=\quad m\right\}=\{V_1^+,V_2^+,\cdots,V_m^+\} \tag{10}$$

Negative ideal solution

$$=\left\{\min V_{ij}\mid i=1,2,\cdots,m\right\}=\left\{V_1^-,V_2^-,\cdots,V_m^-\right\} \tag{11}$$

Negative indicator :

Positive ideal solution

$$V^-=\left\{\min V_{ij}\mid i=1,2,\cdots,m\right\}=\left\{V_1^-,V_2^-,\cdots,V_m^-\right\} \tag{12}$$

Negative ideal solution

$$V^+=\left\{\max V_{ij}\mid i=1,2,\cdots,m\right\}=\{V_1^+,V_2^+,\cdots,V_m^+\} \tag{13}$$

The distance between each city and the positive and negative ideal solution is calculated:

Distance of positive ideal solution

$$D_i=\sqrt{\sum_{i=1}^{m}\left(v_{ij}-v_j^+\right)^2}\,(i=1,2,\cdots,m) \tag{14}$$

Distance of negative ideal solution

$$D_i = \sqrt{\sum_{i=1}^{m}\left(v_{ij} - v_j^-\right)^2}\ (i = 1, 2, \cdots, m) \tag{15}$$

Calculate posting progress:

$$T_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{16}$$

Finally, the value of D_i is calculated for each city, the larger the D_i, the more favorable the region is to the construction of distributed PV, the higher the priority level of promoting the construction of the whole county, according to the size of the relative posting progress, the ranking of each county, then get the final priority level of the whole county to promote the construction of distributed PV.

4. Empirical analysis

According to the pilot list given in the "Notice of the Comprehensive Department of the National Energy Administration on the Submission of Pilot Programs for Rooftop Distributed Photovoltaic Development in Whole Counties (Cities and Districts)" issued by the National Energy Administration [6], 16 counties and districts were selected for the study, using data from 2020, among which Changfeng, Pingyang and Qihe counties were selected in East China, Suning and Fengzhen counties in North China, Northeast China are Donggang and Bei'an, Southwest China are Wanzhou, Xinyi and Yiliang counties, Northwest China are Yuyang and Huating, Central China are Chibi, and South China are Beiliu, Yazhou and Chaoan. These counties and districts are better developed and representative in the respective regions they belong to. For the constructed index system, based on the relevant index data of the counties and districts, the entropy-weight-TOPSIS model is applied to evaluate the overall situation of the above-mentioned counties and districts in terms of PV suitable for promoting construction, and the ranking of the comprehensive development level of distributed PV in the above-mentioned counties and districts is calculated, as shown in Table 2.

Table 2 Distributed PV development level comprehensive ranking

Ranking	City	Proximity	Ranking	City	Proximity
1	Yuyang district	0.9685	9	Suning county	0.2140
2	Changfeng county	0.5653	10	Beiliu city	0.2060
3	Xinyi city	0.3518	11	Donggang city	0.1874
4	Chibi city	0.3357	12	Fengzhen city	0.1393

5	Pingyang county	0.3342	13	Yiliang county	0.0982
6	Qihe county	0.3298	14	Bei'an city	0.0976
7	Yazhou district	0.3167	15	Huating city	0.0758
8	Chaoan district	0.2789	16	Wangcang county	0.0706

Based on this ranking, the 16 counties can be divided into four levels:

The first level is Yuyang District and Changfeng County. Yuyang district is located in Shaanxi, covers a large area, has sufficient light, abundant solar energy resources, and broad prospects for the development and utilization of light , and Yuyang district has developed industry, high industrial demand for electricity, and adequate development of PV industry, with the necessary natural and social resource conditions for distributed PV development, so the priority of installing distributed PV is the highest among the selected regions. Changfeng County is located in Hefei, Anhui Province, with a high comprehensive competitiveness of the county economy, high per capita GDP and disposable income, and many PV enterprises in the region, a well-developed PV supply chain, convenient transportation, and well-developed infrastructure, which is suitable for the installation of distributed PV.

The second level is Xinyi City, Chibi City, Pingyang County and Qihe County. The city of Xinyi is located in Guizhou, rich in solar energy resources, with a large population and a large demand for industrial electricity, and the region has a large number of enterprises installing PV modules, which is conducive to the promotion of PV work in the whole county, but it is located in the mountainous region, the climate is variable, and the assessment of solar energy resources should be done in a targeted manner when installing distributed PV. Chibi City is located in Hubei, with good industrial development, high level of economic development and high demand for electricity. Promoting PV in the whole county can alleviate the pressure of electricity consumption to a greater extent and save the consumption of coal and other thermal power generation natural resources, therefore, the whole county PV promotion work is urgently needed. Pingyang County and Qihe County is located in East China region, the high level of economic and industrial development, electricity consumption, natural resources, light is more abundant, and more photovoltaic enterprises, is conducive to the first development of distributed PV.

The third level is Yazhou District, Chaoan District, Suning County and Beiliu City. Yazhou District is located in Sanya City, Hainan, rich in solar energy resources, and there are many PV enterprises in the region, which is convenient for the installation of distributed PV. Chaoan District is located in Chaozhou City, Guangdong, developed industry, industrial electricity consumption, a large population, convenient transportation, can provide favorable equipment conditions for the whole county to promote distributed PV. Suining County is located in Hebei, abundant light, heat, solar radiation throughout the year, conducive to the construction and development of distributed photovoltaic, and the regional economic level is high, for the purchase of distributed photovoltaic equipment and installation work is more favorable. Beiliu city is located in Guangxi, a large population, distributed PV installation required roof resources are abundant, but the number of photovoltaic enterprises in the jurisdiction is limited, PV supply chain development is relatively lagging behind, to the local installation of distributed PV work

caused some difficulties. The fourth level is Donggang City, Fengzhen City, Yiliang County, Bei'an City, Huating City and Wangcang County, these regional indicators do not have advantages compared to other regions, and the slow development of the PV industry chain, production capacity can not fully support the whole county of distributed PV promotion work. Their indicators are ranked low compared to other regions, so the priority of distributed PV whole-county promotion obtained after data processing by entropy weight-TOPSIS model is also relatively low.

5. Conclusion

This paper constructs the evaluation index system and entropy power TOPSIS model for promoting the priority of distributed PV construction to get the priority promotion development level of the selected counties. The whole county promotion construction of distributed PV involves more investigation indexes, and the level of local economy and industrial development and PV industry chain development are significant investigation factors. However, this paper has limitations in obtaining data, and does not consider government subsidies, residents' acceptance of distributed PV and other indicators, subsequent research for distributed PV promotion and construction can consider the influence of these indicators.

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