Investment Evaluation of Distributed Photovoltaic Power Generation Project Based on TOPSIS-Gray Correlation Analysis

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Abstract. Due to its unique construction mode and operation structure, distributed photovoltaic power generation projects show the particularity of their investment characteristics, which are different from the general construction projects. This paper established a relatively systematic and comprehensive investment evaluation system, formulated investment evaluation criteria for various factors affecting this type of project, and established an investment evaluation model based on entropy weight method, TOPSIS method and grey correlation analysis method. At last, an empirical analysis was carried out on the RG company distributed photovoltaic power generation project, the RG investment is evaluated. This finding will provide a guidance and reference to help distributed photovoltaic industry to form correct investment strategy.

1. Introduction
Distributed photovoltaic power generation projects in China are greatly influenced by national policy, market environment, and sensitive to the the natural environment where the project is located, feed-in tariff, photovoltaic conversion components, KWH subsidy and construction investment cost, it is necessary to evaluate distributed photovoltaic power generation project investment effects. At present, the research on photovoltaic power generation projects in China is mainly focused on photovoltaic power stations, but there are few researches on distributed photovoltaic power generation projects. However, with the rapid development of distributed photovoltaic power generation projects, the research and analysis on the unique characteristics of this type of projects has become more urgent [1, 2].

2. Construction Investment Evaluation System of Distributed Photovoltaic Power Generation Project

2.1. Construct the Investment Evaluation System
Considering the photovoltaic projects important influence on the environmental benefit and social benefit, this paper constructs the investment evaluation system by three level indicators and 12 secondary indicators of distributed photovoltaic investment evaluation system, as shown in table 1.

2.2. Determine the Influencing Factors Related to Investment Evaluation
The criteria for influencing factors of the project is shown in table 2 [3].
(1) Peak electricity price

According to Chinese Shandong province, Hebei, Jiangsu, Zhejiang and other places of the electric power grid sales price list issued by the industry and commerce and other electricity peak electricity prices, according to the third kind of solar energy resources in peak electricity price range of 0.95 ~ 1.10 yuan/degree, so the price interval as project peak price evaluation standard.

(2) Conversion rate of photovoltaic modules

At present domestic main solar photovoltaic components manufacturers association, select the components under different power conversion rate is 16.8-17.7%, and so will be the component conversion rate interval.

Table 1. Distributed photovoltaic power generation investment evaluation system.

| Level indicators       | The secondary indicators                      |
|------------------------|-----------------------------------------------|
| Economic benefit C1    | Total return on investment C11                |
|                        | Payback period C12                            |
|                        | Financial NPV C13                             |
|                        | Financial internal rate of return C14         |
|                        | Loan repayment period C15                     |
|                        | Interest provision rate C16                   |
|                        | Debt service provision rate C17               |
|                        | Break-even point C18                          |
| Environmental benefit C2| The average annual coal saving is C21         |
|                        | Annual emission reduction C22                 |
| Social benefit C3      | Enterprise new energy electric energy ratio C31|
|                        | The photovoltaic coverage rate of the park is C32|

Table 2. Criteria for influencing factors.

|                          | Outstanding | Good | Medium | Poor |
|--------------------------|-------------|------|--------|------|
| Peak price (yuan/KWH)    | 1.10        | 1.05 | 1.00   | 0.95 |
| Pv module conversion rate (%) | 17.7       | 17.4 | 17.1   | 16.8 |
| Unit price of construction investment (yuan/watt) | 5.4       | 5.9  | 6.4    | 6.9  |
| Annual salary and benefits (10,000 yuan/year) | 12.0      | 14.4 | 16.8   | 19.2 |

(3) Unit price of construction investment

The third kind of solar energy resources area distributed photovoltaic power generation project of solar energy resources are relatively weak, the requirements of environmental protection is strict, so compared with the first and second type solar energy resources area construction investment cost is higher, generally between 5.4-6.9 yuan/watt (with the exception of “leader” and other pv projects), and therefore the construction investment unit price range as an evaluation standard of project construction investment unit price.

(4) Annual salary and benefits

Based on the per capita salary data of power industry in Hebei, Shandong, Jiangsu and other places in eastern China published by the national bureau of statistics, the per capita salary and benefit of distributed photovoltaic power generation in the third type of solar resource area is between 120 and 192 thousand yuan. Therefore, this salary and benefit range is taken as the evaluation standard of the project’s annual salary and benefit.
3. Model Construction

3.1. Establish the Original Investment Evaluation Matrix
Each column of the matrix represents a project to be evaluated, and each row represents an evaluation index of each project to be evaluated. Assuming that there are several projects to be evaluated and several evaluation indicators, the original evaluation matrix constructed is as follows [4]:

\[ R = (r_{ij})_{m \times n} = \begin{pmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{pmatrix} \] (1)

\( i=1,2,\ldots,m, \ j=1,2,\ldots,n. \ r_{ij} \): the \( j \)th evaluation index of the \( i \)th item to be evaluated.

3.2. Determine the Weight of Each Investment Evaluation Index
After constructing the original investment evaluation matrix, entropy weight method is used to calculate the weight of each investment evaluation index. First, the original investment evaluation indicators are standardized, and the standardized treatment methods are as follows:

\[ x_{ij} = x_{ij} / \sum_{i=1}^{m} x_{ij} \] (2)

\[ X = (x_{ij})_{m \times n} = \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix} \] (3)

Secondly, the information entropy \( e_j \) of the standardized indicators \( x_{ij} \) is calculated as follows:

\[ e_j = -\sum_{i=1}^{m} x_{ij} \ast \ln x_{ij} \] (4)

Then, the information entropy of each investment evaluation index is normalized to obtain the weight of each investment evaluation index:

\[ w_j = (1 - e_j) / (j - \sum_{j=1}^{n} e_j) \] (5)

3.3. Calculate the Distance between Each Item and the Positive and Negative Ideal Solution [6]
After obtaining the weight of each investment evaluation index, TOPSIS method can be used to calculate the Euclidean distance between each project to be evaluated and the positive and negative ideal solution. First, calculate the standardized value of weight:

\[ y_{ij} = w_j \ast x_{ij} \] (6)

\[ y_{ij} \]: the normalized value of weight.

The weighted standardized investment evaluation matrix is as follows:

\[ Y = (y_{ij})_{m \times n} = \begin{pmatrix} y_{11} & \cdots & y_{1n} \\ \vdots & \ddots & \vdots \\ y_{m1} & \cdots & y_{mn} \end{pmatrix} \] (7)

Secondly, the positive ideal solution \( A^+ \) and the negative ideal solution \( A^- \) are determined according to the weight standardization matrix:

\[ A^+ = (\max_{j \in J_1}, (\min_{j \in J_2} y_{ij}) | j \in J_2) = y_1^+, y_2^-, \ldots, y_n^+ \] (8)

\[ A^- = (\min_{j \in J_1}, (\max_{j \in J_2} y_{ij}) | j \in J_2) = y_1^-, y_2^+, \ldots, y_n^- \] (9)

\( J_1 \): the optimal value of the \( i \)th index of each project to be evaluated; \( J_2 \): the worst value of the \( i \)th index of each project to be evaluated; Finally, the Euclidean distances from the items to be evaluated to the positive and negative ideal solutions are calculated. Given that the distance between each project
to be evaluated and the positive ideal solution and the negative ideal solution is $S^*_i$ and $S^-_i$ respectively:

$$S^*_i = \sqrt{\sum_{j=1}^{n}(y_{ij} - y^*_j)^2}$$  \hspace{1cm} (10)$$

$$S^-_i = \sqrt{\sum_{j=1}^{n}(y_{ij} - y^-_j)^2}$$  \hspace{1cm} (11)$$

3.4. Calculate the Grey Correlation between Each Item and the Positive and Negative Ideal Solution [7, 8]

The positive ideal solution and negative ideal solution are taken as the reference sequence of each project to be evaluated, and the second-order maximum difference and second-order minimum difference between the standardized investment evaluation matrix of each project to be evaluated and the positive ideal solution are obtained. Then the correlation coefficient $\xi^*_j$ and the negative ideal solution $\xi^-_j$ of each project to be evaluated are calculated, which can be calculated by the following formula:

$$\xi^*_j = \frac{\min_{i=1}^{m_1} \min_{i=1}^{m_2} |y^*_i - y_{ij}| + \rho \max_{i=1}^{m_1} \max_{i=1}^{m_2} |y^*_i - y_{ij}|}{\max_{i=1}^{m_1} \max_{i=1}^{m_2} |y^*_i - y_{ij}|}$$  \hspace{1cm} (12)$$

$$\xi^-_j = \frac{\min_{i=1}^{m_1} \min_{i=1}^{m_2} |y^-_i - y_{ij}| + \rho \max_{i=1}^{m_1} \max_{i=1}^{m_2} |y^-_i - y_{ij}|}{\max_{i=1}^{m_1} \max_{i=1}^{m_2} |y^-_i - y_{ij}|}$$  \hspace{1cm} (13)$$

$\rho$: the discrimination coefficient, [0, 1], which is selected by the investment evaluator after comprehensive consideration.

Finally, the grey correlation degree between each project to be evaluated and the positive ideal solution and the negative ideal solution is calculated as follows:

$$R^*_i = \frac{1}{n} \sum_{j=1}^{n} \xi^*_j$$  \hspace{1cm} (14)$$

$$R^-_i = \frac{1}{n} \sum_{j=1}^{n} \xi^-_j$$  \hspace{1cm} (15)$$

3.5. Calculate the Relative Progress of Each Project and the Positive and Negative Ideal Solution

Firstly, the dimensionless processing was carried out for each project to be evaluated with the Euclidean distance value and grey relational value of positive ideal solution and negative ideal solution:

$$U^*_i = \frac{R^*_i}{\max_{i=1}^{m} R^*_i}$$  \hspace{1cm} (16)$$

$$U^-_i = \frac{R^-_i}{\max_{i=1}^{m} R^-_i}$$  \hspace{1cm} (17)$$

$$V^*_i = \frac{S^*_i}{\max_{i=1}^{m} V^*_i}$$  \hspace{1cm} (18)$$

$$V^-_i = \frac{S^-_i}{\max_{i=1}^{m} V^-_i}$$  \hspace{1cm} (19)$$

$U^*_i$ and $U^-_i$ are the gray correlation degree after dimensionless. $V^*_i$ and $V^-_i$ are the Euclidean distance after dimensionless.

Then, the influence of Euclidean distance and gray correlation degree is comprehensively considered, and the following is calculated:

$$T^*_i = \alpha_1 U^*_i + \alpha_2 V^*_i$$  \hspace{1cm} (20)$$
\[ T_i^- = \alpha_1 U_i^- + \alpha_2 V_i^+ \]  

(21)

\( \alpha_1 \) and \( \alpha_2 \) represents the preference degree of decision-makers for Euclidean distance and grey correlation degree respectively, and the specific distribution shall be selected by the investment evaluator after comprehensive consideration.

Finally, the relative closeness between each project to be evaluated and the positive ideal solution is calculated:

\[ \delta_i = \frac{T_i^+}{T_i^+ + T_i^-} \]  

(22)

4. Model Application

RG is a traditional mechanical processing and manufacturing enterprise in Shandong province, plans to invest and build a distributed photovoltaic power generation project in the company park. Equation (1) is used to construct the original investment evaluation matrix of the five projects to be evaluated, as shown in table 3.

Equations (2)-(5) were used to calculate the information entropy and weight (shown in table 4).

| Table 3. Original investment evaluation matrix of the project. |
|-----------------|------|-------|-------|------|--------|
|                | Outstanding | Good | Medium | Poor | RG project |
| C11            | 14.66        | 11.86 | 9.51  | 7.53 | 10.71    |
| C12            | 5.32         | 6.3   | 7.49  | 8.98 | 6.79     |
| C13            | 2753.6       | 1882.25 | 1019.74 | 166.06 | 1477.11 |
| C14            | 20.16        | 16.47 | 13.3  | 10.51 | 15.04    |
| C15            | 5.59         | 6.69 | 8.07  | 9.84 | 7.23     |
| C16            | 457.77       | 374.36 | 304.65 | 245.67 | 340.88 |
| C17            | 125.95       | 123.29 | 120.27 | 116.8 | 121.83 |
| C18            | 37.18        | 42.38 | 48.31 | 55.19 | 45.57    |
| C21            | 2055.25      | 1988.34 | 1922.54 | 1857.84 | 1988.34 |
| C22            | 32.95        | 32.39 | 31.83 | 31.27 | 32.39    |
| C31            | 25           | 20    | 15    | 10   | 21.32    |
| C32            | 25           | 22.5  | 20    | 17.5 | 23.14    |

| Table 4. Information entropy and weight of evaluation indicators. |
|-----------|-------------|--------|
| C11       | 0.7974      | 0.0879 |
| C12       | 0.7899      | 0.0911 |
| C13       | 0.8135      | 0.0809 |
| C14       | 0.8022      | 0.0858 |
| C15       | 0.7855      | 0.0931 |
| C16       | 0.7978      | 0.0877 |
| C17       | 0.8242      | 0.0763 |
| C18       | 0.8018      | 0.0860 |
| C21       | 0.8195      | 0.0783 |
| C22       | 0.8207      | 0.0778 |
| C31       | 0.8211      | 0.0776 |
| C32       | 0.8211      | 0.0776 |
Equations (6)-(11) are used to calculate positive ideal solution and negative ideal solution distance. Equations (12) to (15) were used to obtain the grey correlation degree between the items to be evaluated to the positive ideal solution and the negative ideal solution. Equations (16) to (22) are used to calculate the relative progress of each project to be evaluated (shown in Table 5).

|                | Positive ideal solution grey relational degree | Negative ideal solution grey relational degree | Relative closeness |
|----------------|-----------------------------------------------|-----------------------------------------------|--------------------|
| Outstanding    | 1                                             | 0.6356                                        | 0.7588             |
| Good           | 0.8237                                        | 0.7130                                        | 0.5854             |
| Medium         | 0.7146                                        | 0.8223                                        | 0.4127             |
| Poor           | 0.6356                                        | 1                                             | 0.2412             |
| RG project     | 0.7878                                        | 0.7432                                        | 0.5244             |

TOPSIS and grey correlation evaluation constructed in this paper, the positive ideal solution is the set of profitability evaluation indexes, and relatively posted schedule reflects the relative to a review of the project and the positive ideal solution of progress, so the progress of the project relative to stick it indicates that the project investment value, higher relative posted progress shows its investment evaluation results, the better. Table 5 shows that five to a review of the project of relative stick progress from high to low in turn is: outstanding project > good project > RG project > medium project is poorer project, therefore RG project investment evaluation value is between good and medium level, and RG project investment value and the difference between the good project is less than the difference in value between medium project, explains RG company distributed photovoltaic power generation project is evaluated as higher than medium standard, and closer to the good project standard.

5. Conclusion
On the basis of economic benefit, environmental benefit and social benefit, this paper built three level indicators and 12 secondary indicators of investment evaluation system. According to the situation of photovoltaic industry, it determined main factors influencing the investment evaluation, designed the entropy weight to determine the index weight, constructed TOPSIS and grey correlation analysis model of the investment evaluation. The feasibility of the investment evaluation system and model constructed in this paper is verified through the case analysis of distributed photovoltaic power generation project of RG Company.

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