Research on Comprehensive Benefit Post Evaluation of Photovoltaic Poverty Alleviation Projects Based on FCM and SVM

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Abstract. Photovoltaic (PV) Poverty Alleviation makes full use of the solar energy in poverty-stricken areas so as to achieve stable incomes increase for the poor households for 25 years. It is an advanced mode integrating new energy development, emission reduction and accurate poverty alleviation. Post evaluation of PV poverty alleviation project is of great guiding significance for new energy development planning, poverty alleviation promoting and construction and operation of PV power stations. Under the guidance of the practical experience of PV poverty alleviation in Jiangxi province, China, this paper firstly builds a comprehensive evaluation index system with 7 second-level targets based on the post evaluation theory. Then, considering that projects with different sizes, construction and operation mode have different features in the evaluation, this paper uses pattern recognition method based on fuzzy C-means clustering algorithm and support vector machine to classify the projects. Then comparative analysis is carried out within each class to achieve comprehensive benefits evaluation. The method can reduce the information loss of multi-index weighted aggregation of traditional post evaluation methods. The features of PV poverty alleviation projects are highlighted to help to find the weak points of the projects. So the evaluation results are more scientific and reasonable.

1. Introduction
In 2016, China's distributed energy development presents an explosive trend. Twelve provinces achieved new capacity of more than 100 MW, including Jiangxi of over 300MW. On December 31, 2016, CPC Central Committee released document Opinions on Deepening the Supply-Side Structural Reform of Agriculture and Accelerating the Cultivation of New Drivers of Agricultural And Rural Development. The document clearly puts forward that “the implementation of new energy actions in rural areas, the promotion of photovoltaic (PV) power generation, and the gradual expansion of rural electricity, gas and clean coal supply”. PV poverty alleviation, covering the development and utilization of new energy and infrastructure construction in poverty-stricken areas, can not only promote the transformation of resource advantages into economic development advantages as soon as possible, but also create necessary production and living energy conditions for people in poverty-stricken areas. It is considered as an effective means of accurate poverty alleviation[1].
From the perspective of application status and capacity, PV is the most promising renewable energy generation technology. PV poverty alleviation is an advanced mode integrating new energy development, energy saving, and accurate poverty alleviation[2] -[3]. G.K.Singh used satellite data to evaluate the power generation potential of PV system from the perspective of solar energy resources, energy-saving performance, economic benefits and cost[4] -[5]. Li Yanbin set up the risk assessment system of PV projects, and used the gray correlation and the TOPSIS method to evaluate the risk of PV projects[6]. Zhang Xia studied the reliability of PV generation and grid connection[7]. Li Fen specified that PV power generation can reduce the loss of long-distance power grid construction and transmission[8].

Project post evaluation is a comprehensive and objective analysis on the purpose, process, effect, benefit and impact of projects after the completion[9] -[10]. PV projects requires not only the early evaluation, but also the post evaluation, which is of great guiding significance to the development of related projects.

Combined with PV project comprehensive benefit analysis and project post evaluation theory, this paper proposed a PV poverty alleviation project comprehensive benefit evaluation method based on FCM and SVM, which has important guiding significance for the development planning and decision-making of new energy, PV project construction and operation, etc.

2. Comprehensive benefit post evaluation index system

In this section, based on the extensive collection of comprehensive benefit post evaluation indicators of new energy projects, considering the features of Jiangxi PV poverty alleviation projects, a scientific comprehensive benefit post evaluation index system of PV poverty alleviation projects was established.

| Table 1. Common Evaluation Indicators of New Energy Projects |
|-------------------------------------------------------------|
| **Planning Period** | **Construction Period** | **Operating Period** |
| 1. Installed Capacity | 23. Temperature Coefficients of \( I_{sc} \) | 44. Maintenance Cost |
| 2. Investment Per Unit Capacity | 24. 25-year Power Attenuation | 45. Failure Cost |
| 3. Self-raised Funds Proportion | 25. STC Power Range | 46. Pollutant Discharge |
| 4. Private Capital Proportion | 26. MTTP Voltage Range | 47. Ecological Environmental Impact |
| 5. Public Capital Proportion | 27. Power Factor | 48. 25-year Total Power Generation (Revised) |
| 6. Initial Installation Subsidy | 28. Total Harmonic Distortion | 49. Benchmark on-grid Price of Desulfurization Coal-fired Power |
| 7. Financing Cost of Self-raised Funds | 29. Max. Efficiency | 50. Benchmark on-grid Price of PV Power |
| 8. Financing Cost of Private Capital | 30. Euro-efficiency | 51. Total Subsidy Per Kilowatt (Converted) |
| 9. Comprehensive Evaluation of Planning and Design | 31. MTTP Efficiency | 52. Investment Payback Period |
| **Construction Period** | 32. Electrical Insulation Properties | 53. 25-year Total Income |
| 10. Total Debt with Interest | 33. Comprehensive Evaluation of Relay Protection | 54. Total Income of Poor Household |
| 11. Multiple of Interest Protection | 34. Comprehensive Evaluation of Automatic Safety Control Devices | 55. Poverty Alleviation Population |
| 12. Liquidity Guarantee Multiple | 35. Comprehensive Evaluation of Dispatching Automation | 56. Per Capita Income of Poor Household |
| 13. Liquidity Ratio | 36. Comprehensive Evaluation of Construction | **Grid-connected** |
| 14. Waste Discharge | | 57. Deviation of Voltage |
| 15. Ecological Environmental Impact | | 58. Waveform Distortion |
| 16. Investment in Safety Equipment and Facilities | | 59. Short-term Flicker Severity |
| 17. Work-related Injury and Insurance Expenses | | 60. Short-circuit Current |
| 18. Confirmed and Suspected Occupational Cases | | 61. Tidal Current Distribution Index |
| 19. Maximum Power | | 62. Short Circuit Level Indicator |
| 20. Module Efficiency | | 63. Stability Level Index |
| 21. Temperature Coefficients of \( P_{m} \) | | 64. Reliability Index |
| 22. Temperature Coefficients of \( Voc \) | | 65. Operational Flexibility Index |
| | 37. Comprehensive Evaluation of Network Connection Scheme | 66. Adaptability Index of Network Frame |
| | 38. Operation Mode | 67. Average Outage Frequency of the System |
| | 39. Comprehensive Evaluation of Operation and Management Level | 68. Average Outage Duration of the System |

The common evaluation indicators for new energy projects in advanced enterprises are collected firstly. Indicators with strong correlation were eliminated, and the retained indicators were shown in Table 1. The index values of 52 PV projects in Jiangxi province are collected for case study. Min-max
standardization method is adopted for data preprocessing to convert original data into “benefit type” with value of $[0,1]$. In order to avoid the influence of 0 on the calculation process, a constant term $0.05\alpha$ is added to the index values, and $\alpha$ is the standard deviation. The final index values are shown in Figure 3.

As can be seen from Table 1, some indicators have nothing to do with economic benefits and are easy to be treated based on expert opinions. Three experts, with equal weight, are invited to analyze the common indicators. According to experts, 37 indicators, as shown in the gray shading part of Table 1, have little to do with economic benefits. They are are classified as EHS, engineering quality and regional power grid factors, which are the three primary indicators. The evaluation value of the primary indicators includes objective value $O$ and subjective value $S$. Wherein, the objective value $O$ is equal-weighted integration of the secondary indicator value. If the evaluation data of a certain indicator is missing, the objective value $O$ is integrated by the remaining indicators. The subjective value $S$ is given by the experts with equal weight. The subjective value $S$ and objective value $O$ are integrated with weight of $(0.6, 0.4)$ and the comprehensive evaluation value of EHS, project quality and regional power grid are finally obtained.

Other indicators are related to economic benefits, and there is a certain correlation between those indicators. Thus, it is difficult to extract indicators based on expert opinions. So factor analysis was carried out on the remaining 31 indicators. Figure 1 shows the scree plot of factor analysis. As can be seen intuitively from Figure 1, component 1-4 contains most of the information with eigenvalues greater than 1.

![Figure 1. Scree Plot of Factor Analysis](image)

The load matrix for the first four factors is shown in Table 2. As can be seen from Table 2, factor 1 has large load on installed capacity (1), investment per unit capacity (2), minimum cost (45), etc., most of which are related to project cost, so it is defined as "project cost factor". Similarly, factor 2 can be defined as "project income factor", factor 3 as "poverty alleviation effect factor", and factor 4 as "project financial factor".

| Table 2. Load Matrix of the First four Factors |
|------------------|------------------|------------------|------------------|------------------|
| N | PC1 | PC2 | PC3 | PC4 | N | PC1 | PC2 | PC3 | PC4 | N | PC1 | PC2 | PC3 | PC4 | N | PC1 | PC2 | PC3 | PC4 |
|---|-----|-----|-----|-----|---|-----|-----|-----|-----|---|-----|-----|-----|-----|---|-----|-----|-----|-----|
| 1 | 0.31 | 0.05 | 0.03 | 0.06 | 9 | 0.28 | 0.03 | 0.04 | 0.03 | 40 | 0.37 | 0.37 | 0.11 | 0.05 | 50 | 0.03 | 0.04 | 0.03 | 0.03 |
| 2 | 0.64 | 0.04 | 0.02 | 0.06 | 10 | 0.02 | 0.04 | 0.04 | 0.71 | 41 | 0.05 | 0.44 | 0.03 | 0.05 | 51 | 0.03 | 0.38 | 0.34 | 0.04 |
| 3 | 0.05 | 0.03 | 0.37 | 0.26 | 11 | 0.03 | 0.04 | 0.03 | 0.70 | 42 | 0.04 | 0.51 | 0.05 | 0.04 | 52 | 0.04 | 0.20 | 0.49 | 0.05 |
| 4 | 0.04 | 0.03 | 0.27 | 0.21 | 12 | 0.03 | 0.04 | 0.03 | 0.64 | 43 | 0.04 | 0.19 | 0.04 | 0.02 | 53 | 0.02 | 0.28 | 0.31 | 0.05 |
| 5 | 0.04 | 0.03 | 0.34 | 0.25 | 13 | 0.05 | 0.03 | 0.03 | 0.56 | 44 | 0.24 | 0.03 | 0.04 | 0.03 | 54 | 0.04 | 0.54 | 0.51 | 0.05 |
| 6 | 0.19 | 0.03 | 0.50 | 0.02 | 37 | 0.22 | 0.56 | 0.04 | 0.03 | 45 | 0.28 | 0.05 | 0.03 | 0.04 | 55 | 0.04 | 0.02 | 0.31 | 0.06 |
| 7 | 0.46 | 0.39 | 0.03 | 0.58 | 38 | 0.27 | 0.29 | 0.05 | 0.03 | 48 | 0.03 | 0.58 | 0.31 | 0.03 | 56 | 0.05 | 0.03 | 0.77 | 0.02 |
| 8 | 0.32 | 0.36 | 0.05 | 0.38 | 39 | 0.61 | 0.32 | 0.03 | 0.02 | 49 | 0.03 | 0.47 | 0.02 | 0.03 | - | -- | -- | -- | -- |

Finally, seven evaluation indicators were extracted, which are respectively defined as project cost
factor, project income factor, project finance factor, EHS factor, project quality factor, poverty alleviation effect factor and regional power grid factor. The comprehensive benefit post evaluation index system of PV poverty alleviation projects is shown in Table 3.

| First Grade Indicators | Second Grade Indicators | Index Number |
|------------------------|-------------------------|--------------|
| Economic Benefit Index A1 | Project Cost Factor B11 | 1            |
|                        | Project Return Factor B12 | 2            |
|                        | Project Finance Factor B13 | 3            |
| Environmental Benefit Index A2 | EHS Factor B21 | 4            |
| Social Effectiveness Index A3 | Engineering Quality Factor B31 | 5            |
|                        | Regional Grid Factor B32 | 6            |
|                        | Poverty Alleviation Effect Factor B33 | 7            |

3 Comprehensive benefit post evaluation method

In this chapter, based on Fuzzy c-means Algorithm (FCM), 52 PV poverty alleviation projects in Jiangxi province were clustered to identify different index patterns. Then, the project is classified based on the Support Vector Machine (SVM). Scientific and reasonable classification can highlight the features of PV poverty alleviation projects and help identify the projects that deviate from the typical mode (class center), and thus propose accurate management strategies and improvement suggestions.

3.1 Determine categories based on FCM

The classification criteria of different types of PV poverty alleviation projects cannot be defined in advance, which is an unsupervised learning process and needs to be analyzed with clustering algorithm. Fuzzy c-means clustering algorithm is efficient to achieve the maximum similarity between similar objects and the minimum similarity between different classes. The reasonable clustering number needs to be determined first.

(1) Objective function and evaluation index

Given data set \( X = \{x_1, x_2, \ldots, x_n\} \), \( x_j \in \mathbb{R}^s \), \( x_j \) is the s-dimensional row vector. The objective of the algorithm is to divide \( X \) into class \( c \) \((2 \leq c \leq n)\), and the clustering center is represented by \( V = \{v_1, v_2, \ldots, v_c\} \). The core of FCM algorithm is to introduce the concept of membership degree. Let \( u_{ij} \in [0,1] \) represent the membership degree of class \( i \) that \( x_j \) belongs to, and finally form the membership degree matrix \( U = \{u_{ij}\} \) with \( \sum_{j=1}^{n} u_{ij} = 1, j = 1,2,\ldots,n \). The objective function of the FCM algorithm was defined based on Euclidean distance. After iterative calculation, the objective function value was minimized, as shown in formula (2).

\[
J(U,V) = \sum_{i=1}^{c} \sum_{j=1}^{n} u_{ij}^m d_{ij}^2
\]  

(1)

In the formula: \( d_{ij} = \|x_j - v_i\| \) is the distance between \( x_j \) and \( v_i \), and \( m \) is the fuzzy weighting coefficient, representing the fuzzy degree of the matrix \( U \). The larger \( m \) is, the higher the fuzzy degree of the final classification result will be. Wherein, the calculation formulas of, are shown in formula (3) and (4) respectively.

\[
u_{ij} = \frac{1}{\sum_{i=1}^{c} (d_{ij} / d_{ij})^{2(m-1)}} 
\]  

(2)

\[
v_i = \frac{\sum_{j=1}^{n} u_{ij}^m x_j}{\sum_{j=1}^{n} u_{ij}^m}
\]  

(3)

There are four main standards for the extraction of PV poverty alleviation project model: 1) one class represents a similar project group; 2) obvious differences between groups; 3) project classification is easy to judge; 4) the number of classes should not be too large. FCM needs to provide
a specific number of clusters before clustering. After clustering, it needs to test the clustering effectiveness to determine whether the results obtained are reasonable. In this paper, the clustering number is set to be 2~9, and the three indicators, Bezdek partition coefficients $V_{PC}$, Xie_Beni coefficient $V_{XB}$ and reconstruction error rate $V_{RE}$, are selected to comprehensively judge the rationality of clustering results, so as to determine the appropriate number of clustering and the training data set of SVM. According to the standards, in general, for a clustering number, the larger the $V_{PC}$, the smaller the $V_{XB}$, the smaller the $V_{RE}$, the better the clustering effect will be.

Based on the above analysis, the following steps are designed to determine the clustering category and SVM training data set based on FCM:

1. For a given data set, the clustering number is set to be 2–9, respectively;
2. For each cluster number, FCM algorithm was applied to cluster;
3. Calculate iteration times and objective function value;
4. Calculate Bezdek partition coefficient $V_{PC}$, Xie_Beni coefficient $V_{XB}$ and reconstruction error rate $V_{RE}$;
5. According to the comprehensive judgment of iteration number, objective function value, $V_{PC}$, $V_{XB}$ and $V_{RE}$, the appropriate number of clustering is selected;
6. For clusters corresponding to the clustering number $c$, the category of each item can be determined according to the maximum value corresponding to each item in the membership matrix $U$;
7. Select items with $u_{i}^{\text{max}}$ greater than the threshold value $\alpha$, and set their classification information and original data as the training data set for the next SVM classification.

(2) clustering number and training data sets

The above FCM algorithm was applied to cluster the data collected from 52 new energy construction projects and Jiangxi province PV poverty alleviation project comprehensive benefit post evaluation index. To obtain the clustering number, target function value, $V_{PC}$, $V_{XB}$ and $V_{RE}$ values under different clustering numbers are calculated and shown in Table 4.

| Clustering Number | Iterations | Objective Function | $V_{PC}$ | $V_{XB}$ | $V_{RE}$ |
|-------------------|------------|--------------------|---------|---------|---------|
| 2                 | 6          | 45.69              | 164.67  | 16.75   | 1.16E-33 |
| 3                 | 21         | 24.42              | 155.62  | 38.68   | 1.36E-33 |
| 4                 | 19         | 15.83              | 142.03  | 14.18   | 1.25E-33 |
| 5                 | 6          | 7.47               | 153.3   | 36.3    | 1.21E-33 |
| 6                 | 8          | 6.65               | 137.2   | 14.6    | 1.37E-33 |
| 7                 | 12         | 5.87               | 108.57  | 13.67   | 9.80E-34 |
| 8                 | 19         | 4.93               | 101.38  | 18.19   | 1.10E-33 |
| 9                 | 27         | 4.49               | 99.73   | 26.86   | 1.35E-33 |

As can be seen from Table 4:

1) The minimum number of iterations 6 is obtained when the clustering number is 2 and 5. It suddenly drops and then slowly rises, which means that, from the perspective of iterations, 2, 5 and 6 are all suitable clustering numbers, and the algorithm can converge rapidly.

2) The value of the objective function decreases with the increase of the clustering number, which indicates that the finer the classification, the better the clustering result. However, the target function is in a cliff, and the minimum clustering number at the bottom of the cliff is 5. When the clustering number is greater than 5, the improvement of clustering effect is not significant. Therefore, it is appropriate to consider the clustering number as 5 or 6 (after 5, close to 5) from the perspective of objective function.

3) The maximum value of Bezdek partition coefficient $V_{PC}$ appears when the clustering number is 2, but it fluctuates and a peak appears when the clustering number is 5. The peak has a significant advantage. Therefore, from the perspective of Bezdek partition coefficient, it is appropriate to choose...
2 or 5 for the clustering number.

4) Xie_Beni coefficient VXB takes smaller values when the clustering number is 2, 4, 5, 6 and 7, and the difference is not big. Therefore, from the perspective of Xie_Beni coefficient, the clustering number can be 2, 4, 5, 6 and 7.

5) The reconstructed error rate VRE takes values with two fluctuations. When the clustering number is 5 and 7, VRE takes the valley values. Therefore, from the perspective of reconstruction error rate, the clustering number can be 5 or 7.

Based on the above analysis, it can be determined that 5 is the appropriate clustering number for PV poverty alleviation projects studied in this paper. Set the clustering number as 5 for FCM, and the maximum membership degree of each project are shown in Figure 2.

![Figure 2. Maximum Membership of Each Project](image)

The threshold value $\alpha = 0.85$ was set, and the clustering results of 40 items with the maximum membership degree greater than $\alpha$ are considered reliable. And their classification results and index data are screened out as SVM training data sets.

### 3.2 Classification based on SVM

FCM clustering algorithm only considers Euclidean distance between different projects, and does not consider the fluctuation characteristics of typical model of benefit evaluation index system, which may not be accurate and reasonable. What's more, an efficient classification method is needed to classify the newly added items. Therefore, SVM algorithm is adopted on the basis of FCM clustering algorithm. SVM classifier was trained based on 40 sets of reliable classification data, and 12 items with the maximum membership lower than the threshold were reclassified.

SVM classifier parameters are set as follows:

1) NU-SVC with penalty factor is adopted.

2) The kernel is choice Radical Basis Function (RBF), and its expression is:

$$K(u,v) = \exp(-\gamma ||u-v||^2)$$ (4)

Wherein, $\gamma >0$, this paper set $\gamma$ to $1/7$, the inverse of the number of indicators. There are three reasons to choose RBF kernel functions: 1) in general, RBF kernel is a reasonable first choice. 2) polynomial kernel has more hyperparameter than RBF kernel, which will improve the complexity of model selection. 3) the RBF nucleus has fewer numerical difficulties.

3) The range of model NU-SVC's penalty factor $c$ is $[0,1]$. In this paper, $c$ is set to 1.

By setting the above parameters and using 40 sets of reliable classification data to train SVM classifier, the classification accuracy can reach 100%. The trained SVM classifier was used to reclassify the 12 items with unreliable clustering results, and the classification results were consistent with the FCM clustering results to 83.33%. By comparing the project data, it is concluded that the results of SVM classifier classification are more reliable. The final classification result and class center are shown in Figure 3.

In Figure 3, the red line represents the optimal value. Note that the vertical minimum of Figure 3(c) is 0.65, the vertical minimum of (d) is 0.60, and the vertical minimum of (a), (c), and (e) starts at
The index values of projects in category (a) are generally low, but the value of energy saving and emission reduction factors is high. Projects in category (b) have low cost factors and high income factors, but low financial factors and emission reduction factors. The index values of category (c) and category (d) projects are generally higher, but the values of regional power grid factor and poverty alleviation effect factor of category (d) projects are lower than those of category (c) projects. The index values of projects in category (e) fluctuate at the intermediate level, but the index values of poverty alleviation effect factors are relatively low.

![Figure 3. Final classification result, class center and optimal value](image)

4. Example analysis of new project
A 10MW PV project in Jiangxi province, constructed and connected to the grid in 2016, is taken as example to illustrate the operation steps of the above post evaluation method. The index data of the project are shown as the black solid line in Figure 4.

**Step1** Classify projects based on SVM classifier model. For the newly added item $p^+$, SVM classifier model is used to classify it and determine that it belongs to category (d) project.

**Step2** Calculate and update the optimal value of each index within the class, which is the maximum value in this paper. The updated optimal value of category (d) is shown as the red dashed line in Figure 4, and the updated class center of is shown as the blue dotted line.

**Step3** Based on the index value of item $p^+$, the optimal index value is used for post-evaluation.

According to the evaluation results, some investment, construction and management suggestions are put forward. The index value of newly added project $p^+$ is generally close to the average value, failing to reach the better level of category (d) project, wherein:

1. The index value of the project financial factor is low, but the index value of the income factor is high. It indicates that the project may sacrifice financial performance to improve the project revenue.
2) The index values of EHS and poverty alleviation effect factors are relatively high, especially the poverty alleviation effect factors basically reach the optimal value of such projects.

3) The index value of regional power grid factor of category (d) is low, and the index value of this project is lower than the average value of category (d). This project may have a negative impact on the regional power grid, and the regional power grid has a poor capacity to absorb the power generation of this PV project. Therefore, it is advisable to avoid building similar PV power stations in this region in the future. It may be more reasonable to transform the power grid first.

5. Conclusions

This paper studies the post evaluation of the comprehensive benefits of PV poverty alleviation projects. Firstly, a post-evaluation index system of comprehensive benefits of PV poverty alleviation projects was designed based on factor analysis. Then, a post evaluation method based on FCM and SVM is designed to avoid problems such as poor reference value of optimal value caused by unified standard evaluation. Combined with the practical experience of PV poverty alleviation in Jiangxi province, the rationality of the index system and feasibility of the evaluation method proposed in this paper are verified.

Although the paper has made some progress in the post evaluation of PV poverty alleviation projects, there are still some problems. For example, when using FCM for project clustering, multiple indicators are used to comprehensively judge the clustering effect of different number of clusters. The optimal number of clusters under different indicators is not the same, and the selection of clustering number depends on subjective judgment. In addition, the empirical threshold is also used to determine whether the FCM clustering results are reliable. Threshold setting depends on empirical judgment, subject to the number of projects.

Acknowledgments

This study is supported by the Natural Science Foundation of China (71671065) and the Science and Technology Project of State Grid Corporation of China “Research and Application of Improving the Accommodation Capacity and Guarantee Technologies of Power Grid in PV Poverty Alleviation Areas” (52182017000W).

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