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Research on power grid investment benefit assessment and multi-level optimization strategy based on fuzzy comprehensive evaluation

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ABSTRACT

The rapid development of the electric power market makes the scientificity and rationality of grid investment decision-making particularly important. In this paper, firstly, we design a grid investment benefit assessment method based on fuzzy comprehensive evaluation. And taking the grid investment benefit of M city in 2022 as an example, the fuzzy comprehensive evaluation method is used to quantitatively evaluate the grid investment benefit. Based on the evaluation results, the weaknesses of power grid investment in M city are found. Then the multi-level optimization strategy of grid investment is further proposed to achieve the maximization of investment benefits. The strategy considers the objectives and constraints of different levels, such as grid structure, power supply reliability, operation efficiency, and power sales revenue, and coordinates the interests between all levels by establishing a multi-objective optimization model to achieve the global optimization of the grid investment decision. Finally, after adjusting the allocation ratio and the allocation amount by the multi-level optimization strategy, the overall evaluation of the city's grid investment efficiency in 2023 is improved from “average” to “excellent”. It shows that the multilevel optimization strategy designed in this paper can provide scientific guidance for grid investment decision-making.

Keywords: Fuzzy comprehensive evaluation, multi-objective optimization model, grid investment benefit assessment, multi-level optimization strategy

1. Introduction

Power efficiency assessment is a process of comprehensive assessment of the operation and development of the power industry, through which the operational efficiency, quality and economic benefits of the power industry can be understood [1-2]. Common methods of power efficiency

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assessment include: economic efficiency assessment: it is to assess the input-output ratio of the power industry. The assessment indexes mainly include return on investment, cost-benefit ratio, and benefit period. Through the economic benefit assessment, the economic efficiency of the power industry can be determined to provide reference for the formulation of reasonable development strategies [3-6]. Energy efficiency assessment: it is to assess the energy utilization of the power industry. The evaluation indexes include energy utilization effect, energy utilization rate and so on. Through the energy efficiency assessment, we can understand the energy utilization efficiency of the power industry, avoid energy waste, and improve the energy utilization rate [7-10]. Quality efficiency assessment: quality efficiency assessment is to assess the quality of power supply in the power industry. The assessment indexes mainly include power supply reliability, voltage stability, power factor of power grid and so on. Through the quality and benefit assessment, the power supply quality of the power industry can be judged, and then improve the reliability of power supply and customer satisfaction [11-14].

The optimization strategy of power grid includes technological upgrading, optimizing operation and management, developing clean energy, and enhancing the awareness of sustainable development. Through the development of corresponding improvement strategies, the power industry can be prompted to better meet the needs of society and realize the win-win situation of economic and environmental benefits. The power industry will continue to progress in the continuous assessment and improvement, and make greater contributions to social development [15-17].

References

In this paper, the fuzzy comprehensive evaluation method is used to assess the efficiency of power grid investment. Taking the power grid investment project in M city as an example, the indicators are quantitatively assessed from the input and output dimensions respectively. The grid investment efficiency score is calculated according to the indicator weights and indicator affiliation degree. The overall investment efficiency of the grid is judged to be excellent according to the investment efficiency evaluation score. Aiming at the weak links of power grid investment in M city, multi-level optimization is carried out in four aspects, namely, network structure, power supply reliability, operation efficiency, and income from power sales, and the trapezoidal curve is used to fuzzy each sub-objective function. And corresponding improvement measures are proposed for different levels of grid investment efficiency. After adjusting the allocation ratio and allocation amount by the multi-level optimization strategy, the grid investment efficiency is reevaluated.

2. Grid investment benefit assessment system based on fuzzy comprehensive evaluation

2.1. *Construction of evaluation index system for evaluating the benefits of power grid investment*

Since the construction of power grids varies in different regions, it is difficult to construct a system of indicators that meets the construction characteristics of all power grids, so only indicators that are generally applicable to most power grids are considered.

The accuracy of the comprehensive assessment of grid investment efficiency mainly depends on the selection of input and output indicators. Since substations and lines are the main components of the grid, the total investment cost of the construction of local substations and lines of each voltage level is an important indicator for examining the amount of investment in the grid, and since the construction costs of substations and lines are directly related to the capacity of transformers and the length of lines, respectively, the construction investment costs can be expressed by the total capacity of substations and the total length of lines in the region accordingly. In addition, considering that there is a strong correlation between reactive power compensation devices and voltage regulating devices in the power grid and the main transformer capacity of the substation, e.g., the capacity of reactive power compensation is usually taken as 15%~30% of the main transformer capacity, if reactive power compensation capacity and voltage regulating devices are listed as indicators, it will not satisfy the principle of independence of the indicators, leading to deviation of the evaluation results, and therefore is not taken into account in the establishment of the indicator system.

The selection of output indicators is required to reflect the direct economic benefits obtained from the investment in the power grid and the ability of the power grid to maximize the ability to meet the load demand, which is mainly reflected in the sales revenue of the power grid, such as the total power supply and the maximum load of electricity consumption in a period of time. Therefore, the evaluation index system for the assessment of grid investment efficiency is shown in Table 1. It contains two primary indicators and eight secondary indicators.

Table 1. Evaluation index system of investment efficiency assessment of grid

Target layer	Criterion layer	Index layer
Evaluation index system of investment efficiency assessment of grid	Input index(X)	110kV Transformer capacity X1 (MVA)
		35kV Transformer capacity X2 (MVA)
		Distribution capacity X3 (MVA)
		110kV Line length X4 (km)
		35kV Line length X5 (km)
		10(6)kV Line length X6 (km)
	Output indicator(Y)	Annual electricity consumption Y1 (GWh)
		Maximum annual load Y2 (MW)

2.2. Fuzzy integrated evaluation method

Because there are more qualitative factors in power grid investment efficiency, and it is difficult to find a suitable mathematical relationship to establish a quantitative structure to analyze the qualitative factors [18]. In order to better reflect the completeness of the research on the evaluation of power grid investment efficiency, this paper adopts the fuzzy comprehensive evaluation method to evaluate the investment efficiency. The application of fuzzy comprehensive evaluation mainly includes the following steps:

1) Determine the evaluation factor set $U=\{U_i\}=\{U_1,U_2,......U_m\},U_i(i=1,2,......m)$, indicating that the i nd factor has an influence on the thing being evaluated. The objectives and influencing factors of each level can be determined through calculation, thus constructing the influencing relationship between the upper level and the lower level and establishing the evaluation index system.

2) Determine the weight of each factor $A=(a_1,a_2,\cdots a_n)\in J(U)$. Here, a_i is the importance of factor U_i compared with other factors on the same level, $0\le a_i\le 1$, and $\sum_{i=1}^{n} a_i=1$, generally for the determination of the weight of the indicator is mainly divided into two ways, respectively: the Delphi method and hierarchical analysis (AHP), in addition to the qualitative way can also be determined. Quantitative, qualitative and quantitative combination of ways to complete.

3) Determine the evaluation set $V=\{V_k\}=\{V_1,V_2,\cdots,V_p\},V_k(k=1,2,\cdots p)$, where k indicates the number of evaluation levels.

4) Single factor evaluation between evaluations and construction of a fuzzy judgment matrix R. A single factor is first evaluated so as to determine the degree of affiliation of the factor with respect to the elements of the alternative set, and this is used to construct a single factor evaluation, which ultimately results in the degree of affiliation of the factor with respect to the respective evaluation levels.

In performing a single factor evaluation of a factor, a fuzzy mapping from U to V is given $f:U \to J(V), U_i = (V_i) = R_i = (r_{i1}, r_{i2}, \cdots r_{ip}) \in J(V), (i = 1, 2, \cdots m)$ Fuzzy mapping f Fuzzy relationship $R_i \in J(U \times V)$, i.e., $R_f(U_i, V_i) = f(U_i)(V_i) = R$. Thus, R_f can be represented by a fuzzy matrix $R \in U_{m \times p}$, i.e.,:

$$R = (R_1, R_2, \ldots R_n)^T = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1p} \\ r_{21} & r_{22} & \cdots & r_{2p} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mp} \end{bmatrix}_{m \times p} \tag{1}$$

The R in the above equation is the single-factor judgment matrix, while the r_{ij} in the matrix is the affiliation of the factor U_i in U with the V_j in V, which is the single-factor judgment of the grid project by the ith factor. It lays the foundation for later fuzzy comprehensive evaluation of the grid project.

5) Fuzzy synthesize A and R to get the comprehensive judgment result B:

$$B = A \bullet R = (a_1, a_2, \cdots a_m) \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1p} \\ r_{21} & r_{22} & \cdots & r_{2p} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mp} \end{bmatrix}_{m \times p} = (b_1, b_2, b_p) \tag{2}$$

Indicates the affiliation result of each element.

Where, A indicates the weight of the evaluation of each factor, R is the current determination of the degree of affiliation of each element. B finally indicates the affiliation result of each element.

6) Description of results. The fuzzy comprehensive evaluation is used to obtain the corresponding results and the obtained data are further processed. Through the processing of the data, it makes the problems in the investment of the grid project clearer, so as to make a reasonable judgment for the evaluation of the grid project.

3. Grid investment benefit assessment based on fuzzy comprehensive evaluation

3.1. Determination of weights

For the 8 main indicators involved in the evaluation index system of grid investment efficiency assessment, 14 experts assigned the weights of each indicator, and after several rounds of generalization, feedback and modification, the weight coefficients finally recognized by the experts are shown in Table 2. Among them, the indicator with the largest weight factor is the length of 35kV line, accounting for 16.9%, followed by the annual electricity consumption, accounting for 17.6%. This shows that these two indicators have the greatest influence on the investment efficiency of the power grid.

Table 2. Index weight coefficient

Criterion layer	W_i	Index layer	W_i	Global weight
Input index(X)	0.72	110kV Transformer capacity X1 (MVA)	0.133	0.096
		35kV Transformer capacity X2 (MVA)	0.169	0.122
		Distribution capacity X3 (MVA)	0.154	0.111
		110kV Line length X4 (km)	0.156	0.112
		35kV Line length X5 (km)	0.235	0.169
		10(6)kV Line length X6 (km)	0.153	0.11
Output indicator(Y)	0.28	Annual electricity consumption Y1 (GWh)	0.63	0.176
		Maximum annual load Y2 (MW)	0.37	0.104

3.2. Scoring of indicators

This paper takes the investment efficiency of power grid in M city in 2022 as an example, and asks to calculate the unified evaluation grade and evaluation standard value of each index. In this paper, the evaluation grade of investment efficiency is set as excellent, good, general and poor, and the corresponding evaluation scores are 85, 75, 65 and 55 respectively. Based on the white paper and planning report data reported by the power grid, 14 experts evaluate the investment efficiency of the power grid in M city. The statistical results of the index affiliation are shown in Table 3. The evaluation grades of the factors belong to good, fair and poor, indicating that the investment efficiency of the power grid in M city is not satisfactory.

Table 3. Index membership statistics

Index layer	Superior	Good	Medium	Difference
X1	0	1	5	8
X2	0	1	7	6
X3	0	2	8	4
X4	0	3	7	4
X5	0	1	7	6
X6	0	2	6	6
Y1	0	3	5	6
Y2	0	2	6	6

The results of the evaluation were normalized to obtain a one-factor affiliation matrix for eight different factors, as shown in table 4. The percentage of people with an “excellent” rating for each indicator in the evaluation of investment effectiveness is zero.

Table 4. The results of the index of the index

Index layer	Superior	Good	Medium	Difference
X1	0	0.07	0.36	0.57
X2	0	0.07	0.5	0.43
X3	0	0.14	0.57	0.29
X4	0	0.21	0.5	0.29
X5	0	0.07	0.5	0.43
X6	0	0.14	0.43	0.43
Y1	0	0.21	0.36	0.43
Y2	0	0.14	0.43	0.43

3.3. Fuzzy integrated evaluation

By obtaining the weight set and affiliation matrix of each indicator layer through the above calculation, the first-level fuzzy comprehensive judgment matrix B can be calculated according to equation (3):

$$B = A \cdot R = \left[0, 0.135, 0.455, 0.412\right] \tag{3}$$

The equation is utilized to multiply with the fuzzy composite scoring evaluation set (85, 75, 65, 55) to arrive at a total score for the integrated grid efficiency evaluation:

$$\begin{aligned} V &= 0 \times 85 + 0.135 \times 75 + 0.455 \times 65 + 0.412 \times 55 \\ &= 62.36 \end{aligned} \tag{4}$$

The comprehensive benefit performance is close to the “average” score of 65, which can be regarded as the comprehensive benefit of grid investment in M city is average, indicating that there is still much room for upward improvement in the efficiency of grid investment in M city.

Detailed and specific to the level of each indicator, it is found that the grid investment efficiency of 110kV substation capacity (X1) is the worst. The reason is that the power supply line will generate line length redundancy when it is larger than the shortest power supply radius due to terrain constraints. Line lengths or transformer capacities determined by supply area and base load are assessed as redundant with too much spare capacity relative to the lower annual supply level.

4. Multi-level optimization strategy

Aiming at the above problems such as redundancy formed by too much spare capacity faced by the efficiency of grid investment in M city, this chapter constructs a multi-objective optimization model for grid investment and proposes a multi-level optimization strategy.

4.1. Multi-objective optimization model for grid investment

1) Investment optimization objective function. Considering the different degrees of development and weaknesses of local and municipal power grids, different grids should have different focuses on investment and construction, and it is reasonable to formulate different investment strategies according to the degree of importance and urgency of dealing with weaknesses in each aspect to meet the actual needs of local and municipal power grid construction. In this paper, taking into account the needs of grid enterprises, grid users and society, the development direction of grid investment is divided into four aspects: improving network structure, improving power supply reliability, improving operational efficiency, and improving the income from power sales, and optimizing grid investment from multiple levels. The improvement of output indexes in each category of development direction is taken as the investment optimization sub-objective, and the optimal improvement of output indexes of the grid as a whole is taken as the optimization overall objective of investment allocation [19].

For each type of sub-objective optimization problem, the objective function characterizing the improvement of that type of index of the grid is:

$$\min f = \sum_{i=1}^{m} w_i y_i \tag{5}$$

where f represents the combined results of investment improvements in a particular category of development orientation indicators. ω_i indicates the weight of the first output indicator included in the category. y_i indicates the score of the ith output indicator after investment improvement: m indicates the number of output indicators included in the category.

Where the result of investment improvements in output indicators is:

$$y_i = y_i^{'} + \hat{y}_i = y_i^{'} + \sum_{j=1}^{n} A_{ij} \cdot x_{ij} \tag{6}$$

where: y_i represents the forecast result of the investment improvement in output indicator i for the year. $y_i^{'}$ denotes the actual value of that output indicator in the previous year.

2) Constraints. The goal of grid project investment allocation optimization is to maximize the level of grid development, that is, to make all the above output indicators as close as possible to the ideal value. In practice, the investment capacity of the grid company is limited and cannot meet the investment needs of all output indicators, and the investment capacity constraints are as follows:

$$\sum_{n=1}^{N} x_n = I \tag{7}$$

Where: I is the total amount of investment available for distribution in the grid. x_n is the amount of investment in the n rd project attribute. N is the number of project attributes.

In addition, in a physical sense, the investment cannot improve the result of the output indicator beyond its desired value, i.e:

$$y_i = y_i^{'} + \hat{y}_i \le y_i^{'} \tag{8}$$

where $y_i^{'}$ is the desired value of improvement in that output indicator.

4.2. *Multi-objective function fuzzification*

1) Multi-objective fuzzy function. Optimization of power grid investment strategy is a multi-objective optimization problem, various types of weaknesses in the evaluation of indicators of varying magnitude, and the weight is difficult to determine. Therefore, this paper adopts the fuzzy multi-objective optimization method, using trapezoidal curves to fuzzy each sub-objective function [20]:

$$\mu(f_i) = \begin{cases} 1 & f_i \le S_{fi} \\ (S_{fi} + \delta_{fi} - f_i)/\delta_{fi} & S_{fi} < f_i \le S_{fi} + \delta_{fi} \\ 0 & f_i > S_{fi} + \delta_{fi} \end{cases} \tag{9}$$

Where: S_{fi} represents the single-objective optimization optimal value of negative indicators such as operational efficiency class. δ_{fi} is the difference of the single-objective optimization optimal value.

For positive indicators such as grid structure class, the affiliation function is:

$$\mu(f_j) = \begin{cases} 0 & f_j \le S_{jj} - \delta_{jj} \\ (f_j - S_{jj} + \delta_{jj})/\delta_{jj} & S_{jj} - \delta_{jj} < f_j \le S_{jj} \\ 1 & f_j > S_{jj} \end{cases} \tag{10}$$

Where: S_{fj} denotes the single-objective optimized optimal value of the positive indicator. δ_{fj} is the difference of the single objective optimization optimal value.

The investor's satisfaction is denoted by μ, such that μ is the minimum of all values after fuzzification of all sub-objectives, i.e.:

$$\mu = \min\{\mu(f_1), \ldots, \mu(f_n)\} \tag{11}$$

In this way, the original sub-objectives of different outlines, the weight ratio is difficult to determine the multi-objective optimization problem, into a single-objective nonlinear optimization problem, only need to satisfy all the constraints, the satisfaction index μ to achieve the maximum value, at this time the fuzzy multi-objective optimization model for:

$$\begin{gathered} \max \mu \\ s.t. f_i + \delta_{fi}\mu \le f_i + \delta_{fi} \\ -f_j + \delta_{fj}\mu \le -f_j + \delta_{fj} \\ 0 \le \mu \le 1 \end{gathered} \tag{12}$$

2) Fuzzy model transformation steps:

(1) Input the historical data of the power grid to solve the single-objective optimization problem of the power grid with the objective of optimizing the improvement effect of the development direction of the i category, such as the operational efficiency category, for example, to obtain the optimal expected value of the operational efficiency improvement $f_{1\max}$ and the corresponding improvement value of the other categories $f_n^{'}$.

(2) Similarly, the optimal expected value of all development directions in the single-objective optimization problem can be obtained as $f_{1\max}$, and the minimum improvement expectation as $f_{i\min}$.

(3) Based on the above steps, we set the expansion coefficient ε_i to adjust the difference δ_{ji} of each development direction, and its value range becomes:

$$0 \le \delta_{fi} \le \varepsilon_i (f_{i\max} - f_{i\min}) \tag{13}$$

In the formula, the value of $\varepsilon_i \in [0,1]$, ε_i shows the subjective intention of the grid company's investment, and the smaller the value of ε_i indicates that the grid company's willingness to develop this type of weak link is stronger, and the tolerance of this type of index failing to reach the optimal value is lower.

(4) In summary, the multi-objective optimization problem of grid investment allocation is converted into a single-objective optimization problem to obtain the allocation of grid project investment when maximizing satisfaction.

4.3. Specific recommendations for optimizing the benefits of grid investment

Based on the comprehensive assessment and analysis of the investment benefits of the power grid in M city, combined with the characteristics of China's power grid and the prevailing problems, the following suggestions for reference are put forward for the decision-making of the subsequent investment and construction program of the power grid:

1) Strengthening the importance of grid investment benefits. The investment and construction of power grid is a basic industrial investment and construction project that benefits the quality of life of more than half of China's nationals, and the amount of investment is huge, with great public welfare and social impact. However, in the past investment and construction projects, the phenomenon of over-emphasizing social benefits and neglecting economic benefits often resulted in excessive waste of investment and construction resources and irrational allocation of resources. Therefore, responding to the initiative put forward by the State Grid to carry out three-saving activities, strengthening the importance of grid investment benefits, and reasonably assessing the current situation of the grid will help realize the rational use of grid investment resources and ultimately build a grid that combines reliability and economy.

2) Understanding the main factors affecting the efficiency of grid investment. Compared with the city, electricity consumption has the characteristics of relatively scattered loads, small load density in some areas, and large differences in seasonal electricity consumption, etc. However, the special nature of electric energy cannot be stored, so that the power supply capacity of the power grid to meet the maximum demand for loads in addition to the existence of a certain power supply margin, which will inevitably result in the value of the power grid's investment efficiency is low. In addition, the investment and construction of the power grid will be subject to policy, economy, natural environment and other factors, therefore, based on data, integration of multiple factors affecting the power grid investment, to carry out a comprehensive analysis from multiple perspectives, in order to be more reasonable and accurate to the comprehensive assessment of the investment benefits of the power grid, and then for the development of investment decision-making to provide a reference basis.

3) Improvement measures corresponding to the investment efficiency of power grids of different levels:

(1) For power grids with high investment efficiency, the power grids should be further analyzed in combination with their economic development trend and load growth. Especially for the effective power grids, it should be considered that the higher the value of investment efficiency, the lower the standby capacity of its grid, once the load grows rapidly in a short period of time, it is very easy to lead to the occurrence of overloaded operation of the equipment, which affects the reliability of power supply of the regional power grid. In this regard, it is necessary to scientifically and reasonably predict the growth trend of electricity load, so as to accumulate information with reference value for the subsequent power grid planning and investment construction.

(2) For the general investment efficiency of the power grid, should be combined with the assessment of the redundancy of the input indicators and the scale of the power grid returns, specific grid specific analysis, the power grid investment strategy for reasonable adjustment, for the subsequent grid transformation investment and construction of the direction of the investment and investment efforts to provide a scientific reference basis.

(3) The low investment efficiency of the power grid, mostly because of the weak economic base, the low level of industrialization led to the power supply area of the electricity consumption and load density is too low, for such areas, first of all, we should use the means of power marketing to stimulate the growth of the local electricity load. If the load growth rate is too slow, you can refer to the size of the redundant amount of resources invested in the power grid, where conditions allow, the appropriate downsizing of the power grid in order to achieve resource conservation.

5. Grid Investment Benefit Assessment and Application of Multi-Level Optimization Strategies

Taking the power grid project in M city as an example, applying the fuzzy comprehensive evaluation method to evaluate the overall investment efficiency of the power grid in 2022, the score is 63.36, and the evaluation grade is "general", which indicates that the overall investment efficiency of the power grid in M city in 2022 does not reach the ideal value. Using the multilevel optimization strategy designed in this paper, the optimal improvement of the overall output index of the power grid is taken as the optimization objective of investment allocation. The evaluation scores of each influential factor of grid investment in M city in 2023 are obtained as shown in Fig. 1. After the optimization of the multi-level strategy, the scores of each index are above 83 points, and the highest score can reach 91 points, and the overall evaluation of the optimized grid investment efficiency can reach the grade of "excellent", which indicates that the multi-level optimization strategy designed in this paper can improve the efficiency of the grid investment.

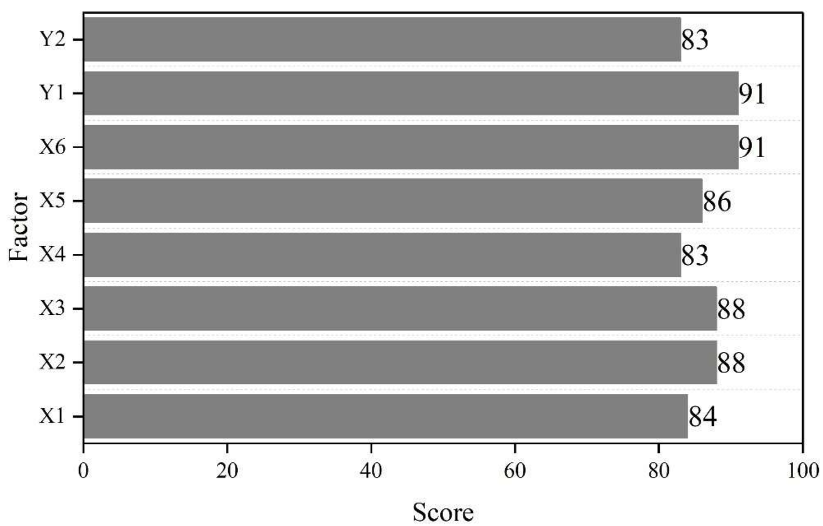

Fig. 1. The impact factors of the network investment are evaluated

Using the fuzzy multi-objective optimization model, the power supply companies in the five regions under the jurisdiction of M city calculate the proportion of grid fund allocation and the amount of investment allocation in 2023 as shown in Table 5. The eighth row in Table 5 shows the actual investment approved in 2023 according to the size of the power sales of each regional company, this investment decision-making method does not take into account the size of the grid and the investment efficiency of the grid project, the power sales of small regional power supply companies are prone to long-term insufficient investment in the grid due to the grid is getting weaker and weaker. The last row in Table 5 shows the investment of each regional company in 2023 after optimization according to the multilevel strategy of this paper, which shows that in the case of a certain grid size, the investment allocated to regional power supply enterprises with small electricity sales but high investment efficiency evaluation scores of individual grid projects is improved compared with the original. This is not only conducive to strengthening the regional power supply companies' grid investment, but also makes the power supply companies maximize their benefits.

Table 5. Proportions and amounts of distribution network's investment allocation

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
35kV Transformer capacity/MVA in 2022	15.28	3.38	9.68	25.21	13.57
35kV Line length/km in 2022	42.876	21.51	42.56	108.395	113.82
10(6)kV Transformer capacity/MVA in 2022	93.783	82.33	130.42	97.12	72.686
10(6)kV Line length/km in 2022	1788.735	1688.46	3209.93	2987.18	1873.28
110kV Line length/km in 2022	2600.313	2954.1	4584.96	3641.95	2935.298
Annual electricity consumption/GWh in 2022	38.79	20.43	52.89	63.83	24.62
The average score of investment benefits in 2023	71.03	71.8	70.53	70.59	70.99
Real investment/ ten thousand yuan in 2023	9998.92	6099.9	12549.08	15294.97	6247.64
The proportion of the allocation after optimization/% in 2023	19.01	15.86	23.86	24.52	16.67
Optimized post-allocation investment/ten thousand yuan in 2023	9610.5	8010.41	11960.01	12255.69	8354.42

6. Conclusion

In order to improve the objectivity and completeness of the comprehensive assessment results of grid investment efficiency, the study uses the fuzzy comprehensive evaluation method for quantitative assessment. Applying this method to analyze the 2022 grid investment efficiency grade of City M, the final quantitative score of the city's grid investment efficiency is 63.36 points, indicating that there is still much room for improvement in grid investment efficiency. Accordingly, a multi-level optimization strategy based on the multi-objective optimization model is adopted. After optimization, the scores of each index are above 83 points, indicating that the method of this paper helps to improve the efficiency of grid investment, which is significant for the sustainable development of grid enterprises and the establishment of investment efficiency-oriented grid evaluation and investment decision-making work system.

References

[1] Lim, S. Y., Park, J. H., & Yoo, S. H. (2015). Assessment of the Economic Benefits from Electricity Consumption. Journal of Energy Engineering, 24(2), 9-16.

[2] Kuihua, W., Zhijie, Z., Hao, L., Bo, L., Zhao, L., Wen, Z., & Shuli, L. (2020, June). Study on economic benefit evaluation model of energy-efficient power plant projects with high energy consumption users. In 2020 5th Asia Conference on Power and Electrical Engineering (ACPEE) (pp. 923-927). IEEE.

[3] Zhang, C., & Yang, J. (2019). Economic benefits assessments of "coal-to-electricity" project in rural residents heating based on life cycle cost. Journal of cleaner production, 213, 217-224.

[4] Wang, H., Zhao, X., Zhang, K., & Wang, W. (2022). Economic assessment of a renewable energy-electricity-hydrogen system considering environmental benefits. Sustainable Production and Consumption, 33, 903-920.

[5] Conchado, A., Linares, P., Lago, O., & Santamaría, A. (2016). An estimation of the economic and environmental benefits of a demand-response electricity program for Spain. Sustainable Production and Consumption, 8, 108-119.

[6] Lu, H., Sheng, X., & Du, F. (2022). Economic benefit evaluation system of green building energy saving

building technology based on entropy weight method. Processes, 10(2), 382.

[7] Xiao, Q. W., Tian, Z., & Ren, F. R. (2022). Efficiency assessment of electricity generation in China using meta-frontier data envelopment analysis: Cross-regional comparison based on different electricity generation energy sources. Energy Strategy Reviews, 39, 100767.

[8] Carranza, E., & Meeks, R. (2021). Energy efficiency and electricity reliability. Review of Economics and Statistics, 103(3), 461-475.

[9] Hank, C., Sternberg, A., Köppel, N., Holst, M., Smolinka, T., Schaadt, A., ... & Henning, H. M. (2020). Energy efficiency and economic assessment of imported energy carriers based on renewable electricity. Sustainable Energy & Fuels, 4(5), 2256-2273.

[10] Craig, C. A., & Feng, S. (2017). Exploring utility organization electricity generation, residential electricity consumption, and energy efficiency: A climatic approach. Applied Energy, 185, 779-790.

[11] Hadjidemetriou, L., Zacharia, L., & Kyriakides, E. (2017, June). Flexible power control scheme for interconnected photovoltaics to benefit the power quality and the network losses of the distribution grid. In 2017 IEEE 3rd International Future Energy Electronics Conference and ECCE Asia (IFEEC 2017-ECCE Asia) (pp. 93-98). IEEE.

[12] Bai, C., Zhang, Y., Zhang, Y., & Han, X. (2019, September). Quality and Benefit Oriented Evaluation of Smart Grid Development Level. In 2019 4th International Conference on Power and Renewable Energy (ICPRE) (pp. 366-370). IEEE.

[13] Zuo, Y., & Liu, H. (2012, June). Evaluation on comprehensive benefit of wind power generation and utilization of wind energy. In 2012 IEEE International Conference on Computer Science and Automation Engineering (pp. 635-638). IEEE.

[14] Gore, K., Rigot-Müller, P., & Coughlan, J. (2023). Cost-benefit assessment of shore side electricity: An Irish perspective. Journal of environmental management, 326, 116755.

[15] De Castro, L., Dutra, J., & Figer, V. (2018). The economics of the smart grid technological innovation. In Handbook of Energy Politics (pp. 351-402). Edward Elgar Publishing.

[16] Shayeghi, H., & Shahryari, E. (2017). Optimal operation management of grid-connected microgrid using multi-objective group search optimization algorithm. J. Oper. Autom. Power Eng, 5(2), 227-239.

[17] Klass, A., Macey, J., Welton, S., & Wiseman, H. (2022). Grid Reliability Through Clean Energy. Stan. L. Rev., 74, 969.

[18] Lu Yan,Lv Ke,Yuan Jingzhong,Li Hongjian,Wu Luofei & Peng Sha. (2020). Evaluation on the Social Benefits of Power grid enterprises' Investment Based on the Fuzzy Matter-element Model. IOP Conference Series: Materials Science and Engineering(5),052047.

[19] Gao Lei,Zhao ZhenYu & Li Cui. (2022). An Investment Decision-Making Approach for Power Grid Projects: A Multi-Objective Optimization Model. Energies(3),1112-1112.

[20] Md. Sanowar Hossain & Md. Mosharraf Hossain. (2024). Multi-Objective Optimization for Integrated Production and Distribution Planning Using Non-Linear Fuzzy Membership Functions. Operations Research Forum(4),110-110.