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Energy-Saving Evaluation and Comprehensive Benefit Analysis of Power Transmission/Distribution System Based on Cloud Model

Xuan Liu [1,*], Lei Tang [2], Yan Lu [1], Jing Xiang [1], Huifang Qin [2], Geqian Zhou [2], Chengwei Liu [2] and Bo Qin [2]

[1] Economic and Technical Research Institute of State Grid Jibei Electric Power Co., Ltd., Beijing 100038, China; hdlyan@163.com (Y.L.); 15124329491@163.com (J.X.)
[2] Central Southern China Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group, Wuhan 430071, China; tl5507@csepdi.com (L.T.); qhf5583@csepdi.com (H.Q.); zgq5706@csepdi.com (G.Z.); liuchengwei@csepdi.com (C.L.); tb5699@csepdi.com (B.Q.)
* Correspondence: 18311035066@163.com; Tel.: +86-183-1103-5066

Abstract: The current situation of the energy crisis requires various industries around the world to seek technological upgrades to achieve energy conservation. The renovation of power grid lines, transformers, and substations significantly affects the comprehensive benefits of power transmission/distribution systems, and the optimization of specific parameters of these elements plays a critical role in their operational performance. In order to determine the effects of these parameters and realize their accurate optimization, herein, we establish a method combining an analytic hierarchy process and an entropy weight method to calculate the weightings of the indexes, and then evaluate the comprehensive benefits through a cloud model. Based on the evaluation system above, a case study was utilized to analyze the power transmission/distribution system of a designated area in Wuhan City, and the results showed that the comprehensive benefits increased by around 5.4% compared to 2022, and could be upgraded to level IV in the cloud model with the technical transformation. This exhibits the effectiveness and the application feasibility of this evaluation system.

Keywords: analytic hierarchy process; entropy weight method; cloud model; comprehensive benefits; energy saving

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1. Introduction

Energy and environmental issues have caught much attention. In order to address climate change and achieve sustainable energy development, global efforts have been put towards developing renewable energy, exploring energy-saving equipment, etc. As an important component of economic development, the power industry has considerable potential in energy conservation. At present, related technologies have been carried out in the power grid for saving energy, including power line reconstruction, transformer replacement, reactive power compensation reconstruction, and so on [1,2]. However, further research is needed to deepen the energy-saving work of the power grid department, and thereby achieve better energy conservation in practical operation.

With the development of energy-conservation research in the field of power grids, evaluating the energy-saving effect of transmission and distribution has become one of the most important topics, and there have been relevant studies and reports on some evaluation systems. Zhao et al. [3] combined the methods of life cycle asset management and the triangle fuzzy analytic hierarchy process for the evaluation of power grids from the aspects of safety, reality, economic efficiency, etc. Zhou et al. [4] proposed a low-carbon assessment model to analyze low-carbon power-generation technology, low-carbon energy utilization, and the low-carbon power dispatch of a smart power grid. Zhang et al. [5] utilized super-efficiency data envelopment analysis to evaluate sequence voltage level on the basis of low-carbon benefits, which was further proved to be effective with the case study of Zhengzhou New Area. In general, establishing a complete and reasonable comprehensive evaluation index system is very important for analyzing the operation status of transmission and distribution grids, which can further guide reductions in energy consumption and total costs.

Therefore, we proposed a complete comprehensive evaluation index system based on the operation status of power transmission/distribution systems, combining the analytic hierarchy process with the entropy weight method for weighting, and a cloud model was established for comprehensive benefit evaluation accordingly. Based on this, parameter optimization was carried out using a regional transmission and distribution power grid in Wuhan as an example, thereby providing technical prospects for the energy-saving operation.

2. Materials and Methods

In order to analyze the performance of the power transmission/distribution system, a method combining the analytic hierarchy process and the entropy weight method was employed for calculating the indicator weights, and a cloud model was used as the evaluation strategy accordingly, thus evaluating the comprehensive benefits of the current and optimized power transmission/distribution systems.

2.1. Calculation of Combined Weightings of Indexes

2.1.1. Analytic Hierarchy Process

The analytic hierarchy process is a method that involves decomposing complex problems into different elements by analyzing the degree of correlation between the factors involved, and merging these elements into different levels to form a multi-level structure. The main steps of the analytic hierarchy process include establishing a decision matrix (A), calculating relative importance, and conducting consistency checks.

The establishment of A can be described as follows [6,7]:

$$\mathrm{A} = \begin{pmatrix} \mathrm{a}_{11} & \cdots & \mathrm{a}_{1\mathrm{n}} \\ \vdots & \ddots & \vdots \\ \mathrm{a}_{\mathrm{n}1} & \cdots & \mathrm{a}_{\mathrm{nn}} \end{pmatrix} \tag{1}$$

where a_{ij} represents the importance of ai relative to a_{j}, and the relationship between a_{ij} and a_{ji} can be described as $\mathrm{a}_{\mathrm{ij}} \cdot \mathrm{a}_{\mathrm{ji}} = 1$.

Constructing the decision matrix requires assigning scores to different indicator elements under the same evaluation scale, and a 1–9 scaling method is commonly used, which was proposed by Professor Saaty [8]. Specific principles can be obtained in the works of Kablan [9] and Tanaka et al. [10]. Based on this, matrix A was normalized and the process proceeded according to Cahyapratama et al. [11] and Wei et al. [12].

In addition, the consistency index (CI) can be calculated according to the matrix above (Equation (2)), which was used for determining the consistency of the decision matrix A [13,14]. That is, if $\mathrm{CR} \leq 0.1$ (Equation (3)), the matrix above has consistency, and the values calculated based on it are meaningful and acceptable.

$$\mathrm{CI} = \frac{\lambda_{\max} - \mathrm{n}}{\mathrm{n} - 1} \tag{2}$$

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{3}$$

where CR is the consistency ratio and RI represents the random consistency index, which can be obtained according to the results of Saaty [15].

2.1.2. Entropy Weight Method

In order to evaluate the various indicators in a power transmission/distribution system better, the entropy weight method was utilized for the calculation based on the analytic hierarchy process in this study. In brief, a more significant difference in the comprehensive benefit evaluation index values indicated a smaller entropy value, and more effective information could be obtained; meanwhile, the corresponding weight should also be larger. The specific calculation process can be found in previous reports [16–18].

2.2. Evaluation via Cloud Model

A cloud model consists of several cloud droplets that represent a specific point and form an uncertain cloud. Briefly, a cloud model can be characterized by Ex, En, and He, which represent expectation, entropy, and super entropy, respectively [19,20].

When building the model for evaluation, the standard cloud model divided the domain U of indicators into five sub-intervals based on the number of standard levels, and the jth sub-interval was $[x_{jmin}, x_{jmax}]$. Correspondingly, the characteristic values of the normal cloud were $[Ex_j, En_j, He_j]$, and the calculation could be obtained as follows (Equation (4)) [21–23]:

$$\begin{cases} Ex_j = \frac{x_{jmin} + x_{jmax}}{2} \\ En_j = \frac{x_{jmax} - x_{jmin}}{6} \\ He_j = k \end{cases} \tag{4}$$

where x_{max} and x_{min} represent the boundary value of the intervals and k is the constant that reflects the uncertainty, which is set as 0.5 in this paper.

Based on this, the parameters of Ex, En, and He of the comprehensive cloud could be obtained as follows (Equation (5)) [23,24]:

$$\begin{cases} Ex = \sum_{i=1}^{m} (Ex_i \cdot w_i) \\ En = \sqrt{\sum_{i=1}^{m} \left(Ex_i^2 \cdot w_i\right)} \\ He = \sum_{i=1}^{m} (He_i \cdot w_i) \end{cases} \tag{5}$$

where w_i represents the weights of each index.

3. Results and Discussion

For the reasonable evaluation of the operation status and energy-saving effects of power transmission/distribution systems, the analytic hierarchy process was combined with the entropy weight method for the weighting and a cloud model was applied for comprehensive benefit evaluation in this paper. Consequently, a regional transmission and distribution power grid in Wuhan was taken as an example, and parameter optimization was carried out to explore the feasibility of the above evaluation system in practical application.

3.1. Designing of Indicators for Evaluation Systems

In this paper, a case study of a power transmission/distribution system in a certain area of Wuhan in central China is utilized for analysis. Voltage level and the length of lines, as well as number of substations in 2022, are shown in Table 1. In order to understand the operational efficiencies of the power grid clearly, the definitions and calculations of the indicators above were obtained from Equations (6) to (21). Thus, the performance of the designated area could be obtained accordingly, and the results are shown in Table 2. It can be observed that the operation efficiencies of 2022 were acceptable on the whole, yet there were still some indexes that could be further optimized to realize higher benefits, such as supply radius qualification rate, the proportion of reactive power compensation capacity, and the comprehensive line loss rate of the substation area. Based on the parameters of 2022, technological upgrades were adopted to achieve energy conservation, including adjusting the number of main transformers, using energy-saving equipment, etc., and the performance of 2023 can be observed in Table 2.

Table 1. Parameters of power transmission/distribution system in 2022.

Voltage Level (kV)	Specific Parameter	Amount
220	Number of main transformers	18
	Capacity of main transformers (MVA)	2496
	Number of lines	31
	Length of lines (km)	990.97
110	Number of main transformers	56
	Capacity of main transformers (MVA)	1776
	Number of lines	95
	Length of lines (km)	1722.23
35	Number of main transformers	175
	Capacity of main transformers (MVA)	995
	Number of lines	179
	Length of lines (km)	2163.44
10	Number of distribution transformers	21,232
	Capacity of distribution transformers (MVA)	2677.63
	Number of lines	821
	Length of lines (km)	20,402.1

Table 2. Operational performance of power grid in 2022 and 2023.

Index	Performance	
	2022	2023
Y_1	72.65	75.63
Y_2	69.72	71.27
Y_3	89.43	91.29
Y_4	100.00	100.00
Y_5	0.69	0.72
Y_6	100.00	100.00
Y_7	6.02	5.34
H_1	91.50	94.90
H_2	66.54	67.63
H_3	56.12	61.33
H_4	8.96	6.46
H_5	4.57	3.63
Z_1	75.88	79.52
Z_2	94.85	97.53
Z_3	7.13	6.46
Z_4	69.24	77.18

For the evaluation of the performance of the power grid and the effects of the technological upgrades, types of indexes were first divided into three parts—power grid lines, transformers, and substations—containing the specific indexes of Y_1~Y_7, H_1~H_5, and Z_1~Z_4, respectively. Subsequent calculations and the optimization of the analytic hierarchy process combined with the entropy weight method, as well as the cloud model, were established based on the indexes above.

The supply radius qualification rate is as follows (Y_1):

$$Y_1 = \frac{A_1}{B_1} \times 100\% \tag{6}$$

where A_1 represents the number of qualified power supply lines and B_1 is the number of total lines.

The rate of economic operation lines is as follows (Y_2):

$$Y_2 = \frac{A_2}{B_1} \times 100\% \tag{7}$$

where A_2 represents the number of economic operation lines.

The qualification rate of line loss for a single line is as follows (Y_3):

$$Y_3 = \frac{A_3}{B_1} \times 100\% \tag{8}$$

where A_3 represents the number of qualified lines of line loss.

The qualification rate of the main trunk line cross-sections is as follows (Y_4):

$$Y_4 = \frac{A_4}{B_1} \times 100\% \tag{9}$$

where A_4 represents the number of lines within the cross-sectional area range that meet industry-standard energy efficiency.

The proportion of new energy-saving conductors is calculated as follows (Y_5):

$$Y_5 = \frac{A_5}{B_2} \times 100\% \tag{10}$$

where A_5 represents the length of new energy-saving conductors and B_2 is the total length of lines.

The qualified rate of the total capacity of line access and distribution is as follows (Y_6):

$$Y_6 = \frac{A_6}{B_1} \times 100\% \tag{11}$$

where A_6 represents the qualified line for connecting to the total distribution capacity.

The comprehensive non-loss line loss rate is calculated as follows (Y_7):

$$Y_7 = \frac{C_1 - D_1}{C_1} \times 100\% \tag{12}$$

where C_1 represents the electricity sold from the grid and D_1 is the total meter power supply of the transformer, except for lossless electricity.

The qualification rate of the power factor in the distribution is calculated as follows (H_1):

$$H_1 = \frac{K_\varphi}{K_\Sigma} \times 100\% \tag{13}$$

where $K\varphi$ represents the number of transformers required for the load power factor and K_Σ is the total number of transformers in the line.

The economic operation ratio of distribution transformers is calculated as follows (H_2):

$$H_2 = \frac{G_2}{K_1} \times 100\% \tag{14}$$

where G_2 represents the numbers transformers in economic operation and K_1 represents the total number of transformers.

The proportion of reactive power compensation capacity is calculated as follows (H_3):

$$H_3 = \frac{G_3}{K_2} \times 100\% \tag{15}$$

where G_3 represents reactive power compensation capacity and K_2 is the reactive power compensation capacity that should be configured.

The proportion of high-energy-consuming distribution transformers is calculated as follows (H_4):

$$H_4 = \frac{G_4}{K_1} \times 100\% \tag{16}$$

where G_4 represents the number of high-energy-consuming transformers.

The average loss rate of the distribution transformers is calculated as follows (H_5):

$$H_5 = \frac{P_{oz} + b^2 P_{kz}}{bS_N\cos\theta + P_{oz} + b^2 P_{kz}} \times 100\% \tag{17}$$

where P_{oz} and P_{kz} represent the iron loss and the variable loss, respectively; S_N is the rated capacity of the transformer; $\cos\theta$ is the power factor; and b is the load factor.

The qualification rate of the substation supply radius is calculated as follows (Z_1):

$$Z_1 = \frac{F_1}{E_1} \times 100\% \tag{18}$$

where F_1 represents the number of substations with qualified supply radius and E_1 is the total number of substations.

The qualification rate of the substation main trunk line cross-sections is calculated as follows (Z_2):

$$Z_2 = \frac{F_2}{E_1} \times 100\% \tag{19}$$

where F_2 represents the number of substations with qualified main trunks.

The comprehensive line loss rate of the substation area is calculated as follows (Z_3):

$$Z_3 = \frac{D_1 - G_1}{D_1} \times 100\% \tag{20}$$

where G_1 represents the total electricity sales volume of the substations.

The qualification rate of individual substation line losses is calculated as follows (Z_4):

$$Z_4 = \frac{F_4}{E_1} \times 100\% \tag{21}$$

where F_4 represents the number of qualified substations with line loss.

3.2. Performance Optimization and Energy-Saving Research

In this section, the calculation of the power grid system is first undertaken using the analytic hierarchy process and the entropy weight method for the combined weighting, and then the cloud model is used for further evaluation. As shown in Table 3, it can be observed that the combined weightings of the first-level indexes did not exhibit a notable difference, yet the substations had the greatest impact on the comprehensive benefits of the power grid system with a value of 0.3739. In addition, the combined weightings of the second-level indexes were also calculated, and it could be obtained that the combined weightings of the indexes were generally similar, while the comprehensive non-loss line loss rate, average loss rate of distribution transformers, and comprehensive line loss rate of the substation area showed the most significant effects on the indexes of power grid lines, transformers, and substations, respectively, providing strategies for the optimization of the performance and the improvement of the comprehensive benefits of the power grid system.

Table 3. Combined weightings of indexes of the evaluation system.

First-Level Index	Combined Weighting	Second-Level Index	Combined Weighting
Power grid lines	0.3023	Y_1	0.0496
		Y_2	0.0341
		Y_3	0.0333
		Y_4	0.0237
		Y_5	0.0551
		Y_6	0.0368
		Y_7	0.0698
Transformers	0.3239	H_1	0.0695
		H_2	0.0450
		H_3	0.0536
		H_4	0.0767
		H_5	0.0790
Substations	0.3739	Z_1	0.0886
		Z_2	0.0529
		Z_3	0.1483
		Z_4	0.0840

In order to evaluate the operational effectiveness of the transmission and distribution grid appropriately, the comprehensive benefits of the system in the designated area were divided into five levels with an evaluation interval of [0, 100]. The specific parameters of the cloud model for each level were determined according to Equation (4), and the results are shown in Table 4. Accordingly, the standard cloud of the comprehensive benefit evaluation could be obtained with the aggregation of several droplets in the intervals above, and the results are displayed in Figure 1.

Table 4. Evaluation grade and normal cloud parameters.

Grade	Scale	Parameters
I	[0, 60]	(30, 10, 0.5)
II	[60, 75]	(67.5, 2.5, 0.5)
III	[75, 85]	(80, 1.67, 0.5)
IV	[85, 95]	(90, 1.67, 0.5)
V	[95, 100]	(97.5, 0.83, 0.5)

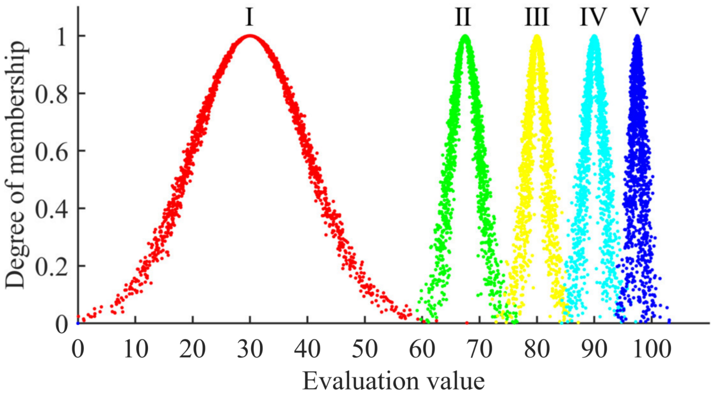

Figure 1. Standard cloud of comprehensive benefit evaluation.

Based on this, for the direct evaluation of the performance of the power grid system, we organized the quantitative indicators and the qualitative indicators into a comprehensive benefit evaluation matrix, and then calculated the corresponding normal cloud model parameters for each indicator through the reverse cloud generator. Then, the comprehensive cloud model parameters could be determined through the weightings of the indicator layer and the criterion layer, as well as the calculation of Equation (5). The corresponding results are shown in Table 5 and further displayed as cloud maps (Figure 2) through the program of MATLAB. It can be seen that the expected values (Ex) of not only each classification indicator, but also the comprehensive benefits increased to a certain extent. Since the comprehensive benefit was calculated based on the first-level indexes with the corresponding weightings, the increase could reflect the improvement in the whole system, including the aspects of power grid lines, transformers, and substations. Therefore, the increase in comprehensive benefits was calculated according to Equation (22), and the results showed that the technical transformation realized an overall increase of around 5.4% compared to 2022. Moreover, a similarity calculation was undertaken according to previous reports [25,26], and the results are shown in Table 6. It can be obtained from the combined results of Figure 2 and Table 6 that the evaluation level of the comprehensive benefits in 2022 can be considered as level III, and the benefits were upgraded to level IV with the technical transformation, demonstrating that the effective renovation of the power grid in the designated area remarkably improved the comprehensive benefits of the system's operation.

$$B_C = \frac{E_{x2023} - E_{x2022}}{E_{x2022}} \times 100\% \tag{22}$$

Table 5. Comprehensive cloud model of overall benefit evaluation.

Normal Cloud	Cloud Model Parameters (Ex, En, He)	
	2022	2023
Line cloud	(86.89, 2.44, 0.19)	(90.88, 2.16, 0.14)
Transformer cloud	(81.90, 2.42, 0.18)	(84.58, 1.87, 0.09)
Substation cloud	(83.87, 1.09, 0.11)	(90.29, 2.66, 0.22)
Comprehensive cloud	(83.78, 2.20, 0.16)	(88.34, 2.26, 0.15)

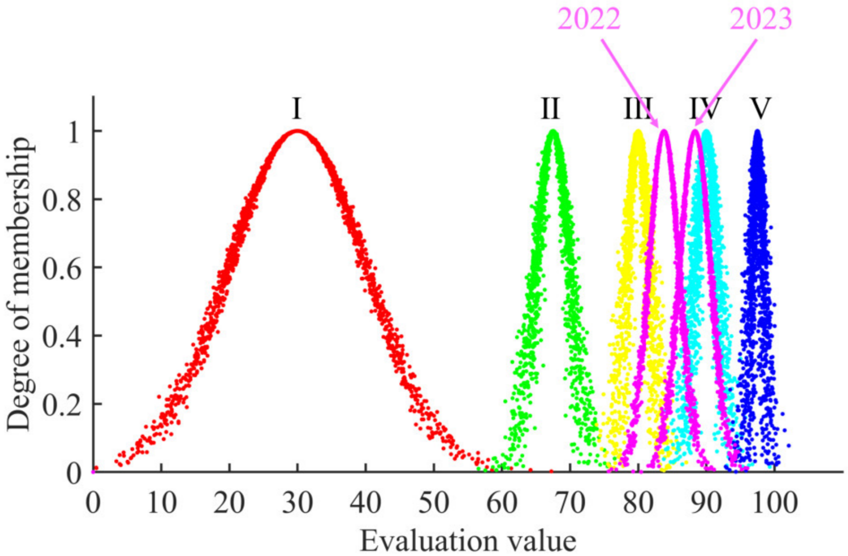

Figure 2. Comparison of comprehensive benefit evaluation with the energy-saving renovation.

Table 6. Similarity calculation of comprehensive benefits.

Similarity of Comprehensive Cloud	2022	2023
I	0.0000	0.0000
II	0.0000	0.0000
III	0.2403	0.0067
IV	0.0481	0.5144
V	0.0000	0.0000

Furthermore, in order to validate the reliability of the evaluation results of the model in this paper, a sensitivity analysis on the changes in model parameters was conducted with the perturbation analysis method [27]. In brief, weightings (w_i) of the 16 evaluation indicators (Y_1~Y_7, H_1~H_5, Z_1~Z_4) were adjusted by changing the disturbance coefficient (δ), and specific calculations were completed using Equations (23)–(26). Among them, δ values were set as 0.9 and 1.1, and the subsequent perturbations were performed accordingly. As shown in Table 7, it can be observed that the comprehensive results were not sensitive to the changes in weightings within a reasonable range, indicating that the model constructed in this study displayed outstanding reliability in evaluating the comprehensive benefits of the power transmission/distribution system.

$$w_i' = \delta w_i \tag{23}$$

$$w_t' = \eta w_t \tag{24}$$

$t \neq i$, t = 1, 2, . . ., 16; where w_i represents the weighting of the disturbance evaluation indicator, w_t is the disturbance weighting of other indicators, and η is the influence coefficient during the disturbance adjustment.

$$\delta w_i + \eta \sum\nolimits_{t=1}^{n} w_t = 1 \tag{25}$$

$$\eta = \frac{1 - \delta w_i}{1 - w_i} \tag{26}$$

In general, the evaluation system designed in this paper could objectively assess the effects of technological transformation on the comprehensive benefits of the power transmission/distribution system; meanwhile, it could also reflect the impact of the specific facilities of the power grid on system performance, which provides a reliable basis for optimizing the energy-saving operation of the power transmission/distribution system in the future. However, the application of the above evaluation system in practice would still face many challenges. Firstly, there are differences in the construction of power transmission/distribution systems in the north and south regions of China, such as differences in grid structure settings, line voltage, and the ability of power equipment to withstand heat/cold, moisture/snow, etc. Therefore, the characteristics of the power grid in the designated area should be fully considered in the construction of evaluation models. Secondly, the design and performance of power grids are affected by climate conditions, economic development level, energy structure of the area, etc. Thus, the specific technological transformation should consider regional characteristics to obtain the most suitable strategy. In addition, the selection of data influences evaluation results. For instance, electricity consumption differs across seasons and levels of urban development in China, and regional differences lead to a variation in power sources, etc. Therefore, the above factors should be fully taken into account in the model construction and benefit evaluation process.

Table 7. Sensitivity analysis of model parameter changes.

Index	Disturbance Coefficient (δ)	Calculation Results	
		2022	2023
Y_1	1.1	83.82%	88.37%
	0.9	83.75%	88.31%
Y_2	1.1	83.80%	88.34%
	0.9	83.77%	88.34%
Y_3	1.1	83.82%	88.37%
	0.9	83.75%	88.31%
Y_4	1.1	83.83%	88.37%
	0.9	83.75%	88.31%
Y_5	1.1	83.70%	88.24%
	0.9	83.87%	88.43%
Y_6	1.1	83.85%	88.38%
	0.9	83.72%	88.29%
Y	1.1	83.78%	88.38%
	0.9	83.79%	88.30%
H_1	1.1	83.84%	88.39%
	0.9	83.73%	88.29%
H_2	1.1	83.84%	88.38%
	0.9	83.73%	88.30%
H_3	1.1	83.77%	88.34%
	0.9	83.81%	88.34%
H_4	1.1	83.55%	88.25%
	0.9	84.02%	88.43%
H_5	1.1	83.85%	88.20%
	0.9	83.72%	88.47%
Z_1	1.1	83.89%	88.45%
	0.9	83.68%	88.23%
Z_2	1.1	83.85%	88.39%
	0.9	83.72%	88.29%
Z_3	1.1	83.55%	88.15%
	0.9	84.02%	88.53%
Z_4	1.1	83.81%	88.41%
	0.9	83.76%	88.26%

3.3. Comprehensive Benefit Analysis and Perspectives

The benefits brought by technological upgrading can generally be elaborated from two aspects: economics and social environment. On the one hand, upgraded power grid systems can reduce energy loss during transmission, thereby improving energy utilization efficiency; meanwhile, the application of new equipment could improve the reliability and stability of the power system, thus cutting down equipment losses and operating costs. On the other hand, the improvement of energy utilization efficiency and the promotion of new energy-saving equipment could directly cut down carbon emissions and reduce environmental pollution; at the same time, technological upgrades could promote the application of green energy technologies such as smart grids and distributed energy, thus achieving sustainable energy utilization and green development, which is in line with the ongoing "dual carbon" and sustainable development strategies of China.

Therefore, based on the background of both the renovation of the power grid and the current energy crisis, upgrading should pay attention to the development of green and low-carbon systems, optimize energy structures, reduce carbon emissions, and promote the sustainable development of power systems. Meanwhile, with the development of smart grids and the Internet, power transmission/distribution systems could achieve a higher degree of intelligence and automation, thereby improving operational efficiency and economic benefits through the real-time monitoring and prediction of the status of transmission and distribution equipment.

However, power transmission/distribution systems are quite complex, and involve numerous types of equipment, lines, and so on. Consequently, the overall and coordinated nature of the system, as well as the diverse needs of different regions and environments, should be taken in consideration into the technological upgrading process. At the same time, the renovation of the power grid requires a large amount of capital investment, which may be one of the challenges for economically disadvantaged regions.

In general, the optimization of power transmission/distribution systems should fully consider various aspects, such as the comprehensive benefits, the application of modern technology, green and sustainable development, regional characteristics, and actual economic conditions.

4. Conclusions

In this paper, a method combining the analytic hierarchy process and the entropy weight method was first established to calculate the weightings of the first-level indexes, including power grid lines, transformers, and substations, as well as specific contained indicators, which can preliminary determine specific effects on power transmission/distribution systems. Accordingly, a cloud model was utilized to analyze the comprehensive benefits, and a direct evaluation was realized through cloud maps and similarity calculations. Based on the evaluation system above, a case study of a power transmission/distribution system in the designated area of Wuhan City was analyzed, and the results showed that the comprehensive benefits increased by around 5.4% compared to 2022, and could be upgraded to level IV in the cloud model with the technical transformation. This exhibited the effectiveness and the application feasibility of this evaluation system. Furthermore, we analyzed the benefits brought by technological upgrading from the perspectives of economics and social environment, and proposed comments about the development and challenges of power grid renovation, which should be undertaken in full consideration of various aspects, such as the comprehensive benefits, the application of modern technology, green and sustainable development, regional characteristics, and actual economic conditions.

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References

1. Zhang, D.; He, Y.; Ou, Q.; Zheng, J.; Zhang, Y. Energy Saving Measurement Methods in Power Grid Engineering. *IOP Conf. Ser. Earth Environ. Sci.* **2018**, *170*, 042161. [CrossRef]
2. Chen, X.; Qiu, Z.; Xu, Z.; Xiao, C. Strategy on energy saving reconstruction of distribution networks based on life cycle cost. *AIP Conf. Proc.* **2017**, *1864*, 020020.
3. Zhao, H.; Li, T.; Fu, L.; Ou, D. The research on comprehensive benefits evaluation of smart grid self-healing. In Proceedings of the 2012 China International Conference on Electricity Distribution, Shanghai, China, 10–14 September 2012; pp. 1–12.

4. Zhou, T.; Chen, Q.; Zhu, W.; Zhang, L.; Kang, C. A comprehensive low-carbon benefits assessment model for power systems. In Proceedings of the 2012 IEEE International Conference on Power System Technology (POWERCON), Auckland, New Zealand, 30 October–2 November 2012.
5. Zhang, Q.; Wang, J.; Li, J.; Yue, J.; Liu, R. Evaluation of the sequence of voltage levels based on low-carbon theory. In Proceedings of the 2012 China International Conference on Electricity Distribution, Shanghai, China, 10–14 September 2012; pp. 10–14.
6. Michalak, M.; Bagiński, J.; Białas, A.; Kozłowski, A.; Sikora, M. A Generic Component for Analytic Hierarchy Process-Based Decision Support and Its Application for Postindustrial Area Management. *Infrastructures* **2024**, *9*, 2. [CrossRef]
7. Goedert, J.D.; Sekpe, V.D. Decision Support System–Enhanced Scheduling in Matrix Organizations Using the Analytic Hierarchy Process. *J. Constr. Eng. Manag.* **2013**, *139*, 05013003. [CrossRef]
8. Saaty, T.L. Decision making with the analytic hierarchy process. *Int. J. Serv. Sci.* **2008**, *1*, 83–98. [CrossRef]
9. Kablan, M.M. Decision support for energy conservation promotion: An analytic hierarchy process approach. *Energy Pol.* **2004**, *32*, 1151–1158. [CrossRef]
10. Tanaka, H.; Tsukao, S.; Yamashita, D.; Niimura, T.; Yokoyama, R. Multiple Criteria Assessment of Substation Conditions by Pair-Wise Comparison of Analytic Hierarchy Process. *IEEE Trans. Power Deliv.* **2010**, *25*, 3017–3023. [CrossRef]
11. Cahyapratama, A.; Sarno, R. Application of Analytic Hierarchy Process (AHP) and Simple Additive Weighting (SAW) methods in singer selection process. In Proceedings of the 2018 International Conference on Information and Communications Technology (ICOIACT), Yogyakarta, Indonesia, 6–7 March 2018; pp. 234–239.
12. Wei, C.; Wei, J.; Kong, Q.; Fan, D.; Qiu, G.; Feng, C.; Li, F.; Preis, S.; Wei, C. Selection of optimum biological treatment for coking wastewater using analytic hierarchy process. *Sci. Total Environ.* **2020**, *742*, 140400. [CrossRef] [PubMed]
13. Jenifer, M.A.; Jha, M.K. Comparison of Analytic Hierarchy Process, Catastrophe and Entropy techniques for evaluating groundwater prospect of hard-rock aquifer systems. *J. Hydrol.* **2017**, *548*, 605–624. [CrossRef]
14. Marinoni, O. Implementation of the analytical hierarchy process with VBA in ArcGIS. *Comput. Geosci.* **2004**, *30*, 637–646. [CrossRef]
15. Saaty, T.L. *Decision Making for Leaders: The Analytical Hierarchy Process for Decisions in a Complex World*; RWS Publications: Pittsburgh, PA, USA, 2001.
16. Zhu, Y.; Tian, D.; Yan, F. Effectiveness of Entropy Weight Method in Decision-Making. *Math. Probl. Eng.* **2020**, *2020*, 3564835. [CrossRef]
17. Zhang, X.; Wang, C.; Li, E.; Xu, C. Assessment Model of Ecoenvironmental Vulnerability Based on Improved Entropy Weight Method. *Sci. World J.* **2014**, *2014*, 797814. [CrossRef] [PubMed]
18. Wu, R.M.X.; Zhang, Z.; Yan, W.; Fan, J.; Gou, J.; Liu, B.; Gide, E.; Soar, J.; Shen, B.; Fazal-E-Hasan, S.; et al. A comparative analysis of the principal component analysis and entropy weight methods to establish the indexing measurement. *PLoS ONE* **2022**, *17*, e0262261. [CrossRef] [PubMed]
19. Li, L.; Liu, L.; Yang, C.; Li, Z. The Comprehensive Evaluation of Smart Distribution Grid Based on Cloud Model. *Energy Proc.* **2012**, *17*, 96–102. [CrossRef]
20. Qin, K.; Xu, K.; Liu, F.; Li, D. Image segmentation based on histogram analysis utilizing the cloud model. *Comput. Math. Appl.* **2011**, *62*, 2824–2833. [CrossRef]
21. Xiong, Y.; Kong, D.; Cheng, Z.; Wu, G.; Zhang, Q. The Comprehensive Identification of Roof Risk in a Fully Mechanized Working Face Using the Cloud Model. *Mathematics* **2021**, *9*, 2072. [CrossRef]
22. Guo, M.; Zhao, J.; Pan, D.; Sun, M.; Zhou, Y.; Yan, B. Normal cloud model theory-based comprehensive fuzzy assessment of wooden pagoda safety. *J. Cult. Herit.* **2022**, *55*, 1–10. [CrossRef]
23. Wu, H.; Zhen, J.; Zhang, J. Urban rail transit operation safety evaluation based on an improved CRITIC method and cloud model. *J. Rail Transp. Plan. Manag.* **2020**, *16*, 100206. [CrossRef]
24. Qin, G.; Zhang, M.; Yan, Q.; Xu, C.; Kammen, D.M. Comprehensive evaluation of regional energy internet using a fuzzy analytic hierarchy process based on cloud model: A case in China. *Energy* **2021**, *228*, 120569. [CrossRef]
25. Ni, C.; Wu, Y. A simplified similarity calculation method based on cloud model overlap. In Proceedings of the 2016 5th International Conference on Computer Science and Network Technology (ICCSNT), Changchun, China, 10–11 December 2016.
26. Yang, J.; Han, J.; Wan, Q.; Xing, S.; Shi, H. A novel similarity measurement for triangular cloud models based on dual consideration of shape and distance. *PeerJ Comput. Sci.* **2023**, *9*, e1506. [CrossRef]
27. Wang, Z.; Zhong, Y.; Chai, S.; Niu, S.; Yang, M.; Wu, G. Product design evaluation based on improved CRITIC and Comprehensive Cloud-TOPSIS–Applied to automotive styling design evaluation. *Adv. Eng. Inform.* **2024**, *60*, 102361. [CrossRef]