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Evaluation of the Implementation Effect of Power Demand Response under the Background of the New Power Reform and Electricity

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Abstract. In recent years, more and more regions have carried out demand response projects. It is urgent to construct an evaluation indicator system and comprehensive evaluation model to evaluate the implementation effect of power demand response under the background of the new power reform and electricity. This paper uses literature research, expert consultation and frequency statistical methods to construct an evaluation indicator system for power demand response implementation in the context of demand response new power reform and electricity; and combine the TOPSIS method with the grey correlation evaluation to construct a grey relational ideal point combination analysis and evaluation model; finally, the theory is applied to practice, to Beijing, Shanghai, Jiangsu and Foshan. The case study of the city is an example to verify the effectiveness of the evaluation model.

1. Introduction

With the rapid development of China's economy, the demand for power resources is increasing, and the peak-to-valley difference of power grid load is increasing. It is more and more difficult to balance the supply and demand balance of power resources by relying solely on the power supply side. At present, China has implemented a series of demand response (DR) pilot projects in Shanghai, Jiangsu, Beijing, Foshan and other provinces and cities.

Based on the above background, domestic and foreign scholars have done relevant research and discussion in theory. Foreign scholars use the system model method to estimate and simulate the demand response effect in the demand response evaluation. Su, Chua-Liang proposed a quantitative evaluation method for demand response to users in different market environments, and designed a centralized compound bidding market clearing mechanism [1]. According to the analysis of relevant data in Germany, Vardakas JS found that the demand response reform measures only on the sales side could not mobilize the enthusiasm of power users [2]. Adela Conchado comprehensively assesses the benefits of the Spanish family's potential disaster recovery plan. The results show that under current conditions, the power generation system has relatively low returns and needs to address costs and the problem of income distribution [3]. E.A.M. Klaassen describes a method for modeling long-term demand response



gains from a system perspective, and combines the actual data of the Dutch power system to prove the applicability of the method [4].

Domestic scholars' research on demand response evaluation mainly focuses on the evaluation of benefits and effects. In the aspect of benefit evaluation, Wang Dongrong put forward the measuring principle and method of short-term and medium and long-term economic benefits of demand response [5]; Zeng Bo proposed by introducing interval data indicators. An interval gray correlation ideal point analysis method combining expert scoring and interval center point distance method [6]; Shen Yunyi established the cost-effectiveness of demand response based on the analysis of the cost and benefit of each participant in the demand response project. The model is empirically analyzed by a numerical example [7]. In terms of effect evaluation, Wang Zhijie established the evaluation indicator system and model of demand response resources, and combined with the data of a certain region of California [8]. Based on the user response characteristics of the price elasticity matrix, Sun Wei constructed the demand response planning evaluation indicators for the performance and economic indicators [9]. Xie Chang divides users into different credit grades to allocate capacity, and proposes a comprehensive response evaluation coefficient for single response, which evaluates the response effect of a specific user and divides the credit rating [10]. Qi Xianjun used the sequential Monte Carlo simulation method to evaluate the operational reliability of the distribution network, and obtained the reliability indicator at each load level [11].

It can be seen that the issues related to DR implementation evaluation in the context of new power reform and electricity have received wide attention from scholars. However, the existing results still have the following shortcomings: (1) in the context of new power reform and electricity, the implementation effect of demand response is more focused on the efficiency of demand response implementation and user initiative. The selection of current indicators cannot clearly reflect its characteristics; (2) at present, domestic demand response evaluation indicators are based on a single perspective and cannot fully meet the new power reform and electricity background. The objective needs of the evaluation of DR implementation effects; (3) In terms of evaluation methods, at present the effect of demand response implementation is more systematic methods such as system dynamics and load simulation, and there are fewer comprehensive evaluation methods.

2. Evaluation system for the implementation of power demand response under the background of the new power reform and electricity

2.1. Design indicator criteria layer

This paper conducts frequency statistics on the influencing factors of the demand response implementation in 69 papers. As shown in Figure 1, it can be found that scholars mainly analyze the influencing factors from two aspects, on the one hand, from user response consciousness and load, reduction, and interactivity directly measure the influencing factors of demand response, and on the other hand, social, economic, and environmental factors that directly measure the effect of demand response.

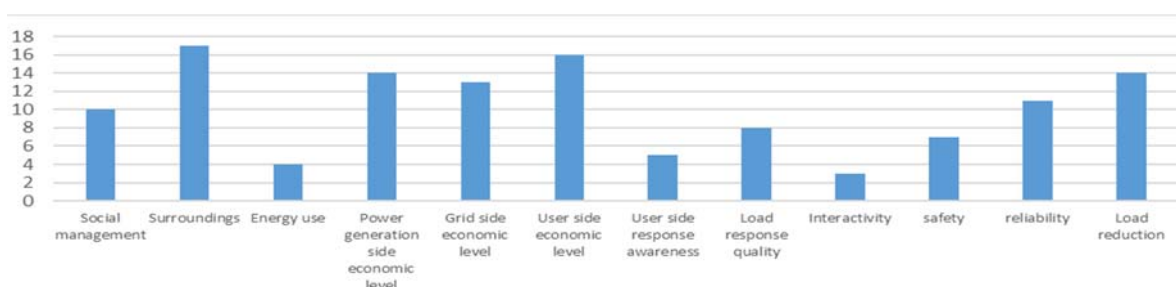


Figure 1. Factors affecting the implementation of demand response

On the basis of the frequency analysis of the literature, 10 experts from who have been engaged in the power industry for more than 10 years have been fully consulted, and the above factors have been summarized: "Power generation, power grid, and user-side economic level" has been merged into "economic effects". "User response awareness" and "interactivity", "load response quality" merged into "demand response execution effect"; "environment", "energy utilization" merged into "environmental effect"; "social management", "safety" "Reliability" is merged into "social effects." Finally, five aspects are designed to evaluate the performance evaluation system of power demand response under the background of the new power reform and electricity: demand response execution effect, load reduction effect, economic effect, environmental effect, and social effect.

2.2. Evaluation Indicators Primary Selection

This paper uses the literature research method to sort out a statistical analysis of the literature on demand side management, demand response, and demand response evaluation published in recent years in mainland China journals. In recent years, there have been 34 published articles in mainland China journals and magazines including in 10 foreign articles, 13 excellent master's thesis, 8 doctoral thesis, 4 series of guidance books, a total of 69 articles, 22 indicators were selected and integrated into the corresponding criteria layer. As shown in Table 1.

Table 1. Evaluation indicator of implementation effect of power demand response

Target layer	Criteria layer	Indicator layer	nature	unit
Evaluation of the implementation effect of power demand response under the background of new power reform and electricity	Demand response execution effect X_1	User average response frequency X_{11}	positive	Times /a
		Average user response time X_{12}	positive	h/a
		Average response duration X_{13}	inverse	h/ Times
		Average response time X_{14}	inverse	min
		User participation rate X_{15}	positive	%
		Load completion rate X_{16}	positive	%
	Load reduction effect X_2	Load rate increase X_{21}	positive	%
		Peak-to-valley difference reduction X_{22}	positive	GW
		Peak load reduction X_{23}	positive	GW
		Electricity reduction X_{24}	positive	GW·h
	Economic effect X_3	User side economic effect X_{31}	positive	¥ Ten thousand
		Grid side economic effects X_{32}	positive	¥ Ten thousand
		Power generation side economic effect X_{33}	positive	¥ Ten thousand
	Environmental effect X_4	Pollution gas emission reduction effect X_{41}	positive	/
		Renewable energy utilization growth rate X_{42}	positive	%
		Free land consumption X_{43}	positive	Km ³
	Social effect X_5	Voltage pass rate increase X_{51}	positive	%
		Power supply reliability improvement X_{52}	positive	%
		Power failure frequency reduction rate X_{53}	positive	%
		Average rate of decline per power outage X_{54}	positive	%
		Industrial efficiency X_{55}	positive	/
		Increased user satisfaction X_{56}	positive	/

2.3. Indicator Connotation and Measurement

(1) Demand response execution effect

① User average response frequency

It indicates the average number of times each user in the year participates in the demand response reduction load. The higher the frequency of participation in demand response, the higher the enthusiasm of user participation.

$$\text{User average response frequency} = \frac{\text{The sum of each user's participation in the number of demand responses}}{\text{User number}} \quad (1)$$

② Average user response time

It represents the average time that the user participates in the demand response to reduce the load each year. Within the allowable range, the user's annual response time is as long as possible.

$$\text{Average user response time} = \frac{\text{The sum of each user's participation time}}{\text{User number}} \quad (2)$$

③ Average duration of each response

Indicates the duration of each response from the start of the response to the end of the response.

$$\text{Average response duration} = \frac{\text{Total demand response time}}{\text{Total demand response}} \quad (3)$$

④ Average response time

Represents the response time from the receipt of the demand response command to the start of execution. The shorter the response time, the higher the efficiency of the demand response execution.

$$\text{Average response time} = \frac{\text{The sum of user response time}}{\text{Number of users participating in the response}} \quad (4)$$

⑤ Average user participation rate

Indicates the proportion of users who actually participate in the response to the number of invited users. The average user participation rate represents the average of the user participation rate in a year.

$$\text{user participation rate} = \frac{\text{Number of invitees participating in the demand response}}{\text{Total number of invited users}} \quad (5)$$

$$\text{Average user participation rate} = \frac{\text{The sum of user participation rates}}{\text{Total demand response}} \quad (6)$$

⑥ Average load completion rate

The load completion rate represents the ratio of the actual response amount of each demand response item to the regulation target, and the average load completion rate represents the average value of the demand response item load completion rate in a year.

$$\text{Load completion rate} = \frac{\text{Actual response}}{\text{Response event schedule}} \quad (7)$$

$$\text{Average load completion rate} = \frac{\text{Sum of load completion rates}}{\text{Total demand response}} \quad (8)$$

(2) Load reduction effect

① Load rate increase

The higher the load rate, the more stable the system is.

$$\text{Load factor} = \frac{\text{Average system load}}{\text{Maximum system load}} \quad (9)$$

$$\text{Load rate increase} = \text{Load rate this year} - \text{Last year's load rate} \quad (10)$$

②Peak-valley difference reduction rate

The difference between the peak and the valley indicates the effect of peak clipping and valley filling. The peak-valley difference reduction rate indicates a decrease in the peak-valley difference due to the implementation of the demand response.

$$\text{Peak and valley difference} = \text{Maximum system load} - \text{Minimum system load} \quad (11)$$

$$\text{Peak - valley difference reduction rate} = \frac{\text{Peak-valley difference without response} - \text{Peak-valley difference after implementing response}}{\text{Peak-valley difference without response}} \quad (12)$$

③Peak load reduction

The peak load reduction value due to the implementation of the demand response, reflects the peak clipping capability of the demand response project.

$$\text{Peak load reduction} = \text{Peak load of demand response system not implemented} - \text{Peak load after implementing a demand response system} \quad (13)$$

④Electricity reduction

The amount of electricity reduction scale represents the reduction in electricity consumption due to the implementation of demand response, reflecting the impact of demand response on total electricity consumption.

$$\text{Electricity reduction} = \text{The amount of electricity that is not implemented in the demand response system} - \text{The amount of electricity after implementing the demand response system} \quad (14)$$

(3) Economic effects

The economic effect is generally measured by the difference method, the ratio method, and the difference expression method. This paper chooses the difference method.

①User side economic effect

The user side economic effect is represented by the user side revenue minus the user side cost. User-side benefits include reduction of revenue from electricity bills, incentive compensation, cost including loss of output value, etc.

$$\text{User side economic effect} = \text{Reduced electricity bill} + \text{Incentive compensation} - \text{Loss of output value} \quad (15)$$

②Grid side economic effects

The economic effect of the power grid side is represented by revenue minus cost. Grid-side benefits include the cost of including optional maintenance costs, including cost of power loss, incentive costs, and so on.

$$\begin{aligned} \text{Grid side economic effects} \\ = \text{Free operation cost} - \text{Cost of electricity loss} - \text{Incentive cost} \end{aligned} \quad (16)$$

③Power generation side economic effect

The economic effect of the power generation side is represented by the revenue minus cost. The revenue from the power generation side includes the cost of the built-in power supply, the operating cost, and the cost of power generation.

$$\begin{aligned} \text{Power generation side economic effect} = & \\ & \text{Free investment cost} + \text{Free running costs} \\ & - \text{Loss of power generation revenue} \end{aligned} \quad (17)$$

(4) Environmental effects

① Pollution gas emission reduction effect

The emission reduction of pollutants indicates the amount of electricity generated by the reduction of demand response.

$$\begin{aligned} \text{Pollution gas emission reduction effect} & \\ & = \text{CO}_2 \text{ reduction} * \text{CO}_2 \text{ emission reduction value} + \text{SO}_2 \text{ reduction} \\ & * \text{SO}_2 \text{ emission reduction value} + \text{NO}_x \text{ reduction} \\ & * \text{NO}_x \text{ emission reduction value} \end{aligned} \quad (18)$$

② Renewable energy utilization growth rate

Indicates the rate of change of renewable energy generation as a percentage of demand response.

$$\begin{aligned} \text{Renewable energy utilization growth rate} = & \\ & \frac{\text{Revenue generation of renewable energy after implementing demand response} -}{\text{Renewable energy generation ratio after demand response is not implemented}} \end{aligned} \quad (19)$$

③ Free of land resource consumption

The land-use-free consumption represents the land resource consumption saved by avoiding grid and power supply construction due to the implementation of demand response.

(5) Social effects

① Voltage pass rate increase

The increase in the voltage pass rate refers to the change in the ratio of the time during which the node voltage of the demand response system is within the acceptable range to the total statistical time.

② Power supply reliability improvement

The ratio of the time between the system's power supply reliability and the total statistical time after the implementation of the demand response.

③ Power failure frequency reduction rate

Refers to the rate of decline in the number of system outages after DR implementation.

$$\text{Power failure frequency reduction rate} = \frac{\text{Reduced power frequency due to implementation demand response}}{\text{Power outage frequency before implementing demand response}} \quad (20)$$

④ System average power outage time reduction rate

Refers to the decrease in the ratio of the total power outage time to the number of power outages after the implementation of the demand response.

$$\text{System average power outage time} = \frac{\text{The sum of system power outages}}{\text{Number of power outages}} \quad (21)$$

$$\begin{aligned} \text{System average power outage time reduction rate} & \\ = & \frac{\text{Average power outage reduction due to implementation demand response}}{\text{Power outage time before implementing demand response}} \end{aligned} \quad (22)$$

⑤ Industrial efficiency

The industrial benefit indicator is a qualitative indicator, which is determined by experts scores, mainly based on the financing of related industries and the support of the results of related projects.

⑥ Increased user satisfaction

The user satisfaction improvement indicator is a qualitative indicator, which is determined by experts scores, mainly based on the number of relevant complaints received.

3. Establishment of evaluation model for power demand response implementation in the context of new power reform and electricity

3.1. Data standardization processing

In this paper, the vector normalization method is used to standardize the original data, and x_{ij} ($i=1,2,\dots,m, j=1,2,\dots,n$) is the original data of the n th evaluation indicator on the m th scheme.

When the indicator attribute of x_{ij} is positive,

$$x_{ij}^* = \frac{x_{ij}}{\sqrt{\sum_{ij}^m x_{ij}^2}}, x_{ij} > 0 \quad (23)$$

When the indicator attribute of x_{ij} is inverse,

$$x_{ij}^* = \frac{1 / x_{ij}}{\sqrt{\sum_{ij}^m (1 / x_{ij})^2}}, x_{ij} > 0 \quad (24)$$

When $x_{ij}=0$,

$$y_{ij}=0 \quad (25)$$

The obtained x_{ij}^* ($i=1,2,\dots,m, j=1,2,\dots,n$) represents the normalized data of the original data of the n th evaluation indicator on the m th scheme, $0 \leq y_{ij} \leq 1$.

3.2. Determine indicator weights

3.2.1. Analytic hierarchy method to determine weights

- (1) According to the evaluation indicator system, a hierarchical structure is established
- (2) Establish a judgment matrix
- (3) Consistency test and relative importance calculation

A consistency check is usually performed after the scale, and the calculation formula is

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (26)$$

Because the order of the judgment matrix is different, CI cannot be uniformly measured. The average random consistency indicator is introduced, and the calculation formula is

$$CR = \frac{CI}{RI} \quad (27)$$

CR is the average random consistency ratio, RI is the average random consistency indicator.

When $C.R. \leq 0.10$, the matrix passed the consistency test, and the average random consistency indicator test values are shown in Table 2.

Table 2. Average random consistency indicator test value

Order	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54	1.56	1.58	1.59

(4) Determine the weight subjective

- 1) Find the eigenvector of the judgment matrix $W = (w_1, w_2, \dots, w_n)$

2) Normalize the matrix W by column

$$w_{ij}^- = \frac{w_{ij}}{\sum_{i=1}^m w_{ij}}, i=1, \dots, m; j=1, \dots, n \quad (28)$$

3) Add the sum by the row $\overline{w}_i$

$$\overline{w}_i = \sum_{j=1}^n w_{ij}^- \quad (29)$$

4) Normalized weight coefficient W_i

$$W_i = \frac{\overline{w}_i}{\sum_{i=1}^n \overline{w}_i} \quad (30)$$

5) Calculation of the comprehensive importance

Assume that the overall importance of all elements $A_1, A_2, \dots, A_m$ in the upper level is $a_1, a_2, \dots, a_m$, and the relative importance of the elements $W_1, W_2, \dots, W_n$ corresponding to A_i is $(b_1^i, b_2^i, \dots, b_n^i)^T$. If

W_j has no connection with A_i , then there is $b_j^i=0$. The comprehensive importance of the element W_j is

$$b_j = \sum_{i=1}^m a_i b_j^i \quad (31)$$

3.2.2. Entropy weight method to determine the weight. Let the standardized data matrix of the evaluation be V_{ij} , there are m evaluation schemes, n evaluation indicators, and the steps of calculating the weights by the entropy weight method are described below:

1) Calculate the characteristic weight of the j th indicator

$$p_{ij} = \frac{v_{ij}}{\sum_{i=1}^m v_{ij}} \quad (32)$$

2) Calculate the entropy of the j th indicator

$$H_j = -\frac{1}{\ln m} \sum_{i=1}^m p_{ij} \ln p_{ij}, \text{ When } p_{ij}=0 \text{ or } p_{ij}=1, p_{ij} \ln p_{ij} = 0 \quad (33)$$

3) Calculate the difference coefficient of the j th indicator

$$G_j = 1 - H_j \quad (34)$$

G_j reflects the importance of the j th indicator to the overall goal. For a certain indicator X_j , the smaller X_j is, the larger H_j is, the smaller G_j is. If each scheme X_j is equal, then $G_j = G_{\min} = 0$, at which point the indicator X_j has no meaning for the comprehensive evaluation.

4) Calculate the entropy weight

$$w_j = \frac{G_j}{\sum_{j=1}^n G_j} \quad (35)$$

3.2.3. Combination Empowerment. The geometric mean weighting method determines the combination weight.

$$W_i = \frac{\theta_i^a * \gamma_i^b}{\sum_{i=1}^n \theta_i^a * \gamma_i^b} \quad (36)$$

3.3. Gray Correlation Ideal Point Combination Analysis Model

The traditional TOPSIS method cannot accurately reflect the relationship structure between the original sample data in some cases, and it is difficult to ensure the validity of the final evaluation result. Aiming at this problem, this paper combines the Gray relational analysis (GRA) with TOPSIS, and proposes a gray correlation ideal point combination analysis method (GRA-TOPSIS), which overcomes the inherent drawbacks of the original method.

There are m plans for the evaluation system, n indicators, and the matrix after standardization is Y . The specific evaluation steps of the TOPSIS method are as follows.

(1) A weighted normalization matrix is calculated based on the normalized data and the combined weight of each evaluation indicator.

$$U = (u_{ij})_{m \times n} = (w_j y_{ij})_{m \times n} = \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1n} \\ u_{21} & u_{22} & \cdots & u_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ u_{m1} & u_{m2} & \cdots & u_{mn} \end{bmatrix} \quad (37)$$

(2) Determine the ideal solution and the negative ideal solution. The standardized processing indicators have been converted into positive indicators, so the calculation method is as follows.

$$U^+ = (u_1^+, u_2^+, u_3^+ \dots u_m^+) \quad , \quad U^- = (u_1^-, u_2^-, u_3^- \dots u_m^-) \quad (38)$$

(3) Calculate the Euclidean distance between each practical solution and the ideal solution and the negative ideal solution.

$$D_i^+ = \sqrt{\sum_{j=1}^n [u_{ij} - u_j^+]^2} \quad D_i^- = \sqrt{\sum_{j=1}^n [u_{ij} - u_j^-]^2} \quad , (i = 1, 2, \dots, m) \quad (39)$$

(4) According to the two Euclidean distances, calculate the relative closeness between each actual scheme and the ideal scheme.

$$D_i^* = \frac{D_i^-}{D_i^- + D_i^+} \quad , (i = 1, 2, \dots, m) \quad (40)$$

(5) Calculate the gray correlation coefficient δ_{ij}^+ , δ_{ij}^- based on the normalized matrix Y

$$\delta_{ij}^+ = \frac{\min_i \min_j |y_{ij} - y_j^+| + \theta \max_i \max_j |y_{ij} - y_j^+|}{|y_{ij} - y_j^+| + \theta \max_i \max_j |y_{ij} - y_j^+|} \quad (41)$$

$$\delta_{ij}^- = \frac{\min_i \min_j |y_{ij} - y_j^-| + \theta \max_i \max_j |y_{ij} - y_j^-|}{|y_{ij} - y_j^-| + \theta \max_i \max_j |y_{ij} - y_j^-|} \quad (42)$$

In the formula, θ represents the resolution coefficient, and the number between 0 and 1 is artificially set, and $\theta=0.5$ is generally taken.

(6) Calculate the gray correlation degree of each scheme:

$$r_i^+ = \sum_{j=1}^n w_j^* \delta_{ij}^+ \quad , \quad r_i^- = \sum_{j=1}^n w_j^* \delta_{ij}^- \quad (43)$$

(7) In the TOPSIS method, the larger the D_i^- is, the closer the scheme is to the positive ideal scheme; in the gray evaluation method, the larger the r_i^+ is, the closer the actual scheme is to the positive ideal scheme. Therefore, in the grey correlation ideal point combination analysis method, the larger D_i^- and r_i^+ indicates that the actual scheme is closer to the positive ideal scheme, and the larger D_i^+ and r_i^-

indicates that the actual scheme is closer to the negative ideal scheme. The calculation steps are as follows:

Firstly, the Euclidean distance $D_i^\pm$ and the grey correlation degree $r_i^\pm$ are normalized, and then the combined results are calculated.

$$C_i^+ = p * D_i^- + q * r_i^+ \quad , \quad C_i^- = p * D_i^+ + q * r_i^- \quad (44)$$

Where p, q are preference coefficients, satisfying $p+q=1$, generally taking $p=q=0.5$;

(8) The larger C_i^+ indicates that the actual scheme is closer to the optimal scheme; the larger the C_i^- indicates that the actual scheme is closer to the worst scheme, and the comprehensive closeness of the scheme is calculated accordingly.

$$F_i = \frac{C_i^+}{C_i^+ + C_i^-} \quad (45)$$

(9) Sort each scheme according to the obtained F_i . The larger the F_i is, the closer it is to the ideal scheme, and the smaller the F_i is, the further away from the ideal scheme.

4. Example application

This paper selects four cities Beijing, Shanghai, Jiangsu and Foshan for analysis. The data sources of this study mainly include the statistical data of the internal website of the power company and the official website of the National Bureau of Statistics. Due to the lag of the publication of the indicator data, this paper conducts evaluation research based on the 2017 data collected. Power companies have confidentiality requirements for data, so only standardized data after processing is shown in the paper. The original data is normalized according to formulas (23-25), and the processed data is shown in Table 3.

Table 3. Raw data standardization processing

indicator	Beijing	Shanghai	Jiangsu	Foshan
User average response frequency X_{11}	0.295644	0.677517	0.517376	0.431147
Average user response time X_{12}	0.437052	0.626047	0.413427	0.496113
Average response duration X_{13}	0.379595	0.189797	0.75919	0.493473
Average response time X_{14}	0.355101	0.538031	0.715581	0.269016
User participation rate X_{15}	0.465261	0.524938	0.509466	0.498415
Load completion rate X_{16}	0.531409	0.543389	0.486275	0.431126
Load rate increase X_{21}	0.452154	0.575081	0.606117	0.312187
Peak-to-valley difference reduction X_{22}	0.410855	0.560653	0.671547	0.256693
Peak load reduction X_{23}	0.305502	0.378945	0.837091	0.249696
Electricity reduction X_{24}	0.25024	0.596239	0.731748	0.215459
User side economic effect X_{31}	0.397721	0.534276	0.688164	0.287746
Grid side economic effects X_{32}	0.245021	0.716217	0.546586	0.358108
Power generation side economic effect X_{33}	0.319951	0.698076	0.49447	0.407211
Pollution gas emission reduction effect X_{41}	0.453609	0.592426	0.538757	0.391166
Renewable energy utilization growth rate X_{42}	0.355939	0.648317	0.529671	0.415262
Free land consumption X_{43}	0.481387	0.604581	0.529785	0.349394
Voltage pass rate increase X_{51}	0.637406	0.453096	0.238067	0.57597
Power supply reliability improvement X_{52}	0.484139	0.515373	0.3592	0.609078
Power failure frequency reduction rate X_{53}	0.433693	0.648411	0.541964	0.312648
Average rate of decline per power outage X_{54}	0.414156	0.649994	0.541226	0.33624
Industrial efficiency X_{55}	0.44586	0.543034	0.514454	0.491589
Increased user satisfaction X_{56}	0.437016	0.544773	0.520827	0.490895

The subjective and objective comprehensive weights are calculated according to the formula (36). The calculation results are shown in Table 4.

Table 4. Subjective and objective comprehensive weights of each indicator

indicator	Subjective weight	Objective weight	Combination weight
User average response frequency X_{11}	0.0183	0.045042	0.033799
Average user response time X_{12}	0.0333	0.014418	0.025796
Average response duration X_{13}	0.0278	0.112487	0.065834
Average response time X_{14}	0.0693	0.071743	0.08301
User participation rate X_{15}	0.0481	0.001036	0.00831
Load completion rate X_{16}	0.0728	0.004261	0.020734
Load rate increase X_{21}	0.1215	0.031999	0.073406
Peak-to-valley difference reduction X_{22}	0.0608	0.060792	0.071573
Peak load reduction X_{23}	0.1131	0.131177	0.143395
Electricity reduction X_{24}	0.0327	0.133542	0.077796
User side economic effect X_{31}	0.0471	0.053263	0.058965
Grid side economic effects X_{32}	0.0077	0.080839	0.029372
Power generation side economic effect X_{33}	0.0191	0.044327	0.034255
Pollution gas emission reduction effect X_{41}	0.1168	0.013193	0.046214
Renewable energy utilization growth rate X_{42}	0.0354	0.027955	0.037035
Free land consumption X_{43}	0.0643	0.019856	0.042065
Voltage pass rate increase X_{51}	0.0175	0.0606	0.038338
Power supply reliability improvement X_{52}	0.0159	0.018095	0.019969
Power failure frequency reduction rate X_{53}	0.034	0.03638	0.041404
Average rate of decline per power outage X_{54}	0.0329	0.032726	0.03863
Industrial efficiency X_{55}	0.006	0.002738	0.004772
Increased user satisfaction X_{56}	0.0058	0.003532	0.005328

According to formulas (39-43), the Euclidean distance and the gray correlation degree calculated by the TOPSIS method are normalized, and $p=q=0.5$ is used to calculate the relative proximity C according to the formulas (44). The calculation results are shown in Table 5.

Table 5. The closeness of the implementation effect of the demand response and the ideal plan

Pilot city	D_i^+	D_i^-	r_i^+	r_i^-	C_i^+	C_i^-	C_i
Beijing	0.5857	0.2111	0.3914	0.5513	0.3012	0.5685	0.3464
Shanghai	0.4540	0.4578	0.5510	0.4051	0.5044	0.4295	0.5401
Jiangsu	0.1239	0.8443	0.6410	0.3665	0.7426	0.2452	0.7518
Foshan	0.6599	0.1818	0.3637	0.6306	0.2728	0.6453	0.2971

According to the calculation result of relative closeness, the order of the implementation effect of demand response under the background of new power reform and electricity can be obtained: Jiangsu>Shanghai>Beijing>Foshan.

In terms of "demand response execution effect", the performances of the four places are not much different, and Jiangsu is slightly better. At present, the responding users have all passed the screening of the power company to confirm that they have certain responsiveness, and the subsidies are high. The enthusiasm of users to participate is strong. How to make all kinds of users participate and maintain the high enthusiasm of users is a key issue. In terms of response efficiency, the main response is still for

large industrial users, and the amount of invitations is basically completed, but the duration and response time should continue to improve.

In terms of “load reduction effect”, the four regions have great differences. Jiangsu has been innovating in the demand response pilot projects every year. There are many types of demand response projects. In the eleventh period of this year, the domestic demand side bidding model was initiated and the power will be the user has been subdivided into large industrial users, non-work air conditioner users, load integrators, etc., and the technology and management methods are at a high level; the Shanghai demand response project is more for residents and intelligent buildings, and the load reduction effect is second to Jiangsu; Beijing and Foshan were built with weaker management capabilities and weaker load reduction effects.

In terms of “economic effects”, Jiangsu and Shanghai have a larger scale of implementation, and the economic effect is better than that of Beijing and Foshan. Jiangsu has a larger investment in technology and management, and its economic effect is slightly worse than that of Shanghai. With the end of the pilot, how to ensure stable financial support is a problem faced by power grid companies.

In terms of “environmental effects” and “social effects”, there is a greater relationship with the reduction of load. The environmental effects and social effects of the load reduction effect will be improved, if the effect of the load reduction is good. It is related to the government guidance and supervision. The government should assume the responsibility to guarantee a stable development of demand response.

Through analysis and discussion, the experts agreed that the evaluation results are in line with the actual situation, and the scientific nature of the evaluation system constructed in this paper is confirmed from the practical level. This result has certain significance for improving the implementation effect of demand response and improving the management ability of grid companies in demand response. At the same time, the research results can be applied to the practice of demand response project implementation and effect evaluation in other regions.

5. Conclusion

According to the results of the implementation effect evaluation of the demand response in the four cities of Beijing, Shanghai, Jiangsu and Foshan, this paper will propose some management inspirations from the following four aspects: (1) In terms of the “demand response execution effect”: Increase publicity, expand participation, and increase user participation. (2) In terms of the “load reduction effect”: the demand response project should be continuously improved and innovated. (3) In terms of “economic effects”: establish and improving long-term working mechanism for demand response and exploring new business models. (4) In terms of “social effects and environmental effects”: speeding up the process of power marketization and strengthening government responsibility of guidance and supervision.

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