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Research Article

Evaluation of New Power System Based on Entropy Weight-TOPSIS Method

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Under the background of achieving the carbon peaking and carbon neutrality goals on time in China, this study constructs a new power system evaluation index system with new energy as the main body from four aspects of "source, network, load, and storage." This study attempts to use appropriate subjective and objective weighting methods to reasonably distribute index weights and construct an effective, reasonable, scientific, systematic, and comprehensively covered key new power system characteristic index model. From 2017 to 2020, the relevant data for the four dimensions of "source, network, load, and storage" of the power system of three provinces are selected for empirical analysis. The results show that, in the past five years, the performance of the power supply side and network side of the power system in the three provinces was the best and the performance of the load side and energy storage side was slightly insufficient. Specifically, the system outage duration, the number of intelligent sensing terminals, etc., still need to be further optimized and improved.

1. Introduction

At the ninth meeting of the Central Committee of Finance and Economics, Xi Jinping gave important instructions on achieving the carbon peaking and carbon neutrality goals. He proposed that "we should build a clean, low-carbon, safe, and efficient energy system, control the total amount of fossil energy, focus on improving utilization efficiency, implement renewable energy alternative actions, deepen the reform of the power system, and build a new power system with new energy as the main body." It points out the basic direction for the transformation of the energy system and the future development of fossil energy in China [1].

In the theoretical research of the new power system, Fan et al. [2] verified the correctness of improving power supply capacity under normal conditions through practical examples and made a sensitivity analysis on the problem of insufficient power supply capacity caused by new energy output accuracy. Wang et al. [3] proposed three control and optimization methods of the new energy power system and the direction of transformation from a traditional power system to a new energy power system. Chen et al. [4] proposed the three-tier network (energy network, information network, and value network) architecture and the overall research idea for a new power system with hierarchical clusters. Wang et al. [5] put forward a cost calculation model for regional power systems according to the carbon peak goal and analyzed the realization path of the carbon goal from an economic perspective. Ren et al. [6] analyzed the technical and economic indices such as the installed capacity and proportion of new energy, the generation capacity and proportion of new energy, and carbon emission of the national interconnection system at different levels in different years, and summarized their development and evolution trend. Wang et al. [3] outlined the concept and basic characteristics of the new energy power system and then introduced three control and optimization methods for the new energy power system. Xiao and Zheng [7] discussed the key technologies for building a new power system from four aspects: safe operation, reliable power supply, economical efficiency, and digital intelligence transformation. Then, they summarized the main challenges in building a new power system from multiple perspectives. Lu [8] presented the safeguard measures for the construction of the new power system from three aspects: establishing a compensation supervision mechanism, perfecting compensation supporting policies and measures, and broadening the sources of compensation funds.

In the study of the new power system evaluation system, Li and Jiang [9] obtained the risk index reflecting the whole system by integrating different types of risk indices, the calculation of the index value, and the index synthesis. Bie et al. [10] established a probabilistic risk assessment and identification system for different risk types with multilevel indices and weak links based on the piecewise multiobjective risk analysis theory. Lu [8] based on the positive externality analysis of the stakeholders involved in the operation of the new power system, a comprehensive value measurement model of energy storage considering externalities was constructed. Wu et al. [11] comprehensively considered four aspects of electricity transaction price, market activity, settlement timeliness, and market benefit, and established a power market transaction index system for power generation enterprises. Yuan et al. [12] considered the multiperiod coordination requirements of the new power system and constructed the simulation evaluation index system of multiperiod collaborative panoramic operation. In addition, as an important guarantee for the stable operation of the power system, their evaluation methods are also worthy of reference. Zhao et al. [13], based on the improved AHP and TOPSIS methods, proposed a complementary evaluation index system of multiple power sources. Hu et al. [14] comprehensively studied the thermal economics of capacity-based and power-based energy storage, considered the political, environmental, and social impacts, and first proposed the thermal-economic-benefit ratio. They also applied it to energy storage systems in three different scenarios, such as pumped storage, compressed air energy storage, and flywheel energy storage to evaluate energy storage technologies in the power system.

To sum up, the theoretical research and evaluation system of the abovementioned new power system have not been considered and evaluated from the overall perspective of "source, network, load, and storage." Therefore, there is no evaluation system that comprehensively covers all indices of "source, network, load, and storage." Under the background of the massive integration of new energy into the network and the inherent needs of achieving carbon peaking and carbon neutrality goals, the development of the new power system needs a complete set of indices to guide and evaluate "source, network, load, and storage" as a whole. Thus, this study constructs a new power system evaluation index system with new energy as the main body from the four aspects of "source, network, load, and storage", uses subjective and objective weighting methods to reasonably distribute index weights, and builds an effective, reasonable, scientific, systematic, comprehensive coverage, and key new power system characteristic index model. Finally, the relevant data of the power system in typical provinces are selected for empirical analysis, and the relevant development suggestions are given based on the evaluation results, which can provide guidance for the reasonable development of the new power system.

2. Construction of Comprehensive Evaluation Index System of New Power System

2.1. Design of Evaluation Index System. As the roles of new energy and traditional power supply change, new energy will become the main body of the current power supply and occupy a dominant position in the power supply system. In the new power system, the power network plays a more significant role as the core hub for consuming a high proportion of new energy [15]. On the basis of fully soliciting the opinions of internal and external experts and considering the availability and measurability of index data, the new power system evaluation index system is constructed based on four dimensions of "source, network, load, and storage," including 7 second-level indices and 13 third-level indices, as shown in Table 1.

2.1.1. Source Side. The new power system with new energy as the main body is the inherent requirement to achieve the carbon peaking and carbon neutrality goals. It is the "new" place in the new power system. However, the randomness and instability of new energy generation also greatly restrict the development of new energy. Therefore, after comprehensive consideration, the source-side indices are divided into two second-level indices, new energy as the main power source and the reliability of the power generation side, and four third-level indices, the proportion of new energy generation, the proportion of nonfossil energy generation, the new power system reserve capacity, and the maximum power supply capacity of the new power system.

(1) New energy as the main power source. this index consists of two third-level indices, which are calculated as follows:

$$EP_{\text{new}} = \frac{E_{\text{newall}}}{E_{\text{All}}} \times 100\%, \tag{1}$$

where EP_{new} is the proportion of new energy generation, $E_{\text{new all}}$ is the total amount of new energy generation, and E_{All} is the total energy generation.

$$EP_{FH} = \frac{E_{FH}}{E_{\text{All}}} \times 100\%, \tag{2}$$

where EP_{FH} is the proportion of nonfossil energy generation and E_{FH} is the total amount of nonfossil energy generation.

(2) Reliability of power generation side. this index includes two third-level indices, which are calculated as follows:

$$E_S = E_J + E_G + E_H, \tag{3}$$

where E_S is the new power system reserve capacity, E_J is the maintenance reserve capacity, E_G is the accident reserve capacity, and E_H is the load reserve capacity.

$$S_G = T_{Ei} \times n, \tag{4}$$

where S_G is the maximum power supply capacity of the new power system, T_{Ei} is the generation capacity of the ith unit, and n is the number of the ith unit.

Table 1: Evaluation index system of new power system.

First-level indices	Second-level indices	Third-level indices
Source-side	New energy as the main power supply	Proportion of new energy generation Proportion of nonfossil energy generation
	Reliability of power generation side	New power system reserve capacity Maximum power supply capability of the new power system
Network-side	Energy-saving level of power network side	Integrated line loss rate
	Reliability of power network side	Voltage pass rate Line N-1 pass rate
Load-side	Reliability of load side	Duration of system power outage Annual average load volatility
	Intellectualization of load side	Number of intelligent sensing terminals
Storage-side	Flexible regulation capacity	Capacity of pumped storage power station New energy storage capacity Proportion of thermal power flexible transformation capacity

2.1.2. Network Side. The construction of a safe, reliable, economical, and efficient power network system is an important support to build a new power system security defense system and is also the key to ensure the safe and stable operation of the power network [16]. Therefore, the network-side indices are divided into two second-level indices, energy-saving level of power network side and reliability of power network side, and three third-level indices, integrated line loss rate, voltage pass rate, and line N-1 pass rate.

(1) Energy-saving level of power network side. this index contains a three-level index, which is calculated as follows:

$$ZP = \frac{\left(E_{\text{All}} - E_D\right)}{E_{\text{All}}} \times 100\%, \quad (5)$$

where ZP is the integrated line loss rate and E_D is the total energy consumption.

(2) Reliability of power network side. this index includes two third-level indices, which are calculated as follows:

$$DP = \frac{DT_p}{DT_{\text{All}}} \times 100\%, \quad (6)$$

where DP is the voltage pass rate, DT_p is the accumulated working time (min) of the actual working voltage within the allowable voltage deviation range, and DT_{All} is the corresponding total working statistical time (min).

$$P_{N-1} = \frac{S_{Y1}}{S_{Y\,\text{ALL}}} \times 100\%, \quad (7)$$

where P_{N-1} is the line N–1 pass rate, S_{Y1} is the number of components in the power network that meet the N–1 principle, and $S_{Y\,\text{ALL}}$ is the ratio of total components.

2.1.3. Load Side. The reliability of the load side and the intellectualization of the load side are not only the internal needs of power users but also the key to the construction of a safe, reliable, and fast response new power system. At the same time, they can greatly improve the service level of power users and increase customer satisfaction. Therefore, the load-side indices are divided into two second-level indices, reliability of load side and intellectualization of load side, and three third-level indices, duration of system power outage, annual average load volatility, and number of intelligent sensing terminals.

(1) Reliability of load side. this index involves two third-level indices, which are calculated as follows:

$$S_{CT} = \frac{T_1}{T_{CT\,\text{All}}}, \quad (8)$$

where S_{CT} is the duration of system power outage, T_1 is the sum of system power outage time, and $T_{CT\,\text{All}}$ is the number of system power outages.

$$\text{Year}_F = \frac{\text{Year}_{Big} - \text{Year}_P}{\text{Year}_P} \times 100\%, \quad (9)$$

where Year_F is the annual average load volatility, Year_{Big} is the annual maximum load, and Year_P is the annual average load.

(2) Intellectualization of load side. this index comprises a three-level index, which is calculated as follows:

$$ZN = \sum_{i}^{n} ZN_i, \quad (10)$$

where ZN is the number of intelligent sensing terminals, ZN_i is the number of the ith intelligent sensing device terminals, and n is the type of intelligent sensing terminals.

2.1.4. Storage Side. Energy storage power stations with flexible regulation capabilities can provide peak regulation, frequency modulation, standby, black start, demand response support, and other services for power network operation, which are an important means to improve the flexibility, economy, and security of traditional power systems. Thus, the storage-side indices are divided into a second-level index, flexible regulation capacity, and three third-level indices, capacity of pumped storage power station, new energy storage capacity, and proportion of thermal power flexible transformation capacity.

(1) Flexible regulation capacity. this index contains three three-level indices, which are calculated as follows:

$$XN_R = \sum_{i}^{n} XN_i, \tag{11}$$

where XN_R is the capacity of pumped storage power station, XN_i is the capacity of the ith pumped storage power station, and n is the number of pumped storage power stations:

$$P_{x\,\text{new}} = P_{dc} + P_{yc} + P_{fc} + P_{cc} + P_{qc}, \tag{12}$$

where $P_{x\,\text{new}}$ is the new energy storage capacity, P_{dc} is the total electrochemical energy storage capacity, P_{yc} is the total compressed air energy storage capacity, P_{fc} is the total flywheel energy storage capacity, P_{cc} is the total heat storage capacity, and P_{qc} is the total hydrogen storage capacity.

$$H_P = \frac{H_W}{H_{\text{All}}}, \tag{13}$$

where H_P is the proportion of thermal power flexible transformation capacity, H_W is the total retrofit capacity of thermal power units, and H_{All} is the total retrofit capacity of thermal power units.

2.2. Standardization of Evaluation Indices. Due to the different measurement units, economic meanings, and degrees of influence of the evaluation indices, it is necessary to standardize the evaluation indices to ensure the scientificity, comprehensiveness, and reliability of the comprehensive evaluation results. In this study, three types of quantitative indices are adopted: extremely large, extremely small, and interval. First, the indices are uniformly transformed into extremely large, and then, the data are standardized.

Treatment methods of interval indices are as follows:

$$x_{ij} = \begin{cases} 1 - \dfrac{q_1 - x_{ij}^0}{\max\{q_1 - d_1, d_u - q_2\}}, & x < q_1 \\ & , \quad x \in [q_1, q_2]. \\ 1 - \dfrac{x_{ij}^0 - q_2}{\max\{q_1 - d_1, d_u - q_2\}}, & x > q_2 \end{cases} \tag{14}$$

Treatment methods for extremely small indices are as follows:

$$x_{ij} = \frac{1}{x_{ij}^0}. \tag{15}$$

After the process of quantitative index and qualitative index is consistent, the standardization of all evaluation indices is as follows:

$$x_{ij}^* = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \; i = 1, 2, \ldots, m \,\text{and}\, j = 1, 2, \ldots, n. \tag{16}$$

3. Comprehensive Evaluation Method of New Power System Based on Entropy Weight-TOPSIS Method

In this study, the entropy weight-order relation integrated weighting method is proposed, and the improved TOPSIS method is used for comprehensive evaluation. By calculating the distance between the evaluation object and the absolute positive and negative ideal solutions, the comprehensive evaluation results of a new power system are finally determined [17, 18].

3.1. Entropy Weight-Order Relation Method Integrated Weighting Method. The index weighting method includes both the subjective weighting method and the objective weighting method. Among them, the objective weighting method assigns weight to the index objectively according to the objective law of the data. The subjective weighting method based on the subjective evaluation of experts is more suitable for the current situation and can correct the error of the objective data. Based on this, this study adopts the entropy weight-order relation method, which is convenient and concise in calculation, strong in execution and combines subjectivity, and objectivity [19]. The specific steps are as follows.

3.1.1. Subjective Evaluation Index Weights Based on Order Relation

(1) Determine the order relationship. for the evaluation index set $\{x_1, x_2 \cdots x_m\}$, the order relationship can be established according to the following procedures:

Step 1: we ask experts (or decision makers) to select the most important index the index set $\{x_1, x_2 \cdots x_m\}$ and record it as $x_1{}^*$

Step 2: we ask experts (or decision makers) to select the most important index from the remaining $m-1$ indices and record it as $x_2{}^*$

. . .. . .

Step k: we ask experts (or decision makers) to select the most important index from the remaining $m-(k-1)$ indices and record it as $x_k{}^*$, after $m-1$ selection of the remaining evaluation indices, and record it as $x_m *$; the unique order relationship $x_1 * \succ x_2 * \succ \cdots \succ x_m *$ is determined

(2) Determine the relative importance of adjacent indices. the importance of the ratio of adjacent indices x_{k-1} and x_k can be expressed as follows:

$$r_k = \frac{\omega_{k-1}}{\omega_k}, \tag{17}$$

where w_k is the weight of the kth index, $k = m, m-1, \ldots, 3, 2$. According to the order relationship between each index, the relative importance of each index is calculated. The assignment of r_k can refer to Table 2. When m is large, r_k can be taken as 1.

When there is an ordered relationship between $x_1, x_2, \ldots, x_m$ and r_{k-1}, r_k must satisfy $r_{k-1} \succ 1/r_k$, $k = m, m-1, \ldots, 3, 2$.

(3) Calculate the index weight: if r_k is given by experts (or decision makers) to satisfy the above relationship, the weight of index x_m is w_m:

$$w_m = \left(1 + \sum_{k=2}^{m} \prod_{i=k}^{m} r_i\right)^{-1}, \tag{18}$$

and $w_{k-1} = r_k w_k$, $k = m, m-1 \cdots 3, 2$, so as to get the weight of each evaluation index.

3.1.2. Weight Assignment of Evaluation Indices Based on Entropy Weight Method

(1) Constructing standardized judgment matrix: let the number of new power systems for comprehensive evaluation be z, the number of indices be n, and the standardized judgment matrix X^* constructed from standardized data be [20]

$$X^* = \left(x_{ij}^*\right)_{z\times n},\ i = 1, 2, \ldots, z;\ j = 1, 2, \ldots, n. \tag{19}$$

(2) Calculating the information entropy of each index:

$$H_j = -q \sum_{i=1}^{z} f_{ij} \ln f_{ij},$$

$$f_{ij} = \frac{x_{ij}^*}{\sum_{i=1}^{z} x_{ij}^*}, \tag{20}$$

$$q = \frac{1}{\ln z}.$$

(3) Index weighting:

$$w_j = \frac{1 - H_j}{\sum_{j=1}^{n}\left(1 - H_j\right)}, \tag{21}$$

where $0 \le w_j \le 1$, $\sum_{j=1}^{n} w_j = 1$.

3.1.3. The Weight of Evaluation Index Combination w_t. The weight of evaluation index combination is as follows:

$$w_t = \alpha w_m + \beta w_j. \tag{22}$$

3.2. Improved TOPSIS Evaluation Method. The TOPSIS method is widely used in the comprehensive evaluation of overall efficiency. The traditional TOPSIS method calculates the closeness of the evaluation object and the ideal solution by approximating the positive and negative ideal solutions. It is considered that the optimal result is the one closest to the positive ideal solution and the one furthest away from the negative ideal solution. On this basis, the comprehensive evaluation objects are sorted. However, in the multiobjective and multiattribute comprehensive evaluation, the traditional TOPSIS method often has the reverse problem; that is, the change of ideal solution or index weight will lead to the change of ranking results and even affect the correctness of future decisions [21, 22]. In this study, an improved TOPSIS method is proposed to redefine positive and negative ideal solutions. It is believed that both positive and negative ideal solutions have their own absolute states, which can effectively solve the reverse problem. Compared with single index analysis, the improved TOPSIS method can reflect the whole situation more centrally, which contributes to more accurately evaluating comprehensive benefits. Therefore, the improved TOPSIS method is used to comprehensively evaluate the new power system.

Table 2: Relative importance relationship among indices.

The value of r_k	Meaning
1.0	x_{k-1} and x_k are equally important
1.2	x_{k-1} is slightly more important than x_k
1.4	x_{k-1} is obviously more important than x_k
1.6	x_{k-1} is more important than x_k
1.8	x_{k-1} is extremely more important than x_k

According to the actual situation of specific targets, combined with the opinions of experienced experts, the absolute positive and negative ideal solutions are determined. Each evaluation index is neither higher than the absolute positive ideal solution nor lower than the absolute negative ideal solution. The comprehensive evaluation steps of a new power system based on the improved TOPSIS method are as follows:

3.2.1. Construct Weighted Judgment Matrix. We construct the weighted judgment matrix:

$$R = \left(r_{ij}\right)_{m\times n},$$
$$r_{ij} = w_j \cdot x_{ij},\ i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n. \tag{23}$$

3.2.2. Determine the Absolute Ideal Point. Absolutely positive ideal point is as follows:

$$X^+ = \left(r_1^+, r_2^+, r_3^+, \cdots r_m^+\right)^T. \tag{24}$$

Absolutely negative ideal point is as follows:

$$X^- = \left(r_1^-, r_2^-, r_3^-, \ldots r_m^-\right)^T. \tag{25}$$

As the original data used for comprehensive evaluation have been standardized, the settings of its absolute positive and absolute negative ideal solutions are usually as follows:

$$X^+ = (1, 1, \ldots, 1)^T,$$
$$X^- = (0, 0, \ldots, 0)^T. \tag{26}$$

3.2.3. Calculate the Distance between Absolute Positive and Negative Ideal Solutions. In this study, the Euclidean distance is adopted, and the Euclidean distance from the absolute positive ideal solution is shown as follows :

$$D^{+} = \sqrt{\sum_{j=1}^{n} w_j \left(X^{+} - x_{ij}^{*}\right)^2}. \quad (27)$$

The Euclidean distance from the absolute negative solution is shown as follows:

$$D^{-} = \sqrt{\sum_{j=1}^{n} w_j \left(X^{-} - x_{ij}^{*}\right)^2}. \quad (28)$$

3.2.4. Calculate the Close Degree. We calculate the close degree as follows:

$$Ci = \frac{D^{-}}{D^{+} + D^{-}}. \quad (29)$$

3.2.5. Ranking of New Power System Evaluation Indices. The value of close degree *Ci* is the comprehensive evaluation score. The ranking results of new power system evaluation indices are based on the value of *Ci*; that is, the larger the value of *Ci*, the better the evaluation results of the new power system.

4. Empirical Analysis

Taking the power systems of three provinces (set as A, B, and C) as examples, we collected their data from 2017 to 2021. Empirical analysis is carried out using the abovementioned new power system evaluation index system and evaluation method. Among them, all kinds of resources in province A are relatively perfect, and the development of the new power system has a good foundation. Province B has been in the development stage in recent years, the power pressure on the load side is relatively large, and the energy storage configuration is relatively backward. Province C is a typical large province of thermal power generation, and resources such as scenery need to be developed.

4.1. Evaluation Calculations

4.1.1. Index Weighting Results. Based on the integrated weighting method of the entropy order relationship, the weighting results of each level index are shown in Table 3 according to equations (17)–(22).

4.1.2. Comprehensive Evaluation. The Euclidean distance obtained by (27) and (28) is as follows: $D^{+} = (0.4091, 0.3595, 0.3402, 0.2932, 0.3697)$ and $D^{-} = (0.1692, 0.1955, 0.1858, 0.2660, 0.1833)$.

By calculating the distance between them and the absolute positive ideal point and the absolute negative ideal point, the closeness degree of the three major power systems of provinces A, B, and C from 2017 to 2021 is obtained, and the results are shown in Table 4.

4.2. Analysis of Evaluation Results. Figure 1 shows the comparison of the evaluation results of power system in Provinces A, B, and C.

It can be seen from Figure 1 that, from 2017 to 2021, the evaluation results of the new power systems in provinces A, B, and C have steadily increased. It shows that the construction of the new power systems in the three provinces is developing well. Among them, the new power system construction scores of provinces A and C have increased steadily in 5 years, from 0.398 to 0.598 and from 0.382 to 0.55, respectively. The new power system construction of province B was slightly behind the power system from 2017 to 2019 compared with the other two provinces, but because it adopted a reasonable power system planning in 2017, it started to grow faster and in 2020. The score exceeds that of provinces A and B, with a score of 0.553, and maintains a stable development trend.

Figures 2–4 display the first-level index scores of the power systems of provinces A, B, and C in the energy industry from 2017 to 2021.

According to Figures 2–4, the scores of "source, network, load, and storage" of the power system in the three provinces showed an overall upward trend from 2017 to 2021. Among them, the power source side of the three provinces has been significantly improved, which is in line with the national construction requirements of a new power system with new energy as the main body. The power network side, load side, and energy storage side show a fluctuating upward trend. Although there are short-term fluctuations, the overall trend is good.

Based on the classification results of indices at all levels, the model calculation and analysis shows the following.

In terms of power source, the power source score of Provinces A and B increased steadily, from 0.26 to 0.57 and from 0.24 to 0.56, respectively. The reason is that the proportion of new energy, the penetration rate of renewable energy, and the system reserve capacity of the new power systems in the two provinces have increased year by year. In addition, Province A is rich in wind power, photovoltaic, and other new energy resources and has great development potential. The score of Province C decreased in 2018 and 2019, due to the large proportion of thermal power and insufficient development of new energy. In 2020, the proportion of new energy increased, so the score of Province C rose from 0.23 to 0.32 and continues to rise.

In terms of power network, the power network scores of the three provinces increased year by year, from 0.24 to 0.55, from 0.25 to 0.58, and from 0.23 to 0.53, respectively. The reason is that the new power system network construction in the three provinces has steadily increased in the transmission and distribution process, thereby, improving power quality, increasing line "*N*–1" pass rate, and enhancing the intelligent level of residential electricity consumption.

Table 3: Index weights at all levels.

First-level index	w_i	Second-level index	w_t	Third-level index	w_j
I_1	0.38	T_1	0.61	J_1	0.72
				J_2	0.28
		T_2	0.39	J_3	0.34
				J_4	0.66
I_2	0.15	T_3	0.52	J_5	1
		T_4	0.48	J_6	0.51
				J_7	0.49
I_3	0.18	T_5	0.41	J_8	0.39
				J_9	0.61
		T_6	0.59	J_{10}	1
I_4	0.29	T_7	1	J_{11}	0.33
				J_{12}	0.41
				J_{13}	0.26

Table 4: Evaluation results of power system in three provinces.

Province	Closeness degree				
	2017	2018	2019	2020	2021
A	0.398	0.432	0.471	0.535	0.598
B	0.366	0.411	0.435	0.553	0.619
C	0.458	0.409	0.400	0.527	0.575

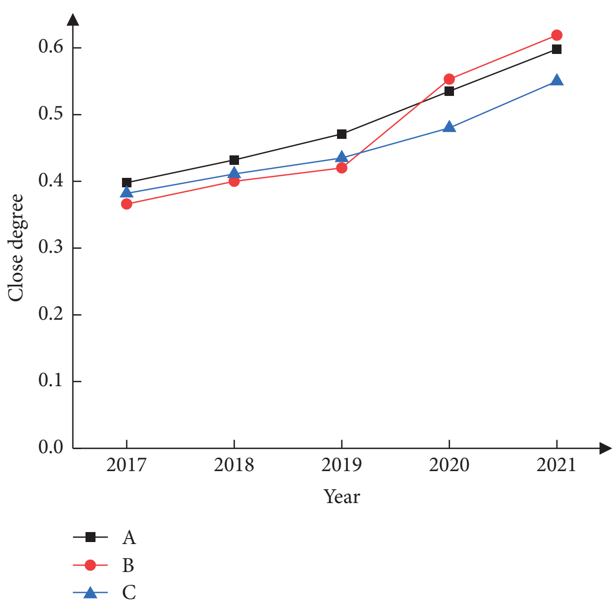

Figure 1: Close degree of power systems in three provinces from 2017 to 2021.

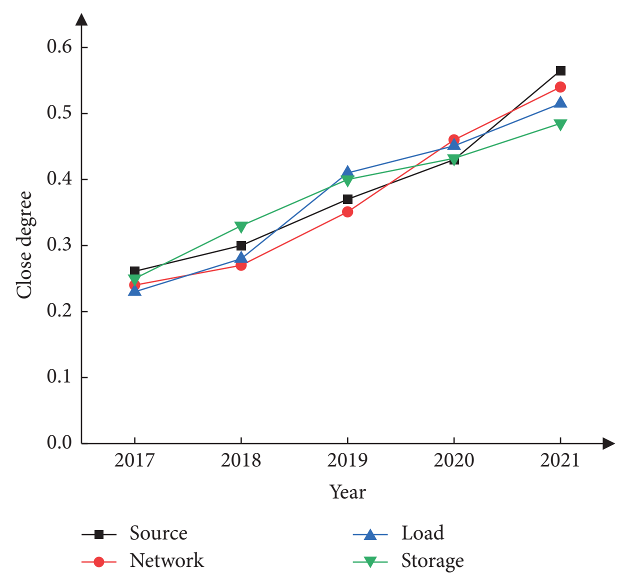

Figure 2: First-level index score of the power system in province A from 2017 to 2021.

Therefore, the energy-saving level and reliability of the network side have been steadily improved.

In terms of load, the load side of provinces A and C shows an upward trend; the scores increased from 0.22 to 0.51, from 0.25 to 0.58, and from 0.21 to 0.57, respectively. The intrinsic factor is that the load-side reliability and load-side intelligence level of the two provinces have made significant progress, load volatility and system outage time have been effectively controlled, and the proportion of intelligent terminals has increased. The reason why Province B's score dropped from 0.46 to 0.41 in 2019 and 2020 is that the province belongs to the high-speed economic development stage, where lateral load power consumption and energy storage configuration are not reasonable. Thus, demand-side management needs to be further perfected. The increase in the score in 2021 is due to the increase in installed capacity and hours of use of energy storage equipment across the province, which enhanced demand response ability and reduced the load side pressure.

In terms of energy storage, the energy storage-side scores in provinces A and B are steadily improving, rising from 0.25 to 0.5 and from 0.25 to 0.54, respectively, due to the

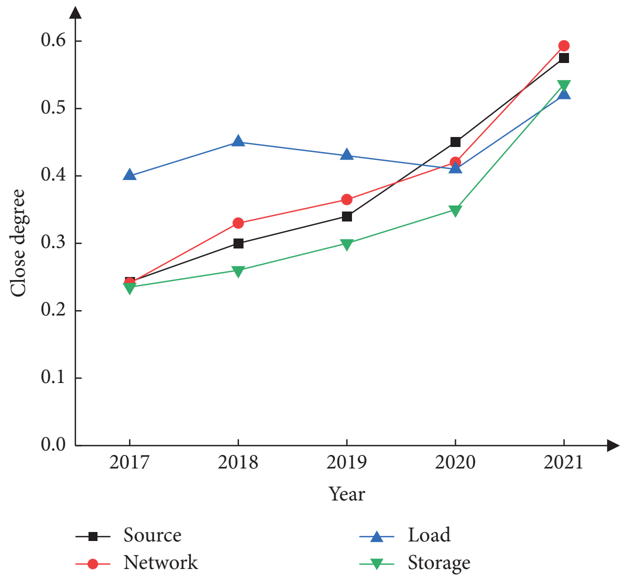

Figure 3: First-level index score of the power system in province B from 2017 to 2021.

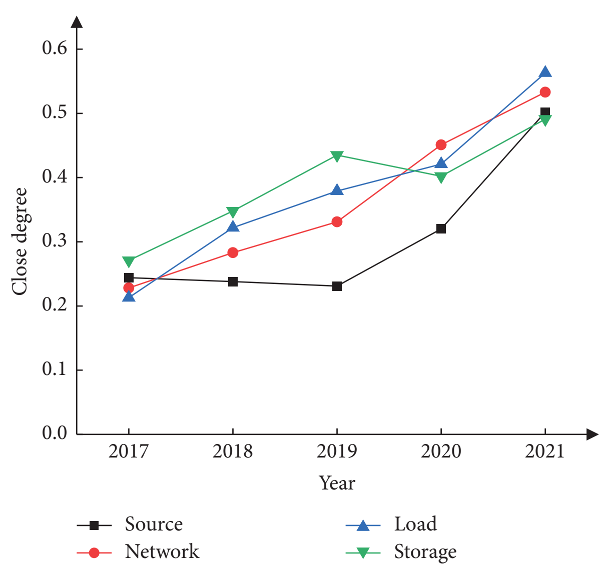

Figure 4: First-level index score of the power system in province C from 2017 to 2021.

improvement in the construction level of relevant indices such as the capacity of pumped storage power stations in the two provinces, the steady improvement in the flexible regulation ability of the energy storage side, and the good demand response effect. Province C as a whole rose but in 2020 the score fell slightly by 0.5, the reason is that Province C, as a thermal power province in 2020, began to accelerate the installed capacity of new energy such as scenery, but due to the slow construction of energy storage, new energy such as scenery and storage failed to form a reasonable configuration, and its demand response capacity needs to be improved.

5. Conclusions

At present, the theoretical research and evaluation systems of new power systems in China lack the consideration and evaluation from the overall perspective of "source, network, load, and storage," and there is no evaluation system that comprehensively covers all indicators of source, network, load, and storage. Under the background of a large number of new energy sources connected to the grid and the inherent demand for a double carbon goal, the development of a new power system needs a set of index systems to guide and evaluate from the overall perspective of "source, network, load, and storage." Based on this, this study constructs a new power system evaluation index system from four aspects of "source, network, load, and storage" with new energy as the main body and uses subjective and objective assignment methods to reasonably assign index weights and build a new power system characteristic index model that is effective, reasonable, scientific, systematic, comprehensive, and focused. Finally, three typical provinces of new power systems are selected for evaluation and analysis, and relevant development suggestions are given with the evaluation results to provide reference and reference for the reasonable development of new power systems. After the evaluation and analysis of typical provinces, the future development of new power systems in each province of China should focus on the following aspects:

(1) We should promote the construction of new power systems in all provinces according to local conditions. Due to the different resource endowments and development stages of the new power system in different provinces, the construction of the new power system should be adapted to local conditions in each province. It is necessary to focus on the development and utilization of hydropower, wind power, photovoltaic power, and energy storage resources in various provinces.

(2) We should vigorously promote the interconnection of wind power, photovoltaic power, and other new energy sources. With the promotion of the carbon peaking and carbon neutrality goals, it is the general trend to develop and build a new power system with new energy as the main body, and it is also the main policy to achieve "carbon peak and carbon neutrality." At the same time, the new energy network connection also helps to improve the maximum power supply capacity and flexible regulation ability of the power system, so as to better ensure the effective supply of power.

(3) We should strengthen the construction of network-side and load-side resources. The network side and load side play an important role in the vertical system of a new power system. They also play an important role in ensuring the balance between power supply and demand and supporting the consumption of new energy. In addition, in the process of promoting the development and construction of resources on the network side and load side of the new power

system, attention should be paid to reducing the comprehensive line loss rate, increasing the voltage qualified rate, reducing the annual average load fluctuation rate, and improving the digitalization level.

(4) We should promote the combined development of electric energy storage and various types of energy storage. Energy storage is an important guarantee for the stable power supply of the power system, and it is also an important resource to realize the rapid response of the demand side. Reasonable energy storage planning helps to improve the reliability of the load side of the system. The main measures are as follows: on the power supply side, we can vigorously promote the configuration of new energy storage in new energy stations and study and promote energy storage for photothermal power generation. On the network side, it can accelerate the construction of pumped storage power stations and promote the rational layout of new energy storage on the network side. On the user side, the diversified development of new energy storage can be promoted, and the combined development of electricity storage, heat storage, cold storage, hydrogen storage, and other types of energy storage can be studied. Aiming at the efficient utilization of new energy, we realize multienergy production and consumption with electric energy as the core.

Data Availability

The data used to support the findings the study are private and commercially confidential.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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