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Evaluation of provincial renewable energy accommodation capacity in China based on an improved TOPSIS method

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Abstract

Renewable energy accommodation capacity is a core pillar of the transition to a low-carbon energy system, directly determining the achievement of emission-reduction targets and the success of energy transformation. Scientifically evaluating this capacity is key to enhancing it. To address the limitations of the entropy-weight method, this paper proposes an improved variable-entropy model for determining indicator weights. To tackle the rank reversal problem of the classical Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method, a new weighted relative closeness degree is proposed. Using 31 provinces in China as research objects, an evaluation index system for renewable energy accommodation capacity was constructed, comprising 4 primary indicators and 10 secondary indicators, and the improved TOPSIS method was applied for comprehensive evaluation. The evaluation results verified the rationality and effectiveness of the proposed method from multiple dimensions. On this basis, policy recommendations are proposed from the perspectives of regional grid planning and cross-provincial accommodation coordination, providing theoretical support for enhancing the capacity for accommodating renewable energy.

Keywords: Renewable energy; Accommodation capacity; TOPSIS method; Variable entropy

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1. Introduction

Against the backdrop of deep global energy structure adjustment and the rigid constraints of the "dual carbon" goals, China's renewable energy development has transitioned from a phase of "incremental expansion" to one of "stock accommodation." Over the past decade, leveraging its resource endowment and policy incentives, China's installed capacity of wind and photovoltaic power has ranked first in the world.[1,2] According to data from the National Energy Administration, by the end of 2024, the national renewable energy installed capacity reached 1,889 GW, accounting for approximately 56% of China's total installed capacity. However, the power generation was only 3.46 trillion kWh, accounting for about 35% of total electricity generation.[3] This structural contradiction of "large installed capacity, small electricity output" is prominent. Furthermore, curtailment of wind and solar power exhibits new characteristics of "regional, temporal, and structural concentration." In 2024, the national average wind

curtailment rate was about 4.1%, and the solar curtailment rate was about 3.2%, with some regions even reaching 10%,[4] exposing bottlenecks in China's power system across technology, market, and institutional dimensions.

From the supply side, the randomness, volatility, and anti-peaking characteristics of renewable energy pose subversive challenges to the real-time balance of the power system. China's flexible resource share is insufficient. According to the *2024 National Electric Power Industry Statistics*[5] released by the National Energy Administration, by the end of 2024, the combined installed capacity of regulating power sources, such as pumped storage and gas power generation, accounted for 5.9%, which still lags far behind the target required for high-proportion renewable energy integration. On the grid side, there is a "time lag" between the transmission capacity of ultra-high-voltage (UHV) outgoing channels and the growth of new energy installation. The *China Electric Power Development Report 2023*[6] points out that the utilization rate of some UHV direct current channels is relatively low, and the willingness of receiving provinces to accept power during surplus periods continues to decline. On the demand side, the response potential has not yet been effectively released; the adjustable capacity of industrial loads is far below international advanced levels, and the existing peak–valley electricity price differential is insufficient to cover users' adjustment costs. This three-side (source–grid–load) coordination failure has turned the new energy accommodation problem into a systemic challenge. Therefore, evaluating the renewable energy accommodation capacity of 31 provinces is crucial for enhancing system regulation capacity, expanding market-oriented trading, improving accommodation and utilization levels, and achieving sustainable economic development.

However, the existing literature rarely examines China's capacity for accommodating renewable energy. Therefore, based on previous studies, this paper proposes an evaluation index system for renewable energy accommodation capacity and an improved Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method combining the classical TOPSIS and entropy-weight methods to evaluate China's renewable energy accommodation capacity, providing necessary theoretical and practical support for formulating relevant policies.

The research objectives of this paper are as follows: (i) to propose an improved weighted relative closeness degree to avoid the rank reversal problem in the TOPSIS method; (ii) to construct a variance-minimization optimization model to achieve adaptive solving of the variable-entropy parameter; and (iii) to apply the proposed method to evaluate the renewable energy accommodation capacity of 31 Chinese provinces and verify its rationality and effectiveness.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature. Section 3 presents the improved TOPSIS method and the modified entropy-weight method. Section 4 constructs the evaluation index system, assesses the renewable energy accommodation capacity of 31 provinces, conducts a sensitivity analysis, discusses the evaluation results, and proposes corresponding policy recommendations. Section 5 concludes the paper.

2. Literature review

This section reviews the literature on renewable energy accommodation capacity and the TOPSIS method.

2.1. Renewable energy accommodation capacity

Current research on renewable energy accommodation capacity primarily focuses on three aspects: first, its connotation. Renewable energy accommodation is a major systematic engineering endeavor, resulting from the joint effects of factors such as coordinated planning of transmission network construction, improvements to market rules, and enhancements to grid operation levels and technologies.[7] Some scholars point out from a micro-perspective that renewable energy needs to be converted through devices such as wind turbines, photovoltaic systems, and hydro-turbine units. The process of generating electricity from power plants, transmitting it through grid lines, and delivering it to users for consumption is referred to as the accommodation of renewable energy.[8]

Second, the influencing factors of renewable energy accommodation capacity. Renewable energy accommodation capacity is a dynamic indicator constrained by multiple factors. Grid peak-shaving capacity and frequency stability have become major constraints on accommodating new energy sources.[9] Some studies indicate that market-based mechanisms can promote renewable energy accommodation.[10] Other scholars have constructed a multi-level evaluation index system for constraints on new energy accommodation from four aspects: source, grid, load, and peak-shaving,[11] and have analyzed bottlenecks from various grid operation indicators.[12] Some scholars have further explored and pointed out that environmental foundations and power facilities are key factors affecting the accommodation of non-hydro renewable energy electricity in China.[13] In addition, the poor scheduling flexibility of thermal power units and the lack of supporting mechanisms for flexible power sources are structural issues that urgently

need to be addressed in the process of renewable energy accommodation.[14,15] Furthermore, China's energy storage technology is plagued by issues such as the choice of technical direction and performance, and high research costs, easily leading to substantial waste of renewable energy resources.[16] Lastly, some studies indicate that government penalty intensity is positively correlated with the completion of renewable energy quota accommodation by the grid,[17] and that government policy preferences play a key role in promoting renewable energy development,[18] while foreign direct investment does not significantly cause changes in renewable energy consumption.[19] Li *et al.*[20] pointed out that the "three-modification linkage" policy can facilitate renewable energy accommodation.

Third, the evaluation of renewable energy accommodation capacity. Li *et al.*[21] established a multi-period, coupled assessment model for renewable energy accommodation capacity based on time-series production simulation. Yu *et al.*[22] proposed a hybrid evaluation model based on a variational autoencoder algorithm and an improved fuzzy comprehensive evaluation method to comprehensively evaluate the organizational performance of coal-fired power enterprises. Shi *et al.*[23] proposed a comprehensive power quality evaluation method based on the Criteria Importance Through Intercriteria Correlation (CRITIC) method and dynamic coefficients. Zheng *et al.*[24] proposed an assessment model for grid renewable energy accommodation capacity that considers wind–solar–hydro–thermal multi-energy synergy, based on two-stage robust optimization. Li *et al.*[25] constructed a day-ahead dispatching model that includes wind and photovoltaic power to separately assess renewable energy accommodation capacity during transitional seasons, summer, and winter. Zhang *et al.*[26] evaluated renewable energy accommodation capacity using a time-segmented multi-objective real-time dispatching strategy for thermal power units.

2.2. TOPSIS method

The classical TOPSIS method was first proposed by Hwang and Yoon[27] in 1981 as a finite-scheme multi-attribute decision analysis method that approximates the ideal solution. In practical applications, scholars have identified two main shortcomings of the TOPSIS method. First, a scheme with a close Euclidean distance to the ideal point may also have a close Euclidean distance to the negative ideal point, resulting in unreasonable ranking. To address this issue, different scholars have proposed solutions from various angles, such as substituting the Euclidean distance with the orthogonal projection method,[28] the angle measure method,[29] and the vector projection method.[30] Although the rank reversal measure function was proposed to accurately quantify the degree of rank reversal for each method, it does not resolve the rank reversal problem itself.[31] Some scholars have also proposed combined evaluation methods based on TOPSIS.[32,33] Although these methods offer new ideas for solving the rank reversal problem, they suffer from issues such as difficulty in understanding and high computational complexity.

Second, the classical TOPSIS method assigns equal weights to all attributes. However, some scholars have pointed out that changes in attribute weights can directly affect decision outcomes.[34] Therefore, accurately and reasonably determining attribute weights is crucial. The entropy-weight method is a commonly used objective weighting method that assigns weights based on the amount of information contained in each attribute value.[35] Sun *et al.*[36] established a multi-criteria evaluation model for floating offshore wind turbine foundation schemes based on the entropy-weight–TOPSIS method. However, there are some unreasonable aspects in determining indicator weights using the entropy-weight method.[37,38] Liang *et al.*[39] proposed a variable-entropy model to address the shortcomings of the existing entropy-weight method. However, it fails to address the situation where $\ln p_{ij}$ lacks mathematical significance when $p_{ij} = 0$.[40] Moreover, the parameter K in the variable-entropy model is artificially specified.[40]

In summary, based on existing research, this paper proposes an improved variable-entropy–TOPSIS comprehensive evaluation model to address the rank reversal problem of the TOPSIS method and the subjective parameter-setting issue of the variable-entropy-weight method. On the one hand, the model avoids rank reversal by introducing a weighted relative closeness degree; on the other hand, it achieves adaptive parameter determination by constructing an optimization model. This method was then used to evaluate the renewable energy accommodation capacity of 31 provinces in China. Through sensitivity analysis and comparison of evaluation results, the rationality and effectiveness of the proposed method were verified, providing theoretical support and a decision-making reference for formulating policies on renewable energy accommodation capacity.

3. Methods

Suppose a decision problem has m feasible alternatives a_i ($1 \le i \le m$) and n decision criteria f_j ($1 \le j \le n$), with corresponding indicator weights ω_j satisfying $0 \le \omega_j \le 1$ and $\sum_{j=1}^{n} \omega_j = 1$. Let u_{ij} denote the effectiveness evaluation value of alternative a_i under criterion f_j. The decision matrix

is thus obtained as $U=\left(u_{ij}\right)_{m\times n}$. To eliminate dimensional differences and enhance comparability, the normalization method is adopted to standardize the original matrix:[38]

$$x_{ij}=\frac{x_{ij}}{\sqrt{\sum_{i=1}^{m}x_{ij}^{2}}}\ \text{(positive indicators)} \tag{1}$$

$$x_{ij}=\frac{1/x_{ij}}{\sqrt{\sum_{i=1}^{m}\left(1/x_{ij}\right)^{2}}}\ \text{(positive indicators)} \tag{2}$$

Thus, the normalized decision matrix is obtained as $X=\left(x_{ij}\right)_{m\times n}$.

The basic idea of the classical TOPSIS method is as follows: based on the constructed weighted normalized matrix, the positive and negative ideal solutions are determined: the positive ideal solution consists of the optimal values for each indicator, and the negative ideal solution consists of the worst values for each indicator. The Euclidean distances from each alternative to the positive and negative ideal solutions are then calculated, and the relative closeness degree of each alternative is subsequently obtained. Let $x_j^+=\max_{1\le i\le m}\left\{x_{ij}\right\}$, $x_j^-=\min_{1\le i\le m}\left\{x_{ij}\right\}$; then the positive ideal solution and negative ideal solution are $X^+=(x_1^+,\ x_2^+,\cdots,x_n^+)$ and $X^-=(x_1^-,\ x_2^-,\cdots,x_n^-)$.

The distances from alternative a_i to the positive and negative ideal solutions are:

$$d_i^+=\sqrt{\sum_{j=1}^{n}\left[\omega_j\left(x_{ij}-x_j^+\right)\right]^2} \tag{3}$$

$$d_i^-=\sqrt{\sum_{j=1}^{n}\left[\omega_j\left(x_{ij}-x_j^-\right)\right]^2} \tag{4}$$

Thus, the relative closeness degree of alternative a_i is:

$$C_i=\frac{d_i^-}{d_i^-+d_i^+}\quad (i=1,2,\cdots,m) \tag{5}$$

where C_i is the relative closeness degree and $0\le C_i\le 1$. The larger the C_i, the better the alternative.

3.1. Improved TOPSIS method

Let A be the negative ideal point, and B be the positive ideal point. Let C, D, E, and F be the effectiveness evaluation values of four alternatives, as shown in Figure 1.

Using the classical TOPSIS method, the ranking of the four alternatives C, D, E, and F yields $C\succ D$, $E\succ F$, which is evidently unreasonable. Let H be the foot of the perpendicular from F to line AB. Denote $AH=z$, $BH=h$, $FH=a$, $EF=b$. Let d_F and d_E be the distance differences from E and F to the positive and negative ideal points. Then:

$$\frac{d_F}{d_E}=\frac{\sqrt{a^2+h^2}-\sqrt{z^2+a^2}}{\sqrt{(a+b)^2+h^2}-\sqrt{z^2+(a+b)^2}} > \frac{\left(\sqrt{a^2+h^2}-\sqrt{z^2+a^2}\right)\left(\sqrt{a^2+h^2}+\sqrt{z^2+a^2}\right)}{h^2-z^2}=1 \tag{6}$$

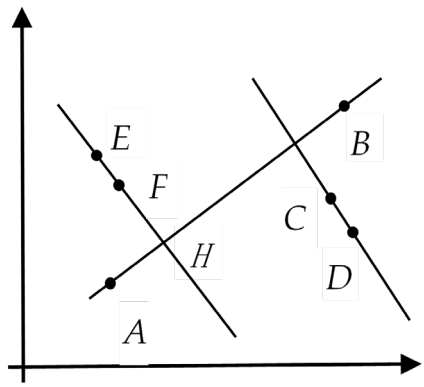

Figure 1. Rank reversal analysis of the classical TOPSIS method

Thus, $d_F>d_E$, i.e., $F\succ E$, proving that the classical TOPSIS method produces a rank reversal phenomenon when ranking alternatives E and F.

The conventional TOPSIS employs a nonlinear ratio form with $d_i^-+d_i^+$ as the denominator, which is susceptible to the influence of extreme outliers or the perpendicular bisector effect. The traditional TOPSIS distance ratio is decomposed into a linear net benefit summation of the positive and negative deviations of each indicator, and the weighted relative closeness degree is constructed as follows:

$$z_i=\frac{\sum_{j=1}^{n}\left(d_{ij}^+-d_{ij}^-\right)}{\sum_{j=1}^{n}d_j^0} \tag{7}$$

where d_j^0 is the weighted distance between the positive and negative ideal solutions. Alternatives can then be ranked by the magnitude of z_i; the smaller the z_i, the better the alternative.

This paper assumes that p_{Ej}^+ and p_{Ej}^- are the compatibility of the scheme E with the positive and the negative ideal points under the attribute b_j; p_{Fj}^+ and p_{Fj}^- are the compatibility of the scheme F; p_j^0 is the compatibility degree between the positive and negative ideal points

under the attribute b_j; and ω_j is the weight of the attribute b_j. Then:

$$z_{Fj} = \frac{\left(p_{Fj}^{+} - p_{Fj}^{-}\right)\omega_j}{p_j^0 \omega_j} \tag{8}$$

$$z_{Ej} = \frac{\left(p_{Ej}^{+} - p_{Ej}^{-}\right)\omega_j}{p_j^0 \omega_j} \tag{9}$$

Therefore:

$$\frac{z_{Fj}}{z_{Ej}} = \frac{p_{Fj}^{+} - p_{Fj}^{-}}{p_{Ej}^{+} - p_{Ej}^{-}} \tag{10}$$

This shows that $\frac{z_{Fj}}{z_{Ej}}$ and $\frac{d_F}{d_E}$ are consistent in form, indicating that the weighted relative closeness degree proposed in this paper is based on the above proof rationale.

3.2. Determination of indicator weights

The entropy-weight method calculates the entropy of each indicator based on the evaluation values of different alternatives for that indicator, and then determines the objective weights. For a given indicator, the greater the variation among alternative values, the lower the entropy, and the larger the assigned objective weight. The process of solving indicator weights using the entropy-weight method is as follows:

$$\omega_j = h_j \Big/ \sum_{j=1}^{n} h_j \tag{11}$$

where $h_j = 1 - E_j$, $E_j = -k\sum_{i=1}^{m} p_{ij} \ln\left(p_{ij}\right)$, $p_{ij} = x_{ij} \Big/ \sum_{i=1}^{m} x_{ij}$, $k = 1/\ln m$. To address the issue where ln p_{ij} is mathematically undefined when p_{ij} = 0, Zhang *et al.*[38] introduced a 10^{-4} correction to p_{ij}:

$$p_{ij} = \frac{x_{ij} + 10^{-4}}{\sum_{i=1}^{m} x_{ij} + 10^{-4}} \tag{12}$$

This correction ensures the validity of the logarithmic operation while keeping the impact on the entropy value E_j within a reasonable range. Therefore, this correction method was adopted in this study for calculating p_{ij}.

Furthermore, Liang *et al.*[39] and Wang[40] pointed out that the weights determined by the entropy-weight method lack flexibility, i.e., $h_j = 1 - E_j$ cannot adapt to different situations. To address this, they proposed a variable-entropy model, where the variable-entropy value of the j attribute is:

$$h_j = \rho - E_j \tag{13}$$

where ρ is a system parameter satisfying $\rho \geq \max\left\{E_1, E_2, \cdots E_n\right\}$. However, the weight vectors obtained by previously established methods[38,40] still require manual assignment of the variable coefficient ρ, introducing considerable subjectivity. Moreover, different values of ρ may cause significant fluctuations in weight allocation. To overcome this issue, following the principle of minimum uncertainty in statistics, we argued that minimizing the volatility of weights yields the most objective and credible ranking of indicator importance. Meanwhile, to circumvent the subjective bias inherent in the artificially specified parameter ρ, we adopted variance as a measure of weight volatility. Minimizing variance implies that the weight vector has the strongest resistance to perturbations in ρ (i.e., the most robust solution). Based on this rationale, we constructed the following optimization model:

$$\min = VAR(\omega_j) = E\left(\omega_j^2\right) - \left[E\left(\omega_j\right)\right]^2 \tag{14}$$

where $s.t. \begin{cases} \sum_{j=1}^{n} \omega_j = 1 \\ \omega_j \geq 0 \end{cases}$.

From **Equation 11**, h_j is normalized. Therefore, let $h_j = \rho - E_j$, and the optimal ρ can be obtained from **Equation 14**.

The process of the improved TOPSIS-based evaluation model for provincial renewable energy accommodation capacity in China is shown in Figure 2.

4. Case study

This section first introduces the evaluation index system for renewable energy accommodation capacity. The proposed improved variable-entropy–TOPSIS method was then applied to assess the accommodation capacity of 31 provinces in China. The evaluation results were analyzed from three aspects: weight distribution, method comparison, and multi-dimensional performance, verifying the rationality and effectiveness of the proposed method.

4.1. Index system

Renewable energy accommodation capacity refers to the maximum capability of a power system to receive and accommodate variable renewable energy generation (such as wind and photovoltaic power) in real time, while ensuring safe and stable operation and qualified power quality. It is essentially the result of the "source–grid–load–storage" synergy. Based on a review of domestic and international literature and the State Grid's *Guidelines for Calculating*

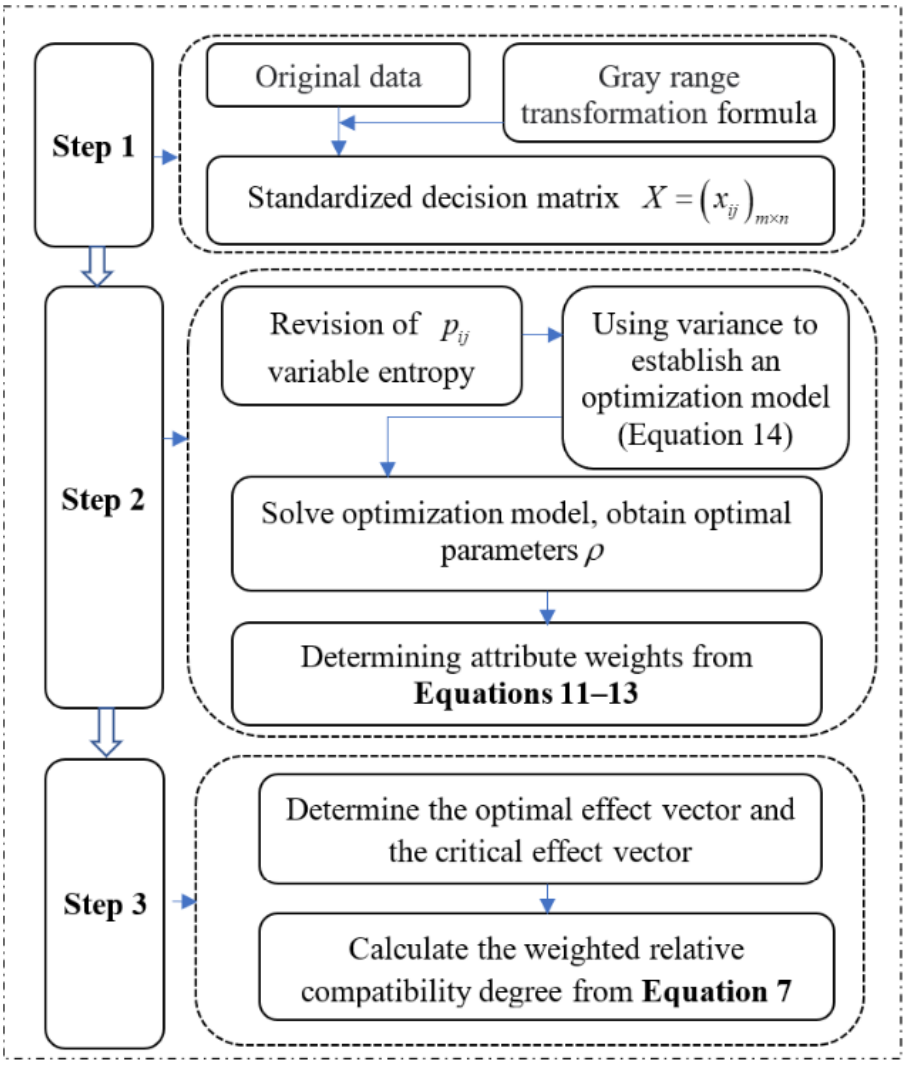

Figure 2. Process of the improved TOPSIS evaluation model

New Energy Accommodation Capacity,[42] we developed an evaluation index system from four dimensions: resource endowment (source), power facilities (grid), energy consumption (load), and economic development (external support). These four primary indicators correspond to supply, transmission, demand, and external environment, respectively, forming a clear logical hierarchy that reflects the systemic nature of the issue. Furthermore, the lengths of 35 kV-and-above transmission lines and the capacity of 35 kV-and-above substation equipment were included to reflect the physical constraints of grid structure on accommodation. Gross regional product and per capita disposable income were selected to reflect the ability to pay for clean energy and the demand-pull effect of economic development. A total of 10 secondary indicators were constructed. All indicators have clear units, and the data were sourced from publicly available channels, such as the *China Electric Power Statistical Yearbook 2024*[43] and the *China Statistical Yearbook 2024,*[44] ensuring accessibility and reproducibility. The indicator evaluation system for factors influencing renewable energy accommodation capacity is shown in Table 1.

4.2. Data sources

We used 31 provinces (excluding Hong Kong, Macao, and Taiwan) as research objects and selected relevant indicator data for 2024. The data were mainly sourced from the *China Electric Power Statistical Yearbook 2024,*[43] the *China Statistical Yearbook 2024,*[44] the National Energy Administration, and announcements from the China

Meteorological Administration.

Table 1. Evaluation index system for renewable energy accommodation capacity

Influence factor	Indicator name	Unit	Code
Resource endowment	Optimal tilted surface total irradiation	kWh/m²	X_1
	Average wind speed	m/s	X_2
	Average wind power density	W/m²	X_3
Power facilities	Renewable energy installed capacity	10,000 kW	X_4
	Length of 35 kV-and-above transmission lines	km	X_5
	Capacity of 35 kV-and-above substation equipment	10,000 kVA	X_6
Energy consumption	Total social electricity consumption	100 million kWh	X_7
	Electric power consumption growth rate	%	X_8
Economic development	Gross regional product	100 million RMB	X_9
	Per capita disposable income	RMB	X_{10}

4.3. Indicator weight analysis

First, the original data were normalized using **Equations 1 and 2** to obtain the normalized decision matrix $X=(x_{ij})_{m\times n}$. The variable-entropy weights were solved using **Equations 11–13**. Using the Lingo software (Version 11.0, LINDO Systems Inc., United States of America), the optimal value of the parameter ρ was 1.0607. The weights of each indicator are shown in Table 2.

From Table 2, the weights obtained by the proposed method (ρ = 1.0607) ranged from 0.0628 to 0.1441. Among them, the weights of renewable energy installed capacity (b_4 = 0.1280), transmission line length (b_5 = 0.1006), and substation equipment capacity (b_6 = 0.1189) under the power facilities dimension all exceeded 0.1, reflecting that the robust backbone grid and cross-regional transmission channels serve as the "highway" for accommodation. The total social electricity consumption (b_7 = 0.1293) under the energy consumption dimension and the gross regional product (b_9 = 0.1441) under the economic development dimension also demonstrated relatively high weights, indicating that the broad electricity market provides economic impetus for accommodation. These results demonstrate that grid infrastructure and the electricity market are key factors affecting accommodation capacity, consistent with the actual situation.

To verify the rationality of the proposed weight-determination method, the method by Wang[40] was employed for comparison. The results are shown in Table 3.

Table 2. Indicator weights and ρ values

Indicator	Value
ρ	1.0607
b_1	0.0644
b_2	0.0628
b_3	0.0774
b_4	0.1280
b_5	0.1006
b_6	0.1189
b_7	0.1293
b_8	0.0971
b_9	0.1441
b_{10}	0.0773

Table 3. Weight distribution under different ρ values

Indicator	E	ρ = 1	ρ = 1.5	ρ = 2	ρ = 3
b_1	0.9962	0.2763	0.1068	0.1035	0.1018
b_2	0.9979	0.4842	0.1071	0.1036	0.1018
b_3	0.9833	0.0621	0.1041	0.1022	0.1011
b_4	0.9326	0.0154	0.0948	0.0973	0.0986
b_5	0.9601	0.0260	0.0996	0.0999	0.1000
b_6	0.9417	0.0178	0.0964	0.0981	0.0990
b_7	0.9314	0.0151	0.0946	0.0972	0.0986
b_8	0.9636	0.0285	0.1003	0.1002	0.1001
b_9	0.9165	0.0124	0.0922	0.0959	0.0979
b_{10}	0.9833	0.0622	0.1041	0.1022	0.1011

The differences in weight allocation among indicators for ρ = 1.5, 2, and 3 are shown in Figure 3.

From Table 3, when ρ = 1, the weights of b_1 and b_2 were as high as 0.2763 and 0.4842, respectively, while the other indicators were generally below 0.07. The weight distribution is overly concentrated, making it difficult

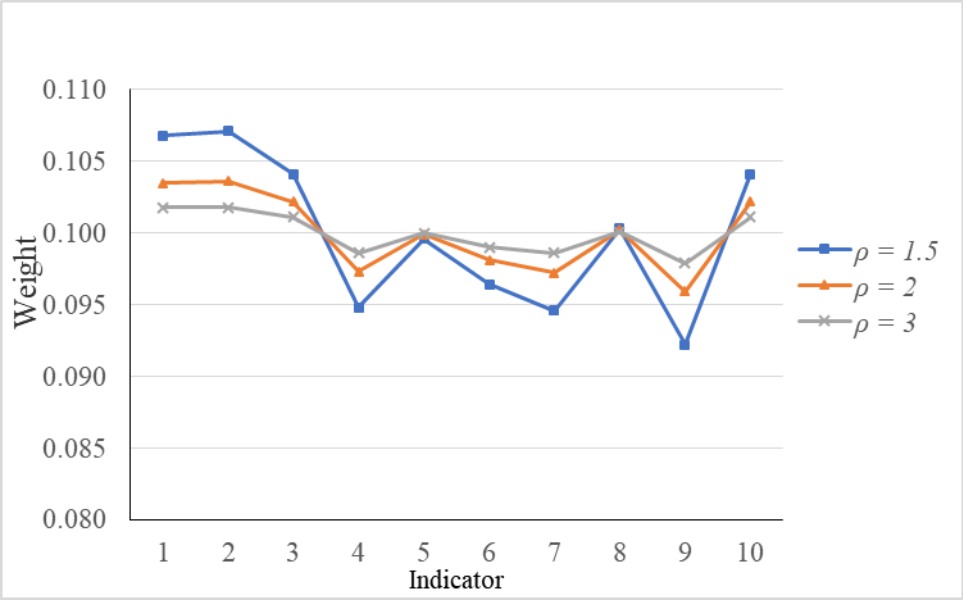

Figure 3. Indicator weight allocation at ρ = 1.5, 2, and 3

to fully reflect the actual contributions of all indicators. From Figure 3, when ρ = 1.5, 2, and 3, the weights of all indicators converged toward 0.1, and the differentiation among indicators diminished rapidly as ρ increased, failing to reflect the differential effects of various indicators on accommodation capacity. This indicates that the method by Wang[40] essentially loses its weight-differentiation function when ρ is large.

In summary, the proposed method effectively identified the core factors influencing renewable energy accommodation while maintaining a reasonable weight distribution, demonstrating greater rationality and practicality compared with the method by Wang.[40]

4.4. Evaluation results and analysis

The weighted distances from each alternative to the positive and negative ideal solutions under attribute b_j were determined using **Equations 3 and 4**. The weighted closeness degree was calculated using **Equation 7**, and the rankings of 31 provinces are presented in Table 4. To further validate the rationality of the proposed method, the results were compared with those from the classical TOPSIS method and the improved TOPSIS method,[41] as shown in Table 4.

From Table 4, the top three provinces in terms of renewable energy accommodation capacity were identical across the three methods: Guangdong, Jiangsu, and Shandong. Furthermore, comparing the proposed method in this paper with the improved TOPSIS method,[41] the rankings of 10 cities (Beijing, Hebei, Shanxi, Shanghai, Zhejiang, Henan, Hubei, Guangxi, Shaanxi, and Gansu) were consistent, and the rankings for the remaining alternatives were also relatively similar, preliminarily indicating the rationality of the proposed ranking method.

From Table 4, it can also be observed that the three methods yielded inconsistent rankings for Xinjiang and Yunnan, two resource-rich regions. To further illustrate the rationality and effectiveness of the proposed method, Xinjiang and Yunnan were taken as examples for detailed analysis. The relevant data for renewable energy accommodation in Yunnan and Xinjiang in 2023 are shown in Table 5.

From Table 5, Xinjiang generally follows a "large-scale centralized development + long-distance transmission" model, primarily relying on wind and solar power. Yunnan follows a "multi-energy complementary, integrated development" model, primarily relying on hydropower, with wind and solar power supplementing it. Xinjiang's wind and solar installed capacity is approximately 70 GW, accounting for 45% of its total installed capacity, making it a typical wind- and solar-driven base. Yunnan's renewable energy installed capacity exceeds 120 GW, of which hydropower accounts for about 75%, making it a clean energy province that synergizes "hydro–wind–solar–storage."

In terms of electricity consumption, although Yunnan's total load was smaller, it has energy-intensive industries, such as green aluminum and silicon, providing a solid

Table 4. Comparison of 2024 provincial renewable energy accommodation capacity rankings using different methods

Province	Classical TOPSIS C_i	Ranking	Improved TOPSIS C_i^*	Ranking	Proposed method Z_i	Ranking
Beijing	0.3037	19	0.6187	21	0.5264	21
Tianjin	0.1951	30	0.5789	30	0.7178	31
Hebei	0.5255	6	0.7510	6	−0.0443	6
Shanxi	0.3371	14	0.6579	14	0.3676	14
Inner Mongolia	0.5488	4	0.7538	5	−0.0165	7
Liaoning	0.3481	13	0.6546	15	0.4075	17
Jilin	0.2733	23	0.6026	25	0.6214	26
Heilongjiang	0.2472	27	0.5934	27	0.6506	29
Shanghai	0.3136	18	0.6246	20	0.4696	20
Jiangsu	0.6698	2	0.8204	2	−0.5186	2
Zhejiang	0.5480	5	0.7644	4	−0.1659	4
Anhui	0.3792	11	0.6844	10	0.2451	12
Fujian	0.3341	15	0.6641	12	0.3155	13
Jiangxi	0.2330	28	0.6087	23	0.5378	22
Shandong	0.6514	3	0.8127	3	−0.4308	3
Henan	0.4362	8	0.7068	8	0.0843	8
Hubei	0.3628	12	0.6656	11	0.2354	11
Hunan	0.3028	20	0.6396	17	0.3847	15
Guangdong	0.6821	1	0.8283	1	−0.5420	1
Guangxi	0.3326	16	0.6518	16	0.4050	16
Hainan	0.2866	22	0.5790	29	0.6400	27
Chongqing	0.1767	31	0.5822	28	0.6464	28
Sichuan	0.5125	7	0.7402	7	−0.0610	5
Guizhou	0.2296	29	0.6015	26	0.5693	24
Yunnan	0.3973	10	0.6637	13	0.2148	9
Tibet	0.2658	25	0.5709	31	0.6876	30
Shaanxi	0.2704	24	0.6279	19	0.4644	19
Gansu	0.3290	17	0.6391	18	0.4499	18
Qinghai	0.2921	21	0.6138	22	0.5590	23
Ningxia	0.2636	26	0.6044	24	0.5981	25
Xinjiang	0.4283	9	0.6933	9	0.2216	10

foundation for local accommodation. Xinjiang's total load was large, but it remained insufficient compared to its enormous generation capacity, making it heavily reliant on transmission. In terms of outgoing electricity, both provinces exported approximately 50% of their own generation, but Yunnan's total clean energy generation (316 billion kWh) far exceeded that of Xinjiang (105.3 billion kWh).

In terms of system flexibility, Xinjiang relied mainly on thermal power for peak shaving and faces difficulties during winter heating periods, with wind and solar curtailment rates of 3.5% and 2.2%, respectively, higher than the national average. Yunnan, with its large-scale hydropower regulation resources, could smooth fluctuations in wind and solar power, offering a superior accommodation environment. Therefore, from the

Table 5. Renewable energy accommodation-related data for Yunnan and Xinjiang in 2023

Indicator	Xinjiang	Yunnan	Advantage
Resource endowment	Extremely strong, primarily wind and solar; nationally top-tier wind and solar resource base	Extremely strong, primarily hydropower, supplemented by wind and solar: hydropower technically developable capacity ranks second nationally, along with high-quality wind and solar resources	Comparable
Renewable energy installation structure	45% (wind + solar)	25% (wind + solar); 85% (including hydropower)	Comparable
Total social electricity consumption	403.1 billion kWh	247.5 billion kWh	Xinjiang
Outgoing electricity	126.2 billion kWh (50% of its own generation)	Over 160 billion kWh (50% of its own generation)	Yunnan
Renewable energy generation	105.3 billion kWh	316 billion kWh (of which hydropower exceeds 300 billion kWh)	Yunnan
System flexibility	Major challenge: primarily reliant on thermal power for peak-shaving, severe shortage of flexible regulation resources, peak-shaving difficulties during winter heating period	Significant natural advantage: large-scale hydropower (especially with annual regulation capacity) provides excellent flexible regulation resources, offering high-quality peak-shaving services for regional wind and solar generation	Yunnan
Accommodation effectiveness	Bottlenecks exist: wind curtailment rate 3.5%, solar curtailment rate 2.2%, higher than the national average	Generally good: mainly seasonal hydro curtailment risk, relatively low wind and solar curtailment rates	Yunnan

Note: Sources: National Energy Administration and State Grid (https://www.nea.gov.cn/2024-01/26/c_1310762246.htm, https://m.bjx.com.cn/mnews/20241105/1408953.shtml#2)

perspective of accommodation robustness, Yunnan is superior to Xinjiang, and the ranking obtained by the proposed TOPSIS method is more reasonable.

To further demonstrate the rationality of the proposed method, it was used to calculate the comprehensive scores of 31 provinces across the four dimensions of resource endowment, power facilities, energy consumption, and economic development, as shown in Table 6.

From Table 6, in terms of resource endowment, the top eight provinces in comprehensive score were, in descending order: Inner Mongolia, Liaoning, Jilin, Heilongjiang, Qinghai, Xinjiang, Gansu, and Tibet. This ranking is consistent with the raw data and highly aligned with the actual resource distribution in China. For example, Inner Mongolia has long ranked first in the country in terms of onshore wind energy resource potential, installed capacity, and electricity generation; Qinghai hosts the world's largest photovoltaic industrial park and has the highest share of photovoltaic generation in China, serving as a leader in China's solar energy sector; and Tibet possesses the richest solar energy resources in the country, with annual sunshine hours reaching 3,000 to 3,400 hours, making it one of the regions with the most abundant solar resources in the world. In terms of economic development, the top eight provinces were Guangdong, Jiangsu, Shandong, Zhejiang, Sichuan, Henan, Shanghai, and Fujian, which align with their gross regional product and per capita disposable income levels. The above results validate the rationality and effectiveness of the proposed evaluation method from both resource and economic dimensions.

The ranking results reveal a notable regional differentiation in accommodation capacity. The top-ranked eastern coastal provinces, such as Guangdong, Jiangsu, and Zhejiang, scored relatively high on the dimensions of "power infrastructure" and "energy consumption," indicating that their well-developed grid infrastructure and large electricity markets provide strong support for renewable energy accommodation. In contrast, western provinces, such as Xinjiang, Gansu, Qinghai, and Inner Mongolia—despite their abundant wind and solar resources—scored lower in the "power infrastructure" dimension due to insufficient transmission capacity and limited local consumption space, exhibiting a typical pattern of "strong resource endowment but weak grid connectivity." This finding is highly consistent with the national policy direction of accelerating the construction of supporting UHV transmission corridors for large-scale wind and solar bases in deserts, such as the Gobi Desert, and barren areas, suggesting that upgrading grid

Table 6. Evaluation results of 2024 provincial renewable energy accommodation capacity across four dimensions

Region	Resource endowment		Power facilities		Energy consumption		Economic development	
	Composite score	Ranking	Composite score	Ranking	Composite score	Ranking	Composite score	Ranking
Beijing	0.0695	9	0.8080	28	0.6209	26	0.2569	10
Tianjin	0.3117	17	0.8166	29	0.6676	28	0.7066	22
Hebei	0.1027	12	−0.4438	4	−0.0974	6	0.4039	13
Shanxi	0.2392	15	0.1371	13	0.3610	14	0.6619	21
Inner Mongolia	−0.9274	1	−0.4135	5	−0.2137	5	0.6572	20
Liaoning	−0.8252	2	0.3480	18	0.4563	19	0.5812	16
Jilin	−0.6857	3	0.6704	26	0.5499	24	0.8334	26
Heilongjiang	−0.5960	4	0.6216	24	0.7376	31	0.8012	25
Shanghai	0.7642	28	0.6769	27	0.5449	23	0.2035	7
Jiangsu	0.4384	19	−0.4806	2	−0.4288	2	−0.7501	2
Zhejiang	0.8004	29	−0.1534	8	−0.2361	4	−0.2107	4
Anhui	0.4964	21	0.1219	12	0.2514	10	0.3562	12
Fujian	0.7050	26	0.3798	20	0.3029	12	0.2282	8
Jiangxi	0.6178	25	0.4379	22	0.6392	27	0.5636	15
Shandong	0.1001	11	−0.6563	1	−0.4236	3	−0.2676	3
Henan	0.5900	24	−0.1477	9	0.1954	9	0.2018	6
Hubei	0.8184	30	−0.0009	11	0.5128	21	0.2349	9
Hunan	0.5231	22	0.2885	15	0.6002	25	0.3129	11
Guangdong	0.2815	16	−0.3439	6	−0.5942	1	−0.7939	1
Guangxi	0.1952	14	0.3304	16	0.2593	11	0.6440	19
Hainan	0.0900	10	0.9536	31	0.3056	13	0.8995	28
Chongqing	1.0000	31	0.6445	25	0.7046	30	0.5832	17
Sichuan	0.4419	20	−0.4591	3	0.1530	8	0.1819	5
Guizhou	0.3214	18	0.3795	19	0.6816	29	0.7367	23
Yunnan	0.7172	27	−0.2353	7	0.4557	18	0.6070	18
Tibet	0.0673	8	0.8753	30	0.4174	16	0.9755	31
Shaanxi	0.5276	23	0.3415	17	0.5293	22	0.5466	14
Gansu	−0.1036	7	0.2032	14	0.4199	17	0.8670	27
Qinghai	−0.1933	5	0.4029	21	0.4712	20	0.9655	30
Ningxia	0.1436	13	0.5562	23	0.3965	15	0.9330	29
Xinjiang	−0.1652	6	−0.0723	10	0.0630	7	0.7578	24

infrastructure and inter-regional transmission capacity is a key breakthrough for improving the accommodation capacity of western provinces.

To further visualize disparities in accommodation capacity across provinces, Figure 4 presents a comparison of the comprehensive scores of the top-10 and bottom-10 provinces.

As shown in Figure 4, the comprehensive scores of the top-10 provinces ranged from −0.5420 to 0.2216, while those of the bottom-10 provinces ranged from 0.5378 to 0.7178, indicating a clear score gap between the two groups. Among them, Guangdong (−0.5420), Jiangsu (−0.5186), and Shandong (−0.4308) demonstrated markedly lower scores than the other provinces, suggesting that their accommodation capacity has a clear advantage. In contrast, provinces such as Tibet (0.6876) and Tianjin (0.7178) demonstrated relatively high positive scores, reflecting notable deficiencies in grid infrastructure or local consumption markets. Combined with the four-dimensional scores in Table 6, it can be observed that the top-10 provinces generally demonstrated lower scores in the dimensions of "power infrastructure" and "energy consumption" (indicating better performance), while the bottom-10 provinces reported higher scores in these two dimensions (indicating poorer performance), further confirming that grid infrastructure and electricity markets are the key factors determining accommodation capacity.

4.5. Recommendations

Based on the evaluation results, policy recommendations are proposed from two perspectives: regional grid planning and cross-provincial accommodation coordination.

4.5.1. Regional grid planning

It involves two aspects:

(i) Differentiate the grid development priorities of each province according to their characteristics. For provinces with strong resource endowments but weak accommodation capacity (e.g., Inner Mongolia, Xinjiang, Gansu, Qinghai, and Tibet), Table 2 shows that both "transmission line length" (b_5) and "transformer equipment capacity" (b_6) weights exceeded 0.1, while Table 4 shows that these provinces ranked low due to their relatively poor performance in the "power infrastructure" dimension, suggesting that weak grid connectivity is the core bottleneck; planning efforts should focus on strengthening UHV transmission channel construction and supporting

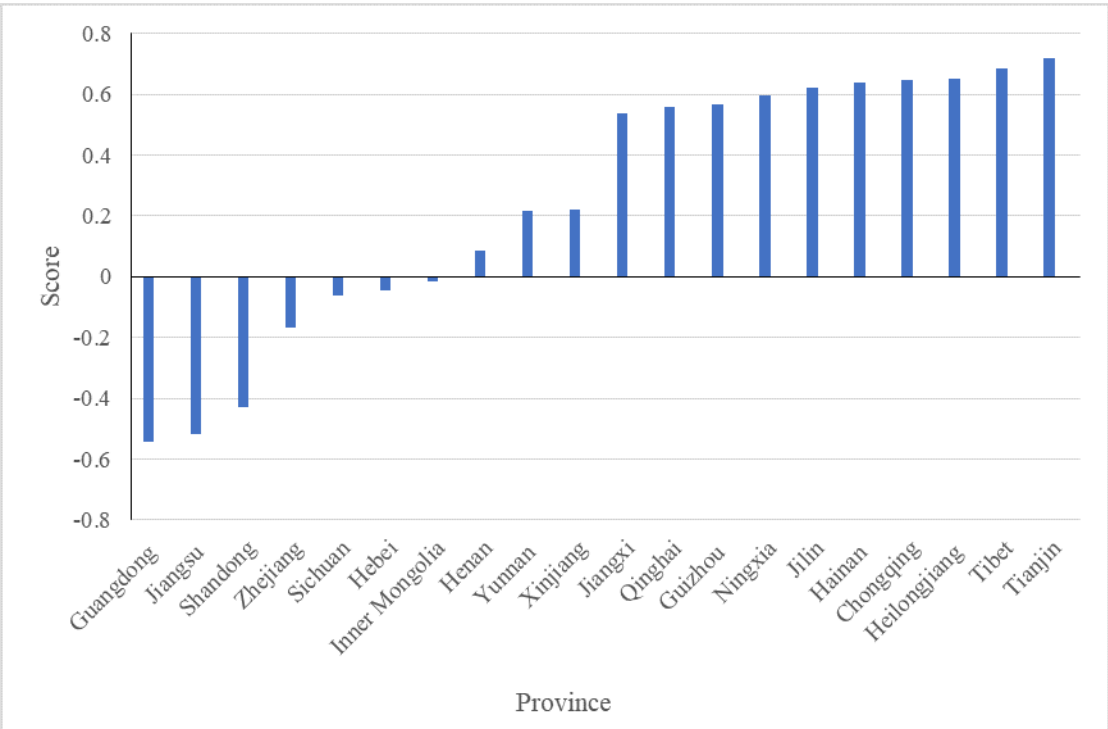

Figure 4. Comparison of comprehensive scores of the top-10 and bottom-10 provinces. A smaller comprehensive score (i.e., a larger negative value) indicates stronger accommodation capacity.

the development of flexibility resources, such as pumped storage and electrochemical energy storage, to enhance local peak-shaving capacity and effectively alleviate wind and solar curtailment. For provinces with strong accommodation capacity and large local markets (e.g., Guangdong, Jiangsu, Shandong, and Zhejiang), Table 4 shows that these provinces ranked among the top, and Table 2 shows that the weight of "total electricity consumption" (b_7) was as high as 0.1293, suggesting that electricity demand is the core driver of accommodation; efforts should focus on accelerating the construction of smart distribution grids and demand response systems to improve the capacity to receive variable renewable energy and encourage distributed photovoltaic and offshore wind power integration. For provinces with moderate resources and markets but poor coordination (e.g., Henan, Hubei, Hunan, and Sichuan), efforts should focus on optimizing the provincial power supply structure, promoting coordinated scheduling of hydropower and wind/solar power, and enhancing the flexible interconnection capability of grids across voltage levels.

(ii) Enhance the grid resilience of provinces with weak power facilities. For load-center provinces with low scores in the power facilities dimension (e.g., Tianjin, Beijing, and Shanghai), efforts should focus on expanding and upgrading 35 kV-and-above transmission lines and substation equipment to improve "last-mile" access capacity. At the same time, new regulatory resources, such as virtual power plants and energy storage stations, should be actively promoted to compensate for the shortage of flexible regulating power sources, thereby enhancing the overall resilience of the grid and its renewable energy accommodation capacity.

4.5.2. Cross-provincial accommodation coordination

It involves three aspects:

(i) Establish a resource–market matching cross-provincial accommodation mechanism. To address the resource–market mismatch between resource-rich provinces (e.g., Inner Mongolia and Xinjiang) and load-center provinces (e.g., Guangdong and Jiangsu), it is recommended to establish a cross-provincial renewable energy accommodation responsibility weighting mechanism, clarifying the minimum accommodation ratio for receiving-end provinces and incorporating it into local government performance assessment. Simultaneously, the "wind–solar–thermal–storage" integrated transmission model should be promoted, with energy storage and regulation facilities built at both ends of UHV channels to enhance transmission stability. A cross-provincial green electricity trading market should also be established, allowing resource-rich provinces to sell green electricity to load-center provinces through market mechanisms, creating effective price incentives.

(ii) Optimize cross-provincial dispatch strategies to alleviate concentrated curtailment issues. For provinces with high wind and solar curtailment rates (e.g., Xinjiang and Yunnan), dispatch priorities can be dynamically adjusted to prioritize renewable power during low-load periods and reduce thermal power output. A cross-provincial reserve-sharing mechanism should be established, allowing provinces to share peak-shaving reserve capacity and enhance overall system flexibility. The "hydropower + wind/solar" cross-provincial collaborative dispatch model should be promoted—for example, by using Yunnan's abundant hydropower resources to provide regulatory services for neighboring provinces' wind and solar generation—to achieve optimal accommodation at the regional level.

(iii) Identify key node provinces for cross-provincial coordination. Provinces with moderate comprehensive capacity but stable rankings, such as Henan, Hubei, and Anhui, have the potential to become hub nodes for cross-provincial power exchange. It is recommended to strengthen inter-provincial interconnection line construction in these provinces and build provincial-level power market transfer platforms to facilitate the efficient flow of electricity between the east and the west, thereby enhancing the overall efficiency of renewable energy accommodation nationwide.

4.6. Limitations

This study has certain limitations. Due to data availability constraints and variations in statistical standards, factors such as energy storage penetration, demand response capability, and electricity market maturity are not included in the current evaluation system. While these factors primarily affect the operational and dispatching aspects of renewable energy accommodation and have limited impact on our structural capacity assessment, future research may incorporate them as data become available to construct a more comprehensive evaluation framework.

5. Conclusion

Renewable energy accommodation capacity serves as a core benchmark for achieving the "dual carbon" goals, as it directly determines whether installed wind and solar capacity can be effectively converted into actual electricity

output. Insufficient accommodation capacity implies that already installed wind and solar capacity faces the risk of curtailment, which may lead to investment inefficiency and hinder the substitution of fossil fuels (i.e., the "carbon lock-in" risk). Therefore, identifying weaknesses in each province's accommodation capacity holds significant policy implications, while balancing the objectives of security, economy, and green development. Taking 31 provinces as the research objects, we have fulfilled all three research objectives: (i) To address the rank reversal problem of the classical TOPSIS method, the proposed weighted relative closeness effectively avoids the rank reversal phenomenon in alternative ranking; (II) To overcome the shortcomings of the entropy-weight method, the variance minimization optimization model successfully achieves an objective solution for the variable-entropy parameters, eliminating the influence of subjective parameter assignment; and (iii) An evaluation index system is constructed from four dimensions: resource endowment, power facilities, energy consumption, and economic development, and the case study verified the effectiveness of the proposed method while identifying the key shortcomings in the accommodation capacity of each province.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Availability of data

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

1. Xie BT, ed. Zhuang ji rong liang lian xu shi'er nian quan qiu di yi, wo guo feng dian hai you duo da qian li [Installed capacity ranked first in the world for 12 consecutive years: How much potential does China's wind power have]. CCTV.com. December 5, 2021. Accessed September 3, 2025. https://news.cctv.com/2021/12/05/ARTI0dIrJp3F60vCTYVQ0MnN211205.shtml. [In Chinese]
2. Tang Y, ed. Ling pao quan qiu, hui ji shi jie: tu shuo zhong guo guang fu chan ye fa zhan [Leading the World and Benefiting the World: A Graphical Overview of China's Photovoltaic Industry Development]. Belt and Road Portal. March 28, 2024. Accessed September 3, 2025. https://www.yidaiyilu.gov.cn/p/05DU7I3F.html. [In Chinese]
3. National Energy Administration. 2024 nian ke zai sheng neng yuan bing wang yun xing qing kuang [2024 renewable energy grid connection and operation situation]. National Energy Administration. January 27, 2025. Accessed September 3, 2025. https://www.nea.gov.cn/20250221/e10f363cabe3458aaf78ba4558970054/c.html. [In Chinese]
4. Wang XL, ed. AI dong feng lai le, chu neng chan ye zen me bian [AI tailwind arrives, how will the energy storage industry change]. Office of the Cyberspace Affairs Commission of Tibet Autonomous Region. May 30, 2025. Accessed September 3, 2025. https://wxb.xzdw.gov.cn/xxh/xxhgzdt/202505/t20250530_574829.html. [In Chinese]
5. National Energy Administration. Guo jia neng yuan ju fa bu 2024 nian quan guo dian li gong ye tong ji shu ju [National Energy Administration releases 2024 national power industry statistics]. National Energy Administration. January 21, 2025. Accessed September 3, 2025. https://www.nea.gov.cn/20250121/097bfd7c1cd3498897639857d86d5dac/c.html. [In Chinese]
6. China Electric Power Planning & Engineering Institute. Bian zhi fa bu "Xin xing dian li xi tong pi pi shu" "Zhong guo neng yuan fa zhan bao gao 2023" deng zhuan zhu he kan wu [Compilation and release of the New Power System Blue Book, China Energy Development Report 2023, and other monographs and publications]. China Electric Power Planning & Engineering Institute. September 12, 2024. Accessed September 3, 2025. http://www.eppei.ceec.net.cn/art/2024/9/12/art_50143_2515807.html. [In Chinese]
7. Cheng R, Zhang Y, Li L, *et al*. Mian xiang gao bi li ke zai sheng neng yuan xiao na de dian li shi chang jian she ji yan jiu jin zhan [Construction and Research Progress of Electricity Market for High-Proportion Renewable Energy

Consumption]. *Strategic Study CAE*. 2023;25(2):89-99. [In Chinese]

doi: 10.15302/J-SSCAE-2023.02.011

8. Fan XF. *Zheng ce gong ju shi jiao xia cu jin wo guo ke zai sheng neng yuan xiao na de zheng ce yan jiu [Policy Research on Promoting the Consumption of Renewable Energy in China from the Perspective of Policy Tools]*. Dissertation. Beijing, China: North China Electric Power University; 2023. [In Chinese]

   doi: 10.27140/d.cnki.ghbbu.2023.000787

9. Sheng SQ, Qiu H, Zhang WC, Zhang ZY, Wang JL, Ke XB. Kao lv wen tai he dong tai you gong ping heng yue shu de xin neng yuan xiao na zong he ping gu fang fa [Comprehensive assessment method of new energy consumption considering steady and dynamic active power equilibrium constraints]. *Power Syst Prot Control*. 2019;47(10):51-56. [In Chinese]

   doi: 10.19783/j.cnki.pspc.180705

10. Chen QX, Liu X, Fang XC, Guo HY, Lin QB. Kao lv ke zai sheng neng yuan bao zhang xing xiao na de dian li shi chang chu qing ji zhi [Consider a market clearing mechanism for the guaranteed consumption of renewable energy]. *Power Syst Autom*. 2021;45(6):26-33. [In Chinese]

    doi: 10.7500/AEPS20200702006

11. Zhao JB, Huang Q, Zhao X, Tang PC, Liu W. Ji yu mo hu hua dong tai ping gu de xin neng yuan xiao na zhi yue yin su fen xi [Analysis of restrictive factors of new energy consumption based on fuzzy dynamic evaluation]. *High Voltage Eng*. 2022;48(4):1286-1295. [In Chinese]

    doi: 10.13336/j.1003-6520.hve.20210930

12. Wang RS, Zhao Y, Ma FY, Gong YZ, Geng GC, Jiang QY. Shou duan dian wang gao bi li ke zai sheng neng yuan xiao na de yun xing ping jing fen xi yu chu neng xu qiu ping gu [Operational bottleneck analysis and energy storage demand assessment for high-proportion renewable energy accommodation in receiving-end grids]. *Power Syst Technol*. 2022;46(10):3777-3787. [In Chinese]

    doi: 10.13335/j.1000-3673.pst.2021.2103

13. Zhou L, Zhang JH, Zhang JX, He XY, Hu WL. Zhong guo sheng yu ke zai sheng neng yuan dian li xiao na liang shi kong yi zhi xing yu ying xiang yin su [Spatiotemporal heterogeneity and influencing factors of provincial-level renewable electricity consumption in China]. *J Environ Eng Technol*. 2026;16(3):943-953. [In Chinese]

    doi: 10.12153/j.issn.1674-991X.20250560

14. Ma Z, Zhong H, Xia Q, Kang C, Jin L. Constraint relaxation-based day-ahead market mechanism design to promote renewable energy accommodation. *Energy*. 2020;198(9):117204.

    doi: 10.1016/j.energy.2020.117204

15. Tong J, Liu W, Mao J, Ying M. Role and development of thermal power units in new power systems. *IEEE J Radio Freq Identif*. 2022;6:837-841.

    doi: 10.1109/JRFID.2022.3205465

16. Liu J. Shi ying ke zai sheng neng yuan xiao na de chu neng ji shu jing ji xing fen xi [Economic assessment for energy storage technologies adaptive to variable renewable energy]. *Energy Storage Sci Technol*. 2022;11(1):397-404. [In Chinese]

    doi: 10.19799/j.cnki.2095-4239.2021.0379

17. Huang TZ, Shang B. Ke zai sheng neng yuan pei e kao he jian guan yu zhu ti xing wei ce lve xuan ze [Assessment and supervision of renewable portfolio standards and strategic selection of stakeholders]. *Resour Sci*. 2020;42(12):2393-2405. [In Chinese]

    doi: 10.18402/resci.2020.12.11

18. Wu DL, Zhou DQ, Zhu QY, Su B, Hu FS, Zhao SQ. Zheng fu shi zheng pian hao dui ke zai sheng neng yuan fa zhan de ying xiang ji zhi yan jiu: ji yu gong xu shuang ce shi jiao [Government policy preferences and renewable energy development: evidence from the supply and demand sides]. *Chin J Manag Sci*. Published online July 14, 2026:1-16. [In Chinese]

    doi: 10.16381/j.cnki.issn1003-207x.2025.1437

19. Fan W, Hao Y. An empirical research on the relationship amongst renewable energy consumption, economic growth, and foreign direct investment in China. *Renew Energy*. 2020;146:598-609.

    doi: 10.1016/j.renene.2019.06.170

20. Li HZ, He LF, Li S. Ke zai sheng neng yuan shi yu xia "san gai lian dong" zheng ce de cheng ben cheng yin yu ding liang ce du—ji yu CGE mo xing de fen xi [The cost causes and quantitative measurements of the "Triple Reform" policy under the perspectives of renewable energy—a CGE model analysis]. *Syst Eng Theory Pract*. 2024;44(11):3501-3519. [In Chinese]

    doi: 10.12011/SETP2023-1726

21. Li H, Sun WQ, Xiang HW, Tian KP, Wang CM. Ying xiang qu yu dian wang ke zai sheng xiao na neng li de bian jie tiao jian fen xi [Analysis of boundary conditions affecting the renewable energy absorption capacity of regional grids]. *Acta Energ Sol Sin*. 2020;41(8):108-114. [In Chinese]

    doi: 10.19912/j.0254-0096.2020.08.015

22. Yu SK, Song YQ. Organizational performance evaluation of coal-fired power enterprises using a hybrid model. *Energies*. 2022;15(9):3175.

    doi: 10.3390/en15093175

23. Shi HT, Liu YF, Jiang ZN, Zhang J. Comprehensive power quality evaluation method of microgrid with dynamic weighting based on CRITIC. *Meas Control*. 2021;54(5-

6):1097-1104.

doi: 10.1177/00202940211016092

24. Zheng WM, Dan YQ, Wang CX, Wu JR, Zhu YF. Ji ji feng-gang-shui-huo duo neng xie tong de dian wang ke zai sheng neng yuan xiao na neng li ping gu [Evaluation of renewable energy consumption capacity in power grid considering the synergistic effect of wind-photovoltaic-hydro-thermal power]. *Electr Power*. 2023;56(12):248-254. [In Chinese]

doi: 10.11930/j.issn.1004-9649.202305105

25. Li LF, Liu CX, Zhu HJ, Rao Z, Li ZY. Kao lv wang luo an quan yue shu de ke zai sheng neng yuan xiao na neng li ping gu fang fa [Absorptive capability evaluation method of renewable energy considering security constraints of power grid]. *J Electr Power Sci Technol*. 2023;38(4):162-168. [In Chinese]

doi: 10.19781/j.issn.1673-9140.2023.04.017

26. Zhang YA, Deng CH, Cao P, Long ZJ, Liu DG, Li GQ. Yi zhong fen shi duan duo mu biao huo dian ji zu shi shi tiao zheng diao du ce lue ji ke zai sheng neng yuan xiao na neng li ping gu [A real-time scheduling strategy for time-segmented multi-target thermal power units and assessment of renewable energy consumption capacity]. *J Wuhan Univ (Eng Ed)*. 2023;56(1):63-70. [In Chinese]

doi: 10.14188/j.1671-8844.2023-01-008

27. Hwang CL, Yoon K. *Multiple Attribute Decision Making: Methods and Applications*. Berlin, Germany: Springer-Verlag; 1981.

doi: 10.1007/978-3-642-48318-9

28. Hua XY, Tan JX. Ji yu "chui mian" ju li de TOPSIS fa—zheng jiao tou ying fa [TOPSIS method based on "vertical" distance—the orthogonal projection method]. *Syst Eng Theory Pract*. 2004;(1):114-119. [In Chinese]

doi: 10.3321/j.issn:1000-6788.2004.01.020

29. Liu SL, Qiu WH. Duo shu xing jue ce de TOPSIS jia jiao du liang ping jia fa [The TOPSIS angle measure evaluation method for MADM]. *Syst Eng Theory Pract*. 1996;7:12-17. [In Chinese]

doi: 10.12011/1000-6788(1996)7-12

30. Wang ZX. Ji yu ma shi ju li de TOPSIS jue ce fang fa ji qi ying yong [Mahalanobis distance-based TOPSIS decision-making method and its application]. *Economics*. 2012;29(2):17-20. [In Chinese]

doi: 10.3969/j.issn.1007-1660.2012.02.004

31. Gao XH, Li XQ. TOPSIS fa de ni xu ce du ji qi gai jin [Backorder measurement of the TOPSIS method and its improvements]. *Stat Decis*. 2026;(13):43-50. [In Chinese]

doi: 10.13546/j.cnki.tjyjc.2026.13.007

32. Zhang K, Liu SS, Wei H, Yu P, Liang X. Ji yu CPSO gai jin de TOPSIS san wei kong jian zu he ding quan tou ying dong tai zong he ping jia yan jiu [Dynamic comprehensive evaluation research on TOPSIS three-dimensional space combined fixed weight projection based on CPSO improvement]. *Chin J Manag Sci*. 2025;33(7):117-127. [In Chinese]

doi: 10.16381/j.cnki.issn1003-207x.2022.1333

33. Wang KK, Ai W, Yin YY, Qian Q. Ji yu dong tai san jiao mo hu shu yu gai jin TOPSIS fa de chong tu xing qun jue ce fang fa yan jiu [Research on conflict-type group decision methods based on dynamic trigonometric fuzzy numbers and improved TOPSIS methods]. *Comput Sci*. 2025;52(S2):790-797. [In Chinese]

doi: 10.11896/jsjkx.241000119

34. Chen W. Guan yu TOPSIS fa ying yong zhong de ni xu wen ti ji xiao chu de fang fa [On the problem and elimination of rank reversal in the application of TOPSIS method]. *Oper Res Manag Sci*. 2005;(3):39-43. [In Chinese]

doi: 10.3969/j.issn.1007-3221.2005.03.008

35. Wang MY, Liu Y, Li MM, Liu YW, Shi WQ. Qu yu jian tan pai neng li xie tong du ping jia mo xing gou jian yu ying yong [Construction and application of evaluation model for coordinated degree of regional carbon emission]. *Syst Eng Theory Pract*. 2020;40(2):470-483. [In Chinese]

doi: 10.12011/1000-6788-2018-0901-14

36. Sun MJ, Chen YJ, Yang FY, Zhan CL, Yuan WY, Zhang M. Ji yu shang quan-TOPSIS fa de piao fu shi hai shang feng dian ji chu jie gou fang an duo zhun ze ping jia yan jiu [Multi-criterion evaluation study of floating offshore wind power infrastructure schemes based on entropy weight-TOPSIS method]. *Acta Energ Sol Sin*. 2025;46(4):406-414. [In Chinese]

doi: 10.19912/j.0254-0096.tynxb.2023-2016

37. Das U, Behera B. Geospatial assessment of ecological vulnerability of fragile Eastern Duars Forest integrating GIS-based AHP, CRITIC and AHP-TOPSIS models. *Geomat Nat Hazards Risk*. 2024;15(1):2330529.

doi: 10.1080/19475705.2024.2330529

38. Zhang JL, Ren J. Shang li lun zhong shang ji shang quan ji suan shi de bu zu yu xiu zheng [The deficiencies and amendments of the calculation formulation of entropy and entropy weight in the theory of entropy]. *Stat Inf Forum*. 2011;26(1):3-5. [In Chinese]

doi: 10.3969/j.issn.1007-3116.2011.01.001

39. Liang CY, Wu J, Lu WX, Ding Y. Yi zhong xin de hun he xing duo shu xing jue ce fang fa ji zai gong ying shang xuan ze zhong de ying yong [A new method on hybrid multiple attribute decision-making problem for choosing the supplier]. *Chin J Manag*. 2006;(6):71-76. [In Chinese]

doi: 10.16381/j.cnki.issn1003-207x.2006.06.014

40. Wang X. Ji yu gai jin TOPSIS de san can shu qu jian hui shu duo shu xing jue ce fang fa [Multi-attribute decision-making

method based on improved TOPSIS under three-parameter interval grey number]. *J Syst Sci Math Sci*. 2021;41(5):1328-1338. [In Chinese]

doi: 10.12341/jssms20383

41. Hu YH. Dui TOPSIS fa yong yu zong he ping jia de gai jin [The improved method for TOPSIS in comprehensive evaluation]. *Math Pract Theory*. 2002;(4):572-575. [In Chinese].

doi: 10.3969/j.issn.1000-0984.2002.04.009

42. State Grid Corporation of China. Xin neng yuan xiao na neng li ji suan dao ze [Guidelines for Calculating New Energy Accommodation Capacity]: Q/GDW 11628-2016[S]. 2016. [In Chinese]

43. China Electricity Council. *Zhongguo dian li tong ji nian jian 2024* [China Electric Power Statistical Yearbook 2024]. Beijing, China: China Statistics Press; 2024. [In Chinese]

44. National Bureau of Statistics of China. *Zhongguo tong ji nian jian 2024* [China Statistical Yearbook 2024]. Beijing, China: China Statistics Press; 2024. [In Chinese]