Based on Multi-Dimensional Benefit Evaluation Index of Integrated Operation of Landscape Storage Study on System Construction

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Abstract. The evaluation index system is one of the key factors to determine whether the multi-dimensional benefit evaluation of the integrated landscape storage operation system is accurate. In view of the redundancy of the multi-dimensional benefit comprehensive evaluation indicators of the integrated landscape storage operation system, a method combining cluster analysis and AHP (hierarchical analysis) is proposed to reduce the dimension of the indicators and initially screen out the indicators that have an important impact on the evaluation objectives. Eliminate low-impact indicators. KMO coefficient is used to judge the degree of overlap between the remaining indicators. Then the coefficient is used to KMa_i delete the overlapping index. Furthermore, the information overlap between the indicators is reduced and the accuracy of the comprehensive evaluation of the system benefit is improved.

Keywords: Screening of wind-solar-storage evaluation indexes; Clustering; AHP

1. Introduction

The integrated wind and solar storage system is a complex with multiple indicators, which combines wind power, optoelectronics, energy storage and hydrogen storage. This paper takes into account the impact of uncertain factors of current social development on the system[1], as well as the direct or indirect impact of the operation and development of the integrated[2] landscape storage system on all aspects of the society. Therefore, all factors should be comprehensively considered when evaluating the efficiency of the integrated landscape storage system. This paper puts forward the evaluation index system of multi-dimensional benefit construction in five aspects[3]: energy efficiency, economy, society, low carbon and enterprise development.

At present, the methods commonly used in the research of index screening can be divided into subjective analysis, objective analysis and subject-objective combination. The representative methods of subjective analysis[4] are theoretical analysis and expert consultation, but these methods are too subjective, resulting in one-sidedness[5] of the results. The commonly used

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methods in objective analysis include principal component analysis, factor analysis and cluster analysis, etc. However, such methods require a large number of sample data of indicators. However, due to the small amount of data available for multi-dimensional benefit evaluation indicators of integrated operation of landscape storage, this paper proposes combining subjective methods with objective methods, that is, cluster analysis and analytic hierarchy process (AHP) are adopted to solve the problem of index redundancy. KMa_icoefficient is used to judge the degree of overlap between indicators, and the KMa_icoefficient is used to delete the overlapping indicators to solve the overlapping problem. Suitable for the screening of evaluation indexes of wind-wind storage integrated operation system.

The accuracy of multi-dimensional benefit comprehensive evaluation index selection is the basis of benefit evaluation of integrated landscape storage system, and determines[6] the accuracy of evaluation results. The benefit evaluation results of the integrated system have important decision-making guidance significance for improving environmental quality, realizing economic, social, carbon emissions, enterprise development benefits and sustainable development, and provide support for the development of the combined power generation system.

2. Construction principle of multi-dimensional benefit evaluation index system for integrated operation of wind-wind storage in the whole life cycle

(1) The selected indicators should reflect the multi-angle of the integrated operation system, and establish a multi-dimensional comprehensive indicator system according to the characteristics of technology, economy, society, low carbon and enterprise development;

(2) The selected indicators should be measurable, available, detectable and traceable;

(3) The selected indicators should not be repeated nor omitted;

(4) The integrated operation system includes wind power, optoelectronics, electricity storage, heat storage and hydrogen storage systems, so the selection of indicators should not only consider the overall system but also reflect the characteristics of each unit;

(5) Compared with the traditional evaluation indicators, the selection of indicators should highlight the characteristics of the whole system life cycle process from initial construction, operation to retirement.

3. Design of integrated evaluation index screening method for wind-wind storage

In the process of selecting indicators, in order to more comprehensively reflect the impact on the evaluation results, as many indicators as possible will be selected, which inevitably leads to the redundancy of indicators. Because of the consistency of the purpose of evaluation and the complexity of the content of economic phenomena, it inevitably leads to the overlap of each index mapping and evaluation information in an index system.

Therefore, in the process of index screening, there are two core problems to be solved by the invention: one is to solve the redundancy of evaluation indicators, that is, to delete the unimportant indicators, that is, those indicators that have little impact on the evaluation target, from the large number of original index data, so as to reduce the complexity of analysis and calculation to a certain extent and reduce the impact on the evaluation results; The second is to solve the overlap of evaluation indicators[7] which is to delete the remaining indicators, eliminate the overlapping indicators for re-screening, and obtain independent evaluation indicators.

3.1 Redundancy index screening method design

3.1.1 Index cluster analysis

Firstly, R clustering is used to reduce the dimension of the newly established index system. Specifically, similar indicators in the index system are grouped into a class, and then a representative indicator is selected from this class to achieve the dimensionality reduction of the index system.

1. Standardization of indicators

There are n evaluation index variables, and the index variable data is $x_1, x_2, x_3 \ldots x_n$,

After standardization, the indicators x_i are converted into standardized indicators x_i^*.

$$x_i^* = \frac{x_i - \overline{x_i}}{S_i} \tag{1}$$

$$\overline{x_i} = \frac{1}{n}\sum_{n}^{1} x_i \tag{2}$$

$$S_i = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x_i})^2 \tag{3}$$

Where, $\overline{x_i}$ is the average value of indicator sample; S_i is the standard deviation of the indicator sample.

2. Simple correlation coefficient method is used to measure the similarity between similar indicators. Correlation coefficient 0 indicates no correlation between variables, while correlation coefficient close to 1 or -1 indicates high correlation between variables. The specific calculation uses the simple correlation coefficient formula as follows:

$$r_{ij} = \frac{\sum_{k=1}^{n}(x_{ki} - \overline{x_i})(x_{kj} - \overline{x_j})}{\sqrt{\sum_{k=1}^{n}(x_{ki} - \overline{x_i})^2 (x_{kj} - \overline{x_j})^2}} \tag{4}$$

3. Combine indicators with high correlation into one category, select representative indicators from each category, and separate other indicators into one category. The $\overline{R_i}$ variable with the largest value is selected as the representative variable.

$$\overline{R_i} = \frac{\sum_{i \neq j} r_{ij}^2}{m_j - 1} \tag{5}$$

Where, r_{ij} represents the index x_i and x_j simple correlation coefficient, and m_j is the number of x_j variables in the class.

3.1.2 Indicator weight selection

After cluster analysis, AHP (hierarchical analysis) was used to delete indicators with low weight, and the ownership threshold was selected as 0.05. The details are as follows:

(1) Construct judgment matrix

The judgment matrix is constructed by comparing each index of the first layer by pairwise comparison. $(U_{ij})_{n\times n}(i = 1\sim n, j = 1\sim n)$ represents the value of the relative importance comparison between elements. The judgment matrix formed by the comparison results is as follows. The comparison principle is shown in Table 1.

$$U = \begin{bmatrix} u_{11} & \cdots & u_{1n} \\ \cdots & \cdots & \cdots \\ u_{n1} & \cdots & u_{nn} \end{bmatrix}$$

Table 1: Scale of the nines

A indicator is higher than B indicator	vital	of great importance	importance	Slightly important	On an equal footing	Slightly secondary	Secondary	Very secondary	secondary
A index evaluation value	9	7	5	3	1	1/3	1/5	1/7	1/9
remark	Take 8,6,4,2,1/2,1/4,1/6,1/8as the median value in the above review								

(2) Test the consistency of judgment matrix

After constructing the judgment matrix, the consistency test should be carried out. The analytic hierarchy process converts people's subjective judgment into objective description as far as possible, gradually selects the subjectivity, and expresses and deals with people's subjective judgment in a formal way. The reasonable proportion of objective weight directly affects its correctness and success. The consistency of judgment matrix is very important in AHP method[8], which directly affects the objective ranking of indicators. The consistency index is used to determine whether the consistency of the judgment matrix is satisfied, and the consistency test index CI is introduced to solve the problem of maximum feature and eigenvector of the judgment matrix.

$$\lambda_{max} = \frac{1}{n}\sum_{n}^{1}\frac{(AW)_i}{w_i} \tag{6}$$

$$CI = (\lambda_{max} - n)/(n-1) \tag{7}$$

λ_{max} Is the largest eigenroot of the judgment matrix; The calculated value of CI should be compared with the corresponding value of the average random consistency index RI, and the consistency ratio is introduced. When CR<0.1, the judgment matrix has satisfactory consistency.

(3) Weight calculation

The root method of judging the maximum eigenroot of the matrix and its corresponding eigenvector λ_{max} is as follows:

$$M_I = \prod_{j=1}^{n} b_{ij}, i = 1,2,3 \ldots n \tag{8}$$

Calculate the NTH root of M_I

$$\overline{W_i} = \sqrt[n]{M_i} \tag{9}$$

To normalize the vector $u = [\overline{W_1}, \overline{W_2}, \ldots \overline{W_n}]^T$,

$$w_i = \overline{W_i} / \sum_{i=1}^{n} \overline{W_i} \tag{10}$$

Where M_i is the product of each row element of the judgment matrix; w_iIs the index weight, and W is the feature vector.

3.2 Index system overlap screening

(1) KMO coefficient is used to judge the overall degree of overlap between indicators. The specific formula is as follows:

$$KMO = \frac{\Sigma \sum_{i \neq 1} r_{ij}^2}{\Sigma \sum_{i \neq 1} r_{ij}^2 + \Sigma \sum_{i \neq 1} a_{ij}^2} \tag{11}$$

$$\alpha_{ij} = -\frac{P_{ij}}{\sqrt{P_{ii} P_{jj}}} \tag{12}$$

Where, r_{ij}^2represents the simple correlation coefficient between indicators x_i and x_j, and α_{ij}represents the partial correlation coefficient between indicators x_i and x_j; At that time, $KMO \geq 0.7$ indicated a high level of overlap in the information of this group of indicators. The corresponding element of the inverse of the P_{ij} correlation coefficient matrix.

If the calculated KMO coefficient is greater than 0.7, it means that the overlap level of the remaining indicators is high, and the next step is to delete the overlap indicators.

(2) The sampling appropriateness measure KMa_i of each indicator x_i is used to delete the overlapping indicators. The details are as follows:

$$KMa_i = \frac{\sum_{i \neq j} r_{ij}^2}{\sum_{i \neq j} r_{ij}^2 + \Sigma \sum_{i \neq 1} a_{ij}^2} \tag{13}$$

If the value of KMa_iin the calculation result is close to 1, it means that the correlation between this indicator and other indicators is strong, and it is deleted. On the contrary, if the KMa_i value is close to 0, it means that the correlation between the indicator and other indicators is weak, and it is retained.

4Analysis of numerical examples

4.1 Original indicator selection

Because there are many multi-dimensional benefit evaluation index systems of integrated wind-wind storage operation, the low carbon benefit index is selected to verify the method of the invention. The data comes from the data of the wind-storage integrated operation system of a power company in Jilin Province and the data of other power companies.

Table 1 Original evaluation index of low carbon benefit

Low carbon benefit (U4)	Achievement rate of CO2 emission reduction target (U401)	40%
	Coal power emission reduction benefits(U402)	65%
	Original installed specific gravity(U403)	43.5%
	CO Emission Reduction target completion rate (U404)	48.4%
	Demand-side benefit(U405)	45.9%
	Energy conservation and emission reduction achieved rate (U406)	13.5%
	Curtailment rate(U407)	17%
	Ecological environment impact rate (U408)	13%
	Proportion of new energy installed capacity(U409)	43.5%
	Energy substitution emission reduction benefits(U410)	80%
	Line loss reduction of energy saving and emission reduction benefits(U411)	23%
	Cleaning substitution benefit(U412)	80%
	SO2 emission reduction target completion rate (U413)	74.6%
	Power side benefit(U414)	50%
	Grid side benefit(U415)	40%
	Rate of completion of soot reduction targets(U416)	84.9%
	Pollutant discharge(U417)	33%
	New energy consumption change value (U418)	90.3%
	Light rejection efficiency(U419)	5%
	NOx reduction target achievement rate (U420)	23.3%

4.2 Index Screening

Step 1: After cluster calculation, the indicators are divided into 15 indicators from the original 20 clusters.

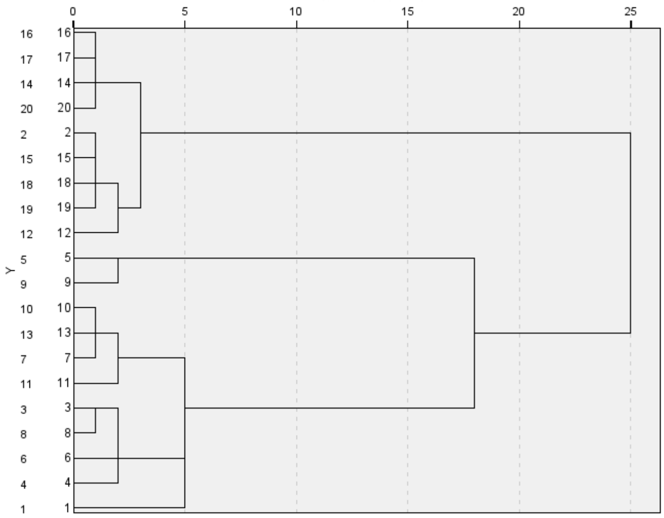

Figure 1 Cluster tree of low-carbon benefit evaluation index

Step 2: According to Figure 1The weights of 15 indicators after clustering are determined by analytic hierarchy process, and the weights of indicators are calculated as shown in Table 2.

Table 2 Evaluation indexes of low-carbon benefits after clustering

	index	weight	Index screening result
Low carbon benefit(U4)	CO2 Reduction target achievement rate (U401)	0.15372963	Temporary reservation
	Coal emission Reduction Benefits (U402)	0.12376082	Temporary reservation
	Original load ratio (U403)	0.02625466	eliminate
	CO Emission Reduction target completion rate (U404)	0.17514879	Temporary reservation
	Energy saving and emission reduction achievement rate (U406)	0.11681415	Temporary reservation
	Curtailment rate (U407)	0.01662942	eliminate
	Ecological environment impact rate (U408)	0.03369882	Temporary reservation
	Proportion of new energy installed capacity (U409)	0.06885268	eliminate
	Energy substitution emission reduction benefit (U410)	0.02309224	Temporary reservation
	Line loss reduction Energy saving and emission reduction benefits (U411)	0.00282211	eliminate
	SO2 Emission Reduction target achievement Rate (U413)	0.08645554	Temporary reservation
	Soot reduction target achievement rate (U416)	0.02851219	Temporary reservation

	Change value of new energy Consumption (U418)	0.08664499	Temporary reservation
	Light rejection rate (U419)	0.02473583	eliminate
	NOx reduction target achievement rate (U420)	0.03284813	Temporary reservation

The 5 indicators with less weight will be removed, leaving 10 evaluation indicators, as shown in Table 3:

Step 4 ,Step 2: Calculate KMO=0.861 > 0.7 of the indicator, indicating that the overall information overlap rate of the original indicator is high, and further screening is needed.

Step 5: Measure the sampling appropriateness of each indicator.

Table 3 Low carbon benefit evaluation index value KMa_i

	index	KMa_i
Low carbon benefit (U4)	CO2 Reduction target achievement rate (U401)	0.575
	Coal emission Reduction Benefits (U402)	0.923
	SO2 Emission Reduction target achievement Rate (U413)	0.754
	Nox reduction target achievement rate (U420)	0.774
	CO Emission Reduction target completion rate (U404)	0.692
	Soot reduction target achievement rate (U416)	0.603
	Energy saving and emission reduction achievement rate (U406)	0.623
	Change value of new energy Consumption (U418)	0.642
	Ecological environment impact rate (U408)	0.742
	Proportion of new energy installed capacity (U409)	0.903

According to Table 4, $\text{KMa}_{402} = 0.923$ of coal emission reduction benefit is the largest, so the index of coal emission reduction benefit should be excluded. At the same time, KMO=0.651 < 0.7 of the remaining indicators is calculated, indicating that the overlap correlation of the remaining indicators is small, and the low-carbon benefit evaluation indicators are finally obtained, as shown in Table 4.

Table 4 Low carbon benefit evaluation index

Low carbon benefit (U4)	CO2 reduction target achievement rate (U41)
	SO2 Emission Reduction Target completion Rate (U42)
	Nox reduction target achievement rate (U43)
	CO Emission Reduction target completion rate (U44)
	Soot reduction target achievement Rate (U45)
	Energy saving and emission reduction

	achievement rate (U46) New energy consumption change value (U47) Ecological environment impact rate (U48) Proportion of new energy installed capacity (U49)

For the rest, energy efficiency indicators, economic indicators, social benefits, and enterprise development benefit indicators are screened according to the above methods. The final evaluation index system is shown in Table 5.

Table 5 Multi-dimensional benefit evaluation system of integrated operation of wind-wind storage

Energy efficiency benefit (U1)	Integrated Energy Efficiency (U101) Power Prediction Accuracy (U102) Power Quality Index (U103) Power Schedulability Index (U104) Power Reliability (U105) Integrated Landscape Forecasting Capability (U106) Energy Conversion Efficiency (U107) Planned generating capacity (U108) Average equipment failure rate (U109) Equipment Operation (U110) Equipment Consumption (U111) Energy Network Energy Loss (U112) Multi-type equipment unification rate (U113) Device Monitoring Rate (U114) Equipment cycle life (U115) Energy storage efficiency per unit (U16) Power density (U17) Energy density (U18) Energy storage System Response Time (U19)
Economic benefit(U2)	Investment and construction cost per unit in the whole life cycle (Yuan) (U201) Return on Energy Input (U202) Return on project Assets (U203) Project asset turnover (U204) Life Cycle operating and maintenance costs (U205) Direct revenue from Operation (U206) Participating in the power market to obtain the peak-Valley price difference (U207) Grid loss reduction benefits from integrated operation (U208) Average investment per unit of installed capacity (U209) Unit cost of power generation (U210) Environmental Tax on Pollutant Discharge (Yuan) (U211) Deferred Benefit Capacity (U212) Operating cost per unit over the life cycle (U213) Equipment Salvage Value Income (U214)
Social benefit (U3)	Energy form impact rate (U301) Industrial structure impact rate (U302)

	Contribution rate of fiscal and tax revenue (U303) Employment Benefits (U304) Boost to Regional economy (U305) Continuity and Reliability contribution rate (U306) Comprehensive benefits of the industry (U307) Improvement of residents' Quality of Life (U308) Land value added (U309) Coal saving (U310) Backup Power Savings (U311) Average GDP Gini coefficient (U312) Social Investment Enhancement (U313)
Low carbon benefit (U4)	CO2 reduction target achievement rate (U41) SO2 Emission Reduction Target completion Rate (U42) Nox reduction target achievement rate (U43) CO Emission Reduction target completion rate (U44) Soot reduction target achievement Rate (U45) Energy saving and emission reduction achievement rate (U46) New energy consumption change value (U47) Ecological environment impact rate (U48) Proportion of new energy installed capacity (U49)
Enterprise development benefit (U5)	Return on assets (U51) Enterprise Asset Load Ratio (U52) Corporate asset depreciation rate (U53) Business Performance (U54) Asset Allocation Benefit (U55) Return on Investment (U56) Investment net present value ratio (U57) Innovative equipment technology (U58) Electrification level (U59)

5 Conclusion

This paper provides a screening method for multi-dimensional benefit evaluation indicators of integrated operation of landscape storage, and proposes to establish a benefit evaluation index system from five dimensions: energy efficiency level, economic benefit, social benefit, low-carbon benefit and enterprise development benefit. Construct a comprehensive benefit evaluation system for the whole life cycle of integrated operation of wind-wind storage, taking into account the uncertain influencing factors and the influence and correlation among multiple dimensions. A comprehensive, scientific and referential evaluation index system of wind-storage-integrated system is given to promote the development of wind-storage-integrated power generation system and the optimization and adjustment of energy structure.

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References

[1] Li Wei, Bao Zhe, Yang Hansheng et al. Analysis of benefits and influencing factors of distributed integrated energy system in parks based on interval number theory [J]. Journal of Solar Energy, 2020,

[2] Tan Xue,Luan Hao,Jin Yanming. Multi Dimensional Benefit Evaluation of Green Development of Power System Under the Target of Carbon Peak， Environmental protection2021，(Z2):15-21.

[3] XIAO Shuai1, ZHANG Yan2, ZHANG De1, YU Haifeng1,. Comprehensive Evaluation Indexes Framework and Evaluation Method for Transmission Planning of Wind Power Cluster [J].China Power，2019,52(10):115-122.

[4] Chen Honghai.Method of Screening Evaluation Indicators Based on Anti-image Correlation Matrix [J]. Chinese management science，2022，30(11):149-156.

[5] Li Peng. Research of New Clustering Validity Index in Cluster Analysis [D].Hefei:Anhui University, 2018.

[6] Wang Xue. Research on New Cluster Validity Index for Overlapping Datasets in Cluster Analysis [D].Hefei:Anhui University, 2019.

[7] Otero C E，Peter A.Research directions for engineering big data ana lytics software ［J］.IEEE Intelligent Systems，2014，30(1)：13-19.

[8] Darányi András,Dörgő Gyula,Ruppert Tamás,Abonyi János. Processing indoor positioning data by goal-oriented supervised fuzzy clustering for tool management[J]. Journal of Manufacturing Systems. 2022.02.010