Collaborative Evaluation of Wind Power Supply Chain Node Enterprises Based on Matter-element Extension

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Abstract

On the basis of analyzing the wind power supply chain node enterprise cooperation, an evaluation index of wind power supply chain node enterprise collaboration is established. Matter-element extension method is used to evaluate reasonably the information flow collaboration, logistics collaboration and capital flow among wind power supply chain node enterprises. It also provides some understanding and opinions on the supply chain coordination to enhance the participation of energy storage.

Keywords

Wind power supply chain; Node enterprise collaboration; Matter-element Extension; Comprehensive evaluation.

1. Introduction

The operation and maintenance of wind power supply chain involves all relevant nodes and links of the wind power industry, including the supply of raw materials, parts processing, equipment renewal and development, wind farm construction and operation and maintenance activities. In recent years, China's wind power industry has developed rapidly, and the development of supply chain is also maturing. The coordinated development of node enterprises in the supply chain is conducive to improving the competitiveness of the entire wind power supply chain, saving costs and broadening the customer base[1-2]. However, there are also some problems in the development of wind power supply chain, such as uneven distribution of benefits among supply chain node enterprises, insufficient self-help innovation ability and imperfect information management mechanism[3-4]. Based on the above situation, this paper uses matter-element extension method to analyze and evaluate the collaboration of wind power supply chain node enterprises.

Domestic and foreign scholars have carried out certain research and analysis on wind power supply chain coordination. Ma Ti, Kou Deqian and others used Synergetics Theory to construct wind power supply chain node enterprise synergy model, and used AHP to evaluate the synergy degree[5-6]. Based on the analysis of the design principles of the fourth-party logistics(4PL) supply chain coordination evaluation index, Wang Ling and others evaluated the four-dimensional logistics chain-based supply chain coordination degree using the analytic hierarchy process[7]. Li Shuying and others used the Entropy Weight method to determine the weight, and then used the Fuzzy Comprehensive Evaluation to evaluate the information sharing, market capacity and other indicators of an enterprise for supply chain collaborative management[8]. Zhang Yinghua et al. proposed a comprehensive evaluation method based on the similarity of Trapezoidal Fuzzy numbers to comprehensively evaluate the performance of the coordination of a bus company's entire supply chain[9]. However, most scholars choose the AHP or Fuzzy evaluation method to evaluate comprehensive evaluation after constructing the collaborative index. These methods have strong subjectivity and can not make an objective evaluation of the synergy of node enterprises in the supply chain. In order to reduce this subjectivity, this paper uses the Matter-element Extension model to evaluate the synergy of node enterprises in the wind power supply chain.

2. Wind Power Supply Chain Construction and Coordination

Having a complete wind power supply chain system is the basis and premise for wind power supply chain node enterprise collaboration. We need to understand and build a more perfect wind power supply chain before the node enterprise collaboration.

2.1 Construction of wind power supply chain

Considering the current development situation, this paper constructs a wind power supply chain with three sub-supply chains. The sub-supply chain of the supply chain is the wind power generation equipment supply chain, the energy storage equipment supply chain and the wind power operation and maintenance supply chain. The three sub-chains are related to each other but have their respective functions. The detailed structure of the wind power supply chain is shown in Fig.1.

As shown in the figure, due to the instability of wind power generation, we have added energy storage links in the wind power supply chain to improve the utilization of wind power generation and achieve safe consumption of wind power generation.

2.2 Collaborative Model Construction of Wind Power Supply Chain Node Enterprises

Since the wind power supply chain operation activities include many node enterprises, these nodes cooperate through some means, and the wind power supply chain node enterprises want to achieve the overall optimal supply chain, and the nodes in the supply chain need to cooperate. Based on this, we build a collaborative model of the wind power supply chain node enterprise as shown in Fig. 2.

For the wind power supply chain node enterprise collaboration model of Fig.2, a brief analysis can be made from different levels. From the basic function point of view the collaborative model focuses on the operation between the supply enterprise and the users, and its purpose is to ensure the great operation of logistics activities between the upstream, midstream and downstream node enterprises in the supply chain. From the middle meaning, the cooperation of wind power supply chain node enterprises can guarantee the normal flow of logistics, information and capital in wind power supply chain. From the deep strategic, the coordination of the wind power supply chain can organically unify all the nodes in the supply chain, and achieve the goal of maximizing the overall benefit of the wind power supply chain through mutual cooperation.

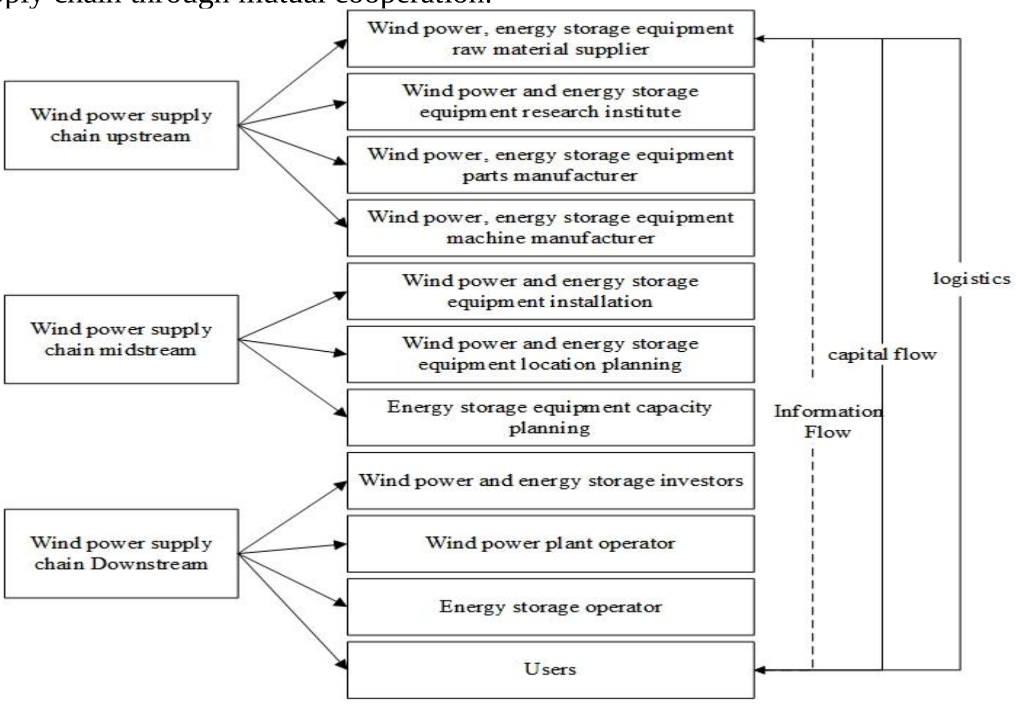

Fig.1 Wind power supply chain

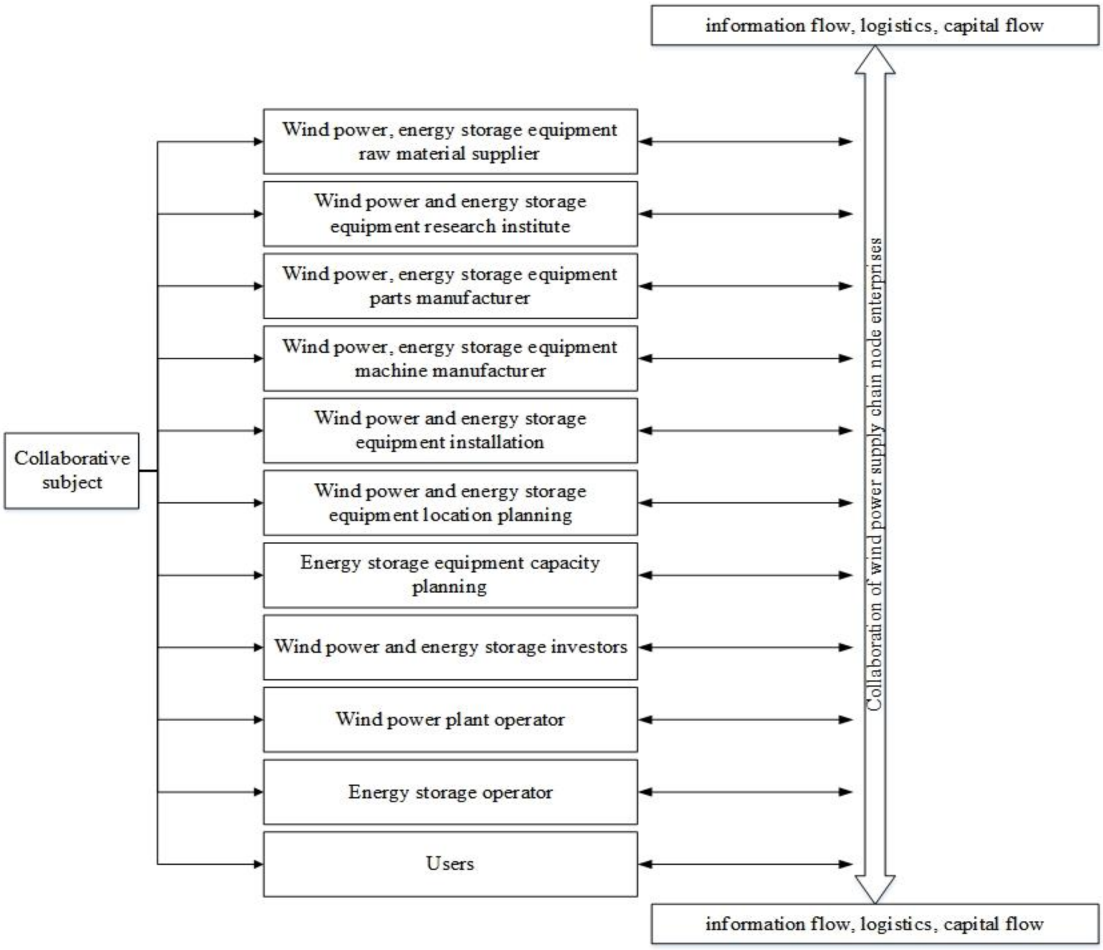

Fig.2 Wind power supply chain node enterprise collaboration model

3. Wind power supply chain node enterprise collaborative evaluation index

Aiming at the coordination problem of wind power supply chain logistics node enterprises, this paper will construct a scientific and reasonable collaborative evaluation index system. A reasonable evaluation is made through the establishment of the index system.

3.1 Principles for the construction of collaborative indexes

The construction of collaborative indicators needs to conform to certain principles.

(1) The principle of combining achievability with scientificity. To construct a supply chain collaborative evaluation index system needs to meet the actual needs, and to achieve the overall goal of the supply chain as the fundamental goal. At the same time, scientific theoretical methods should be used as a guide to establish reasonable, rigorous and scientific evaluation indicators. Following the principle of combining achievability and scientificity, the selected indicators can accurately and comprehensively represent the actual situation of the supply chain.

(2) The principle of combining economics and adaptability. The selected indicators should be basic and easy to obtain data indicators to reduce the cost of the enterprise. At the same time, the selected indicators should be adapted to the actual situation of the enterprise and the supply chain, and should be compatible with the development planning of the supply chain. Following the principle of combining economics and adaptability, we can obtain the most appropriate evaluation indicators with optimal cost.

(3) The principle of combining objectivity and particularity. Based on the realistic and objectivity of the evaluation, the selection of each evaluation index needs to be objective ,realisticb and in line with actual needs, also it cannot rely excessively on empirical selection of evaluation indicators. However, due to the particularity of the wind power industry, special evaluation indicators need to be considered.

(4) The principle of combining operability and practicality. The meaning of evaluation indicators should not be ambiguous or misunderstood. It is necessary to avoid duplication of meaning between each indicator, simplify the work, and make the evaluation easy to operate. The source of the data information needed to evaluate the indicators must be authentic.

3.2 Construction of Collaborative Evaluation Index

Based on the above principles and wind power supply chain node enterprise collaboration model, considering various factors, this paper constructs the wind power supply chain node enterprise collaboration evaluation index system as shown in Tab.1. The index system is divided into three parts: information flow, capital flow and logistics, including 16 indicators.

In terms of information flow, information accuracy, information breadth, information sharing degree, information agility and information transmission length are the key factors affecting the overall operation and maintenance of the supply chain. Timely and accurate transmission and sharing of information can reduce the cost of the supply chain and improve the efficiency of the overall supply chain.

In terms of capital flow, the delivery rate of goods, the payback period, the investment recovery rate, the profit growth rate, the liquidity turnover rate and the bad debt rate of accounts receivable are directly related to the value creation and value-added operation process of the entire industry of the wind power industry. .

In terms of logistics, it mainly involves inventory turnover rate, on-time delivery rate, cargo loss rate (abandonment rate), supply time flexibility and transportation mode selection, which directly affect the smooth operation of the entire supply chain.

Tab.1 Wind power supply chain node enterprise collaborative evaluation index

First-level index	Secondary index	Index types
information flow $\boldsymbol{B_1}$	Information accuracy C_1	Cost
	Information breadth C_2	Cost
	Information sharing degree C_3	Benefit
	Information agility C_4	Benefit
	Information transmission length C_5	Cost
capital flow $\boldsymbol{B_2}$	Delivery rate of goods C_6	Benefit
	Payback period C_7	Benefit
	Investment recovery rate C_8	Benefit
	Liquidity turnover rate C_9	Benefit
	Profit growth rate C_{10}	Benefit
	Bad debt rate of accounts receivable C_{11}	Cost
logistics $\boldsymbol{B_3}$	Inventory turnover rate C_{12}	Cost
	On-time delivery rate C_{13}	Cost
	Cargo loss rate (Abandonment rate)C_{14}	Cost
	Transportation mode selection C_{15}	Cost
	Supply time flexibility C_{16}	Benefit

4. Constructing Matter-element Extension Model

The Matter-element Extension model was developed by Professor Cai Wen's theory of Matter-element Extension analysis. The Matter-element Extension model uses the evaluation index system and its eigenvalues as the matter elements, and obtains the classical domain, the node domain and the correlation degree based on the evaluation index grading and the measured data set. The Matter-element Extension method combines quantitative and qualitative two angles to deal with real problems[10-11].

4.1 Determination of matter elements, classical domains and sections

Usually things have multiple features and their quantities, that is, things L can be divided into j levels, the eigenvalues and corresponding ranges of values are used, that is, the classic domain is as shown in Eq.1.

$$R_j=(L_j,C_i,V_{ji})=\begin{bmatrix} L_j & c_1 & v_{j1} \\ & c_2 & v_{j2} \\ & \cdots & \cdots \\ & c_l & v_{jl} \end{bmatrix}=\begin{bmatrix} L_j & c_1 & <a_{j1},b_{j1}> \\ & c_2 & <a_{j2},b_{j2}> \\ & \cdots & \cdots \\ & c_l & <a_{jl},b_{jl}> \end{bmatrix} \quad (1)$$

Use q to indicate the object to be evaluated, use $v_{p1},v_{p2},...,v_{pl}$ to denote the range of values of q with respect to $c_1,c_2,...,c_l$, that is, the section domain. As shown in Eq.2.

$$R_q=(q,C_i,V_{qi})=\begin{bmatrix} L_j & c_1 & v_{q1} \\ & c_2 & v_{q2} \\ & \cdots & \cdots \\ & c_l & v_{ql} \end{bmatrix}=\begin{bmatrix} L_j & c_1 & <a_{p1},b_{p1}> \\ & c_2 & <a_{p2},b_{p2}> \\ & \cdots & \cdots \\ & c_l & <a_{pl},b_{pl}> \end{bmatrix} \quad (2)$$

At the same time, q_0 is used to represent the matter element, and $v_1,v_2,...,v_l$ respectively represents the measured data of q_0 on $c_1,c_2,...,c_l$, which can be expressed by Eq.3.

$$R_0=\begin{bmatrix} p_0 & c_1 & v_1 \\ & c_2 & v_2 \\ & \cdots & \cdots \\ & c_l & v_l \end{bmatrix} \quad (3)$$

4.2 Evaluation of Relevance Degree, Weight and Grade evaluation

(1) The correlation coefficient reflects the degree of association between the evaluated object and the evaluation level. In order to avoid the phenomenon that the measured data exceeds the node domain and the correlation function is calculated, we adjust the correlation function[12], which is obtained from Eq.4,5.

$$S_j(q_0)=1-\sum_{i=1}^{l}\omega_i d_{ij} \quad (4)$$

$$d_{ij}(v,V'_{ji})=\left|v-\frac{a+b}{2}\right|-\frac{b-a}{2} \quad (5)$$

(2)The method of determining the weight directly affects the quality of the evaluation results. This paper intends to use AHP to determine the weight.

(3) Grade evaluation. The greater the correlation coefficient of the level, the higher the degree of relevance of the evaluation object to the level. If $S_j(q_0)=\max\{S_j(q_0)\}$, the level of the object to be evaluated is j_0.

5. Matter-element Extension analysis of wind power supply chain node enterprise collaboration

5.1 Constructing Classic Domain Matrix and Section Domain Matrix

Based on the indicator system shown in Tab.1, the evaluation criteria of the indexes in the table are divided into five grades: excellent, good, medium, poor, and very poor(Expressed by A, B, C, D, E respectively). The evaluation criteria corresponding to each index are given by expert experience, and the scope is set to [0, 10], and then construct the classic domain matrix R_1, R_2, R_3, R_4, R_5 and the node matter matrix R_q of the wind power supply chain node enterprise collaboration. As shown in Eq.6.

$$R_1 = \begin{bmatrix} L_1 & C_1 & (0,2) \\ E & C_2 & (0,2) \\ & \cdots & \cdots \\ & C_{16} & (0,2) \end{bmatrix} \quad R_2 = \begin{bmatrix} L_1 & C_1 & (2,4) \\ \mathrm{D} & C_2 & (2,4) \\ & \cdots & \cdots \\ & C_{16} & (2,4) \end{bmatrix} \quad R_3 = \begin{bmatrix} L_1 & C_1 & (4,6) \\ \mathrm{C} & C_2 & (4,6) \\ & \cdots & \cdots \\ & C_{16} & (4,6) \end{bmatrix}$$
$$R_4 = \begin{bmatrix} L_1 & C_1 & (6,8) \\ \mathrm{B} & C_2 & (6,8) \\ & \cdots & \cdots \\ & C_{16} & (6,8) \end{bmatrix} \quad R_5 = \begin{bmatrix} L_1 & C_1 & (8,1) \\ \mathrm{A} & C_2 & (8,1) \\ & \cdots & \cdots \\ & C_{16} & (8,1) \end{bmatrix} \quad R_N = \begin{bmatrix} L & C_1 & (0,10) \\ & C_2 & (0,10) \\ & \cdots & \cdots \\ & C_{16} & (0,10) \end{bmatrix} \tag{6}$$

The object matrix R_0 to be evaluated is constructed according to the measured data of wind power supply chain node enterprise collaboration. It can be expressed by Eq.7.

$$R_0 = \begin{bmatrix} L_0 & C_1 & 9.6 \\ & C_2 & 8.5 \\ & C_3 & 8.2 \\ & C_4 & 7.2 \\ & C_5 & 6.9 \\ & C_6 & 8.1 \\ & C_7 & 0.9 \\ & C_8 & 6.9 \\ & C_9 & 3.7 \\ & C_{10} & 6.9 \\ & C_{11} & 8.3 \\ & C_{12} & 5.0 \\ & C_{13} & 7.6 \\ & C_{14} & 8.6 \\ & C_{15} & 9.3 \\ & C_{16} & 5.5 \end{bmatrix} \tag{7}$$

5.2 Determine weight and Relevance Degree

In this paper, AHP is used to calculate the weight coefficient of each index. Because the analytic hierarchy process is simple and widely used, this paper does not introduce the detailed introduction and calculation process. Use SuperDecesions to derive the final weighting factors as shown in Eq8 and Eq.9.

$$\begin{aligned} \omega &= (0.61, 0.27, 0.12) \\ \omega_{B_1} &= (0.14, 0.19, 0.37, 0.17, 0.13) \\ \omega_{B_2} &= (0.14, 0.1, 0.19, 0.04, 0.31, 0.22) \\ \omega_{B_3} &= (0.12, 0.23, 0.31, 0.09, 0.25) \end{aligned} \tag{8}$$

$$\omega_j = (0.085, 0.116, 0.226, 0.104, 0.079, 0.038, 0.027, \\ 0.051, 0.011, 0.084, 0.059, 0.014, 0.028, 0.037, 0.011, 0.03) \quad (9)$$

Combining Eq4 and Eq 5 and the classical domain, node domain Matter-element matrix and the Matter-element matrix to be evaluated, the correlation coefficients between each index and evaluation grade are calculated. The results are shown in Tab.2. The correlation degree is derived from Eq.11.

Tab.2 Relevant Number of Indicators on Evaluation Level

Level / Index	Excellent	Good	Medium	Poor	Very poor
C_1	-0.1	0.1	2.1	4.1	6.1
C_2	-0.5	1.5	3.5	5.5	7.5
C_3	2.6	0.6	-0.6	1.4	3.4
C_4	2.3	0.3	-0.3	1.7	3.7
C_5	1.1	-0.9	0.9	2.9	4.9
C_6	-0.1	0.1	2.1	4.1	6.1
C_7	7.1	5.1	3.1	1.1	-0.9
C_8	7.3	5.3	3.3	1.3	-0.7
C_9	4.3	2.3	0.3	-0.3	1.7
C_{10}	1.1	-0.9	0.9	2.9	4.9
C_{11}	-0.3	0.3	2.3	4.3	6.3
C_{12}	4	2	0	0	2
C_{13}	6.1	4.1	2.1	0.1	-0.1
C_{14}	-0.6	0.6	2.6	4.6	6.6
C_{15}	-0.7	1.3	3.3	5.3	7.3
C_{16}	2.5	0.5	-0.5	1.5	3.5

$$\begin{aligned} S_1(L_0) &= 1-\sum_{i=1}^{16}\omega_j d_{ij} = 0.503 \\ S_2(L_0) &= 1-\sum_{i=1}^{16}\omega_j d_{ij} = 0.797 \\ S_3(L_0) &= 1-\sum_{i=1}^{16}\omega_j d_{ij} = -0.861 \\ S_4(L_0) &= 1-\sum_{i=1}^{16}\omega_j d_{ij} = -2.725 \\ S_5(L_0) &= 1-\sum_{i=1}^{16}\omega_j d_{ij} = -4.617 \end{aligned} \quad (11)$$

It can be seen from the above equation that the comprehensive extension degree of $S_2(L_0)$ is the largest, which is 0.797. Therefore, the coordination level of the supply chain is good, which shows that the supply chain can achieve the overall optimal goal of the supply chain to a certain extent. According to the comparison of the index weights of wind power supply chain nodes, the information flow is the main factor affecting the coordination of wind power supply chain nodes. This shows that the effective coordination of node enterprises in the wind power supply chain needs to strengthen the circulation of information in the supply chain. Improve the breadth and accuracy of information transmission in the supply chain, and expand the sharing of information.

6. Conclusion

Through the Matter-Element Extension model, the wind power supply chain node enterprise collaboration is analyzed. The evaluation results show that the supply chain is well coordinated. The results show that the coordination of node enterprises in the supply chain should focus on information coordination. The supply chain system should establish perfect information transmission mechanism to reduce the bullwhip effect and ensure the authenticity and effectiveness of information transmission. At the same time, the process of information transmission should ensure the breadth of information transmission, grasp the appropriate information sharing degree, and ensure that the upstream enterprises in the supply chain can accurately understand the user market dynamics. Secondly, do a good job of turnover of funds, avoid shortage of funds, increase the delivery rate of goods, and try to reduce the bad debt rate. Finally, improve energy storage technology and warehousing and transportation technology in logistics, reduce wind power abandonment rate and cargo damage rate of wind power and energy storage equipment; coordinate order time and transportation cycle to optimize supply chain flexibility. The synergy of the wind power supply chain can promote the rapid development of the wind power industry. With the increasing attention and input of the global wind power industry, the synergy of the wind power supply chain node enterprises will be newly developed.

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