

Risk Identification and Optimization of Clean Energy Supply Chain under the "Dual Carbon" Goal

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Abstract

The rational development and utilization of renewable clean energy resources such as hydropower, wind energy, and biomass energy is in line with the trajectory of energy development, and plays a major role in establishing a sustainable energy system and promoting national economic development and environmental protection. The race to net zero will redefine global energy security, with secure, resilient and sustainable clean energy supply chains at the heart of the global energy transition. This paper firstly screens and analyzes the risk factors of clean energy supply chain in the context of China's "dual carbon" goals, and preliminarily constructs a risk assessment index system with reference to the SCOR model. The fuzzy comprehensive evaluation method and entropy value method were used to evaluate the impact of risk factors in China's clean energy supply chain, establish a risk assessment model, and then analyze the risk factors of China's clean energy supply chain. Finally, based on the previous research, some suggestions are put forward for the risk management and optimization of China's energy supply chain.

Keywords

Risk Assessment; Clean Energy Supply Chains; Risk Identification; Optimization Mechanism.

1. Introduction

Speaking at the launch of the Energy Technology Outlook 2023, IEA Administrator Fatih Birol said: "The International Energy Agency (IEA) emphasized two years ago that a new global energy economy is rapidly emerging. "The world is in the early stages of a new industrial age – the era of clean energy technology manufacturing. "Clean energy is an important direction for sustainable development in the future, and it is also a "sharp blade" to deal with global climate change and environmental problems. Energy security is becoming increasingly important on the road to net-zero emissions. At a time when countries are stepping up investment in clean energy, with total global clean energy spending surging by 17% to US\$1.8 trillion in 2023, the clean energy market is highly competitive, and ensuring the stable supply of fuel and related key energy commodities at the right price is the most basic energy policy goal of all countries. In addition, the accelerated growth of domestic clean energy consumption demand is crucial to ensuring the safety, green and stability of the clean energy supply chain, and promoting the green and low-carbon transformation of energy is the only way to achieve the "dual carbon" goal.

In the context of economic transformation, new supply chains led by clean energy are gradually emerging. The clean energy supply chain refers to the equipment manufacturing chain involved in the development, transportation, storage and consumption of clean energy. In the era of accelerated energy transition, a country's shaping of the clean energy supply chain has

significant geopolitical implications, and some actions in the industrial category can trigger changes in national power and the international political landscape. Therefore, the development of the global clean energy industry will trigger international competition in the clean energy supply chain, and its situation is undergoing significant changes and becoming the focus of the resource game between major powers[2]

This paper analyzes the types and characteristics of clean energy supply chain, uses SCOR model to identify supply chain risks, and then uses the combination of fuzzy evaluation method and entropy planting method to evaluate supply chain risks, so as to provide a theoretical basis for clean energy supply chain risk management.

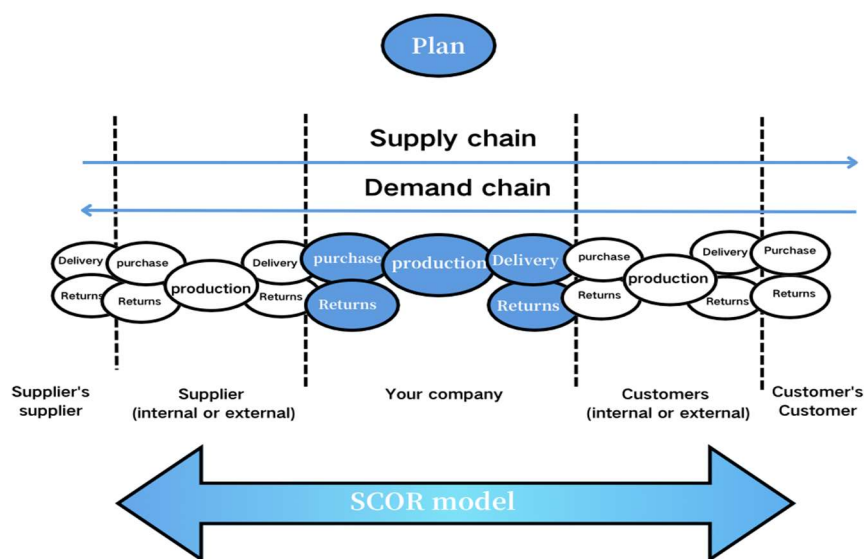


Figure 1. Reference of enterprise supply chain operation model

2. Construction of Risk Assessment Index System

The development of clean energy supply chains is related to a variety of factors and involves a wide range of factors. Therefore, in order to accurately evaluate the level of energy security transition and development in some regions of China, it is necessary to select multiple impact indicators to comprehensively evaluate them[3] With reference to the SCOR system, according to the operation mode of the enterprise, this paper identifies risks from the five basic stages of planning, procurement, production, distribution and return, and establishes these five indicators as the first-level indicators. After that, the determined first-level indicators were further subdivided in different aspects of the same level, and 10 indicators such as the degree of adaptation to supply chain plans and policy changes, the qualified rate of supplier product quality, the amount of production investment funds, and quality inspection standards were determined as the second-level indicators, and finally the risk assessment index system of clean energy supply chain was constructed, as shown in Table 1:

The planning stage is the baton of the middle and back office operations of the supply chain, and its importance is now to create competitive advantages and achieve supply chain performance, and the realization of the five indicators (reliability, responsiveness, agility, cost, and asset management efficiency) given by the SCOR model is closely related to the planning of the supply chain[4]; Procurement plays an important role in the supply chain to control costs and ensure product quality, which is the link between enterprises and suppliers, and is the key to improving the competitiveness of enterprises. The production stage is the core of the clean energy supply chain, and the production process needs to coordinate upstream suppliers and

downstream distributors, and the quality inspection stage is one of the main sources of supply chain risks. The logistics and distribution phase usually includes a series of activities to maintain and manage the entire supply chain, which is of great significance for maintaining the quality of energy products and improving customer satisfaction[5]; The returns phase is critical to the proper functioning of the supply chain and maintaining customer relationships, and can have a significant impact on additional costs.

Table 1. Comprehensive evaluation index system of energy security transition and development level in some regions of China

| Level 1 indicators | Secondary indicators | Risk consequences |
|--|---|---|
| Risk factors during the planning phase U_1 | Supply chain end-user demand accuracy U_{1-1} | Products are overstocked or out of stock |
| | Adaptability of supply chain planning to develop policies U_{1-2} | Sales are blocked |
| Risk factors at the procurement stage U_2 | The reasonableness of the supplier's selection or the accuracy of the assessment U_{2-1} | Raw material procurement issues |
| | Supplier delivery product compliance rate U_{2-2} | The product quality is not up to standard |
| Risk factors in the production phase U_3 | The amount of capital invested in the production line U_{3-1} | Low production efficiency |
| | Implementation of quality inspection standards U_{3-2} | Increase the cost of returns and exchanges |
| Fulfillment stage risk factors U_4 | Rationality of logistics and delivery U_{4-1} | Increase the cost of invalidity |
| | Logistics and transportation security U_{4-2} | Causing economic losses |
| Risk factors at the return stage U_5 | A payment method for the delivery of the order after the deposit has been delivered U_{5-1} | Inventory risk after order cancellation |
| | Returns and exchanges processing efficiency U_{5-2} | Affect the quality of service and after-sales service |

The five stages of planning, procurement, production, distribution, and returns are the core of the clean energy supply chain, and they are also the main sources of risk in the clean energy supply chain.

3. A comprehensive Evaluation Model based on Fuzzy Evaluation Method

3.1. Research Methodology

In this paper, the combination of entropy method and fuzzy evaluation method is used to evaluate the risk of clean energy supply chain. The fuzzy evaluation method has the advantages of considering multiple factors, a wide range of applications, reasonable weight setting, and clear evaluation results, and can deal with fuzzy evaluation objects through accurate numerical means[6] reflecting the relative importance of each index, and making the comprehensive evaluation results more scientific and reasonable. The entropy value method can use the entropy value of each index to obtain a more objective index weight, which avoids the deviation caused by human factors and avoids the influence of subjective factors to a certain extent, so as to achieve the purpose of improving the objectivity and accuracy of the evaluation results.

3.2. Identify Risk Factors

According to the commonly used interval division method, the risk level is divided into five levels: "high, high, medium, low, and low", and the risk assessment set is $V = \{V_1, V_2, V_3, V_4, V_5\}$, the values are assigned: 5, 4, 3, 2, 1. Due to the wide range of clean energy supply chain and the

difficulty of data collection, this paper adopts the statistical method of survey report, collects a large number of experts' assessment data on the risk of clean energy supply chain, and standardizes the data to obtain the risk assessment table of digital retail supply chain, as shown in Table 2:

Table 2. Risk assessment table for clean energy supply chain

| Level 1 indicators | Secondary indicators | high | Higher | medium | Lower | low |
|--|---|-------|--------|--------|-------|-------|
| Risk factors during the planning phase U_1 | Supply chain end-user demand accuracy U_{1-1} | 0.052 | 0.211 | 0.340 | 0.190 | 0.207 |
| | Adaptability of supply chain planning to develop policies U_{1-2} | 0.046 | 0.187 | 0.516 | 0.238 | 0.013 |
| Risk factors at the procurement stage U_2 | The reasonableness of the supplier's selection or the accuracy of the assessment U_{2-1} | 0.117 | 0.109 | 0.471 | 0.271 | 0.032 |
| | Supplier delivery product compliance rate U_{2-2} | 0.010 | 0.270 | 0.260 | 0.270 | 0.190 |
| Risk factors in the production phase U_3 | The amount of capital invested in the production line U_{3-1} | 0.405 | 0.101 | 0.288 | 0.100 | 0.106 |
| | Implementation of quality inspection standards U_{3-2} | 0.299 | 0.203 | 0.200 | 0.198 | 0.100 |
| Fulfillment stage risk factors U_4 | Rationality of logistics and delivery U_{4-1} | 0.020 | 0.096 | 0.417 | 0.217 | 0.250 |
| | Logistics and transportation security U_{4-2} | 0.086 | 0.266 | 0.387 | 0.190 | 0.071 |
| Risk factors at the return stage U_5 | A payment method for the delivery of the order after the deposit has been delivered U_{5-1} | 0.026 | 0.109 | 0.487 | 0.251 | 0.127 |
| | Returns and exchanges processing efficiency U_{5-2} | 0.029 | 0.123 | 0.492 | 0.270 | 0.086 |

3.3. Determine the Membership Matrix of Fuzzy Relationships

According to Table 2, membership matrix $R_i (i=1,2,3,4,5)$ and comprehensive membership matrix R of first-level indicators are obtained:

$$\begin{aligned}
 R_1 &= \begin{pmatrix} 0.052 & 0.211 & 0.340 & 0.190 & 0.207 \\ 0.046 & 0.187 & 0.516 & 0.238 & 0.013 \end{pmatrix} \\
 R_2 &= \begin{pmatrix} 0.117 & 0.109 & 0.471 & 0.271 & 0.032 \\ 0.010 & 0.270 & 0.260 & 0.270 & 0.190 \end{pmatrix} \\
 R_3 &= \begin{pmatrix} 0.405 & 0.101 & 0.288 & 0.100 & 0.106 \\ 0.299 & 0.203 & 0.200 & 0.198 & 0.100 \end{pmatrix} \\
 R_4 &= \begin{pmatrix} 0.020 & 0.096 & 0.417 & 0.217 & 0.250 \\ 0.086 & 0.266 & 0.387 & 0.190 & 0.071 \end{pmatrix} \\
 R_5 &= \begin{pmatrix} 0.026 & 0.109 & 0.487 & 0.251 & 0.127 \\ 0.029 & 0.123 & 0.492 & 0.270 & 0.086 \end{pmatrix} \\
 R &= \begin{pmatrix} 0.049 & 0.199 & 0.428 & 0.214 & 0.110 \\ 0.064 & 0.190 & 0.366 & 0.271 & 0.111 \\ 0.352 & 0.152 & 0.244 & 0.149 & 0.103 \\ 0.053 & 0.181 & 0.402 & 0.204 & 0.161 \\ 0.028 & 0.116 & 0.490 & 0.261 & 0.107 \end{pmatrix}
 \end{aligned}$$

3.4. Determine the Weight Matrix

The steps of the entropy method are as follows:

(1) Construct an initial data matrix: $A = (a_{ij})_{m \times n}$.

(2) Standardize the raw matrix data:

In this paper, to ensure the validity of the index after dimensionless processing, the effective value of 0.0001 is added to the dimensionless result to get the normalized matrix $C = (c_{ij})_{m \times n}$.

Among them:

$$c_{ij} = \frac{a_{ij} - a_j^{min}}{a_j^{max} - a_j^{min}}$$

(3) According to the normalized matrix C, a new eigengravity matrix P_{ij} is calculated. Then calculate the entropy e_j , difference coefficient g_j and entropy weight w_j of each index of digital retail supply chain risk. Among them:

$$p_{ij} = \frac{b_{ij}}{\sum_{i=1}^n b_{ij}}$$

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^n p_{ij} \ln p_{ij}$$

$$g_j = 1 - e_j; w_j = \frac{g_j}{\sum_{j=1}^m e_j}$$

According to the above steps, the weight vectors of each risk indicator are as follows:

A weighted vector of risk during the planning phase $W_1 = (0.423, 0.557)$.

A weighted vector of risk at the procurement stage $W_2 = (0.529, 0.471)$.

A weight vector of risk at the production stage $W_3 = (0.541, 0.459)$.

A weight vector of risk at the fulfillment stage $W_4 = (0.524, 0.476)$.

A weighted vector of risk at the return stage $W_5 = (0.495, 0.505)$.

Vector weights of overall risk factors in the clean energy supply chain. $W = (0.207, 0.202, 0.175, 0.197, 0.219)$.

4. Comprehensively Assess the Risks of the Clean Energy Supply Chain

4.1. Calculate the Comprehensive Evaluation Value of the First-level Indicators

According to fuzzy comprehensive evaluation formulas $B_i = W_i \cdot R_i = (b_1, b_2, b_3, b_4)$, $i = 1, 2, 3, 4, 5$ to calculate comprehensive evaluation index of each class value $B_i (i = 1, 2, 3, 4, 5)$, including:

$$B_1 = W_1 \cdot R_1 = (0.049 \ 0.197 \ 0.442 \ 0.218 \ 0.095)$$

$$B_2 = W_2 \cdot R_2 = (0.067 \ 0.185 \ 0.372 \ 0.271 \ 0.106)$$

$$B_3 = W_3 \cdot R_3 = (0.332 \ 0.145 \ 0.237 \ 0.145 \ 0.095)$$

$$B_4 = W_4 \cdot R_4 = (0.051 \ 0.177 \ 0.403 \ 0.204 \ 0.165)$$

$$B_5 = W_5 \cdot R_5 = (0.028 \ 0.116 \ 0.490 \ 0.261 \ 0.106)$$

4.2. Calculate the Evaluation Value of the First-level Risk Index

Based on indicators of risk evaluation formula $F_i = B_i \cdot V = B_i \cdot \begin{pmatrix} 5 \\ 4 \\ 3 \\ 2 \\ 1 \end{pmatrix}$ ($i = 1,2,3,4,5$), is

calculated for each level of risk index value F_i ($i = 1,2,3,4,5$), one of them:

$$F_1 = B_1 \cdot V = 2.886;$$

$$F_2 = B_2 \cdot V = 2.835;$$

$$F_3 = B_3 \cdot V = 3.334;$$

$$F_4 = B_4 \cdot V = 2.746;$$

$$F_5 = B_5 \cdot V = 2.689;$$

Based on the above results, it can be obtained:

$$F_3 \text{ Production Risk} > F_1 \text{ Planning Risk} > F_2 \text{ Procurement Risk} > F_4 \text{ Distribution Risk} > F_5 \text{ Return Risk}$$

4.3. Calculate the Comprehensive Risk Evaluation Value

Comprehensively assess clean energy supply chain risks. According to the formula, $B = W \cdot R$. The comprehensive risk assessment value of clean energy supply chain is calculated:

$$B = (0.207, 0.202, 0.175, 0.197, 0.219) \cdot R = (0.101, 0.167, 0.392, 0.222, 0.118)$$

According to the above calculation results, the membership degree of digital retail supply chain risk is 10.1% for high risk (V1). The affiliation for those with higher risk (V2) was 16.7%. The affiliation for medium risk (V3) was 39.2%. The affiliation for low risk (V4) was 22.2%. The affiliation for Very Low Risk (V5) is 11.8%. Confidence was selected for this study. $\lambda = 0.75$. According to the principle of maximum membership, since the lower the risk of the clean energy supply chain, the better, so start with a very low risk to look at the confidence: V5 has a confidence level of $0.118 < 0.75$, this is not advisable. The confidence level of V4 is, $0.118 + 0.222 = 0.340 < 0.75$, this is not advisable. The confidence level of V3 is, $0.118 + 0.222 + 0.392 = 0.732 < 0.75$, this is not advisable; V2 has a confidence level of, $0.118 + 0.222 + 0.392 + 0.167 = 0.899 > 0.75$, the confidence level is very high. Finally, the risk level of the clean energy supply chain is determined to be "high" and enter a "high-risk state", and the risks need to be identified and optimized as soon as possible.

5. Conclusion and Suggestions

This paper analyzes the types and characteristics of clean energy supply chains through research and investigation and the actual situation of clean energy supply chains. Firstly, the SCOR model is used to identify the risks of the clean energy supply chain, and the risk assessment index system of the clean energy supply chain is constructed from the five stages of planning, procurement, production, distribution and return, and then the risk is evaluated by combining the fuzzy comprehensive evaluation method and the entropy planting method. The final assessment results show that the risk of clean energy supply chain is affected by multiple indicators such as the accuracy of supply chain end-user demand, the reasonableness of supplier selection or the accuracy of evaluation of cooperation risk, and the amount of capital invested in the production line, and the risk in the production stage > the risk in the planning stage > the risk in the procurement stage > the risk in the distribution stage > the risk in the

return stage. At the same time, according to the principle of maximum membership, the risk of the digital retail supply chain is comprehensively evaluated, and it is found that the risk level of the digital retail supply chain is "high" and has entered a "crisis state", and the risks need to be identified and optimized in a timely manner.[7]

Under the "dual carbon" goal, promoting the development and utilization of clean energy and accelerating the green and low-carbon transformation of energy have become the needs of the times, and the development of clean energy has also become a common choice for all countries. Promoting energy transition, building a clean, low-carbon, safe and efficient energy system, and achieving green development are the goals of the energy industry in China and the world, and strive to inject new momentum into the global clean energy industry chain and supply chain. Based on the above risk assessment results, this paper puts forward the following suggestions for the risk control of China's clean energy supply chain:

(1) Optimize the production process and ensure product quality. The stability and predictability of the policy are crucial to attract investment and promote the development of the industry, so it is necessary to reasonably determine the production plan and production target in accordance with the policy development to avoid the gap between supply and demand. Secondly, in the procurement stage, it is necessary to ensure the quality of raw materials, establish a stable cooperative relationship, strengthen the control and management of the production process, and improve product quality and production efficiency; Finally, it is necessary to establish a product quality data analysis and improvement mechanism to continuously optimize the production process and ensure product quality.

(2) Diversify your supply chain. The energy industry is the cornerstone of global economic development, which is of great significance to national energy security and economic development, and the energy industry market is diversified. There is a competition and substitution relationship between different energy sources, and the market supply and demand are unstable, so it is necessary to strengthen the bond with the leading enterprises in the overseas supply chain, carefully select suppliers, do market research in advance, ensure the quality of raw materials, promote the diversification of the industrial supply chain, strengthen cooperation, and improve the ability to resist risks, so as to help achieve the "double carbon" goal.

(3) Innovate clean energy technologies. Scientific and technological innovation is the key to promoting the progress and development of clean energy technology, and science and technology are also the key to improving competitiveness. At present, the world's energy technology innovation has entered an active period, and countries have seized the opportunity of energy progress to seek a new round of scientific and technological revolution and industrial transformation. The commanding heights of competition. On the one hand, energy science and technology innovation needs to be led by the country's innovation mechanism, and on the other hand, it is necessary to give full play to the role of enterprises as the main body of innovation. Carry out technology research and development in the field of clean energy, promote the recycling and utilization of clean energy products, make full use of resources, protect the environment, make use of the advantages of China's natural energy, market, and talent reserves, increase investment in technology research and development in the field of clean energy, and enhance the core competitiveness of China's clean energy field, so that China's clean energy science and technology innovation ability will change from "following" to "running", and finally to "leading".

(4) Strengthen the risk awareness of member companies. The supply chain involves many external companies, including suppliers and customer companies, in the process of procurement, production and sales. Therefore, the clean energy supply chain is a serial or parallel hybrid network structure formed by the participation of multiple member enterprises, which also means that the operation and status of the member enterprises in the supply chain

will directly affect the operation between member enterprises. Therefore, it is necessary to establish an information exchange mechanism, a joint meeting mechanism, and a collaborative operation mechanism to better avoid risks. In addition, it is essential to have a dedicated body responsible for supervising and managing suppliers, as well as dealing with various disputes with suppliers. At the same time, companies with the same supplier can work together to share information to identify problems in a timely manner, which can also greatly reduce the risk of supply chain disruptions.

(5) Establish an emergency early warning system. The supply chain is a complex system with multiple links and channels, and some emergencies are prone to occur. Therefore, it is necessary to establish a corresponding early warning system and emergency response system, and if the risk is uncontrollable, it is necessary to take emergency action in time. It depends on the state of the bundle of interests of the supply chain partners, and whether it is a dependent cooperative relationship is the basis for solving this problem. In the reality of continuous business risks, it is the common mission of the entire supply chain to continuously explore feasible risk control methods.

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