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Review of Research on the Evaluation of Critical Mineral Supply Chain Resilience

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Abstract: Critical minerals are vital to national economic development and indispensable to strategic emerging industries. In the upstream of these strategic industries, critical minerals supply chain are at risk of supply interruption, which affects the supply security of these crucial industries. How to evaluate and improve the resilience of the critical mineral supply chain has become an urgent problem to be solved. This paper combs through the relevant research on the resilience of critical mineral supply chain. It divides the research into two major categories: evaluation of supply chain resilience and critical mineral supply chain, forming a literature review. The research results of relevant scholars are elaborated on respectively. Further summaries of critical mineral supply chain resilience and future research direction are put forward.

Keywords: Critical Mineral Supply Chain, Resilience Evaluation, Power Battery Industry, Literature Review.

1. Introduction

Since the 21st century, with the rapid development of strategic emerging industries such as information technology, artificial intelligence, and renewable energy, the connotation of critical minerals has been continuously extended and closely linked with the industrial chain, demonstrating its important position in intensified global industrial competition and security significance. Currently, sudden public events break out frequently, like COVID-19 pandemic, Red Sea Shipping Crisis, and terrorist attacks, which cause critical mineral supply chain disruption and even break down. Besides, trade protectionism, resource nationalism, geopolitics, and regional conflicts also block the critical mineral supply chain, especially its upstream raw mineral part. Now, critical mineral supply chain is facing practical problems such as insufficient self-sufficiency, high dependence on foreign countries, and weak innovation accumulation. The supply chain is facing a series of issues and its resilience is under pressure. So it is crucial to improve the resilience of the supply chain to resist the risk of supply interruption or blockade.

In recent years, supply chain resilience and critical mineral security have aroused the concern of scholars at home and abroad. “Supply chain resilience evaluation” “Supply chain resilience influencing factors” “Supply chain resilience definition” “Critical mineral security strategy” and so on become hot issues explored by scholars. Based on this background, the paper combs the current research on critical mineral supply chain resilience, summarizing the main research directions and problems of current scholars. On this basis, it further puts forward the future research directions, providing certain theoretical references for subsequent research.

2. Evaluation of Supply Chain Resilience

2.1. Supply Chain Resilience Definition

Resilience, also known as flexibility, is an academic concept that originated in the field of engineering and was introduced in the fields of ecology, sociology and management, such as “evolutionary resilience” in the ecological field, “urban social resilience” in the sociological field and “supply chain resilience” in the management field. After the outbreak of COVID-19 epidemic, supply chain resilience has gradually become a hot topic in the field of supply chain management. But there is still no clear and unified statement on the definition of “supply chain resilience”.

The concept of “supply chain resilience” was first put forward by Christopher and Peck [1] in 2004. They identified supply chain resilience as “the ability of the supply chain to recover to its original state or more ideal state after being disturbed”. At present, scholars have not reached an agreement on the definition of supply chain resilience. Some of them define supply chain resilience from the perspective of supply chain discontinuity [2-3], and some scholars explain supply chain resilience from the perspective of system dynamics [4]. From the perspective of discontinuity, there is three stages, which are “before the interruption” “at the time of interruption” and “after the interruption”, in the first stage, Masoud and Mahour [5] selected the expected capacity into the supply chain resilience, and defined the expected capacity as “the positive thoughts and plans of the enterprise's supply chain resilience before the interruption disaster”. At the time of interruption, Liu et al [2] defined supply chain resilience as the ability to maintain and stabilize the original function in supply chain when interruption occurs. After the interruption, Sheffi and Rice [3] defined supply chain resilience as the ability of enterprises to absorb the interruption or make the supply chain network return to the original state more quickly, thus having a positive impact on enterprise performance. From the perspective of system dynamics, scholars such as Sheng et al [4] emphasized that the research on supply chain resilience should not be limited to “discontinuity” and “continuity”. They defined supply chain resilience as the ability of the whole behavior and function of the supply chain system to adapt to changes in environmental complexity, and called for an in-depth study of supply chain resilience under specific situations to dig its uniqueness.

2.2. Supply Chain Resilience Evaluation

Current research on supply chain resilience evaluation has two major directions: the construction of evaluation indicators and the selection of evaluation methods.

In terms of "the construction of evaluation indicators," internal and external scholars mainly adopt qualitative and quantitative methods to screen evaluation indexes, among which qualitative methods include literature analysis, expert interview and field investigation, and quantitative methods include questionnaire survey and coefficient of variation. Xu and Yu [6] used the literature analysis method to select 13 secondary indicators, such as information sharing degree and cold chain network efficiency, then constructed an index system for evaluating the resilience of cold chain logistics supply chain. Ma et al [7] invited 15 experts to screen and identify the resilience index of prefabricated building supply chain by questionnaire survey.

In terms of "selection of evaluation methods", from the source of weighting data, it can be roughly divided into subjective weighting method and objective weighting method. The former mainly relies on subjective experience to score weights, while the latter is mainly based on objective data. In the field of supply chain resilience, most scholars select AHP and ANP, two different subjective weighting methods, to determine the weight of evaluation index system, among which ANP is widely used in the field. Wang et al [8] pay attention to the assessment of green building supply chain resilience and choose ANP to determine the weights of 19 secondary indicators. In addition, some scholars use objective weighting methods such as entropy weight method, CRITIC weight method, principal component method, and factor analysis method to complete the weighting, among which entropy weight method is more common in the field. Jin et al [9] used E entropy weight method and TOWA operator to weigh the evaluation system and time level with 12 indicators twice to complete the evaluation of agricultural supply chain resilience.

3. Critical Mineral Supply Chain

By combing the related literature in recent five years, it is found that representative pieces of literature pay more attention to the field of "security of critical mineral supply chain". We expand this research perspective to three aspects: the definition of critical mineral supply chain, supply chain risk assessment, and supply chain resilience assessment.

3.1. Critical Mineral Supply Chain Definition

The definition of critical mineral supply chain has not yet reached a consensus. Some scholars define it from the perspective of supply chain links [10-11], and some scholars explain the concept from the perspective of supply chain [12]. Li et al [12] believe that critical mineral supply chain covers all the activities involved in the process from mining to the final formation of consumer goods, and it is also a logistics chain, information chain, capital chain, and value chain. Wang and Yuan [10] proposed that the critical mineral supply chain includes prospecting, exploration, mining, mineral processing, smelting, processing, material research and development, product manufacturing, and resource recovery; Wang and Wan [11] divided the critical mineral supply chain into resource collecting, resource processing and refining, and advanced material manufacturing.

3.2. Critical Mineral Supply Chain Risk Assessment

According to the literature in recent years, it is found that "Import Dependence" has been widely discussed by scholars and has become an important factor affecting the risk of critical mineral supply chain. Cheng et al [12] evaluated the supply risk of copper resources in China from 2008 to 2021. The calculation results show that import dependence has the greatest impact on the supply risk of copper resources. Song and Wang [13] said that the shortage of minerals in China's critical mineral supply chain is highly dependent on foreign countries, and the risk of obtaining overseas resources may continue to increase. Liu [14] believes that the serious dependence on imports has brought uncertain risks to the critical mineral supply chain. In addition to "Import Dependence," many scholars put forward the influence factor of "Price" [15-16]. Sun et al [15] focused on the factors affecting the sustainable supply of critical minerals, and believed that price was the main factor affecting the sustainability of the global supply of critical mineral resources; Yin et al [16] pointed out that the critical mineral supply chain in China is facing the risk of increasing price fluctuation. Besides, the level of economic development, reserves, demand, and output will also affect the sustainability of critical mineral resources supply, and multiple factors such as technical cooperation, geopolitics, labor rights, and interests and a single mineral transportation channel also bring many uncertain risks to the critical mineral supply chain.

3.3. Critical Mineral Supply Chain Resilience Assessment

By combing the relevant literature in recent years, it is found that most scholars focus on a certain critical mineral, such as rare earth, copper, nickel, cobalt, and lithium, and explore its supply chain resilience, supply chain network resilience, and industrial chain supply chain resilience. In the discussion of the resilience of the rare earth supply chain, Mancheri et al [17] take the resilience of rare earth supply chain as the research object, and demonstrate the influence of China's REE policy on the resilience of rare earth supply chain for the first time from the perspective of policy. Sprecher et al [18] also focused on rare earth supply chain and studied the role of resistance, rapidity, and flexibility in the resilience mechanism of the supply chain from the perspective of capability. In the discussion of the resilience of the lithium supply chain, Shao and Jin [19] studied the lithium supply chain and used the method of system dynamic modeling to evaluate the network resilience of the lithium supply chain under short-term supply interruption risk and long-term supply interruption risk. Jin et al [20] used the attack model to evaluate the resilience of China's lithium supply chain network.

It is found that scholars mostly establish evaluation indicators from the perspective of supply chain capacity, like flexibility, robustness, and adaptability. Zhou et al [21] takes the agility, robustness, and dependence of the supply chain as evaluation dimensions, and puts forward evaluation indicators such as response time, response speed, and network fragmentation; Wu et al [22] divided 13 secondary indicators such as risk management, reserve scale, and industrial technology level according to reserve capacity, absorption capacity, and adaptability. Wu et al [23] divided 21 secondary indicators such as international crude oil price, production cost, flexible production capacity, and technical personnel according to absorption capacity, adaptability, recovery capacity, and self-learning ability.

4. Conclusion

In this paper, from the perspective of evaluation of supply chain resilience and critical mineral supply chain, the current scholars have sorted out part of the research on the evaluation of critical mineral supply chain resilience, formed a literature review, and obtained the following conclusions and insights through the research sorting.

By combining the existing research, there are fruitful research results in the evaluation of supply chain resilience and the related research of mineral resources security. First, the discussion on the definition of supply chain resilience is increasing. Defining supply chain resilience from the perspective of "Supply chain interruption or not" has become mainstream in the field. However, there is a trend to define supply chain resilience from the perspective of "interruption or not" to the perspective of "system dynamics". Actually, the critical mineral supply chain is easily influenced by social environment and natural environment factors, such as big country games, geopolitics, environmental pollution, and so on. So, in future research, it is possible to discuss more resilience based on "system dynamics" perspective. Second, the methods involved in the assessment of supply chain resilience are diverse and mature, forming two steps, construction of evaluation indicators and selection of evaluation methods. In terms of "the construction of evaluation indicators," internal and external scholars mainly adopt qualitative and quantitative methods to screen evaluation indexes. In terms of "selection of evaluation methods," from the source of weighting data, it can be roughly divided into subjective weighting method and objective weighting method. Third, there are many high-quality research results on the risk or resilience evaluation of single strategic mineral resources supply chain, such as copper, lithium, nickel, and rare earth, which provide an important reference for screening the resilience indicators of critical mineral supply chains in China.

However, from the above research, it can be found that in the current research related to critical mineral supply chain, scholars mostly focus on single strategic mineral resources and their supply resilience or risk problems. The discussion of critical mineral supply chain is single, and the critical mineral supply chain resilience in specific industrial situation is not taken into account. In fact, new energy, new materials, and electronic information technology industries are developing rapidly. These industries need not only one key mineral but also a combination of three or more minerals to provide raw materials for the operation and production for these industries and their factories. Besides, the downstream of critical mineral supply chain involves many industries, including the power battery industry, chip industry, new material industry, new energy automobile industry, new generation information technology industry, aerospace equipment industry, and so on, it is difficult to distinguish the different changes of supply chain and its resilience under the influence of different industries by only paying attention to one critical mineral supply chain and ignoring its industrial background. Therefore, in future research, it is not only necessary to continue digging out and evaluating single critical mineral supply chain resilience, but also to classify the industry in the market, and further take into account the industry characteristics, to obtain more scientific conclusions and provide more effective guidance for the actual and comprehensive critical mineral supply chain resilience evaluation.

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