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Adopting an objective approach to criticality assessment: Learning from the past

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ABSTRACT

Criticality assessment has been widely used in considering resource securement strategies. However, the selection and aggregation of the various risk factors remain a major challenge because these largely depend on subjective judgment by the evaluator. Therefore, it is necessary to introduce an objective perspective, which would develop criticality assessment as a more practical decision-making tool in combination with past subjective approaches. As a first attempt at an objective approach, this study conducted a case-based analysis of 448 supply disruption events for 22 metals. The results indicate 19 categories of causation of disruption, in which accidents, strikes, a fall in metal prices, natural disasters, and policy disputes are dominant. The analyses also reveal the differences in influential risk component between metals and supplier countries. For example, a fall in the metal price has more impact on developed supplier countries than developing countries. The knowledge gained from this case-based approach is useful in highlighting the risk components that have been overlooked in past assessments, in quantifying the integrated risk considering the relative importance of risk components, and in exploring strategies for criticality mitigation.

1. Introduction

Resource securement is considered a high-priority issue for most governments and companies. Over the past decades, there has been much discussion concerning the depletion of underground mineral resources due to their finiteness and nonrenewable properties. Ecologists and environmental scientists have emphasized the conservation of mineral resources to avoid resource exhaustion; such opinions have been strongly influenced by the classic work *The Limits to Growth* (Meadows et al., 1972). At the same time, economists consider that what will happen in the future is not a physical depletion but an economic one, because a shortage of resources will be controlled by autonomous price changes based on the supply and demand principle (Tilton, 2002).

Besides long-term depletion stress, in recent decades, resource securement has often been threatened by sudden supply disruptions that lead to limited access to resources and price hikes, as witnessed in the case of cobalt due to conflict in Democratic Republic of the Congo (former Zaire), indium because of the rapid growth in demand for flat-panel displays, and rare-earth elements (REEs) resulting from China's market control including export restrictions. To mitigate the damage caused by serious supply disruptions, a criticality assessment has been developed to evaluate the risks behind the supply of mineral resources quantitatively. Following the publication of pioneering work by the National Research Council (2008) and the European Commission (2010), a number of studies and reviews were reported by governmental institutes, academic researchers, and private companies (Blengini et al., 2017; Duclos et al., 2010; Graedel et al., 2015; Hatayama and Tahara, 2015; Jin et al., 2016; Sonnemann et al., 2015).

Based on these analyses, it is now widely acknowledged that the criticality of minerals is determined by two criticality aspects: supply risk and vulnerability to supply restriction. Furthermore, each of the aspect comprises several components. Supply risk looks at technical, economic, regulatory, and political aspects (Achzet and Helbig, 2013; Dewulf et al., 2016). Vulnerability considers the economic impact of supply restriction (usually represented by gross domestic product), substitutability, and strategic importance for assessment targets (Helbig et al., 2016a). Thus, analyses propose a dozen likely risk components that may function as a warning of supply disruption. However, substantial guidelines for the choice of those components have not yet been established to date because there is little evidence to judge which components are to be employed and which are irrelevant. Furthermore, once risk components used in the assessment are selected, the individual components within the supply risk and vulnerability must be relatively weighted. It is clear that a representation of the

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comprehensive risk with fewer indicators would be more helpful for decision-makers to understand and utilize the results of criticality assessments. Indeed, a two-dimensional criticality matrix represented by supply risk and vulnerability prevails because of its graphic simplicity. Even for the simple matrix, however, a measure to identify critical materials from matrix needs further discussion (Glöser et al., 2015; Frenzel et al., 2017). Some studies such as NEDO (2009) and Graedel et al. (2012) have proposed a single index, which would be the most suitable form in which to prioritize minerals that are to be secured. However, these integrated indices are not cogent and could mislead recognition of resource risks if the degree of influence of each component is not evaluated. Therefore, most studies have avoided comparing the relative strength of different properties of risk components by employing equal-weighting integration.

Many criticality assessment studies reported in recent years have developed diverse methodologies under the basic concept of criticality. In other words, there is limited consensus concerning the method of calculating the degree of criticality. Therefore, traditional criticality assessments are rather subjective, depending on the evaluator's thinking about the respective risks. In such subjective assessment, the methodologies that include a variety of parameter settings could be adjusted (or distorted) so that the results implicate a widely recognized crisis. Such an assessment may indeed be a pragmatic one that is likely to be preferred by decision-makers. However, at the same time, it may fail to detect the potential risk that could cause unexpected hardship. To avoid this scenario, existing subjective assessments need to be supported by knowledge about criticality issues. Thus, the question is: How do we obtain and accumulate knowledge? The first and most reliable method is to analyze past events with respect to criticality issues and their backgrounds. For many well-known events such as those mentioned above, much of the analysis and discussion has been presented via academic publications and various media. However, the subject of supply disruption events has been given little attention to date. Therefore, this study introduces an objective approach to criticality assessment through a case-based analysis.

2. Structure and approach toward a multicriteria decision-making process

Criticality assessments generally comprise a hierarchy structure as shown in Fig. 1. The assessment results are often represented by a two-dimensional matrix of supply risk and vulnerability, although some studies manage to aggregate them to represent a degree of criticality with a single index. As noted, further development is needed for a criticality assessment to consider which risk factors should be included and how to integrate them by means of appropriate weighting. These are not specific problems for a criticality assessment, but a common challenge for multicriteria decision-making processes in various situations. One common approach to this type of problem is to use an analytic hierarchy process (AHP), which was originally developed in the 1970s and has been applied to many case studies (Vaidya and Kumar, 2006). AHP determines the weighting between model components based on pairwise comparisons represented by a large number of experts and stakeholders. Although AHP is an integration of many subjective weightings, the results reflect diverse values, and its calculation process can be explained in mathematical means. Therefore, AHP constructs a model that would be more convincing to decision-makers than the criticality assessment so far. A small number of criticality assessment studies have adopted an objective perspective. Helbig et al. (2016b, 2018) uses AHP to determine the relative importance between supply risk components. Another theoretical approach is seen in the study by Gleich et al. (2013), which determines the weighting factors for criticality components with a regression analysis of metal prices.

Although subjectivity cannot be entirely excluded from the multicriteria decision-making process, objective approaches have been explored in other fields such as life cycle assessment (LCA). The purpose of LCA is to enhance the diffusion of environmentally friendly products and services toward a sustainable society, by evaluating the environmental performance of products, technologies, and services based on a life cycle perspective. Performance is quantified by considering multiple environmental problems, such as greenhouse gas emissions, mineral resource depletion, and biodiversity. Since different product options often involve trade-offs between these environmental impact categories, multicriteria decisions are required to adopt a more environmentally friendly product. To solve this problem, LCA often uses AHP with a comprehensive questionnaire to stakeholders to weight the different impact categories. Furthermore, the degree of each impact is quantified by the analyses using statistics or observed data, as well as scientific models (Huijbregts et al., 2017; Itsubo and Inaba, 2010).

LCA methodology development shows that a multicriteria decision-making process that is supported by objective approaches becomes more convincing and therefore more widely accepted. In the same way, introducing an objective perspective to criticality assessment would become a trigger of methodology development (Fig. 2). However, criticality assessment has not paid much attention to objective approaches because the underlying methodology development is relatively new. The present study is the first to address this issue by analyzing past disruption events and observing the nature of their criticality.

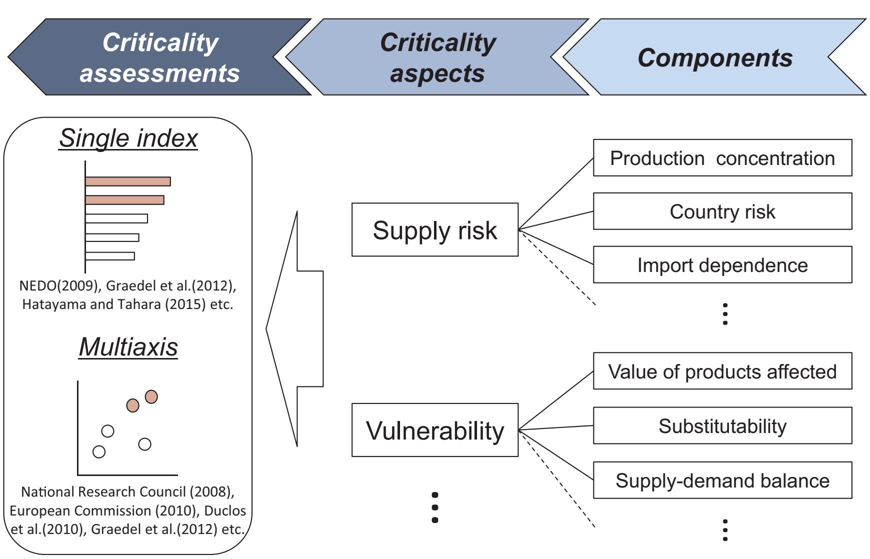

Fig. 1. Typical hierarchy structure of criticality assessment. The figure and explanation for a multi-step criticality assessment process are also illustrated in Achzet and Helbig (2013).