Western Australian Critical Minerals Research Priority Scheme

K K C Sineth Kannangara

Yanrui Wu
Business School
University of Western Australia

David Trotter
CEED Client: Minerals Research Institute of Western Australia

Abstract

Critical minerals are assuming an increasingly significant role within various industrial sectors, including but not limited to renewable energy, defense, and aerospace applications. Nations heavily invested in mineral-related industries are allocating substantial financial resources to bolster the critical mineral sector, while concurrently trying to broaden the spectrum of critical mineral applications. Existing literature discourse concerted efforts to devise methodological frameworks tailored towards the systematic assessment of mineral criticality. This entails the incorporation of multifaceted criteria such as supply risk, economic value, and disruption vulnerability etc. Western Australia, renowned for holding the largest reserves of battery and critical minerals globally, is committed to meet the escalating global demand for these invaluable resources. In light of this, the present study undertakes a comprehensive review of prominent methodologies utilized in evaluating the criticality of selected minerals within the jurisdiction of application. Thus, this research endeavors to furnish both researchers and policymakers with valuable insights into the pivotal role of minerals, thereby facilitating informed decision-making and research planning initiatives.

1. Introduction

Critical minerals play an increasingly pivotal role across diverse industries such as renewable energy, defence, telecommunications, medicine, and aerospace applications. Countries engaging mineral-related industries, including the USA, China, and the European Union, are investing billions in the critical mineral sector, particularly with a heightened focus on promoting the green energy transition. Concurrently, respective industry players are proactively working towards establishing secure supply chains and diversifying the applications of critical minerals. Western Australia, endowed with the world's largest deposits of battery and critical minerals, is committed to meeting the growing global demand for these resources. Despite having already established a multi-billion-dollar industry centred around various minerals, including lithium, nickel, and rare earth elements in Australia, the focus is now directed towards research and development, prioritizing investment, and fostering high-value-added businesses in critical minerals, all while achieving environmental sustainability.

Researchers and different government agencies have attempted to formulate methodologies aimed at the systematic ranking of minerals based on their criticality. For this purpose, the concept of a mineral's criticality is explained by incorporating a range of criteria including supply risk, economic value, disruption vulnerability, and environmental implications.

Western Australia emerges as a pivotal player, being a primary supplier of critical minerals within the Australian landscape. The economic importance of the mineral sector for Western Australia's future underscores the need to recognize priority minerals and essential areas for research. This imperative goes beyond just the current landscape, it is about both what is happening right now and future scenarios. Despite its strategic importance, Western Australia has yet to attempt an official initiative to compile a state-specific list of critical minerals. This study focusses on developing a customised methodology for ranking minerals in the Western Australian context. To meet this requirement effectively, existing mineral ranking methodologies are assessed as a preliminary step. The project aims to discern which minerals should be prioritized for Western Australian research and explores the variations in outcomes resulting from different methodologies already adopted. This analysis is useful for both researchers and planners, aiding in the understanding of the importance of minerals and facilitating strategic planning. Further, it establishes the groundwork for developing a comprehensive and customized methodology for ranking those minerals that need support now and in the future.

2. Process

2.1 Mineral Ranking Criteria

The methodologies employed for ranking critical minerals can differ, and need to be tailored to the unique characteristics and strategic priorities of each economy. Importantly, by referring to such criteria, researchers could gain an in-depth understanding of a mineral's criticality, enabling them to formulate strategies for research priorities. In this analysis five key methodologies, including, the USA Methodology, the EU Methodology , the UK Methodology, the Criticality Space, the Criticality System of Minerals, were considered for ranking critical minerals.

In the USA, the method developed by Nassar et al. (2020) detailed in the "2021 Review and Revision of the U.S. Critical Minerals List". The method provides a quantitative assessment of supply risk, based on disruption potential, trade exposure, and economic vulnerability. It systematically evaluates the dependence of the U.S. critical mineral sector on foreign sources, geopolitical risks, and the economic significance of critical minerals (USGS, 2021). The EU's methodology, outlined in "Critical Raw Materials in Technologies and Sectors in the EU - A Foresight Study", Bobba et al. (2020). This comprehensive indicator-based system canters on the assessment of two key determinants: economic importance and supply risk. The "Risk List 2015", released by the British Geological Survey (BGS, 2015), serves as a compilation of minerals deemed critical to the UK economy. The methodology considers the vulnerabilities in the supply chain due to globally concentrated production and limited reserve distribution. It also reflects potential disruptions in the supply chain, by factors such as geopolitics, resource nationalism, and infrastructure availability. The analysis incorporates six key criteria, namely: “production concentration, reserve distribution, recycling rate, substitutability, governance of top producing and top reserve-holding countries, and companion metal fraction”. The analysis employs the A-C-E approach: **A**ccelerate the UK’s domestic capabilities, **C**ollaborate with international partners and **E**nhance international markets. It evaluates criticality based on two primary indicators: global supply risk and the economic vulnerability of the UK.

Graedel et al. (2012, 2015) introduce a three-dimensional "Criticality Space" framework for assessing the criticality of minerals. It is also an indicator-based methodology, which combines three dimensions: supply risk, vulnerability to a supply disruption, and environmental implications. Each indicator is referred to several sub-indicators, and each sub-indicator contributes uniquely to the overall evaluation. Yuan et al. (2019) propose an agent-based system, “the criticality systems of minerals”, as static-indicator-based methodologies face limitations in capturing time-dependent changes and lack statistical validation for relationships between indicators and industry dynamics. This innovative method offers a comprehensive perspective on mineral criticality by considering the interactions among four key agents: mineral suppliers, consumers, market regulators, and additional stakeholders such as communities near mining operations.

3. Results and Discussion

This section presents the establishment of a basic criteria for ranking minerals. This exercise is undertaken with the intention of demonstrating that the research requirements for minerals can vary significantly depending on the chosen criteria for ranking. This can be developed into a comprehensive methodology in ranking minerals in the future.

3.1 Developing a mineral ranking criterion

We establish this criterion drawing insights from both the UK methodology and the framework proposed by Graedel et al. (2015), focussing on the following key parameters;

- **Economic Importance:** A mineral that significantly augments revenue for the Western Australian economy has heightened economic importance. Consequently, research actions are necessary to enhance the economic benefits associated with the extraction, utilization, and cost-effectiveness of the resource.
- **Trade Exposure:** A mineral with increased trade exposure, measured by Western Australia’s global market share for each mineral, is supposed to deliver greater benefits to Western Australia. Research efforts should be directed towards bolstering trade competitiveness, product diversification, and similar factors to enhance the advantages associated with each mineral's market presence.
- **Disruption Potential:** A mineral with higher disruption potential (when production is concentrated within a few countries) is considered as, bringing higher benefits to WA, if disrupted by others. It is measured as the supply of each mineral by the leading three countries, excluding Australia. In this scenario, research is required in supply chain optimization, product diversification, etc.
- **Recyclability:** A mineral exhibiting enhanced recyclability, measure by the end-of-life recycling rate, holds greater potential for delivering increased benefits to Western Australia. To leverage this advantage, research is essential, particularly in the areas of recycling technologies and processes, understanding market demand for recycled minerals, and establishing quality and purity standards
- **Environmental Impact:** A mineral with a low toxicity and a low energy intensity will stand out as bringing higher benefits to WA. Research is required for toxicity assessment and mitigation, energy efficiency in extraction and processing, regulatory compliance and certification, supply chain sustainability, etc.

3.2 Findings

The results for selected minerals are presented in Table 1. The observed trends in mineral characteristics reveal distinct patterns. The highest overall score is achieved by Nickel followed by rare earth elements. For each criteria, the ranking is as follows. Lithium and nickel emerge as minerals with high economic importance. Moreover, lithium and rare earth elements exhibit the highest trade exposure, highlighting their substantial impact on international trade. The potential for supply disruptions is notably elevated for cobalt, platinum group elements, rare earth elements, graphite, magnesium, and vanadium. Magnesium and copper stand out for their high substitutability, followed by alumina. On the other hand, recyclability is most pronounced for nickel and cobalt, indicating the potential for sustainable practices in their usage and extraction. Considering environmental impacts, graphite and copper lead with the highest positive score. This signals the environmental friendliness of these minerals, which aligns with growing global concerns about sustainable resource utilization

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The insights derived from the economic importance analysis, as illustrated in Figure 1, offer valuable information for research planning. To optimise economic benefits and enhance cost-effectiveness, research initiatives are essential and can be organised into three distinct clusters: economically embryonic, economically developing, and economically sustainable. Emphasising extensive research within the economically developing cluster is paramount, given its potential for growth and economic impact. This sequential approach is designed to facilitate the progression of minerals from the economically developing cluster to the economically sustainable cluster, and from the economically embryonic cluster to the economically developing cluster in the future.

The insights derived from the environmental impact analysis, presented in Figure 2, provide valuable guidance for research planning with a focus on optimizing environmental benefits and transitioning towards a zero-emission future, while reducing carbon footprints and minimizing water, land and air pollution. Research initiatives are crucial and can be strategically organized into three distinct clusters: environmentally at risk, environmental impact manageable, and environmentally sustainable. Prioritizing extensive research within the environmentally at-risk cluster is imperative, given its potential for achieving greater environmental sustainability. Subsequent efforts should be dedicated to the environmental impact manageable and environmentally sustainable clusters. This approach aims to facilitate the progression of minerals from the environmentally impact manageable cluster to the environmentally sustainable cluster, and from the environmentally at-risk cluster to the environmental impact manageable cluster in the future.

4. Conclusions and Future Work

Western Australia confronts specific challenges demanding a unique approach in analysing mineral criticality. For various reasons, it is not feasible for Western Australia to adopt the exact methodologies employed by another country, such as the United States, or the European Union. This deviation arises from the unique factors influencing supply vulnerabilities within Western Australia, the trade-related considerations pertinent to the state as well as minerals and reserves availability compared to other countries. For example, geopolitical concerns in the United States may diverge significantly from those in other countries; or trade relations, such as disruptions encompassing measures like a country's willingness to supply index, could introduce a crucial dimension of divergence across different pairs of countries. Therefore, the

Mineral	Criteria						
	Economic importance	Trade exposure	Disruption potential	Substitutability	Recyclability	Environmental impact	Total Score
Alumina	1.5	2.0	2.0	2.5	2.0	2.5	1.98
Cobalt	1.5	2.0	3.0	2.0	3.0	1.0	2.08
Copper	1.5	2.0	2.0	3.0	2.0	3.0	1.88
Lithium	3.0	3.0	1.0	2.0	1.0	1.5	2.15
Manganese	1.0	1.0	2.0	2.0	2.0	2.5	1.55
Nickel	3.0	2.0	2.0	2.0	3.0	2.0	2.35
PGE	1.0	2.0	3.0	1.0	2.0	2.5	1.90
REE	1.5	3.0	3.0	2.0	1.0	2.0	2.23

Notes: Data is obtained for several sources including Department of Mines, Industry, Regulations and Safety, Western Australia, World Mineral Production published by British Geological Survey, Materials critical to the energy industry, An introduction published by the University of Augsburg, Recycling Rates of Metals published by United Nation Environment Programme.

Table 1 Summary of Scores Allocation

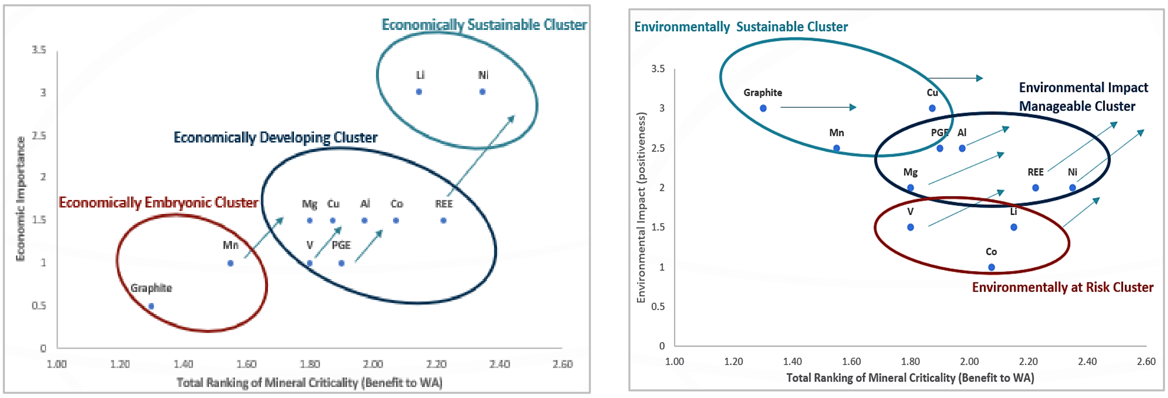

Figure 1 (Left) Analysis and apparent clusters of minerals based on economic importance for Western Australia. (Right) Analysis and apparent clusters of minerals based on environmental impact for Western Australia. Both figures include the likely progress in research towards 2050 assessed by MRIWA

selection of indicators must be meticulously tailored to the specific context of the Western Australia economy and policies, accounting for its distinctive characteristics. Emphasis must also be placed on scrutinizing data availability and utilizing locally relevant data sources. For instance, some indicators like the value addition of a particular mineral or substitution indexes inherently differ for each country and state. This ensures the need for a more context-specific assessment of each mineral based on criticality.

As a leading mineral exporter, Western Australia’s primary focus should be directed towards understanding global demand for minerals and anticipating potential disruptions within the supply chains, all viewed through the lens of the exporter. Trade war tensions and global geopolitical conditions may have a substantial impact on shaping future criticality conditions. Consequently, it is imperative to take into account such factors when devising a future mineral ranking methodology. The team tasked with formulating such a comprehensive methodology will need to have diverse expertise. The collaborative effort of an economist, a statistician with a mathematics background, a mineralogist and an individual with a background in geo-political studies will ensure a well-rounded and effective team to develop a mineral ranking methodology that encompasses economic, statistical, trade and geopolitical considerations.

5. Acknowledgements

Sincere gratitude is extended to the individuals and organizations whose support and contributions played a vital role in shaping the outcome of this project. Specifically, thanks are given to MRIWA CEO Nicole Roocke and the staff, and CEED Director Dr. Jeremy Leggoe and the staff.

6. References

British Geological Survey (BGS), 2015. Risk List 2015.

Bobba, S., Carrara, S., Huisman, J., Mathieux, F., Pavel, C. European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, 2020. Critical raw materials for strategic technologies and sectors in the EU – A foresight study, Publications Office.

Graedel, T.E., Barr, R., Chandler, C., Chase, T., Choi, J., Christoffersen, L., Friedlander, E., Henly, C., Jun, C., Nassar, N.T. and Schechner, D., 2012. Methodology of metal criticality determination. Environmental science & technology, 46(2), pp.1063-1070.

Graedel, T.E., Harper, E.M., Nassar, N.T., Nuss, P. and Reck, B.K., 2015. Criticality of metals and metalloids. Proceedings of the National Academy of Sciences, 112(14), pp.4257-4262.

USGS, Methodology and Technical Input for the 2021 Review and Revision of the U.S. Critical Minerals List - Methodology and Technical Input for the 2021 Review and Revision of the U.S. Critical Minerals List, last accessed 29 November 2023.

Nassar, N.T., Brainard, J., Gulley, A., Manley, R., Matos, G., Lederer, G., Bird, L.R., Pineault, D., Alonso, E., Gambogi, J. and Fortier, S.M., 2020. Evaluating the mineral commodity supply risk of the US manufacturing sector. Science advances, 6(8), p.eaay8647.

Yuan, Y., Yellishetty, M., Muñoz, M.A. and Northey, S.A., 2019. Toward a dynamic evaluation of mineral criticality: Introducing the framework of criticality systems. *Journal of Industrial Ecology*, 23(5), pp.1264-1277.