Critical Minerals Assessment

A White Paper from the Critical Minerals Consortium

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DOI: 10.13140/RG.2.2.26046.10566

Executive Summary

Critical minerals assessment (CMA) is concerned with the mineral inputs to a system, the risks of a disruption to supply occurring, and the impacts that such a disruption would have. The focus in this White Paper is on CMA for minerals that are input to the economy of a sovereign entity. The first comprehensive CMA was published for the U.S. in 2008. Since then many sovereign entities have conducted and published CMAs, particularly those with large industrialised economies that are reliant on the importation of minerals and raw materials derived from minerals.

Australia's main interest in CMA is as a potential supplier of critical minerals to the global market. It sees the criticality of minerals as an opportunity. Australia is indeed a major exporter of minerals and has the potential to increase the supply of minerals that other sovereign entities deem critical. However, Australia's large exports mask the fact that it is also a significant importer of minerals and minerals-derived materials (USD15b p.a.). Australia's economic exposure to critical minerals has not been examined in the same way as it has been for other major economies. This is a gap that should be addressed and gives rise to the first recommendation of this White Paper.

Recommendation 1: CMA from an Australian perspective

To undertake a scoping study to determine the need for a CMA to be conducted from an Australian economic (import) perspective. The scoping study would necessarily include an examination of what minerals are imported to Australia, their uses in Australian industry and the degree to which these same minerals can be produced domestically.

Given Australia's untested exposure to critical minerals and the significant opportunity to increase exports of critical minerals to other countries, there is a great deal to be gained by Australia improving its own analysis of minerals criticality.

Recommendation 2: Framework for CMA and policy development in Australia To undertake a scoping study to determine the need for Australia to adopt a framework in which CMA should occur, with direct links to policy development.

Australia is presently involved in international efforts to determine best practices in and standardisation of CMA such as its involvement with the International Round Table on Materials Criticality. Given Australia's likely ongoing interest in CMA applied from multiple perspectives, it is recommended that such international involvement be maintained if not increased.

Recommendation 3: Continue involvement with international efforts to improve CMA To continue or increase Australia's involvement in international efforts to determine best practices in and standardisation of CMA.

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Introduction

A project titled "Evaluating Critical Raw Material Supply for Australia's Defence Sector" was instigated in 2018. It was funded by a Defence Science Institute (DSI) Grant and its key aim was to investigate raw material supply risks for the Australian defence sector and improve the long-term stability and resiliency of mineral and raw material supply into the Australian defence sector. The project, headed by Associate Professor Dr Mohan Yellishetty, consulted widely with stakeholders in the defence sector, Geoscience Australia and State-based geoscience groups, CSIRO, University based researchers and the mining industry. The findings were reported in July 2019 (Yellishetty & Yuan, 2019): Australia's defence forces and defence industries are dependent on many raw materials, but these raw materials do not generally include minerals, or processed minerals. Instead, it is often defence-related raw materials suppliers in other countries who are reliant on minerals inputs. Australia in turn acquires more highly processed materials, from allied countries. A raw material is deemed to be critical, if it is assessed to have a risk of supply disruption, and if the impact of such a disruption is also assessed as being high. As a country with a considerable minerals endowment, and an advanced mining industry, Australia's role in de-risking the supply chain for defence-related critical raw materials (CRMs) is therefore principally as a potential supplier of minerals and processed minerals to its trade and security partners. If the Australian minerals sector is to contribute to increases in supply of critical minerals, it must overcome a number of challenges. These challenges include a need to stem the decline of the domestic minerals processing industry, and to find a way to be internationally competitive in the face of high energy and labour costs. It must do so in compliance with our high environmental standards. The process of identifying CRMs is called CRM assessment. On the topic of CRM assessment, the following needs were identified:

- The ability to be able to customize the assessment approach for different stakeholders.
- The ability to track material flows through allied regions and also companies based in allied countries.

In response to those needs, an agent-based approach to CRM assessment was proposed. In related research conducted at Monash University and supported by Geoscience Australia, such a methodology has been developed (Yuan, Yellishetty, Mudd, et al., 2020; Yuan, Yellishetty, Muñoz, & Northey, 2019; Yuan, Yellishetty, Northey, et al., 2020).

This White Paper builds on the work completed under the DSI grant and seeks to update the initial findings in light of recent developments, with the following scope:

- Focus on minerals and processed minerals: CRM assessment that is focused on minerals and raw materials derived from minerals is called *critical minerals assessment* (CMA).
- Consider impact on economic resilience rather than (only) impact on the defence sector: In 2018, Australia's National Resilience Taskforce released a paper profiling Australia's societal and economic vulnerabilities to systemic disasters (National Resilience Taskforce, 2018). The focus was on natural disasters, and the prescience of the report has been illustrated by the impacts of the 2019 bushfires and 2020 Covid-19 pandemic. In late 2019 and early 2020, the Institute for Integrated Economic Research-Australia (IIER) made the case for consideration of resilience in the face of a wider range of risk events, including conflict (Blackburn, 2019, 2020). The IIER also made the link between broader resilience risks and Australia's ability to maintain a defence capability. The IIER research identified particular supply chain issues relating to fuels and medicines but did not seek to identify issues relating to minerals and raw materials derived from minerals.

The rest of this White Paper is organised as follows:

- <u>Critical minerals assessment</u> re-examines the history of CMA, including developments since the DSI funded project reported in July 2019.
- <u>Policy responses when a mineral is deemed critical</u> examines the possible interrelationships between CMA and a government's response to CMA findings, a topic that is generally overlooked in the CMA literature.
- <u>CMA from an Australia perspective</u> discusses the various perspectives Australia must consider.
- <u>The case for CMA research in Australia and research questions</u> summarises the previous sections and concludes with a set of research questions.
- <u>A conceptual rational sovereign framework for Australian CMAs</u> seeks to illustrate an approach to addressing several of the research questions.
- <u>Recommendations</u> includes three recommendations pursuant to the aforementioned research questions.

Critical minerals assessment

Critical minerals assessment (CMA) is concerned with the mineral inputs to a system, the risks of a disruption of supply occurring, and the impacts that such a disruption would have. The system can

be the global economy, a sovereign entity's economy or a sovereign entity's defence capability. Some large corporations are also interested in CMA focused on their industrial systems. However, the focus in this White Paper is on CMA from a sovereign entity's perspective. In particular, we consider a sovereign entity's present and future mineral needs for its economy.

The focus in this White Paper is on critical minerals assessment (CMA) from a sovereign entity's economic perspective.

In 2008 the U.S. National Research Council (NRC) released a report on critical minerals and the U.S. economy (National Research Council, 2008). The paper established and applied a *CMA matrix* with major dimension *Supply Risk* and *Impact of Supply Restrictions* (Figure 1). A *critical mineral* is one for which the supply risk and the impact of a supply disruption are both high. Suppose CMA is used to determine that some mineral is critical. Then the implication is that this mineral should be the focus of efforts to either reduce the probability of a supply disruption, reduce the impact of such a disruption, or both. The NRC's use of a CMA matrix has all the hallmarks of multiple-criteria decision analysis (MCDA) (Zionts, 1979) though no reference is made to this in the 2008 report. At a high level, the NRC treats CMA as a two-dimensional problem. However, ranking a mineral on each major dimension involves the use of several indicators. Each indicator contributes to an overall ranking of a mineral on one of the two major dimensions. The use of multiple indicators makes this a high-dimensional MCDA problem.

Since 2008, CMA has been a topic of interest in the literature. One of the authors of the

abovementioned 2008 NRC report collaborated with others to publish a refinement of the original CMA method (Graedel et al., 2012). The paper provided detailed specifications for the indicators for the two major dimensions, and mathematical formulation for calculations of rankings. Graedel et al. also added a third major dimension: *Environmental Implications*. In later

The Yale methodology is a multicriteria decision analysis approach to CMA with *supply risk* and *impact of supply disruptions* as the two major dimensions. publications the method described by Graedel et al. is referred to as the *Yale methodology* (Graedel & Reck, 2016).



Figure 1: Example results of CMA - Critical minerals to the U.S. Economy (National Research Council, 2008)

The inclusion of an Environmental Implications dimension in the assessment is contentious. Graedel et al. (Graedel et al., 2012) did not make a case for the orthogonality of Environmental Implications to the Supply Risk dimension, which would be necessary to qualify it as a separate dimension. The authors instead suggest environmental implications are causally correlated to supply risk, though it is not clear that this can be established in practice. Take for example thermal coal. Coal mining has always caused high levels of environmental damage, with direct links to health risks and climate change. However, it is not clear that this record of environmental damage has led to a supply risk. There continues to be a lively global market. Thermal coal is not assessed as a mineral with high supply risk by U.S. (Fortier et al., 2020), U.K. (British Geological Survey, 2015), Germany (Glöser-Chahoud, Tercero Espinoza, Walz, & Faulstich, 2016) or the European Union (European Commission, 2014). A recent review paper (Schrijvers, Hool, et al.,

2020) states "clear cause-and-effect mechanisms are not yet formulated on the influence of environmental and social implications on criticality, it is recommended to present environmental and social implications as a separate dimension for the identification and resolution of possible trade-offs".

Clear cause-and-effect mechanisms are not yet formulated on the influence of environmental (and social) implications on criticality. This appears to be an area in which more research is needed.

Schrijvers et al. do not elaborate on how such a separate dimension is intended to be used for the identification and resolution of possible trade-offs. However other

literature has emphasised the use of such information in the identification and selection of substitutes for minerals.

More recently the U.S. has employed a method that replaces the two dimensions of the Yale methodology with three dimensions: *disruption potential; trade exposure;* and *economic vulnerability.* The geometric mean of these three dimensions is used to calculate a *strategic risk* metric. The economic vulnerability dimension is calculated as the sum of, for each industry, the product of the industry fraction of GDP and a measure of the industry's vulnerability (Nedal T Nassar et al., 2020).

Between 2008-2014 there were several contributions of note to the literature, and a useful review was published by (Graedel & Reck, 2016). The review covered the development of the Yale methodology and variants through several major studies covering U.S. (National Research Council,

2008); European Union (European Commission, 2010, 2014; Moss et al., 2013); United Kingdom (Roelich et al., 2014) and global (Achzet et al., 2011; British Geological Survey, 2011, 2012; Graedel et al., 2012). Based on analysis of these and other cases Graedel & Reck proposed the list of desirable attributes for CMA shown in Figure 2.

Since 2008, CMA has been applied by or for the U.S., the European Union, the U.K. and other sovereign entities.

Ten desirable attributes of a CMA methodology:

- 1. **Broad** in terms of minerals addressed including both common minerals and the increasingly used scarce minerals.
- 2. Considers all factors that are generally important to criticality.
- 3. Addresses the issue of substitutability or lack thereof.
- 4. Addresses the issue of companion metals.
- 5. **Considers** the degree to which **recycling** can affect virgin metal demand.
- 6. Addresses different using entities (e.g., corporations and countries) as target customers for the assessments.
- 7. Periodically updated.
- 8. Authoritative in nature, a stature achieved by such actions as scholarly peer review and/or governmental review.
- 9. **Transparent**: The methodology should be clear, and the data used for the evaluations should be described in detail and be made publicly available.
- 10. Addresses uncertainty, so that the reader has a sense for the rigor and confidence related to a criticality analysis.

Figure 2: Ten desirable attributes of an CMA method (Graedel & Reck, 2016). Original reference to 'elements' has been changed to 'minerals'.

Graedel and Reck originally referenced 'elements' (on the periodic table) rather than minerals in their list of ten desirable attributes of a CMA. Graedel and Reck seem to make two arguments for this restriction, one implicit and the other explicit. The implicit argument is for completeness: Every mineral, indeed, every material thing, is comprised of elements on the periodic table. The second argument is provided by example: The authors argue that assessments of fluorspar and graphite have shown them not to be very high on the criticality list and also that their analysis is problematic. However, subsequent, well qualified CMAs include non-elemental minerals. For example, the European Union in 2014 determined metallurgical coal and natural graphite to be critical, but not other carbonaceous minerals (e.g. diamonds and energy coal). In the same analysis, Magnesium and Magnesite (magnesium carbonate) rate differently in their economic importance (European Commission, 2014). Similarly, the U.S. assesses four non-elemental minerals, iron ore, phosphate, graphite and feldspar (Nedal T Nassar et al., 2020). Further, vulnerabilities associated with minerals do not necessarily occur at the mining or processing phases. In a review of raw material needs for the European defence industry, it was found that important raw materials included specialised highperformance processed materials (Pavel & Tzimas, 2016). These raw materials included specific alloys of aluminium, titanium, steel, nickel and magnesium, materials that are produced further along the supply chain than mining or normal refining and smelting. Similarly, a report by the U.S. Geological Survey (Fortier et al., 2020) found:

"It is not always the case that the strategic vulnerability for a given mineral commodity is a mining and concentrate production issue. The vulnerabilities often lie further down the supply chain. Simply establishing domestic mining and concentrate production does nothing to mitigate risks if downstream processing is highly concentrated geographically, imported and unreliable."

This points to some complexity in establishing the scope of a CMA - in as much as there is no clear

demarcation as to how much of the supply chain needs to be considered. This complexity is compounded by practical matters: In a recent review paper (Schrijvers, Hool, et al., 2020) attention was drawn to a divergence of approaches used to select minerals for a particular study, and noted that the availability of data was often a constraint. That is, if some CMA method requires a certain set of data to evaluate a mineral's criticality, the unavailability of any part of that data for a given mineral, precludes that mineral from evaluation. We conclude with respect the

The determination of scope for a CMA is a complex matter, and should not be arbitrarily constrained to elements, or to mined materials. The scope should be subject to detailed examination in every CMA.

establishment of scope for a CMA, that it is a complex matter, and one that requires detailed examination in each case.

Item 9 in Figure 2 emphasises transparency and calls for data to be made public. Whilst this is important from an academic standpoint, from a sovereign perspective, the use of only public information has some disadvantages:

• The choice of indicators is constrained to the publicly available information. The constrained choice of indicators in turn constrains the type of *supply risk* and *impact of supply disruption* models that can be built.

• A sovereign state undertaking CMA gets no advantage from its private information (for example, un-published information about technology, markets, defence, intelligence and diplomatic relations). Accordingly, the criticality assessments may not be as accurate as they could be.

The Yale methodology, and its variants, are static implementation of multiple-criteria decision analysis (MCDA). This means that they are not necessarily well suited to use as predictive tools, though they have been used iteratively to track past trends (Nedal T Nassar et al., 2020). Dynamic approaches, which are more suited to be used as predictive tools, have also been proposed and applied. A framework for an agent-based model was proposed in 2013 (Knoeri, Wäger, Stamp, Althaus, & Weil, 2013). The proposed framework was geared towards understanding environmental implications of substitution decisions. A further development in capturing the dynamics of supply risk was published in 2014 (Roelich et al., 2014). The approach was to use bottom-up agent-based modelling (ABM), with a focus on substitution decisions made by individual companies in an

The inclusion of private information may improve the quality of CMA outputs. industry. In 2019 research led by Monash University and joined by the University of Melbourne gave rise to a new agent-based model for evaluation of mineral criticality (Yuan et al., 2019). While retaining the basic twodimensional structure and the indicators of some earlier CMA methodologies, the static analysis was replaced by a dynamic multi-period agent-based machine learning model with feedback loops. Statistical learning techniques and machine learning are used to determine coefficients in the model. Benefits of this methodology include:

- the ability to model more complex relationships between indicators and the two major dimensions in CMA;
- availability of a suite of statistically rigorous methods to test the efficacy of the model, using historical time-series data, and;
- the capability of instantaneous assessments of mineral criticality, as well as assessments of future trends.

In the sequel this approach will be referred to as the *Monash methodology*. The Monash methodology has been applied to the analysis of the global supply and demand of platinum (Yuan, Yellishetty, Mudd, et al., 2020). In this analysis, global supply and demand were broken up into regions and the application of the new framework was able to provide nuanced insights into the relationship between indicators, supply risk and impact of supply disruption. Examples include: a disproportionate influence of South African supply on supply risk; consumption in North America has greater influence on commodity price; Europe is more at risk of supply disruptions. In addition, a paper in draft (Yuan, Yellishetty, Northey, et al., 2020) adapts the Monash methodology to examine a previously unexplored connection between metal criticality: the movements and impulse responses of metal prices, and the relevant external factors affecting metal market dynamics (e.g. energy price) using econometric methods.

Evaluating the Monash methodology against the ten desirable attributes for CMA (Figure 2), it seems that, applied correctly, the method is capable of rating highly in most respects. The one exception is that its complexity would count against it in terms of transparency, when compared to the more simplistic approaches. However, the method is likely to be well within the reach of appropriately supported analysts.

The Monash methodology, when applied correctly, is expected to rate highly in terms of the ten desirable attributes for CMA.

We can expect others to pursue advanced methodologies in the future. For example The U.S. Geological Survey has heralded improvements in their capability to assess critical minerals (Nedal T. Nassar, 2020):

"At USGS, we continue to improve our capability to analyze mineral supply chains and assess the associated supply risk through advanced modeling techniques that will soon allow us to quantify how different supply disruptions may ripple through and impact the economy. We are also expanding our capability to develop forward-looking supply and demand scenarios that will help anticipate how certain trends and disruptive technologies, such as vehicle electrification, may impact the minerals industry."

The Monash methodology is a mathematically rigorous method for dynamic CMA. It builds on the Yale methodology by applying statistical learning and machine learning techniques. The Monash methodology can model more complex relationships between indicators and the two major dimensions in CMA. Benefits include the ability to apply a suite of model validation tools, and more nuanced outputs and to use the methodology for the assessment of future trends. Whether or not a particular CMA exercise determines a mineral to be critical depends on many factors including:

- The perspective of the CMA (For example, a CMA from the perspective of U.S. domestic consumption will produce very different results to a similar study conducted from the perspective of (say) Brazil).
- The choice of indicators and their weighting in the assessment of ranking on the major dimensions and the complexities of the underlying data.
- The choice of methods (Yale, Monash, etc.).

As a result, comparing the results of one study to another is difficult, if not impossible (Schrijvers, Hool, et al., 2020). This may not be an issue from the perspective of a sovereign entity that is primarily focused on its domestic requirements. Such a sovereign entity can carry out its own CMA. However, some sovereign entities are also

Comparing the results of one CMA study to another is difficult, if not impossible.

interested in a global picture and of CMA from the perspective of its trade and security partners, and rivals on the global stage. This interest may stem from a general concern for global order and stability. In Australia's case, being a major producer and exporter of minerals, interest extends to investigating opportunities to develop capacity to supply critical minerals to the global market.

The literature on CMA is silent on the linkages between the analysis of minerals criticality, and the way in which economic impact is measured during policy development. Why might this be of concern?

Take for example the assessment of "vulnerability to supply restrictions" (VSR) in the Yale methodology: It uses an equation to calculate a VSR metric based on the weighted sum of eight indicator values including indicators such as *national economic importance, net import reliance ratio* and *global innovation index* (Graedel et al., 2012). The more recent method employed by the U.S. replaces the two dimensions of the Yale methodology with three dimensions *disruption potential, trade exposure,* and *economic vulnerability.* The geometric mean of these three dimensions is used to calculate a *strategic risk* metric. The economic vulnerability dimension is calculated as the sum

The literature does not demonstrate that the methods used to estimate strategic risk in CMA, track well to other methods used to measure the economic impact of a disruption event.

The risk to a sovereign entity is that attention is directed to the wrong set of minerals.

of, for each industry, the product of the industry fraction of GDP and a measure of the industry's vulnerability (Nedal T Nassar et al., 2020). Both of these methods produce abstract metrics, and are intended to drive a government's attention to a set of minerals that are deemed critical. Policy will then be implemented, and funding applied in response to the perceived economic and strategic risks.

Suppose one of the aforementioned methods ranks mineral *A* higher in terms of vulnerability than mineral *B* and as a result *A* is deemed critical but *B* is not. Now suppose disruptions to supply of *A* and *B* are reassessed using another more detailed economic modelling method that determines that there is a greater economic cost to a mineral *B* disruption than to a mineral *A* disruption. How should this inconsistency be dealt with?

This seems to be an important unknown and one that should receive some attention in future research.

Policy responses when a mineral is deemed critical

If a mineral is deemed to be critical, what does that mean at a high level?

One interpretation is that it is a failure of the market to deliver supply of a mineral in a way that satisfies all the needs of a given sovereign entity. This is consistent with views expressed by Hon. David Fawcett, chair of the Parliamentary Joint Standing Committee on Foreign Affairs, Defence and Trade (Defence Connect, 2020). Consider for example, China's dominance of the global supply of rare earth elements (REEs). The global market conditions represent an REE supply risk to any country in the world that requires REEs, other than China. This supply concentration of REEs, arises in part due to happenstance of global distribution of REEs in the Earth's crust. Other factors leading to the supply risk include:

- In countries that have high environmental standards (e.g. Australia, U.S.), it is more difficult to mine REEs profitably.
- There are distortions in the market, commencing in 2009 with an announcement that China would reduce export quotas.

To continue with the REE example, the free market can be expected to overcome the risks only partially. Chinese supply restrictions in the period 2011-2015 applied an upwards pressure on commodity prices, a motivator for those who could develop supply outside of China. However, the market is less likely to be able to overcome disruptions that arrive in certain probabilistic forms. Suppose for example that there is a 10% chance that REE supply is suddenly and dramatically constrained sometime in the next ten years. This is a low probability event with a high potential impact. Regardless of the expected impact of such an event, it seems unlikely that the free market

The free market is unlikely to be able to adequately reduce the risk associated with a critical mineral. This is particularly so when supply disruption is a low probability and high impact event. This implies that if critical minerals risks are to be managed well, that additional strategies need to be considered.

alone can be relied upon to build reserve REE production capacity to cater to such a scenario.

COVID-19 has provided a timely example of what a low probability and high impact event can do to supply chains of critical materials. Although most focus in the media has been on medical supplies, critical minerals have also been impacted (Murkowski, 2020):

"Border closures in Africa have impacted the export of cobalt from the Democratic Republic of Congo and platinum from South Africa. Mines in Argentina, Peru, and Brazil have temporarily shut down, restricting supplies of lithium, copper, and iron. ... We're fortunate those supply impacts haven't been more acute or widespread. ... But it's also hard not to conclude that we have been lucky here, and luck usually isn't a very good strategy."

Following the above examples, it can be concluded that sovereign entities cannot rely solely on the free market to overcome their mineral supply risks, particularly in relation to low probability and high impact risks. That implies there is a need for sovereign entities to employ some other strategies to manage critical minerals risks in order to:

- reduce the probability of a supply disruption occurring;
- reduce the magnitude of a supply disruption, should one occur; and/or,
- reduce the impact of a supply disruption should one occur.

However, there is nothing in the literature to suggest what the process has been or ought to be in deciding on a policy response to a determination that a particular mineral is critical. In the opinion of Dorsey & Whitney partner Nora Pincus, the gap in the literature is mirrored in real life (Lazenby, 2020):

"What we saw [in the U.S.] was a lot of debate around what was going to be designated a critical mineral, but there was a surprising lack of dialogue in what we were going to do to [sic] as a government to try to stimulate some of this development."

Perhaps a good place to start is to consider the typical steps in a rational decision-making process:

- 1. Identify the problem or the opportunity.
- 2. Identify how to measure success in solving the problem or accessing the opportunity (the success criteria).

A good place to start is to consider the typical steps in a rational decision-making process.

- 3. Identify possible solutions.
- 4. Model the implementation of the possible solutions and evaluate using the success criteria.
- 5. Choose the best solution.
- 6. Implement the solution.
- 7. Measure the effectiveness of the solution.

The process starts in step 1 with the identification through CMA that a particular mineral is critical. Measures of success (step 2) will often include the stimulation of development of alternative mineral supplies by exploration and mining companies.

Possible solutions (step 3) may include:

- Development of strategies to deal with critical minerals risks and opportunities. For example, Australia released such a strategy in 2019 (Department of Industry Innovation and Science, 2019).
- Reducing administrative barriers to starting up production of critical minerals. An example is included in a bill to encourage domestic mining of rare earth element, recently introduced by Senator Ted Cruz in the U.S. Senate (Cruz, 2020).
- Providing economic support for the development of critical minerals production. Examples include Australia backing a domestic rare earth project (Mining Journal, 2020) and the U.S. providing capital related tax incentives (Cruz, 2020).
- Entering into scientific cooperation agreements to improve understanding of critical minerals. An example is the recent signing of an agreement between the U.S. and Australia (Mining Journal, 2019).

Other policy responses may include the provision of subsidies, various forms of tax incentive, direct investment, price guarantees and in select cases, the imposition of tariffs.

Step 4 requires an understanding of how various agents might respond to the implementation of a solution. Those agents include other governments, the buyers and sellers in the relevant markets, and of course exploration and mining companies.⁶ In making investment decisions, exploration and mining companies consider a broad range of factors including geological and regional economic and infrastructure conditions, development costs and future costs and prices (Walsh, Northey, Huston, Yellishetty, & Czarnota, 2020). They often use discounted cashflow analysis as a primary tool in

⁶ Such an agent-based approach is a feature of the aforementioned Monash Methodology.

investment decision-making, and consider uncertainties around future cashflows (Whittle, 2011). Their responses to interventions that reduce barriers to entry (e.g. reducing capital requirements or reducing approval delays) will be quite different to interventions that promise to improve long term cashflows (e.g. future tax incentives).

Choosing the best solution (step 5) ought to be done using the pre-defined success criteria (Step 2).

Step 6 is the implementation of the solution.

Finally, step 7 provides vital information as to the effectiveness of the solution, for the purposes of improving steps 1-6, next time they are done.

Even in a world where political decisions may be influenced by other factors, a rational process such as that described above, is likely to help by identifying a range of alternative solutions, all evaluated against an agree set of success criteria. Further discussion of such a rational approach is included in the section <u>A conceptual rational sovereign framework for Australian CMAs</u>.

CMA from an Australian Perspective

The focus of CMA in Australia has historically been on minerals that are deemed critical by other sovereign entities, and on Australia's potential to contribute to the supply of these critical minerals. Given this context, the focus of CMA and policy development in Australia has been on de-risking minerals supplies to Australia's trade and security partners. The most obvious (and potentially

profitable) way to de-risk supply of a given mineral is to mine more of it in Australia. This approach is evident in a recent review paper 'CMA in Australia – a review of opportunities and research needs' (Mudd et al., 2018). Examples of policy responses by the Commonwealth government are:

CMA from an Australian economic perspective does not appear in the public domain. There is a prima facie case for doing so.

- announced grants for research into processing innovations to increase in the supply of certain energy storage critical minerals (Andrews, 2019),
- released a strategy with respect to critical minerals (Department of Industry Innovation and Science, 2019),
- formalized a partnership with the U.S. to improve both nations' understanding and supply of critical minerals (Mining Journal, 2019), and,
- announced a new agreement with India to develop reliable supply chains in strategic sectors, including critical minerals (Packham, 2020).

Given that Australia is known to export much greater quantities of minerals than it imports, this focus on increased export potential seems obvious. However, what, if any, minerals are critical from an Australian import perspective?

Australia has not conducted CMA from the perspective of its own domestic requirements, but some analysis has been conducted in relation to other materials. For example, Australia is known to be heavily reliant on imported fuels and medicines and these imports represent significant economic and strategic risks (Blackburn, 2019, 2020).

Despite the lack of an exhaustive CMA study, some major minerals are known to be *potentially* critical, such as those shown in Table 1. In the case of phosphates, Australia has significant economic and inferred resources, and also significant production, but not enough to meet domestic needs. In the case of potash, the biggest producer globally is Canada (29%) with Russia, Belarus and China

accounting for 47%. Australia has significant potash resources, but no production. A global supply disruption to either phosphates or potash would likely have a significant impact on the Australian agriculture sector. In the case of lithium, Australia is a significant global supplier, and it imports batteries containing lithium. In this case, batteries (containing lithium) may be critical raw materials to Australia, but not lithium.

Commodity	Usage	Import	Australian	Australian	Australian	Australian
Group		value US\$ ⁷	Imports ⁸	production	economic	inferred
					resources ⁹	resources ¹⁰
Phosphate	Agriculture	\$722M	2Mt	1.4Mt	178Mt	387 (P2O5)
				(P2O5)	(P2O5)	
Potassium	Agriculture	\$1,230M	2Kt	-	72Mt	124Mt
(includes potash)					(K2O)	(K2O)
Lithium (includes	Batteries	\$509M	n/a	57Kt	4718Kt	1404Kt
batteries)						

Table 1: Some	minerals that are	potentially	critical from	an Australian	domestic perspective.
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Are any other mineral imports to Australia potentially critical?

Australia imports US\$15B of mined minerals, bulk or simple products obtained from mined materials and scrap substitutes, across over 700 commodity codes¹¹. It is impossible to know how many of these imports might represent critical minerals without conducting a CMA. However, in a May 2020 report, the Henry Jackson Society (a foreign policy think-tank) claimed that Australia was critically dependent on China¹² for nearly 600 categories of imports, including some classes of aluminium, steel, graphite, fertilizers and various chemicals (Rogers, Foxall, Henderson, & Armstrong, 2020).

These observations indicate that there is a prima facie case for the conduct of CMA from an Australian domestic requirements perspective.

The case for CMA research in Australia and research questions

CMA has historically been carried out by major industrialized sovereign entities that have heavy reliance on imported minerals. Australia has not conducted CMA from its own economic perspective. Despite this, Australia has contributed to the science of CMA through the development of the Monash Methodology (Yuan, Yellishetty, Mudd, et al., 2020; Yuan et al., 2019; Yuan, Yellishetty, Northey, et al., 2020). In addition, it is globally engaged in research efforts. For example, Gavin Mudd (RMIT) is a member of the International Round Table on Minerals Criticality, a European Union funded research investigation into best practice and standardisation of CMA (Schrijvers, Blengini, et al., 2020; Schrijvers, Hool, et al., 2020). It can therefore be said that Australia has a demonstrated research capability in the field of CMA.

There remain many challenges in implementing CMA and in using the results of CMA:

⁷ Source: UN Comtrade International Trade statistics 2018.

⁸ Ditto.

⁹ Source: Economic demonstrated resources, as defined by Geoscience Australia.

¹⁰ Source: Geoscience Australia.

¹¹ Source: UN Comtrade International Trade statistics 2018.

¹² The Henry Jackson Society test for critical dependency: 1. More than 50% of the country's imports in an industry, a sector, or a category of goods come from China, 2. A country is a net importer of that industry, sector, or category of goods, and, 3. China has a greater than 30% market share of global trade in that industry, sector or category of goods.

- Deciding on the scope for a CMA is a complex matter that must consider an indeterminate part of the materials supply chain.
- Environmental issues are usually seen to be contributors to assessments of criticality, but the mechanisms are unclear.
- The variations in CMA methodologies used by different sovereign entities mean that it is difficult or impossible to compare and consolidate the results. This is a particular issue for Australia, as it seeks to prioritize development of domestic supply of minerals for export.
- A preference to use only publicly available information potentials hinders the effectiveness of CMA.
- It is unclear whether the disruption impact metrics generated by the various CMA methods correlate to the economic cost of a supply disruption, as measured using the best available economic modelling.
- With the exception of the Monash methodology, CMA is not well suited to predictive analysis.

Given these observations, the research questions in Figure 3 are proposed.

Research questions

- 1. Is there a case for Australia to conduct CMA from its own economic perspective?
- 2. How can Australia best make use of CMAs published by other sovereign entities, when there is a lack of standards in the conduct of the assessments?
- 3. In applying CMA to its own economy, and in using the CMA results from other sovereign nations, is there a case to include private information (confidential commercial information and intelligence) to improve the results?
- 4. Can the quality of CMA outcomes be improved by establishing a defined process (e.g. a rational approach) to CMA and associated policy development?

Figure 3: Research questions.

A conceptual rational sovereign framework for Australian CMAs

In conducting the research for this White Paper, the authors developed a conceptual framework to address research question 2, 3 and 4. The intention of including this in this White Paper is to solicit discussion as to how Australia might best conduct CMA to inform the development and deployment of effective policies with respect to critical minerals.

We first provide an overview of a conventional framework for the application of CMA applied by several sovereign states in Figure 4. The perspective is that of a sovereign state and its domestic consumption of minerals. In this framework, mineral choice (3) sets the scope for a criticality assessment (5) using one of the static methods (4). For each chosen mineral, publicly available information (1) is used to construct indicators (2) which are fed to the method (4), which is used to produce a static criticality assessment (5). The criticality assessment and domestic mineral endowment information (7) are used for the formulation and implementation of policy (8).

In this conventional framework, no formal link is presumed to exist between the way in which mineral criticality is assessed, and the policy toolkit and approaches that are used by policy developers. For example, there may be no reconciliation between the way impact of a supply

disruption is measured in CMA, and the way it is economically measured in a policy development environment.



Figure 4: Conventional approach to CMA applied by various sovereign states from the perspective of domestic consumption.

Australia is very interested in CMA from the perspective of a wide range of other sovereign entities and should also be interested in CMA from its own economic perspective. To meet this need, and to address some of the deficiencies of a conventional CMA framework, an alternative framework is presented in Figure 5. We call this a Rational Sovereign Framework (RSF) for Australia's application of CMA.



Figure 5: A conceptual RSF for the application of CMA by Australia.

The conceptual RSF for Australia differs from the conventional framework in the following ways:

- A perspective choice must be made for each CMA conducted. Australia may conduct CMAs from its own perspective and from the perspective of other sovereign entities.
- Given Australia's interest in many perspectives, CMAs conducted by others are of great interest. However, due to the lack of standardisation in the conduct of CMAs globally, they are used as inputs (1) to the RSF, rather than relying on them directly as criticality assessment (5).
- Indicators (2) can be informed by both public (1) and private information (7, 10). The addition of private information un-constrains the choice of indicators. Private information on mineral endowment (7) can be used to build a more sophisticated picture of current and future domestic supply. Information from policy development and measurement of policy effectiveness (8, 9) may be useful in construction of indicators (2) and can be used to ensure alignment of value measurement between (4), (8) and (9).
- The static method (4) in the conventional approach is replaced with the Monash methodology (Yuan et al., 2019) in the RSF.
- A formal step of measuring the effectiveness of policies (9) is added. The purpose of (9) in the RSF is specifically to inform the improvement of the indicators and models in CMA.
- A cycle repeating every 2-3 years is envisaged to ensure continuous improvement in the CMA method and policy development.

The use of private information in the development of criticality assessments potentially makes the assessments themselves private. This differs from the apparent approach of the U.S., E.U. and other sovereign entities, which release their CMA reports.

Potential advantages of the application of such an RSF include:

- The application of the Monash methodology and the inclusion of private information can improve the sophistication of the assessment.
- A regular cycle can lead to continuous improvement.
- The use of a game theoretical model for policy development can potentially lead to improvements in the development of criticality assessments, including in the choice of indicators and the measurement of value.

Recommendations

Pursuant to the research questions posed in the section <u>The case for CMA research in Australia and</u> <u>research questions</u> the following recommendations are made:

Recommendation 1: CMA from an Australian perspective

Undertake a scoping study to determine the need for a CMA to be conducted from an Australian economic (import) perspective. The scoping study would necessarily include an examination of what minerals are imported to Australia, their uses in Australian industry and the degree to which these same minerals can be produced domestically.

Recommendation 2: Framework for CMA and policy development in Australia

Undertake a scoping study to determine the need for Australia to adopt a framework in which CMA should occur, with direct links to policy development. This scoping study would address research question 2, 3 and 4.

Recommendation 3: Continue involvement with international efforts to improve CMA

Continue or increase Australia's involvement in international efforts to determine best practices in and standardisation of CMA.

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