

MINERAL RESOURCE GOVERNANCE AND POLICY FRAMEWORKS IN AFRICA; A CASE STUDY OF EAST AFRICA COUNTRIES- KENYA

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Abstract

Mineral resources are important contributors to the global economy and societal wellbeing. Directly, they provide employment, revenue and taxes through the extraction, processing and sale of minerals. Indirectly, they are essential to all modern industries, including: energy, manufacturing, construction, biotic and abiotic resource extraction and agriculture. The principle that 'one cannot understand the value of what they have until they measure it' is particularly relevant with critical raw materials (CRMs).

CRM is a concept that categorizes select resources (mainly minerals and metals) as critical in the sense that, at a national level, they are essential and difficult to replace, and their supply is prone to disruption. It is becoming increasingly recognized that the continuity of civilization and living standards as some have envisioned them in the future is constrained by the quality and quantity of various minerals. National-level strategic planning, including energy policy, foreign relations policy, geopolitical operations, national defense, education and infrastructure planning, among others, all require knowledge of the requirement and supply of raw materials towards a practical strategic implementation. Hence, a national CRM framework is essential for a prosperous, productive and stable future. To effectively manage the supply and use of CRMs, it is important to comprehend both their formal (e.g., economic) and informal (e.g., social and environmental) values, and to measure and monitor these values effectively over time. This study examines international practices and methodologies as components of a comprehensive CRM framework. We then propose a prototype CRM framework for East African Countries particularly in Kenya where such a framework is not in place.

All CRM frameworks feature one or more rating schemes to identify the degree of criticality of raw materials. The actual rating metrics are divided into dimensions (or factors), such as: socio-economic importance, technological importance, environmental, social and governance risks. Such dimensions are important due to the following reasons.

- *Delineating criticality from non-criticality: by rank-ordering CRMs based on various factors, a country can identify which ones are the most important for its economy, industry and national security. This information can help policymakers prioritize the development of domestic production and secure a stable supply of CRMs.*
- *Assessing resource sustainability and supply stability: by rating CRMs based on environmental, social and ethical factors, a country can assess the sustainability of its resource use and identify areas for improvement. This information can help policymakers develop strategies to mitigate resource depletion, and supply chain disruption, minimize negative environmental and social impacts, and promote responsible resource management.*
- *Supporting informed decision-making: an ordered ranking of CRMs provides quantitative and qualitative information to governmental bodies, industry and other stakeholders to support informed decision-making, including strategic planning. This information can help stakeholders make informed choices about the sources and types of CRMs they use and the sustainability of their resource use.*
- *Promoting transparency and accountability: adopting suitable business ethical dimensions, such as through a corporate social responsibility framework, enables a country to promote transparency and accountability in its resource use and supply chains. This approach can help reduce illicit financial flows, corruption, and abuse of power, while increasing trust and confidence in the resource sector.*
- *Innovation and investment opportunities: a CRM framework enables a nation to establish policy conditions that foster innovation and investment in key activities such as measuring, monitoring, sustainability, extracting, responsible processing, and efficient use of CRMs.*

Findings from this study underscores the necessity of a structured CRM framework in Kenya to effectively manage the complexities of resource management, economic ground, and sustainability. Integrating these frameworks into national policies can enable Kenya to secure a sustainable, economically viable, and environmentally responsible future. Such strategic initiatives are important for national security, industrial policy, structural transformation, and economic stability, as well as aligning with global initiatives for responsible sourcing and climate change.

Key words: CRMs, Kenya Ranking, Circular economy Mineral resources Policy, ESG

1. Introduction

Many raw materials are increasingly becoming critical to the continuity of modern societies. In East African countries, the concept of critical raw materials (CRMs) is increasingly well developed and has already begun to shape national policy, economic growth, scientific inquiry and infrastructure planning. The exact needs of various countries generally vary, the definition, value and importance of CRMs also vary by country or super-national groups (Hayes and McCullough, 2018).

Kenya is a country undergoing a transition towards greater socio-economic equality by integrating customary indigenous practices, modern rule-of-law principles, while taking global trends towards sustainability into account. Presently, there is no established CRM list for Kenya or even a CRM list with an identifiably African focus. This means that other CRM lists have less meaning for Africa, mainly because of disparities in economic, infrastructure and societal development, as well as cultural differences. This unfortunately creates an unequal footing for the planning of the Kenyan economy, infrastructure, national policy and international engagement, because other global interests interact with Kenya with an informed goal, while Kenya does not yet have an equivalent vision. This potentially creates a situation that could enable 'mineral colonialism' the targeting of under-informed but resource-rich countries, such as African countries, by mineral-poor countries to secure their future supplies. This study attempts to create a framework that generalizes known methodology and rationale to permit the creation of a CRM list that benefits to Kenya. Consistent with existing methodologies, we define Kenyan CRMs as materials that:

- 1) Make a significant economic contribution to key sectors;
- 2) Have a notable high supply risk(s) due to very high import dependence;
- 3) Exhibit a high level of concentration in other countries and/or regions; and
- 4) Have generally limited, to no (viable) substitutes, because of their unique and reliable properties for current and future applications (Ferro and Bonollo, 2019).

Kenya is a major producer of many CRMs, as per non-Kenyan definitions, including: chromium, iron and manganese, and hosts the world's largest known reserves of platinum group metals (PGMs; Hofmann et al., 2018; Nwaila et al., 2022a).

In absence of a Kenyan CRM list, we here discuss the contribution of externally-defined CRMs to Kenya. The benefits of a Kenyan CRM list would obviously extend these contributions in the future.

The mining and processing of CRMs is a significant contributor to the Kenyan economy, providing employment and revenue for the country (Van der Merwe, 2011; Marais et al., 2022). The value-adding stages after mineral processing are generally foreign to Kenya. However, the supply of CRMs in Kenya faces several challenges (Nwaila et al., 2022a). Notably, the increasing global demand for CRMs is adding pressure on existing supplies (Martin et al., 2022), and declining ore grades are making it increasingly difficult to extract these materials (Nwaila et al., 2022a).

Additionally, the extraction and processing of CRMs can have significant environmental and social impacts, including air and water pollution (Nwaila et al., 2022a), land degradation and displacement of communities (Fayiga et al., 2018). These impacts can have long-term consequences on the wellbeing of affected communities, as well as the sustainability of the minerals industry (Olufemi et al., 2018).

To effectively manage its CRMs, Kenya needs to adopt a comprehensive and strategic approach that considers the country's long-term needs and goals. Key considerations for creating an effective CRMs policy framework in Kenya include.

Identifying and prioritizing needed CRMs and developing a strategy to secure a reliable supply of these materials. This may involve incentivizing the development of a domestic production of CRMs, establishing partnerships and collaborations with other countries, and promoting the recycling and re-use of these materials.

Ensuring that the extraction and processing of CRMs are congruent with societal customary and statutory standards (health and safety, environmental and sustainability). This may involve revising current legislation and establishing regulatory frameworks, promoting best practices, mineral chain-wide integration and innovation, and supporting the development of sustainable and responsible value chains.

Investing in research and development to promote short- and long-term supply and substitution of CRMs, particularly through the use of modern technologies such as mineral exploration drones, geothermal energy and advanced recycling methods.

Promoting transparency and accountability in the CRMs sector, through the publication of data, supply chain transparency and the implementation of reporting requirements.

Encouraging collaboration and information sharing among different stakeholders in the CRMs sector, including industry, academia and civil society.

Considering these challenges and the importance of CRMs associated with their supply and use, it is important to have a comprehensive and strategic approach to managing the materials. In this study, we review the importance of CRMs for Kenya and identify key considerations for measuring the criticality and managing these materials in a sustainable and responsible manner.

A brief history of CRM

Awareness of the necessity and preciousness of various minerals and metals predate modernity. In history, various civilizations that have sought materials such as iron, copper, silver and gold, recognized their intrinsic preciousness and leveraged them to build economies that were highly characteristic of the materials that empowered them (e.g., the bronze and iron ages, in particular). As time and therefore societies evolve, material requirements also change.

The assessment of economic importance is carried out by the Joint Research Centre (JRC) of the European Commission.

- **World Bank:** The World Bank's Commodity Markets Outlook analyses commodity markets. The report includes information on production, consumption, trade, prices and other economic indicators for a range of commodities, including CRMs.
- **Global Risk Insights:** Global Risk Insights is a consultancy that analyses and forecasts global risks. The company publishes research and reports on CRMs risks and trends, including supply chain disruptions, price volatility and geopolitical risks.
- **Bloomberg:** Bloomberg is a financial news and data provider that publishes information and analysis for a range of commodities. The company's commodities team provides insights and analyses CRMs markets, trends and forecasts.

Current methodologies to assess the criticality of materials differ by country (and presumably the data that were used to support the assessments), although many CRMs consistently overlap across assessments.

The EU uses a single-stage process, whereby all materials are assessed for their economic importance and supply risk, while a hard threshold is also overlaid to delineate criticality (European Commission, 2017b). The differences between these methods are not substantial as the guiding principles are essentially identical. This is the key reason why many CRMs overlap across individual assessments. Critical analysis of CRM frameworks and lists is currently sparse and a single example exists that analyzed the EU's evolving CRM lists with specific implications for Kenya. The analysis revealed that the EU's methodology exhibits a few weaknesses that enable spontaneous criticality of materials ('emerging criticality') that include (Zhang et al., 2023):

- (1) A hidden nomination phase;
- (2) Non-dynamic criticality baselines;
- (3) Insufficiently pragmatic motivations;
- (4) A blurring of civilian and military needs;
- (5) A lack of foresight; and
- (6) No explicit consideration of system behaviors.

Key observations for Kenya and similar countries include (Zhang et al., 2023):

- (1) Just energy transition is important to transition away from energy poverty;
- (2) A locally relevant definition of criticality;
- (3) The possibility of an export-bound CRM list and a domestic-needs CRM list, due to relative economic development differences between the Global North and the Global South.

The current assessment methodologies in all published CRM frameworks employ a dimension-based, metric and threshold-delineated combination using a minimum of two (qualitatively) orthogonal dimensions along which metrics are calculated. Properties of CRMs and their mineral value chain that are not fully quantitative are nevertheless assigned numerical scores to facilitate calculation.

Essentially, two key and semi-independent dimensions are always assessed, one along supply and the other demand. The supply dimension is intended to capture the temporal-spatial robustness of the supply chain of materials, such that the assessments along this dimension relate to the reliability of such supply chains. The substitutability of materials is also generally considered, which can modify the considerations of risk under the supply dimension, depending on the range and extent of substitutions possible for known material uses. Similarly, the demand dimension is intended to anticipate the level of demand given a certain forecasted or vision of the future state of the society. This is due to the supply and demand behavior of market systems, in which the CRM value chain resides.

3. The importance of rating CRMs for Kenyan policy

The Kenyan policy landscape is evolving rapidly, driven partly by its rapid pace of social and economic changes, and with it comes significant changes to the country's consumption of materials. As the Global North countries attempt to move towards a more sustainable future, Global South countries are facing a dichotomous set of realities that involves the staging of their own economies (e.g., many are primary or secondary and less involved in tertiary beneficiation industries). Global South countries face a delicate balance between international and domestic consumption needs, and need to secure primary energy generation resources as such nations seek to industrialize and increase their standards of living. Consequently, Kenyan material needs is exceptionally diverse, compared to Global North CRMs (e.g., of high-tech minerals like REEs), and compared to nations that are in the early stages of industrialization (e.g., of base metals, coal and shale for brickmaking);

- **Prioritizing domestic production and stockpiling of CRMs:** Rating CRMs based on economic and technological importance allows a country to determine which CRMs are most essential for its industry and economic growth (Fessehaie and Rustomjee, 2018). This information can assist policymakers in prioritizing the development of domestic production and processing of CRMs, which can create jobs, promote economic growth and reduce import dependency (Government of Canada, 2022).
- **Attracting investment in the resource sector:** Rating CRMs based on resource availability enables a country to provide investors with pertinent information regarding potential resource development (Guzik et al., 2021). Policy mechanisms including the provision of financial and taxation incentives, priority exploration and focused education curriculum can all contribute to attracting investment. This can help attract investment in the resource sector, contributing to economic growth, employment creation and generating revenue for the government.
- **Promoting sustainable resource use:** Rating CRMs through business ethics frameworks allows a country to encourage the utilisation of CRMs with fewer negative impacts on the environment and communities, thus promoting sustainable resource usage (Government of Canada, 2022). This can help reduce resource depletion, minimize
- **Assume a realizable future societal state and identify the materials to be rated:** The first step is to create a realistic vision of the future and identify materials that are currently or will be important for the country's industry, economy and national security.
- **Define the rating dimensions:** The next step is to establish the rating dimensions to be used, which may include economic importance, environmental risk, social risk, governance risk, technological importance, among others.
- **Construct metrics and weights for each rating dimension:** Metrics and weights should be assigned to each criterion to assess its relative importance. For example, if the objective is to emphasize CRMs that are crucial for the country's industry and economic growth, economic importance may be given a higher weight.
- **Collect data on the CRMs:** Data must be collected on the CRMs to be rated in accordance with rating criteria. This data may include information regarding location, economic importance, environmental, social and governance (ESG) risks, technological importance, among others. Data can be sourced from various locations, such as government statistics, industry reports, market dynamics and academic research.
- **Calculate ratings:** Using the collected data, metrics and weights, ratings can be calculated for each CRM. This will provide a score for each CRM based on the chosen rating criteria.
- **Analyze and interpret ratings:** Ratings can then be analyzed and interpreted to understand the strengths and limitations of each CRMs and identify areas for improvement. Ratings can also be used to guide decision-making, prioritize domestic production development and ensure a stable supply of CRMs.
- **Documentation:** The final adopted ratings must be accurately documented and secured. Models that allow automatic rating updates based on the formulae and rating criteria used need to be created for easy analysis in case of a national change in priorities. Ultimately, the knowledge management model detailing the governance of the CRM list in terms of updates, sharing and use must equally be developed.

4. The role of the CRM list for corporate social responsibility (CSR) initiatives

A CRM list can facilitate CSR initiatives, such as the effective usage of ESG frameworks in several ways. The list can be used to optimize exploration and exploitation of materials, as well as to manage acceptable risks and impacts to the environment and society (Kemp and Owen, 2022; Jannesar Niri et al., 2024; L'ebre et al., 2020). Once a list is compiled, organizations and governments will be better positioned to prioritize their efforts to engage stakeholders, reduce risk(s) and minimize impact(s) (Ferro and Bonollo, 2019; Chipangamate et al., 2023), for example, by providing informed scenario planning and simulating various outcomes in advance of an activity. Furthermore, the list can help organizations and governments identify opportunities to source materials from more sustainable and/or responsible sources (e.g., locally recycled resources). A CRM list can promote research and development efforts to find alternative sources of materials or substitutes, especially for high-risk materials, thus reducing resource extraction-associated Environmental and social impacts, while bolstering supply chain resilience (Wall et al., 2017). In addition, data supporting the evaluation of CRMs can be used to perform socio-economic cost-benefit analyses to rank-order various ESG initiatives, and therefore, shape national policy. Designating a CRM implies that more scrutiny around its supply chain must necessarily occur. Hence, a CRM list can help increase transparency around the supply of materials, which can, in turn, help improve the accountability of organizations and governments (Ghamisi et al., 2021a, b). This can help ensure that materials are sourced in a responsible and sustainable manner, and that the potential risks and impacts of their extraction and processing are adequately addressed (Christmann, 2021). A CRM list can help facilitate stakeholder engagement on resource management challenges by providing a common set of materials and issues for different stakeholders to discuss and address. This can include engaging with industry, academia, communities and other relevant groups to identify shared goals and priorities, and to develop strategies to address shared challenges and create opportunities.

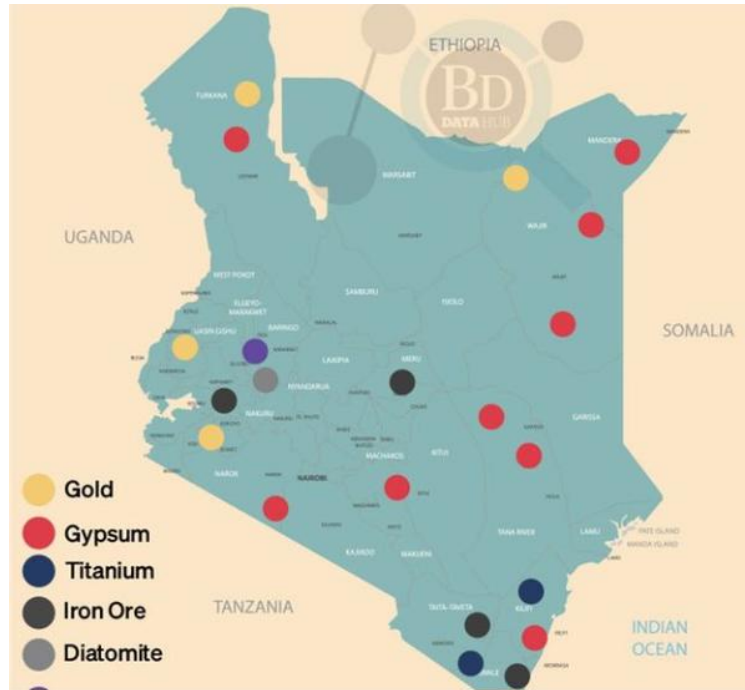


Fig. 1. Historically known and actively mined deposits for the economic and energy prosperity of Kenya. Data sourced from Padilla et al. (2021)

5. The role of a CRM list for research, development and innovation

Numerous operations have been shut down and mining companies have expressed low interest in the continuation of mineral resource extraction. A future effect of the continuation of this reality is that Kenya will likely become more reliant on foreign supplies of materials. This exacerbates the criticality of non-local materials. Innovation is a significant component to solve issues encountered in the minerals sector, particularly if it can be integrated seamlessly. At the moment, the challenges facing the Kenyan minerals sector are many:

- (1) Declining ore grades;
- (2) Worker unrest and labour conditions;
- (3) Low technological and innovation investment;
- (4) Increasingly more complex geology/ore bodies;
- (5) Increasing ESG scrutiny and investor sentiment; and

Although these challenges seem harsh, they are technically solvable. Indeed, innovation is critically needed in the Kenyan minerals sector to modernize it towards:

- (1) Faster and more targeted exploration;
- (2) Increased operational agility;
- (3) More energy-efficient operations;
- (4) Enhanced extraction capability;
- (5) Better environmental monitoring; and
- (6) Safer working environments.

The establishment of a Kenyan CRM list has the potential to catalyze the growth of research, development and innovation (RDI) in the minerals industry, as well as other linked sectors. This is because ideas and innovation on the extraction, processing and use of CRMs altogether depend on their perceived value by stakeholders. Therefore, having clear ratings for Kenya’s CRMs will help the country’s policymakers prioritize funding of various RDI activities. Hence, designation of materials as ‘critical’ creates the necessary conditions for effective policy conditions to catalyze RDI through directing research and development funding and the re-focus of academies, institutions and private entities, which are critical to the rejuvenation of Kenya’s minerals industry. The effect of RDI enabled by the existence of a CRM list is tripartite, because any RDI that assists with the exploration, extraction, processing and recycling of CRMs would necessarily alleviate the criticality of those CRMs.

6. The challenges associated with ranking CRMs in Kenya

Establishing a CRM list can be challenging for several reasons. The ideal of ‘critical’ exhibits geographical, economic and temporal characteristics, which implies that the definitions of criticality are subject to change, especially with rapidly evolving global economic and geopolitical conditions. Kenya is facing an unprecedented energy supply challenge with rolling blackouts (load shedding) that limit all forms of productivity (Ibrahim et al., 2021). This is probably the most rapidly developing social concern and could destabilize society at large. Minerals related to the energy infrastructure are needed to stabilize the energy grid until an energy transition can be reasonably achieved (e.g., Fig. 1).

7. A link between CRMs and a ‘just’ energy transition

CRMs are often used in the production of clean energy technologies, such as solar panels, energy storage facilities, wind turbines and electric vehicles (Dewit, 2021). This could also include nuclear power and biomass energy. Specifically, critical elements include: REEs, lithium, cobalt and copper (Pommeret et al., 2022; Ghorbani et al., 2024a). In addition to clean energy technologies, CRMs are used in other energy-adjacent sectors, such as transportation, construction and industry (Furszyfer Del Rio et al., 2022). For example, CRMs are used in the production of light-weight materials for the automotive and aerospace industries, which can help reduce fuel consumption and greenhouse gas emissions (Pommeret et al., 2022; Jan- nesar Niri et al., 2024). Therefore, the availability and sustainable use of CRMs are important for the transition to a low-carbon, energy-efficient and resource-efficient economy (Valero et al., 2021). Since required CRMs in the energy transition are invariant with respect to the country utilizing them, it is imperative that Kenya establishes its own CRM list to balance between domestic needs versus exports, such that the energy transition remains just. Additionally, it is important to also consider current sources of energy supply, because the energy transition process itself requires energy and its implementation should be smooth and productive. By rating CRMs based on various factors, such as economic importance, ESG risks and technological importance, South

Examples of CRMs used in the green energy sector include (Fig. 2).

- **REEs:** Neodymium, dysprosium and cerium are used in the production of permanent magnets, which are essential components of wind turbines and electric vehicles.
- **Lithium:** Used to produce lithium-ion batteries, which are in turn widely used in electric vehicles, portable electronics and energy storage systems.
- **Cobalt:** Used in the production of cathodes for lithium-ion batteries, in turn used in electric vehicles and portable electronics.
- **Copper:** Used in the production of electrical wiring, printed circuit boards, motors and transformers, all of which are needed in a range of energy-related applications, including electric vehicles, renewable energy systems, and energy transmission and distribution.
- **Graphite:** Used to produce lithium-ion batteries, fuel cells and nuclear reactor-core components.
- **Gallium:** Used in producing photovoltaic cells and producing high- temperature superconductors, which have potential applications in energy transmission and distribution.
- **Silicon:** Used to manufacture photovoltaic cells and semiconductor devices, which are in turn used in a range of energy-related applications, including renewable energy systems and energy-efficient electronics
- **Tungsten:** Used in producing light-weight materials for the automotive and aerospace industries and in producing X-ray tubes and high-speed cutting tools.
- **Zinc:** Used to produce galvanized steel, needed for constructing wind turbines and producing zinc-carbon batteries.
- **Tellurium:** Used in producing photovoltaic cells and in producing alloys for the aerospace industry.
- **Nickel:** Used in producing stainless steel, needed for constructing wind turbines and in producing nickel-metal hydride batteries.
- **Platinum:** Used in producing catalysts for fuel cells, internal combustion engines, jewelry and other luxury products.
- **Calcium:** Used to produce steel alloys, which are in turn used in constructing wind turbines, create cement and other building materials.
- **Iron:** Used in the production of steel, which is needed for constructing wind turbines, and in the production of a range of other products including automobiles, machinery and appliances.

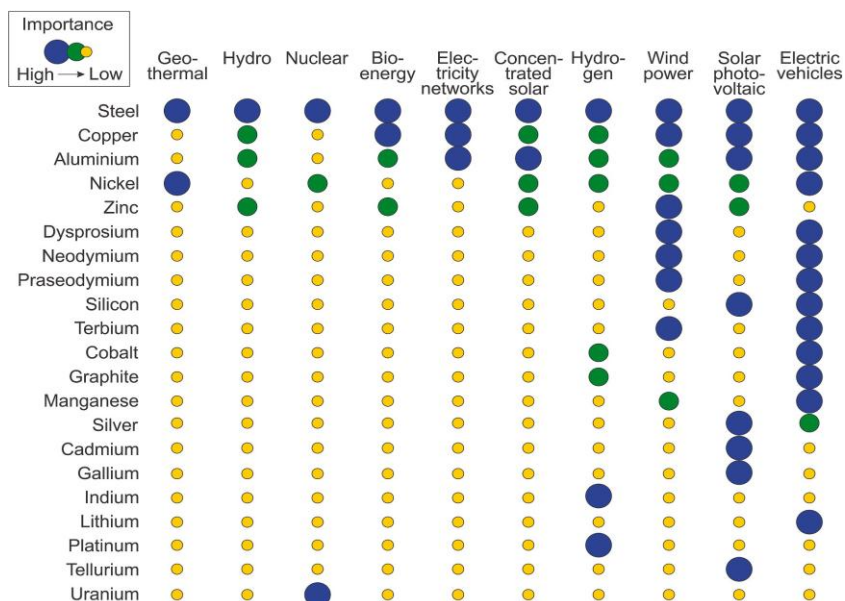


Fig. 2. Materials critical for the transition to a low-carbon economy by technology type (<https://www.mining.com/sponsored-content/minings-energy-challenge/>).

8. Role of stakeholders

Stakeholders play a vital role in ensuring the availability of CRMs. From governments to industry and academia, stakeholders can engage in a variety of activities to ensure the responsible and secure supply of CRMs. From the technical side of mineral resources, geological surveys can play an important role in updating lists of CRMs by providing data and information on the occurrence, distribution and availability of these materials, unless CRMs are designated for national security reasons (Lawley et al., 2021). Geological surveys can collect and analyse data on the geology, mineralogy and geochemistry of different materials, which can be used to evaluate their potential as CRMs. This information can help identify new sources of CRMs and assess the potential risks and opportunities associated with their extraction and processing (Deetman et al., 2018). Geological surveys can also provide data on the environmental and social impacts of CRM mining and processing, which can be used to inform policy decisions and support sustainable resource management. They can also collaborate with other government agencies and stakeholders to share knowledge, develop strategies and plans for the responsible and sustainable supply of CRMs (Ghorbani et al., 2024a, b; Kelley et al., 2021). In this way, geological surveys can contribute to the updating and revising of CRM list by providing data and information that can assess the criticality of different materials.

The private sector can have input on lists of CRMs through a variety of channels. For example, companies that are involved in the mining and processing of CRMs, or original equipment manufacturing (technology and innovation sector), play a crucial role in the identification and revision of CRMs (Cimprich et al., 2022; Applegate, 2022). They can provide information about the materials they use, the sources of these materials, and the challenges and opportunities associated with their supply and use. This information can help inform policy decisions and support the development of strategies for the responsible and sustainable supply of CRMs. Private Sector organizations can also engage with policymakers and regulators through consultation and stakeholder engagement (Chipangamate et al., 2023). For example, they can provide input on draft CRM lists or policy proposals through written submissions, public hearings, or other consultation processes. Private sector organizations can also participate in industry associations or forums that address CRM-related issues and provide a platform for dialogue and collaboration with policymakers and other stakeholders. In addition, private sector organizations can support RDI efforts focused on improving the sustainability of CRM extraction, their processing and/or developing alternatives to these materials. This can help reduce environmental and social impacts of CRM use and mitigate supply disruption risks.

9. Development of the methodology for ranking CRMs in Kenya

Several methods are already published to identify and select CRMs (Tkaczyk et al., 2018; Černý et al., 2021; Hackenhaar et al., 2022). These methods always consider multiple important dimensions (or characteristics), notably: material importance, supply risk and geopolitical impact. Thereafter, the crafting of performance indicators and metrics along dimensions depends on the definition of criticality in a socio-economic and technological context. The importance dimension captures the significance of a material to some current or envisioned future societal state. The risk dimension captures the probability that a significant (e.g., prolonged) discontinuation of supply would occur given a set of probable considerations. The impact dimension captures the repercussions of a discontinuation of material supply. The product of risk (probability of occurrence) and impact is an effective proxy of the net economic cost of inaction, whereas material importance proxies net economic gain of action. A dimensional framework would also work for Kenya, but material importance cannot be solely based on present needs, given its developing nation status, but also in a large proportion, driven by forecasts that are guided by a vision of the future state of the society. This was also a conclusion reached by Khan et al. (2022), which identified a potential vision of the society and linked it to technologies with known material requirements.

- **Economic importance:** selection based on economic considerations, including contribution to the gross domestic product (GDP), employment and trade. A material's economic significance can be influenced by its strategic importance. For instance, a CRM that is dual-use would be significantly affected by its consumption rate or stockpiling in the defense sector.
- **Strategic importance:** selection based on strategic national concern. Moreover, strategic importance can also exhibit significant system-level feedback with supply risk, as materials critical to national security may face supply chain vulnerabilities due to geopolitics.
- **Supply risk:** selection based on notions of probability of disruption. Supply risk must be examined in context of complex systems, such as geopolitical and market competitions, because the dynamics of either is difficult to predict and includes competitive and anti-competitive behaviors, and system behaviors such as panic hoarding.
- **Environmental impact:** selection based on notions of environmental costs and benefits, which include lifecycle assessments of CRMs. Materials with a lower environmental impact may be preferred to those with a higher impact. Additionally, materials with a high environmental impact may face regulatory scrutiny and pressure to adopt more sustainable practices, potentially influencing their supply and societal impacts.
- **Agenda impact:** selection based on democratic agendas, which could include poverty reduction, which is a part of the sustainable development goals. Agendas are essentially a type of societal principle, whose interpretation and implementation depends on pragmatic context. Favorable interpretation could be associated with reduction in supply risk (e.g., diversification of energy mixture), for example.
- **Societal impact:** selection based on potential societal impacts of a disruption in supply, e.g., employment, social stability, continuity of society, health and quality of life. Disruptions in the supply of materials crucial for essential services or industries can have cascading effects on society, affecting employment, social stability, and overall quality

of life. Clearly there could be overlap of indicators along this dimension and economic importance, since societal activities contribute to economic activity.

10. A potential CRM list for Kenya

Based on the metrics that were demonstrated in an example implementation of our framework (section 9), we perform an actual prototype assessment using available data. In this assessment, we use uniform weighting of all indicators across all dimensions. This is because the weights depend strongly on an overall supply and consumption chain analysis (e.g., to increase weighting on supply-bottleneck components), and political focus (e.g., focus on primary resource or infrastructure development versus decarbonisation), which are beyond the scope of this study.

However, the assessment of non-technical and non-economic aspects is intrinsically more qualitative than the other aspects, because there are no universally adopted accountability frameworks (e.g., ESG frameworks) that could be used in data poor and high poverty regions. We do not regard the confidence of social and governance risks at the same level as technical and economic data-informed aspects.

11. A CRM list as an opportunity for Kenya

Kenya has an opportunity to take advantage of the changing global economic landscape and reposition its economy to become a leader in the production, processing and further value-adding of CRMs. With a strategic focus on developing the country’s resources and expanding its industrial base, Kenya can emerge as a major supplier of the essential materials needed to drive the world’s modern economy. Kenya has several opportunities to position itself for success in the production of CRMs and clean energy. One key strategy is the development of a comprehensive CRM strategy that identifies the CRMs that are most important for the country’s energy goals, and outlines strategies to secure stable supply and promote sustainable resource use.

Table 12
Potential list of South Africa’s CRM based on the proposed framework using commodity and economic data sourced from S&P Global (<https://www.spglobal.com/en/>) and Minerals Council of South Africa (<https://www.mineralscouncil.org.za/>). Note: DRC = Democratic Republic of Congo.

Ranking 2022	CRM	Supply Risk	Environmental Risk	Social Risk	Governance Risk	Economic Importance	Average score	Region in Africa
1	Cobalt	0.78	0.79	0.87	0.62	0.72	0.76	DRC, Zambia and South Africa
2	Heavy Rare Earths	0.92	0.68	0.75	0.59	0.64	0.72	Malawi, Namibia and South Africa
3	Niobium	0.97	0.72	0.51	0.55	0.61	0.68	Tanzania
4	Coal, Natural Gas and Oil	0.60	0.65	0.83	0.58	0.66	0.67	Botswana, Mozambique, Nigeria, South Africa and Zimbabwe
5	Light Rare Earths	0.88	0.61	0.57	0.54	0.61	0.65	Malawi, Namibia and South Africa
6	Aluminum	0.63	0.45	0.64	0.55	0.79	0.62	Guinea, Mozambique and Ghana.
7	Graphite	0.75	0.53	0.60	0.49	0.64	0.61	Mozambique and Tanzania
8	Chromium	0.62	0.47	0.57	0.48	0.79	0.60	South Africa
9	Antimony	0.71	0.55	0.65	0.43	0.41	0.57	South Africa
10	Vanadium	0.69	0.42	0.63	0.42	0.55	0.56	South Africa
11	Tungsten	0.67	0.41	0.54	0.38	0.68	0.56	Zimbabwe
12	Tantalum	0.55	0.54	0.76	0.32	0.54	0.55	Rwanda and Mozambique
13	Germanium	0.53	0.39	0.57	0.29	0.49	0.49	DRC and Namibia
14	Manganese and Iron	0.43	0.43	0.49	0.22	0.85	0.48	Morocco and South Africa
15	Copper	0.44	0.37	0.44	0.19	0.82	0.46	Botswana, South Africa, Namibia, DRC, Zambia
16	Platinum Group	0.34	0.45	0.44	0.18	0.57	0.46	South Africa and Zimbabwe

Fig. 3. Historically known and actively mined CRM deposits in Kenya using the proposed list presented in Table 12. Data sourced from Padilla et al. (2021)

12. Policy positions to enable comprehensive management of CRMs

Kenya’s approach to CRM management should be timely, strategic and proactive. One crucial step in this direction is identifying and prioritizing CRMs that are critical to the country’s present and foreseeable future needs, while also directly measuring any discrepancy between domestic production and use, as well as measuring international demand and consumption (Løvik et al., 2018). Establishing a national CRM strategy that considers the long-term needs and goals of the country, and that is reviewed and updated regularly can help to ensure that Kenya’s approach to CRM management is sustainable and effective (Ferro and Bonollo, 2019).

After a CRM framework and a list have become available, stakeholder engagement and collaboration can more effectively occur on a basis of mutual understanding of national CRM goals (Tomazini et al., 2022). A strategic and coordinated approach to CRM policy, guided by a national vision and strategy, across different sectors and levels of government will ensure that: (1) the needs of all stakeholders are considered (Bartekov’a and Kemp, 2016); (2) informed international cooperation and dialogue on CRM issues can occur (Bartekov’a and Kemp, 2016); and (3) a regulatory framework governing the extraction, processing and use of CRMs, including environmental and social responsibility standards becomes available (Cimprich et al., 2022).

Policies aimed to encourage the development of CRM supplies and downstream industries occur primarily as domestic and foreign. Domestic policies could, for example, be focused on the capacity building of the minerals industry, energy and transport infrastructures, knowledge and data acquisition, and talent development. Promoting the recycling and re-use of CRMs including the re-use of mine waste can reduce reliance on primary production and minimize environmental impacts. Developing contingency plans to mitigate the potential impact of supply disruptions, such as stockpiling and alternative sourcing strategies, are also important to stabilize society and ensure future prosperity (Løvik et al., 2018). Encouraging the use of substitute materials where possible can reduce the demand for CRMs and reduce reliance on a

single source of supply (Nova'k et al., 2021).

13. Benefits for regional collaborations between Kenya and other African countries

Regional trade is a significant enabler of a Kenyan CRM market (Table 13). This is because nearby countries are likely to share a substantial amount of ethnography and cultural heritage, as well as challenges (e.g., climate, supply of energy and level of industrialization). Fostering local trade and regional collaborations strengthens Kenya's image and leadership role and enables an overall more

Table 13 Some globally recognized CRMs and countries of recorded presence in Africa based on field studies by the authors. Note: DRC = Democratic Republic of Congo. Metals such as gold, copper, nickel and others are also recorded in many other African countries and not limited t

CRM	Use	Country of recorded CRMs presence
Cobalt	A metallic element used in the production of batteries and other electronic products.	DRC Zambia Morocco
Copper	A metallic element used in the production of wire and cable, and in a variety of other applications.	DRC Zambia Morocco
Iron Ore	Used in the production of steel.	Liberia Gabon Mauritania
Manganese	A metallic element used in the production of steel and other alloys.	Ghana Gabon South Africa
Nickel	A metallic element used in the production of stainless steel and other alloys, and in the production of batteries.	Madagascar Zambia South Africa
Uranium	A radioactive element used as fuel in nuclear power plants.	Niger Namibia Zambia
Zircon	Used in the production of ceramics and refractories, and in the production of abrasives.	South Africa Sierra Leone Senegal
Limestone	A sedimentary rock used in the construction industry as a raw material for cement and other building materials.	Egypt Morocco Tunisia
Gypsum	Used in the production of cement and plaster.	Morocco Tunisia Algeria
Platinum	A metallic element used in a variety of applications, including catalytic converters for vehicles, electronics, and jewellery.	South Africa Zimbabwe Tanzania
Gold	A metallic element used in a variety of applications, including jewellery, electronics, and as a store of value.	South Africa Ghana Mali
Palladium	A metallic element used in producing catalytic converters for vehicles and in other industrial applications.	South Africa Zimbabwe Tanzania

Overall, there are several ways in which Kenya can benefit from trading CRMs with other African countries.

- **Diversification of supply:** Trading CRMs with other African countries enables Kenya to diversify its sources of supply and reduce its reliance on any single country or region. This can help to reduce the risk of supply disruptions and increase the overall security of supply for Kenya.
- **Economic benefits:** Kenya can derive economic benefits from trading CRMs with other African countries by generating new markets and opportunities for local producers. This can boost economic growth and development in the nation, spurring greater development in the southern African region, and leading to the creation of dependent markets, such as beneficiation, battery manufacturing and recycling industries.
- **Strengthening regional ties:** Trading CRMs with other African countries can help to strengthen regional ties and promote collaboration and cooperation within the continent. This can help foster a sense of shared interests and goals among African countries, leading to greater political stability and economic development in the region.
- **Environmental benefits:** Kenya can reduce its reliance on long distance shipping by increasing regional trades. This would also help to improve the social acceptance factor for Kenyan companies in the regional context.

14. Opportunity to collaborate with the Global North countries

There are several ways Kenya can use its CRM-derived policies to collaborate with the Global North countries.

- **Identify areas of mutual interest:** Kenya can leverage its policies to identify areas of mutual interest with the Global North, particularly regarding the common CRMs of importance to both regions. This can help to create opportunities for cooperation and collaboration in terms of CRM production, processing and recycling.
- **Promote Kenyan expertise:** Kenya can use its policies to highlight its expertise and capabilities in the CRM sector, and to showcase its potential as a partner for CRM projects in the Global North. This can help attract investment, talent exchange and collaboration from the Global North and create opportunities for Kenyan companies to participate in CRM projects in other countries.

- **Share information and best practices:** Kenya can use its CRM policies to share information and best practices with the Global North, particularly regarding sustainable resource management and recycling of CRMs. This can help to promote the adoption of more sustainable practices in the global CRM sector, and can help to reduce the environmental impacts of CRM extraction and processing.
 - **Participate in international engagements:** Kenya can use its CRM policies to participate in international engagements and initiatives that focus on CRMs. This can help raise Kenya's profile as a participant in the global CRM sector, providing opportunities for Kenya to engage with other countries and regions on CRM-related issues.
- Overall, well-crafted CRM policies can provide a range of opportunities for Kenya to collaborate with Global North countries on CRM-related challenges, promoting the country's expertise and capabilities in this sector.

15. Conclusions

CRMs play an important role in the economy and society, but are at risk of supply disruption due to a variety of factors, including: resource depletion, geopolitical conflicts, environmental and social impacts. Many countries and super national entities have established their own CRM frameworks, which are followed by the establishment of a CRM ecosystem through legislation and policies. Kenya is in a period of rapid societal evolution and exhibits unique characteristics, for example, in terms of its staging of economy, social wellbeing and energy supply stability. The development of a Kenyan CRM framework can help formalize the importance of materials and provide the necessary context for a national strategic approach to CRM management and governance. In this study, we have reviewed the history of CRMs and their assessment methods, and identified key areas of positive contribution of a comprehensive and timely CRM framework to Kenya, as well as discussed the role of different stakeholders, including the private sector, civil society and the general public. Based on our review and analysis, we recommend that a national CRM framework be established, followed by CRM policies to create a CRM ecosystem. This can involve a range of actions, including developing/updating CRM lists based on robust and transparent indicators and data, promoting research and development efforts focused on improving the sustainability of CRM extraction and processing, and engaging different stakeholders in the policy-making process.

Domestic and foreign policies in pursuit of CRMs must be driven by a combination of present and future needs, altogether shaped by a local context. A CRM ecosystem for Kenya, starting with a prototype CRM framework and list, not only serves Kenya, but also other aspiring nations to consider their interests, assess their developmental state and geopolitical position, and develop a convincing and achievable vision. Lastly, we recommend that policymakers and regulators consider the broader implications of CRM use and supply, including system behaviors (e.g., formation of trade blocs), as well as environmental and social impacts.

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