UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE

Critical Minerals for the Sustainable Energy Transition

A Guidebook to Support Intergenerational Action

UNECE

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This Guidebook is a publication of the Resource Management Young Member Group (RMYMG) of the UNECE Expert Group on Resource Management

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Foreword

Climate change is a global challenge that requires a significant shift towards low-carbon energy technologies. Clean energy transitions contribute to curbing greenhouse gas emissions and decarbonizing our industrial systems, keeping the 1.5 Goal of the Paris Agreement within reach. However, current climate and energy policies remain highly resource-intensive: it is expected that by 2040, the demand for critical minerals will increase fourfold if the world is on track to achieve net zero.

This specifically concerns the UNECE region which unites some of the world's key clean energy technologies manufacturers and consumers. If managed responsibly, critical minerals might become a backbone of sustainable economic growth, benefiting communities both in Europe and globally. On the other hand, if no common approach prevails, there is a risk for our climate ambition to cause more environmental pollution through mining, processing, and disposing of critical minerals.

This challenge reminds us again of the pressing need for international cooperation with intergenerational equity at its core. To inform the debate and enable meaningful change, young professionals from the Resource Management Young Member Group of the UNECE Expert Group on Resource Management have developed this comprehensive Guidebook for intergenerational action. The main idea behind this paper is straightforward: to make our energy transition truly clean and just, we need to make sure that the whole critical minerals value chain from mining to processing and, eventually, to disposal is environmentally sound and ecologically sustainable while embedding intergenerational equity in resource management.

The Guidebook maps out key challenges associated with sustainable use of critical energy minerals across their life cycle and provides actionable recommendations to stakeholders whose engagement is crucial to manage critical mineral resources responsibly. In particular, the Guidebook emphasizes the ways in which the United Nations Framework Classification for Resources (UNFC) and United Nations Resource Management System (UNRMS) could enable a common approach to critical minerals management at a time when multilateral collaboration is urgently needed, including on a number of novel aspects such as circular economy in the clean energy technologies sector and environmental regulation of deep-sea mining.

Critical minerals are a crucial element underpinning our clean energy transitions. Looking ahead to 2030, this Guidebook is an important and timely contribution from young experts to the ongoing work at the UN Secretary General's Working Group on Transforming the Extractive Industries for Sustainable Development and the Panel on Critical Energy Transition Minerals announced at COP28. It is by joining forces with youth that we can deliver on this issue and make intergenerational action work.

Tatiana Molcean
United Nations Under-Secretary-General
UNECE Executive Secretary

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List of Abbreviations

CETM	Critical energy transition mineral
CRIRSCO	Committee for Mineral Reserves International Reporting Standards
DRC	Democratic Republic of the Congo
EGRM	Expert Group on Resource Management
EV	Electric Vehicles
GDP	Gross Domestic Product
GHG	Greenhouse Gas
ISA	International Seabed Authority
LCE	Lithium Carbonate Equivalent
LIB	Lithium-Ion Battery
NGO	Non-Governmental Organization
NZE	Net Zero Emissions
PGM	Platinum Group Metals
REE	Rare Earth Element
RMYMG	Resource Management Young Member Group
SLO	Social License to Operate
UNECE	United Nations Economic Commission for Europe
UNFC	United Nations Framework Classification for Resources
UNRMS	United Nations Resource Management System
USGS	United States Geological Survey
WBCSD	World Business Council for Sustainable Development

(Abbreviations excluding the Annex)

What is EGRM and the RMYMG?

Youth engagement in resource management

Despite the centrality of resource management in addressing the interlinked environmental crises, international governance on resource management has been limited. This is in stark contrast to international environmental and climate processes, which bring together thousands of negotiators, policymakers, and civil society stakeholders each year in an attempt to raise the bar for multilateral action. The primary international coordination mechanisms for advancing sustainability efforts in the extractives sector are led by the *International Council on Mining and Metals (ICMM)*, an industry body, and *the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF)*. United Nations entities such as the *UN Environment Programme (UNEP)* and the *UN Industrial Development Organisation (UNIDO)* as well as intergovernmental institutions such as the *International Resource Panel, Organisation for Economic Cooperation and Development (OECD)*, and *International Energy Agency (IEA)* provide advice to governments on best practices and policy-setting. However, governance of mineral resources and their sustainability lies within the domain of national governments.

This means that the ability of young people and other civil society actors to provide input on policy processes pertaining to resource management is mainly limited to national engagement mechanisms, such as those during permitting and planning processes. At the international level, the only stakeholder-inclusive governance mechanism is found at the *United Nations Environment Assembly (UNEA)*, held biennially at the UNEP Headquarters in Nairobi, Kenya.

At the recent UNEA-6, RMYMG members took part in negotiations on the *resolution on minerals and metals* through the *Children and Youth Major Group to UNEP*, working with NGOs and member states to support principled and inclusive language. Despite a *lack of ambition in the final agreed text*, UNEA-6 highlighted the role of young people as not just advocates for a sustainable future but also professionals and experts who can provide substantive input into international governance processes.

Furthermore, the continued spotlight on the contentious topic of seabed mining means that the *International Seabed Authority (ISA)* and the *Intergovernmental Oceanographic Commission of UNESCO (IOC/UNESCO)* are also emerging fora through which civil society stakeholders can engage and ensure that the best available scientific evidence can inform policy guidance in support of intergenerational equity.

Separately, the *Expert Group on Resource Management (EGRM)* of the *United Nations Economic Commission for Europe (UNECE)* develops, promotes, and supports the implementation of the *United Nations Framework Classification for Resources (UNFC)* and the *United Nations Resource Management System (UNRMS)*, comprising principles, specifications, guidelines, application protocols (procedures and checklists)and best practices to aid sustainable management of energy, raw materials, and other resources.[1]

The *Resource Management Young Member Group (RMYMG)* is a working group of the Expert Group. The initiative officially began in 2023 to promote youth engagement in the energy and resource industries within the

[1] A complete list of activities of the RMYMG in 2023 is available here: *https://unece.org/sites/default/files/2024-04/EGRM-15-2024-INF.2-RMYMG-Activities2023.pdf*

framework of sustainable resource management. In April 2023, the Expert Group noted with appreciation the revised *Terms of Reference of RMYMG*.

RMYMG is established to ensure intergenerational equity where the views of the youth are considered in current decision-making on resource management. In parallel, RMYMG is recognized as a learning platform for the youth to partake in research, resource policies, and regulation processes on sustainable resource management.

RMYMG represents youth perspectives in current decision-making on resource management. The Group consists of young experts who contribute and exchange knowledge and information within the Group itself and with the Expert Group. RMYMG's aims are threefold:

1. Bring innovative perspectives and skills into current discussions;
2. Form leading decision makers for comprehensive, resilient, and sustainable energy transition and resource development;
3. Ensure a long-term continuation of sustainable resource development beyond 2050.

Introduction

Intergenerational equity entails a notion of equal opportunity across generations. It emerges out of the growing recognition of the devastating consequences (and potential opportunities) that widespread environmental degradation (and solutions to repair them) and increasing financial debt will pose in the coming decades. The collective goals of the Paris Agreement, and the *interim commitments* to triple renewables capacity, double energy efficiency, and *bring clean energy to all by 2030,* mean that we face a monumental task of reconciling extracting the requisite natural resources required for the transition with its social and environmental harms and benefits.

The complexity and geopolitics of transforming our energy systems are one of the most prominent challenges of today, with significant intergenerational social and environmental implications. Moving beyond the fossil fuel-dominated global economy requires change at multiple earth systems levels. Mining activities, including prospecting, exploration, construction, operation, maintenance, expansion, closure, decommissioning and, where possible, repurposing[2] can pose a range of social, environmental, and economic impacts, both positive and negative. On the one hand, the mining of critical energy transition minerals (CETMs)[3] can impact many natural resources (the *shared inheritance of humanity*) which deplete, transform, or dissipate with extraction. On the other hand, we should not underestimate the strategic importance of CETMs for the energy transition and economic development of resource-rich communities.

Low-carbon energy technologies, such as electric vehicles (EVs), battery storage systems, wind and solar power plants, are generally *more mineral-intensive* than their fossil fuel counterparts. This heightened demand for minerals is driven by their integral role in various components of these technologies: a typical EV requires *six times more* mineral inputs than a conventional car, while an onshore wind farm requires nine times more minerals than a gas-fired power plant of the same capacity.

The inventory of global CETMs indicate a high level of overlap with territories that are less impacted by historic forces of industrialization, wherein over *54% of CETM resource base* is located on or near the lands of Indigenous peoples, whose rights to consultation and *free, prior and informed consent* are embedded in United Nations declarations.

The intergenerational implications of how we tackle challenges around CETMs is fundamentally about equity, not least because the lifespan of a mine can last over a generation's time, or that mining-related employment tends to have generational legacies, but also because mining activities often have irreversible impacts on the environment and on sustainable development, casting long shadows over the well-being of future generations.

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[2] Mine closures can leave behind a legacy of environmental degradation. Environmental rehabilitation and repurposing of land infrastructure can make land available for future use after their usage for industrial activities. For more on repurposing and mining land potential, see: *https://ccsi.columbia.edu/content/circular-economy-mining-land-potential*

[3] Here, we use the term "critical energy transition minerals" (CETMs) to broadly categorize the critical minerals that are needed for the energy transition, while acknowledging that the categorization of "criticality" is a political designation, as explored further in this Guidebook.

Tracing the minerals lifecycle, this Guidebook intends to elevate the importance of discussions around CETMs to a diverse, non-technical audience in an accessible manner. The Guidebook aims to serve as a hub of accessible information that can facilitate knowledge exchange and encourage further intergenerational action on this topic. Lastly, we hope that the Guidebook can support the alignment of the youth climate and environmental movements with ongoing initiatives relevant to extractive industries, so intergenerational considerations are meaningfully embedded in all aspects of a just transition towards sustainable systems.

Understanding the Global Critical Minerals Lifecycle: Environmental, Social, and Economic Opportunities and Impacts for Sustainable Development

The reality remains that a significant increase in production and international trade of critical minerals is likely to be required to meet the projected demand for the transition to net zero, barring significant behavioral changes in global approaches to well-being and sufficiency. This thus poses a series of questions, including (1 how much of the finite mineral reserves can and should we realistically extract to meet future energy demands, and (2 how can the requisite extraction be operationalized without worsening existing issues such as environmental integrity, health, safety, and social equity?

What is a Value Chain?

To gain a holistic understanding of how we can sustainably and inclusively manage the global critical minerals landscape, let's first understand the value chain. A value chain is described as the end-to-end life cycle of a product or process that starts from sourcing of materials, production, consumption, and disposal or recycling. This also follows the *pathway* of the product from suppliers, producers, and consumers.

Moreover, value chains are characterized by a complete array of activities needed for a product or service to be transformed from its conception to different phases of production. Those may involve combinations of *physical transformation and input* from various producer services, delivery to final consumers, and final disposal after use.

The supply of critical minerals is particularly vulnerable to external shocks due to its geographic concentration and the importance to global trade. For example, the COVID-19 pandemic posed severe challenges to global critical mineral supply chains in the past few years. The lockdowns implemented in many countries affected the global output of many critical commodities, highlighting the risks associated with clean energy value chains. In Peru, copper mining activities, which were responsible for 12% of the world production, were halted due to lockdown measures. In South Africa, travel and trade restrictions associated with the pandemic constrained the production, refining, and export of platinum-group metals, sending prices skyrocketing in 2021. Similar imbalances between supply and demand have put upward pressure on global commodity prices in the post- COVID recovery, adversely affecting the importing countries' economies and exerting inflationary pressures worldwide.

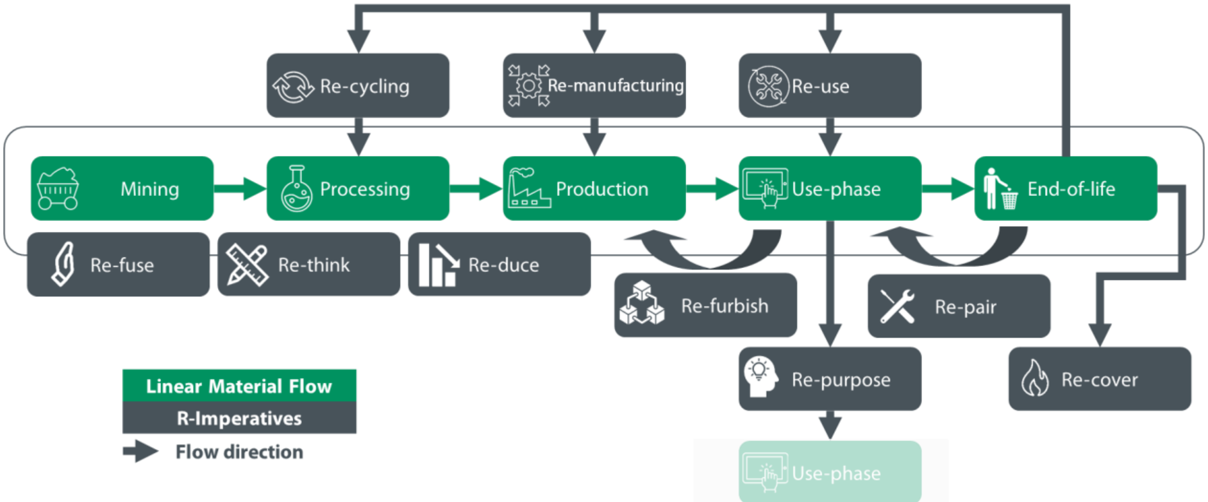

Figure 1. An overview of the critical minerals value chain (Source: Emerging Battery Technologies to Boost the Clean Energy Transition)

The possibility, affordability and speed of the energy transition will be heavily influenced by the availability of critical minerals for clean technologies. In the *Net Zero Emissions Scenario*, the demand for critical minerals for clean energy applications is expected to increase by 400% between 2022 and 2030. EVs and battery storage are the primary drivers of this growth, with additional demand for renewable energy technologies. By 2030, the clean energy sector is projected to account for nearly 90% of total lithium demand, compared to 60% in 2022. Lithium is today a key component in the production of rechargeable batteries, making it essential for the growing electric vehiclemarket and energy storage systems. Despite recent increases, the current projected supply falls short of meeting these requirements, emphasizing the need for additional investment in new mining and refining facilities. While there has been encouraging progress with increased capital spending and exploration, diversifying supply sources remains a concern, particularly for nickel and cobalt. We will explore the challenges around geographic concentration further below. The majority of planned refining and processing projects are centralized in established producers, with China overseeing half of the proposed lithium refining projects, and Indonesia accounting for nearly 90% of the planned nickel smelting facilities.

Exploration and Project Development

The first phase begins with **the development of the project and the exploration of potentially viable mineral deposits**. This exploratory phase comprises different components, such as locating mineral deposits through the conduct of geological surveys, and studying rock formations and soil types. Methods of such include remote sensing technologies (e.g. satellite imagery to identify patterns and anomalies indicating mineral presence), geophysical methods (e.g. seismic, magnetic and gravity surveys) or geochemical analysis of soil, rock, or water samplings. The collected data is then gathered and integrated to create an understanding of the geological setting of a potential mine. This stage also encompasses a technical, environmental and economic risk assessment associated with developing a mining project in a specific location. Explorative activities have comparably small environmental and social implications compared to an actual mining site. However, they are not to be underestimated. Understanding the implications of the exploratory phase is crucial, particularly when considering the high exploration-to-mine ratio. This ratio, on average, reveals that for every mine opened, there were over *100 unsuccessful exploration projects*. This statistic underscores the challenges and uncertainties inherent in the exploratory phase, highlighting the need for thorough and meticulous approaches to understanding social and environmental impacts and technical feasibility.

Production: Extraction, Processing, and Refining

After successful exploration, the second phase, production, begins. **Production** entails three main steps: extraction, refining, and processing.

Various options exist for extracting minerals from the earth, depending on the deposit's characteristics, location, environmental impact, geological and hydrogeological factors, geotechnical characteristics, technology, and economic potential. For instance, given that a considerable amount of excavated material needs to be removed before reaching the mineral, open-pit mines must build waste rock dumps, which alter the ground and landscape. Underground caving methods can cause rock to collapse, which causes surface subsidence.

Whatever extraction method is used, the materials extracted are often then transported to the second stage, **processing** (or pre-processing where needed, including sorting or crushing). Here, the main goal is to **separate the valuable minerals or resources from the waste material** surrounding them. Possible processes include hydrometallurgy, pyrometallurgy, and electrometallurgy to extract valuable components' concentrate. This stage can be water, energy, chemicals, and waste-intensive.

Some metals can be manufactured immediately after processing, but more often than not, **smelting** or **refining** comes next. In the case of *pyrometallurgical* refining, high temperatures are used to separate precious metals from contaminants, by increasing metal concentration. To ensure that the extracted material fulfills the appropriate quality and composition standards, the material must be purified. Once ready, the resource can be used as a raw material in other sectors.

Numerous goods and services are offered to the mining sector for all of these processes to occur, which means that the mining industry has a complex value chain. Additionally, minerals' smelting and refining processes generally don't take place in the same region, which adds to the globalized complexity of the entire value chain, both upstream and downstream.

Significance of the Geographic Concentration of Mineral Supply Chains

A key characteristic of today's critical minerals value chain is its high geographical concentration of production. Over *three-quarters of the global output* for lithium, cobalt, and rare earth elements congregates in the top producing nations: China, Australia, Chile, and the Democratic Republic of the Congo (DRC). Such a high level of concentration in complex supply chains of critical minerals can pose risks to supply chain resilience, which can arise from physical disruption, trade restrictions, or other factors. This takes place against a global trend of resource-rich nations seeking to capture higher positions in the value chain while importing nations aim to diversify their source of refined supplies. We will dive into the challenges of diversifying midstream supply chains further below.

To illustrate the geographic concentration of critical minerals, the *United States Geological Survey's 2024 Mineral Commodity Summaries* reports that global cobalt mine and refinery production not only reached an all-time high in 2023, but also that the increase was highly concentrated in the DRC. According to the same document, in 2023, the DRC accounted for 74% of world cobalt mine production, South Africa 67 % of global platinum production, and Russia 44% of the world's palladium.

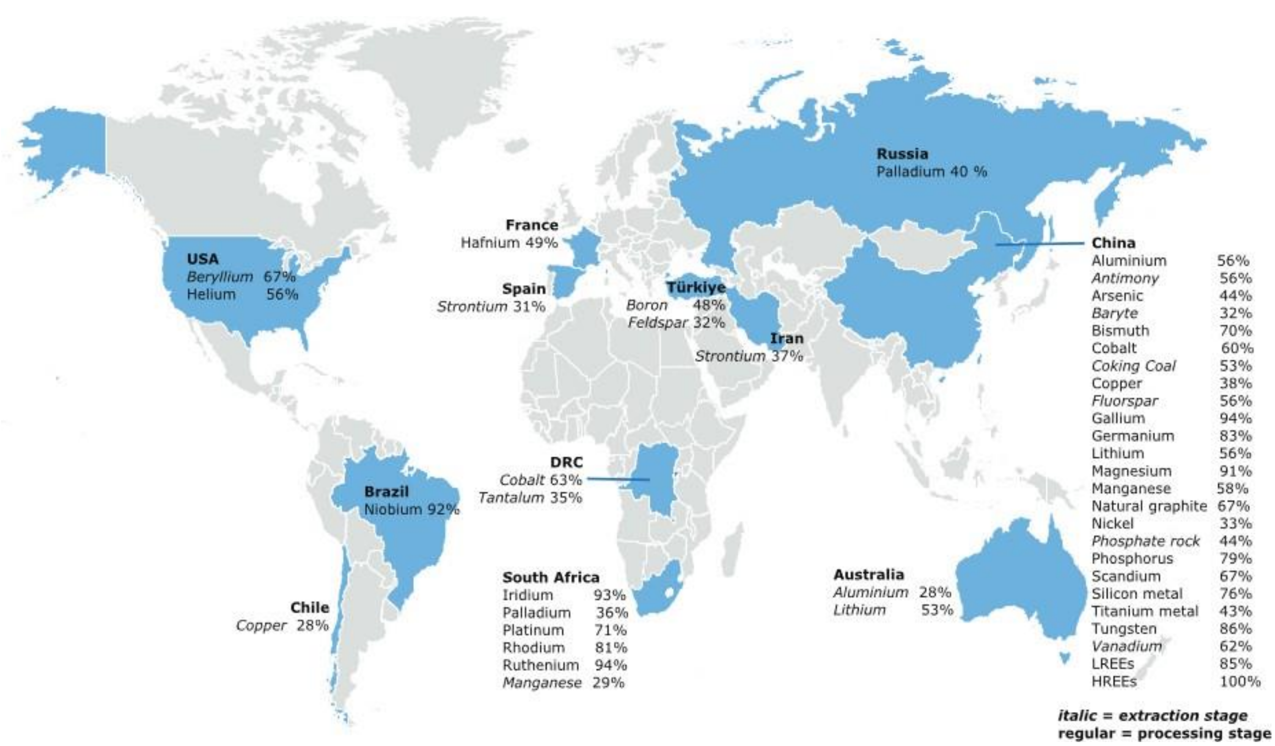

Figure 2. Countries accounting for largest share of critical raw materials (Source: Study on the Critical Raw Materials for the EU 2023)

Figure 2 highlights the leading global producers of raw materials that have been identified as critical for the European Union in 2023. An analysis of the global supply landscape confirms that China is the largest supplier of several key raw materials. In addition, other countries play a crucial role as global suppliers of specific materials. For example, Russia and South Africa are the world's leading suppliers of Platinum Group Metals (PGMs), the United States is a leader in beryllium production, and Brazil plays a key role in niobium production.

As the demand for EVs continues to rise, the need for minerals such as cobalt, lithium, nickel, and manganese will rise exponentially. Demand for cobalt is expected to increase *substantially*, with a forecast growth of 3.7 times from 2017 to 2030, mainly due to the growing electric vehicle market and expansion of energy storage systems. From 2022 to 2030, demand for nickel is also *expected* to double from 2022 to 2030. These figures underscore the importance of the geographic concentration factor in the global critical minerals value chain.

We have looked at some of the effects of mining operations up to this point. However, it's crucial to recognize that mining operations have broader effects that extend beyond what we've discussed so far. These outcomes and effects encompass economic, social, and environmental factors, all of which play significant roles in shaping the results and consequences of mining. They are also all not negative impacts: with adequate social and environment safeguards, meeting the demand of CETMs can also generate *employment opportunities* and structural transformation[4] with local content policies and in-country value addition mechanisms.

Mining operations can also happen not only on land but also in the deep sea, which presents a unique and specific set of challenges that need to be very carefully assessed.

[4] For more on the concept of "structural development" in the concept of industrial policy and economic development, see *https://unctad.org/system/files/official-document/gds2016d1_en.pdf*

Deep-Sea Mining

The deep sea, which entails any *area under 200 metres (656 feet)*, contains a vast amount of *mineral resources* such as copper, nickel, aluminum, manganese, zinc, silver, gold, cobalt and rare earth metals. The mining of the deep seabed, at depths of 2,000 meters and greater, is being considered as a potential solution to reach the required components of "transition-critical" minerals to meet emission reduction targets. The primary sources of deep-sea minerals are polymetallic nodules which come in various sizes ranging from peas to bowling balls and are found resting on abyssal plains, seafloor sulfide deposits on active or inactive hydrothermal vents, and cobalt-rich crusts, which are mainly located in deep-sea mountain ranges and slopes.

It is important to focus specifically on **polymetallic nodules**, which are considered the most important metal deposits in the sea today. Polymetallic nodules found in the Clarion Clipperton zone are estimated to be around *21 billion dry tons and* contain cobalt, nickel, copper, and manganese. These nodules typically have an average growth rate of 1-3 mm per million years and ar*e located in abyssal plains at about 3000-6000m water depth*. They are usually found resting within the first 10 cm of sediment and are located in all major oceans.

It is assumed that the polymetallic nodules contain more minable manganese than reserves on land. Research *estimates* a global tonnage of 21×10^{10} dry tons for manganese nodules; hence, they are commonly known as "**manganese nodules**". Mining the nodules is by no means a cheap process, and there is still no economical way to extract them. However, they are still considered the most significant deposit of metals and other mineral resources in the sea today.

There is also an ongoing debate about the possibility of an environmentally sustainable energy transition if we extract minerals from the deep sea. Potential regulations of deep-sea mining in international waters are still being discussed at the **International Seabed Authority** with multiple countries advocating for a precautionary pause until common rules are established. The deep sea in international waters is the last pristine ecosystem in the ocean, where humans have not engaged in extractive activities. Additionally, the deep sea serves as a carbon reservoir, and even minor disturbances could disrupt the necessary carbon cycle that sequesters it, turning the ocean from one of our main allies in the fight against climate change into an emitter and part of the problem. The complete scale of existing biodiversity and services provided by the deep sea are still *relatively unknown*.

A *comprehensive understanding* of the deep-sea environment and the potential impacts of mining is crucial for compliance with the International Seabed Authority's obligations to prevent "serious harm" and ensure the "effective protection of the marine environment from harmful effects" required by the **United Nations Convention on the Law of the Sea**. Despite increased research, publicly available scientific knowledge for evidence-based environmental management in deep-sea mining is limited. Closing scientific gaps in deep-sea mining is vital to prevent severe harm and ensure environmental protection, requiring substantial resources and coordinated efforts.

Manufacturing

After the processing or refining stage, comes the manufacturing stage. For instance, in the production of EVs, manufacturing *entails* the processing of refined minerals to form battery materials that are incorporated to produce battery cells and packs for EVs.

An array of social and economic factors is posing increased pressure on natural resources, including interrelated population growth, economic demand, and technological advances, all of which can lead to greater use and consumption of minerals. Scientific progress has allowed researchers to identify elements with properties that can be adapted to their specific needs and apply them to new technologies. However, having access to abundant raw materials is not the sole indicator of the successful deployment of clean energy technology value chains. Countries endowed with mineral resources will need **critical infrastructure, investment, and skills** to leverage the required technology to harness opportunities for the low-carbon future.

Currently, battery cell and component manufacturing are largely confined to Asia. Specifically, China, the Republic of Korea, Japan, and other developed countries *capture* most of the world's lithium manufacturing capacity. Furthermore, China accounts for 67% of the world's exports of lithium oxide and hydroxide at the processing stage, and maintain lithium-based battery materials for domestic use, specifically in battery packs manufacturing, and *exports* these battery packs to major industrialized EV exporters such as Germany and the U.S. In terms of cobalt, as mentioned above, while the DRC produces over 70% of the world's cobalt (extraction and partial refinery), China is the world's leading producer of refined cobalt, most of which is produced from partially refined cobalt imported from the DRC. Nearly *87% of China's cobalt consumption* is used by the lithium-ion battery industry. Demand for high-purity battery-grade lithium chemicals is *expected to reach* 700,000 tonnes by 2025, and 1.6 million tonnes of lithium carbonate equivalent (LCE) by 2030. Considering the fact that a handful of countries lie central to the major consumers of lithium-ion battery (LIB), this presents an opportunity for resource-rich nations.[5]

Aside from battery minerals, Rare Earth Elements (REEs), such as neodymium, dysprosium and praseodymium, are key ingredients of permanent magnets (magnets that retain their magnetic properties over an extended period without external influence), used in high-performance wind turbines and electric motors.[6] Global wind power capacity additions are expected at an annual average of 77GW from 2020 to 2029, according to *Wood Mackenzie.* This represents a growth of 112% in global installed capacity from 2019 to 2029. In terms of REE consumption, this equates to an average increase in global REE consumption of 15,400 tonnes per year in wind turbines alone, a clear indication of robust growth in the global REE market.

[5] Abridged version of the draft African Green Minerals Strategy, prepared by the African Development Bank Group and its Partners (AU/AMDC, ALSF and UNECA) that document's data and analysis to support the strategy for Africa's green minerals, 2023.

[6] Rare earths are a group of 17 elements composed of scandium, yttrium, and the lanthanides. They are difficult and costly to extract and process, although they are relatively abundant across the world.

What Makes Critical Minerals "Critical"?

Global Criticality Assessments

In an increasingly raw materials-constrained world, criticality assessments have become crucial in addressing the challenges facing the energy transition and raw materials safeguarding at national and regional levels. It is globally understood that critical minerals are a prerequisite to the sustainable energy transition, as they are the building blocks for green technologies.

Dealing with the arbitrary distribution of critical minerals and the geopolitical implications surrounding their access, various screening exercises have been developed by the different stakeholders to identify the degree of criticality of mineral resources. These exercises, also known as **criticality assessments**, plays a pivotal role in enlisting the critical mineral resources that underpin economic prosperity and security, enabling policymakers and industry stakeholders to comprehend the vulnerability of their supply chains and ensure the security of their raw materials availability.

Typically, the criticality assessments result in a list of minerals that are labeled "critical" once they surpass the predefined thresholds. However, it is important to note that criticality assessments are *not standardized across regions*. Against this background, **different geographical areas employ unique criticality assessment methods and consider different criticality indicators according to the geographical scope of the system under question**. This lack of standardization is often a result of differences in goals, scopes, and outcomes of criticality studies. Additionally, the availability of high-quality data limits the evaluation of criticality, making it crucial for methods to be more transparent to support interpretation.

Purpose of Criticality Assessments

As governments worldwide continue their quest for sustainable and green energy systems, criticality assessments serve as an essential screening tool in ensuring a stable supply of raw materials. Conducting criticality assessments allows the identification and prioritization of the critical minerals, as a preliminary step towards a resilient supply chain and sustainable energy. In simple terms, safeguarding critical minerals begins with criticality assessments. These assessments also facilitate policy formulation, which serve the overarching purpose of sustainable resource management, including exploration, extraction, trade, and recycling of critical minerals. Additionally, criticality assessments inform investment decisions by highlighting areas of growth, technological advancements, and emerging markets, attracting investment and promoting economic development. On a different note, identifying critical minerals fosters international cooperation through platforms for knowledge sharing, technological exchange, and policy harmonization at national and regional levels.

Most Common Criticality Indicators in Criticality Assessments

As previously mentioned, criticality indicators vary from method to method depending on the scope and goal of the assessment, geography, and supply and geopolitical risks. Yet, many criticality assessment methods share similar indicators. The economic importance is a popular indicator amongst most methods.

This factor focuses on the role of a specific raw material in a region's economy, including evaluating the material's contribution to GDP, employment, and industrial sectors in the case of countries. Economic importance is often measured through market value, utilization rate, and downstream sector dependence indicators. Supply risk is also a common indicator in criticality assessments. Its evaluation considers the potential risks associated with a raw material's supply chain, including geopolitical risks, production concentration, import dependency, and substitutability. *Supply risk assessments* typically involve analyzing domestic and global production, trade flows, and historical supply disruptions. Some criticality assessments also consider the environmental impacts associated with the production, use, and disposal of raw materials. Such impacts are measured based on carbon footprint, water usage, and waste generation. This *criticality indicator* is crucial and helps guide sustainable resource management strategies and promotes environmentally sound decision-making. Lastly, several criticality assessments include technological importance, which considers the role of a raw material in enabling key technologies or industries.

Criticality Assessment Methods[7]

Region/ Country	Conducting authority	Primary aim of assessment	Methodology and Main Criticality Indicators	Outcome of the Assessment
European Union	European Commission	Upscaling and accelerating European Critical Raw Materials production, monitoring, criticality, prioritizing requirements and actions, diversifying the supply streams, informative policy making, addressing trade alteration measures, increasing competitiveness of the EU economy	Economic importance and supply risk considerations, including factors like market concentration, governance issues, substitutability, recycling potential, and geopolitical risks	Critical Raw Materials list, Strategic Raw Materials
United States	US National Research Council (NRC)	Establish a concept of a general framework to assess material criticality, identify minerals essential for	NRC: Economic importance, supply risk, susceptibility to supply disruption	NRC: Framework for material criticality, risks include material unavailability and market prices

7 For more compilation of criticality assessment methods, also refer to *this* iterative, live document developed in the context of the International Roundtable of Material Circularity (*IRTC*): *https://docs.google.com/spreadsheets/d/1fsVpnTd6uV1J8tEflvYmVQn7CwcziQN-HJAY8tdjZM0/*

	US Geological Survey (USGS)	the U.S. economy and national security	USGS: Economic importance, supply risk, current production levels, export dominance of specific countries	USGS: Identification of critical minerals, challenges include lack of comprehensive data on reserves and reliable indicators for supply risk
Japan	New Energy and Industrial Technology Development Organization (NEDO)	Determine the need for substitutes, inform decision-making, enhance mineral efficiency, promote international collaboration for secure and sustainable resource supply	Supply and demand risks, market prices and variations, recycling restrictions, and usage constraints related to minerals	Risks related to mineral supply, price and demand perils, recycling constraints, and environmental implications
Canada	Geological Survey of Canada (GSC), Natural Resources Canada (NRCan)	Identify potential mineral resources, assess supply risks, develop and implement policies for secure and sustainable access to critical minerals	Economic importance, supply risks, geopolitical factors, environmental and social impacts associated with mineral extraction	Inform mineral policies, guide investment decisions, promote responsible resource development, balancing economic development with environmental and social considerations
Australia	Geoscience Australia, Department of Industry, Science, Energy, and Resources	Evaluate economic significance, supply risk, potential impacts of critical minerals on Australia's economy and manufacturing sector	Market concentration, global production, substitution potential, and future demand growth	Support policy development, resource exploration, and investment decisions; positioning Australia as a global supplier of critical minerals
China	Ministry of Land and Resources of the People's Republic of China	Evaluate strategic importance, supply risks, potential impacts of critical minerals on China's industrial development and national security	Economic importance, resource concentration, substitution potential, protection of resource bases	Secure supply of strategic resources by upscaling and amplifying production from the mining industry, foresees limitations in resource accessibility and potential hindrance to

				sustainable development
United Kingdom	British Geological Survey (BGS)	Update policy makers, industry, consumers, and stakeholders on the necessity of expanding supply channels, increasing recycling reliability, and responsible resource use	Supply risk relative to the chemical element, competition and demand from emerging economies, geopolitical factors	List of critical elements with economic value, anticipated risks include supply disruption from competition, demand, geopolitical factors

Common Critical Minerals

While specific criticality assessments may vary in terms of the materials considered, some critical minerals are commonly identified across various assessments in the different geographies. These include, but are not limited to:

- REEs: REEs are a group of minerals that are essential for various high-tech applications, such as electronics, automotive, and renewable energy technologies.
- Lithium: Lithium is a key component in the production of rechargeable batteries, making it essential for the growing electric vehicle market and energy storage systems.
- Cobalt: Cobalt plays a vital role in lithium-ion batteries, particularly for electric vehicles and portable electronic devices.
- PGMs: Platinum, palladium, and rhodium are crucial in catalytic converters for vehicles, helping reduce harmful emissions.
- Tungsten: Tungsten is widely used in industrial applications due to its high melting point, hardness, and strength, making it important for manufacturing tools and machinery.

Based on the latest policy and technology developments, the IEA's 2023 Critical Minerals Market Review projects a 3.5-fold growth in demand for criminal minerals to 2030 in the NZE scenario, reaching over 30 million tonnes. **Importantly, the designation of "critical mineral" is not necessarily rooted in geological characteristics but rather a political one.**

As an example, in the U.S., the Energy Act of 2020 introduced a new definition of "critical minerals", making a significant departure from the conventional geological classification. Under this act, a "critical mineral" is any non-fuel mineral or mineral material essential to the economic or national security of the U.S. and which has a supply chain vulnerable to disruption. Specifically, critical minerals are also "*characterized as serving an essential function in the manufacturing of a product, the absence of which would have significant consequences for the economy or national security.*"

Similarly, for the European Union, critical minerals play an instrumental role in the economy, as they are fundamental in the value chain of the manufacturing industry, and in the advancement of new technologies. The importance of minerals to a country's economy can *vary* according to the country's specific economic circumstances at any given time.

End-of-Life: The Challenge of Waste and the Need for Circularity

We have thus far outlined explicit and implicit challenges along the critical minerals value chain, many of which are complex. The process of metal production is also energy intensive. Primary raw materials require massive amounts of energy for exploring, mining, smelting, refining, and transportation which causes significant amounts of GHG emissions, to the figure of approximately *10% of global emissions.*

Circular Economy

The concept of **circular economy** plays a key role in the global critical minerals value chain. While it is no new invention in the case of critical minerals, it offers a viable resource-gathering option in the energy transition. The environmental movement of the 1970s revived recycling and circular strategies to conserve energy and reduce emissions.

A circular economy aims to (1) reduce waste, (2) prolong the lifetime of materials at the highest possible value, and (3) design products for materials to be re-utilized and cycled back into the economy and regenerate nature.

The circular economy includes ***closed-loop*** *and* ***open-loop*** systems. The former tries to accomplish a (hypothetical) full cycle of materials, while the latter adopts a more realistic and feasible approach by allowing downcycling. Both methods increase the concentration of demanded materials and, therefore enable the recirculation and reintroduction into the economy.

Implementing circular economy measures can reduce linked emissions, especially in the case of metals. This is often due to the lower emission factors of secondary production than primary production. Yet, metals' recycling rates are often low; we explain the reasons below.

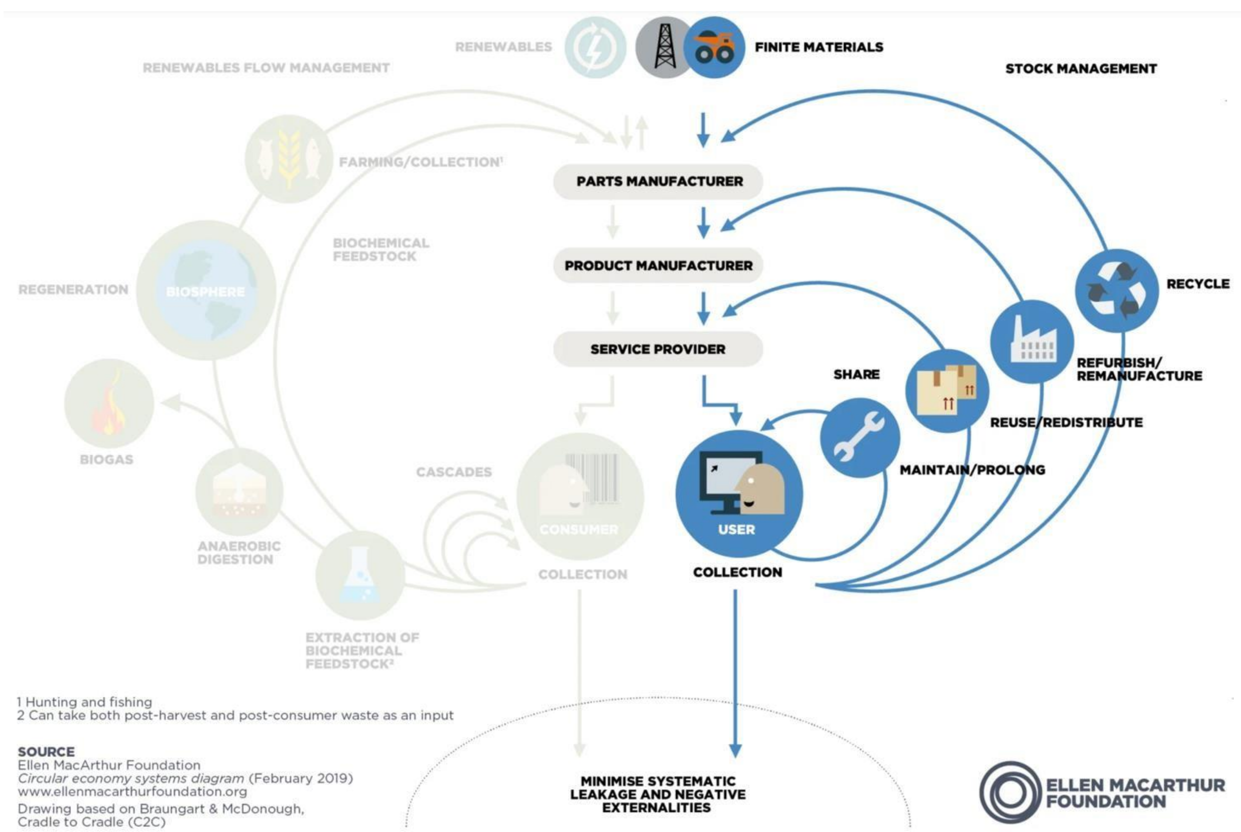

Figure 3. Circular Economy Systems, the technical cycle (Source: Ellen MacArthur Foundation)

But why is a circular economy pivotal for critical minerals? Looking at the challenges around critical minerals waste can offer some insights.

Waste is defined as an unwanted by-product with limited economic value. In the context of critical minerals, waste management is a highly important issue economically and socially, particularly against the broader trend of depletion, and due to limited resource availability. Waste is not only generated along the mineral production value chain - from exploration to mining (tailings), processing and refining - but also along the whole production value chain - from design to product production, reuse, collection, recycling and finally to the end of life of a product. Figure 4 shows the general waste management approach and shows the preference of each level of the planning, from most to least preferred.

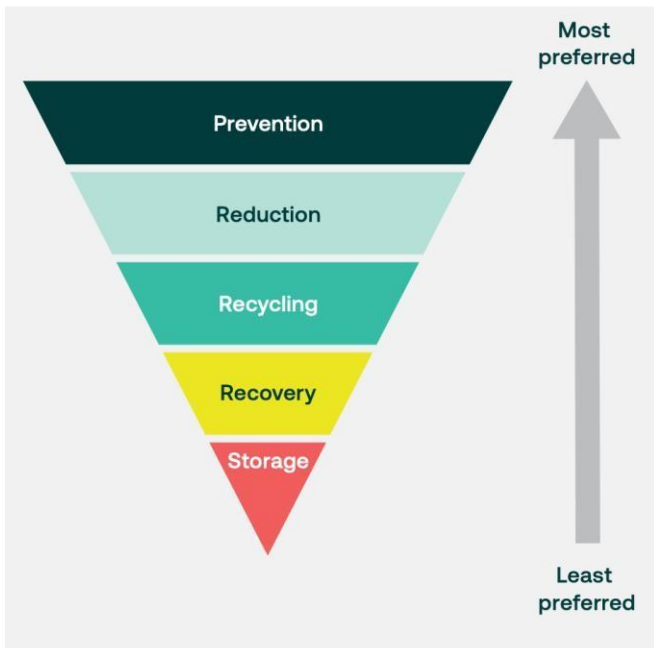

Figure 4. Waste Management Hierarchy, which illustrates that the more upstream the waste elimination andmetal-bearing materials concentration, the higher impact there can be on final waste and tailing reduction (Source: ICMM Tailings Reduction Roadmap)

Prevention entails avoiding waste generation in the first place, while **reduction** includes minimizing the amount of waste produced. **Recycling,** perhaps one of the most commonly known steps in the waste management system, requires converting waste into new materials or products. Then, **recovery** involves retrieving usable energy or materials from waste; and **storage** consists of safely holding waste, often pending a final disposal method.[8]

Waste can pose significant challenges and impacts on the surrounding environments and on human health. As ore grades and quality are decreasing, more bedrock, waste rock, partly soil and overburden has to be excavated to mine the minerals effectively. This holds huge **environmental implications.** In the case of zinc, the average

[8] For more information on this topic, see *ICMM Tailings Reduction Roadmap*

grade decreased by around *23% compared to 1965, whereas for copper by 2016*, it decreased by *25% compared to the decade before*. Owing to these reasons, energy consumption and tailing production have increased significantly. In the case of REEs, they are mainly found and processed from ores containing uranium and thorium. These elements are toxic and if not disposed of or recycled accordingly, can contaminate the surrounding environments. In addition to this, the wastewater and acid mine drainage containing fine dust particulate and heavy metals must be contained and should not be mixed with groundwater or nearby water bodies thus minimizing the harm to potential life forms. According to the Chinese Society of Rare Earths, it is estimated that for every ton of REE produced, 13 kg of flue dust and 8.5 kg of fluorine is generated; while if refining is done with sulfuric acid, it *generates* 9,600–12,000 m3 of gas containing flue dust concentrate, hydrogen fluoride, sulfur dioxide, and sulfuric acid. In essence, land, water and air in surrounding areas of waste disposal sites can be contaminated due to improper handling of waste, which may lead to ecosystem pollution for a long period of time.[9]

Numerous studies *underscore the potential* for hazardous **health issues** arising from improper mining waste management, encompassing threats posed by mining wastes such as metalliferous mine dust, acid drainage, or sedimentation[10]. The Case of La Oroya in Peru is a stark illustration of the severe health consequences that can arise from mining waste and industrial pollution. La Oroya, a town located in the central Andes, has long been a center for mining activities, particularly the extraction and processing of metals such as lead, zinc, and copper. The metallurgical complex in La Oroya has been a major source of environmental contamination and health problems for the local community. These substances not only contaminated local water sources but also became airborne, posing a direct threat to the health of the residents. Respiratory issues, cardiovascular problems, and various other health implications were significantly more prominent within the affected community compared to non-affected communities. Furthermore, the agricultural lands surrounding La Oroya had been negatively impacted by the mining activities, making it difficult for local residents to grow their own food. Despite the mounting evidence of the health hazards associated with the mining operations, the situation in La Oroya has been *exacerbated* by a lack of stringent environmental regulations, inadequate monitoring, and insufficient enforcement of existing standards. While the case of La Oroya is a particularly extreme one, it is not unique.

Inadequate waste management holds the potential to profoundly impact communities on a **social level** as well. This includes human rights violations, environmental pollution, and a disregard for community concerns, leading to substantial harm to both the environment and society. A prominent example of this is the case of the Bougainville Copper mine in Papua New Guinea in the late 1980s. The land dispossession, water pollution from mine wastes discharged, and indigenous people displacement were among the issues documented in that area. It eroded the cultural foundations that laid a fundamental base for the community. Efforts to address the environmental damage and restore the livelihoods of the affected population have been slow and fraught with difficulties. Reconciliation within the community and with external actors remains an ongoing and *delicate process.*

[9] For further research on this topic, see *Paul and Campbell 2011; Schüler et all 2011*

[10] For other research on this topic, see *Entwistle et al. 2019; Stewart 2019; Guadarrama et al. 2021*

These incidents are just two among numerous contributing to the persistently negative perception of the mining industry. The increased protest against mining projects and standards for mining projects have led to the increasing importance of a "**social license to operate**" (SLO). It refers to the level of acceptance or approval a mining company receives from the local community and broader society for its operations. It emphasizes the importance of addressing concerns and expectations of the communities affected by mining activities. The SLO is essentially a form of social contract, acknowledging that a company's right to extract resources is contingent upon responsible and sustainable practices that align with the values and well-being of the affected communities. Key elements include community engagement, environmental and social responsibility, transparency, benefit sharing, conflict resolution and cultural respect. *Studies* suggest that SLO is being applied widely in the mining sector. On the flip side, the loss of the SLO can lead to mining activities having to be discontinued, resulting in stranded assets (assets that have to be written off prematurely) or additional liabilities.[11]

Managing waste can also be economically expensive, considering the cost associated with environmental compliance, collection, transportation and treatment of waste. In addition, there are challenges regarding the site and infrastructure developments that require a substantial amount of resources alongside capital expenditure and operational and maintenance costs.

Failing to enhance circularity can limit our ability to reach 2030 and 2040 climate targets. A lack of secondary raw materials will *constrain supply and inflate prices*, making the clean energy transition more expensive. More importantly, given the emission-intensity of primary production, one of the most effective ways to reduce emissions in the transition is to increase the share of secondary production. Circularity thus becomes an essential framework for sustainable disposal strategies, but the road to implementation is by no means easy.

Downcycling, a reduction in the quality of recycled materials, poses a significant challenge for circularity. Downcycling describes the unintended or undesired quality reduction of materials reprocessed from waste relative to their original quality regarding the material's thermodynamic, functional, and economic properties. Downcycling can occur due to dilution, contamination, the lack of demand, and can be design-induced.

The vast majority of today's battery recycling capacity is located in China (230 ktpa established recycling capacity), but new facilities are being developed, especially in Europe and the United States. Figure 5 shows an overview of battery recycling capacities globally.

[11] For other research on this topic, see *Moffat and Zhang, 2014; Santiago et. al. 2021*

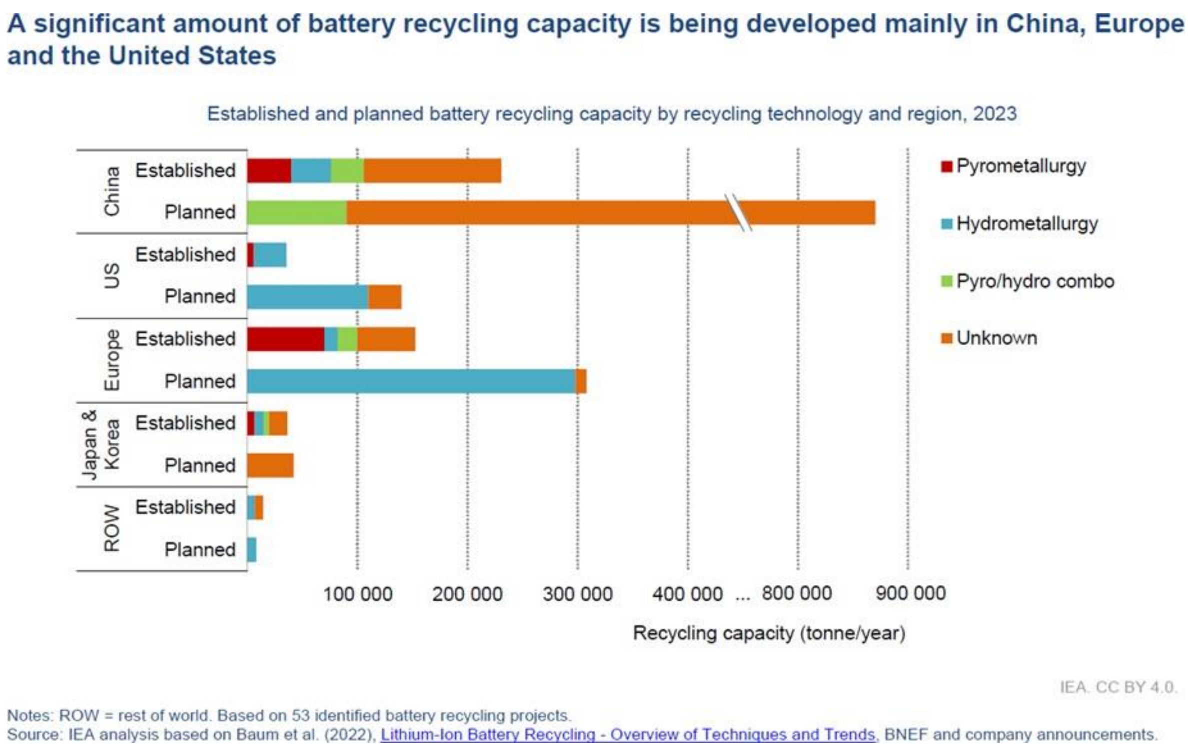

Figure 5. Geographic concentration of battery recycling capacities (Source: IEA Critical Minerals Market Review 2023)

At the moment, recycling of batteries predominantly focuses on **batteries of consumer electronics and new scrap**, therefore scrap from manufacturing processes. This is unlikely to change until there are sufficient quantities of other batteries, like EV batteries, at the end of life to be recycled. Used EV batteries are expected to be *retired at scale starting around 2030*. For other clean technologies, the situation is similar, leading to severely limited possibilities of recycling and easing the need for material supply in the coming years. The *end-of-life recycling input rate*, the percentage of a material in discards that is actually recycled, is a good measurement for the actual state of recycling.

Even though recycling and other circular economy measures are a good idea in most cases in order to reduce GHG emissions, metals, especially other materials, are *not recyclable indefinitely*. Metals will be lost from the global cycles through *dissipation*, meaning the technical or economical irrecoverability. Therefore, primary production will always be needed to replace thermodynamically unavoidable losses and to *expand in-use stocks for economic growth*.

Another challenge for a circular economy can be the ***rebound effect***: the increasing use of products by increasing overall production and, therefore, environmental impact. Secondary materials and goods that might lack quality do not always replace virgin materials but supplement them. Lowered prices by deployed circular economy measures could also foster higher consumption.

Besides its sheer necessity, as outlined above, and its challenges in implementation, a circular economy also ensures that materials maintain their highest utility amidst a pressing need to deliver a consistent supply for the growing clean technologies sector.

Transitioning to a circular economy necessitates technical or social innovations, such as design modifications for recycling or extended product lifespans. Recycling might be the most commonly known mechanism in the circular economy framework, the broader process entails much more than just recycling, as seen from Figure 1.

That said, it is important to restate that **a 100% fully closed-loop circularity is not possible**, due to dissipative losses during all stages of the value chain. A balanced share between primary and secondary production can theoretically be calculated or depreciated, such as based on the cumulative energy demand which is correlated with the process of path-specific GHG emissions. Due focus should also be given to the limitation of dissipation, for example by optimizing the collection of batteries and other products that contain relevant desired critical minerals. As such, policymakers should aim for an optimal market and minimize dissipation, especially in battery collection.

Various global and national standards and frameworks are advocating for responsible recycling

Region	Governmental body	Policy name	Description
China	Ministry of Industry and Information Technology	*The Interim Measures for the Administration of Recycling and Utilization of New Energy Vehicle Power Batteries*	Manufacturers would have the responsibility to close the loop for batteries
United States	States of California and Washington	*Bills for battery recycling*	Foster recycling of batteries
European Union	European Commission	*Critical Raw Materials Act*	25% of annual consumption for strategic raw materials, in which most are used in batteries, is required to be from recycled sources by 2030
European Union	European Commission	*EU Battery Regulation*	From 18 August 2031, electric vehicle batteries shall demonstrate that those batteries contain the following minimum percentage share of, respectively, cobalt, lithium or nickel that has been recovered from battery manufacturing waste or post-consumer waste: (a) 16 % cobalt; (b) 85 % lead;

			(c) 6 % lithium; (d) 6 % nickel.
Global Battery Alliance	International	*Battery Passport*	Assists in tracking and proper management of batteries

Towards a Globally-Aligned Resource Management Standard: The United Nations Framework Classification for Resources and the United Nations Resource Management System

In the complex and dynamic landscape of global energy, the urgency for a comprehensive and unified approach to resource management is more pronounced than ever. The rapid transition of energy sources and the escalating demand, particularly for critical minerals, have highlighted gaps and inconsistencies in existing frameworks. It is in this context that the **United Nations Framework Classification for Resources (UNFC)** and the **United Nations Resource Management System (UNRMS)** have emerged as pivotal tools. These frameworks are not just administrative conveniences but essential instruments that offer structured, principles-based, and adaptable methodologies for the sustainable development and management of energy and mineral resources. They are tailored to address the multifaceted challenges of a world in the midst of an energy transition, balancing the imperatives of economic growth, environmental sustainability, and social equity.

Why Do We Need Interoperable Resource Management Standards?

The intricate nature of global supply chains, characterized by their complexity and diversity, necessitates the implementation of robust resource management standards. These standards are not merely procedural but are instrumental in ensuring transparency, traceability, and effective risk management. In a world where the extraction and utilization of resources are often marked by a degree of opacity, UNFC and UNRMS embed the best features from various national frameworks, including from Europe, North America, and Russia, to enhance international communication, facilitate policy alignment, and promote sustainable practices. Additionally, since critical minerals do pose serious sourcing challenges, they necessitate a great deal of investment influx to produce, process, and use critical minerals with low-carbon technologies. Needless to say, securing the supply of critical minerals begins with a scale-up in sustainability-centered investments for their development, which in return, require timely and environmentally, socially, and economically referenced information. These aspects are at the core of UNFC and UNRMS.

UNFC and UNRMS serve as bridges over the chasms of miscommunication and misalignment, ensuring that policies are not only locally relevant but globally resonant. For businesses, the frameworks provide a compatible and easy-to-use structure, based on a numerical coding scheme, ensuring consistency and coherence in resource management across various scales. For investors, they enhance the distillation of robust Environmental, Social, and Governance (ESG)-compliant, comparable, and decision-useful information across geographies. For governments, they allow for the management of their national resources based on quality information for decision-making, as well as harnessing international cooperation and collaboration on our shared resources in the global energy transition. In a world marked by diversity, these standards ensure uniformity, offering a common language and methodology that transcends regional and national boundaries.

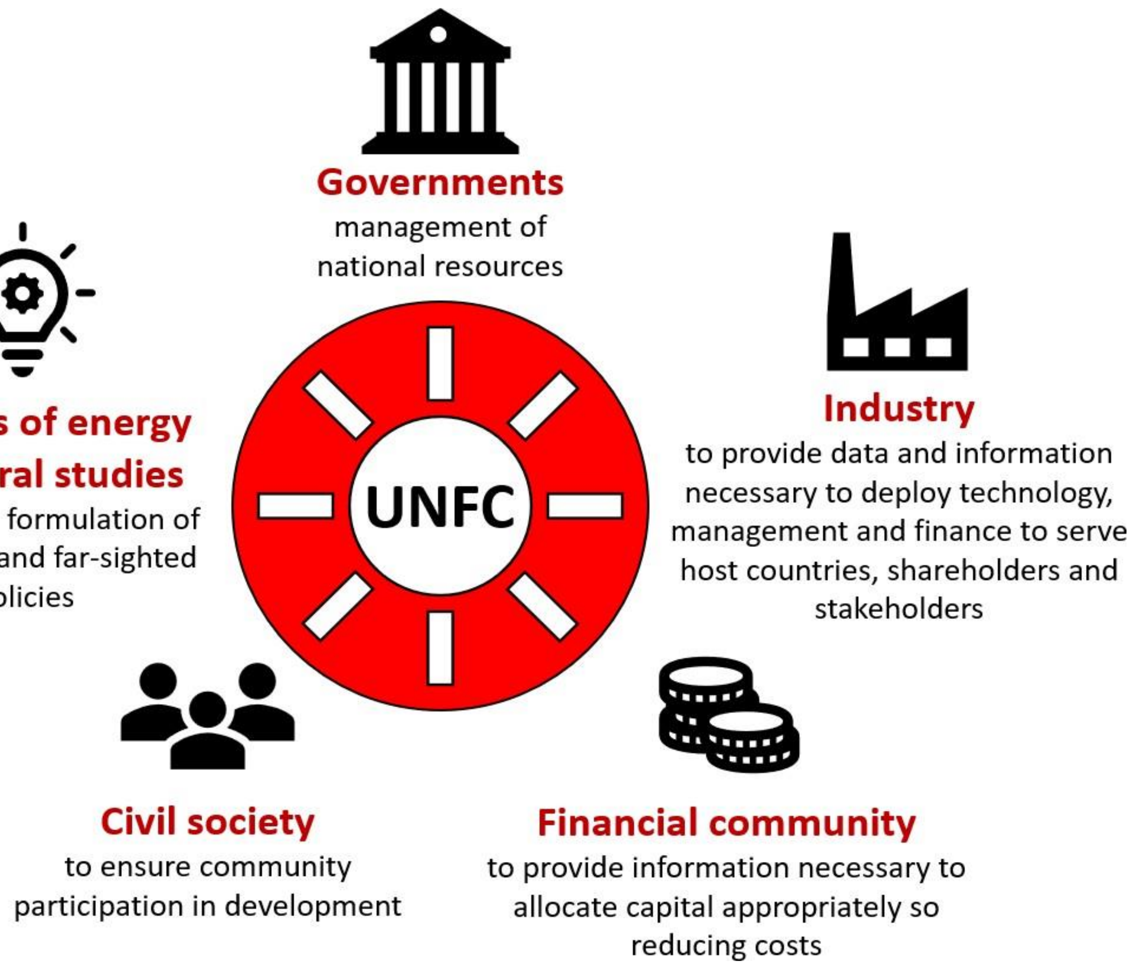

Figure 6. UNFC use by the different stakeholder groups (Modified from: Source: S. Solar, 2023, UNFC Basics, EIT Raw Materials and UNECE Workshop, RE-SOURCING Conference)

UNFC is establishing itself as a universal language for the classification, management, and reporting of energy and mineral resources. It is not confined to a narrow band of resources but caters to a diverse range, integrating **environmental-socio-economic viability, technical feasibility,** and the **degree of confidence** in the product estimates linked to a project. These three major classification pillars are represented in UNFC as the E, F, G axes respectively as shown in Figure 7. The universality of this tool's application allows for cross-resource comparison within a nation's energy and resource project inventories, and beyond. UNFC provides stakeholders with a holistic perspective, ensuring that each resource is understood and managed in the context of a broader ecosystem. Moreover, it fosters a harmonized approach, mitigating the risks of duplication and inconsistency in international initiatives. Despite today's digital advancement, data on raw materials in general are incomplete and non-interoperable, which hinders informative decision-making. With UNFC, harmonizing available critical minerals data on national and regional levels is possible.

UNFC classifies natural resources and reserves based on geological knowledge and certainty about the minerals' availability, the technical maturity for extraction, processing, or recycling, and the environmental-socio-economic viability of doing so. Notably, UNFC is not static but dynamic, flexible, and designed to evolve with the changing contours of technology, economy, and policy.

The framework is not an abstract theoretical model but is grounded in practical realities, designed to facilitate the market introduction of clean and affordable energy resource projects. Likewise, it addresses the growing consumer preoccupation with the value chain sustainability of the end-use products. More importantly, it integrates social and environmental considerations, ensuring that the production and utilization of resourcesare not just economically viable but also socially and environmentally sound. In a world where the tensions between economic growth, social equity, and environmental sustainability are often pronounced, UNFC offers a balanced approach, ensuring that each dimension is given its due consideration and weight.

At the EU scale, UNFC and its benefits have been recognized by regulatory bodies, in particular by the European Commission (EC). Securing the supply chains of CRMs is of high importance to the EU, as they are key enablers for the energy transition. Against this background, the EC has proposed, as of March 2023, the EU Critical Raw Materials Act (CRM Act), with the aim to address this pressing challenge while ensuring lower negative impacts on the environment and society, commonly associated with CRM projects. This is corroborated by the UNFC provisions highlighted in the CRM Act itself. Once in force (foreseen by the second half of 2024), the act will mandate EU Member States to apply UNFC when reporting on their exploration results (Article 18 "National exploration programmes"), for the monitoring of new extraction, processing, and recycling CRM projects (Article 20 "Information obligations for monitoring"), and for extractive wastes from closed facilities as part of national measures on circularity (Article 26 "Recovery of critical raw materials from extractive waste"). A UNFC classification is also a required criterion for the recognition of a Strategic Project as per the CRM Act, which serves as a cornerstone to streamline sustainable funding of Strategic Projects (Article 5 "Criteria for recognition of Strategic Projects").[12] UNFC is thus of important support to the CRM Act, ensuring sustainable sourcing of CRMs in the EU, based on harmonized, quality data. In comparison with other existing systems UNFC is indeed apt for the CRM Act, as it allows for the comparison of different resource projects such as minerals, secondary raw materials, and hydrogen, classification of the projects at any point of the value chain (exploration, mining, processing, recycling), assessment of environmental and social performance of projects, monitoring of project's development over time, and the translation of information from most reporting systems into UNFC.

[12] For more, see: European Union. "EUR-Lex: 52023PC0160" (*https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023PC0160*)

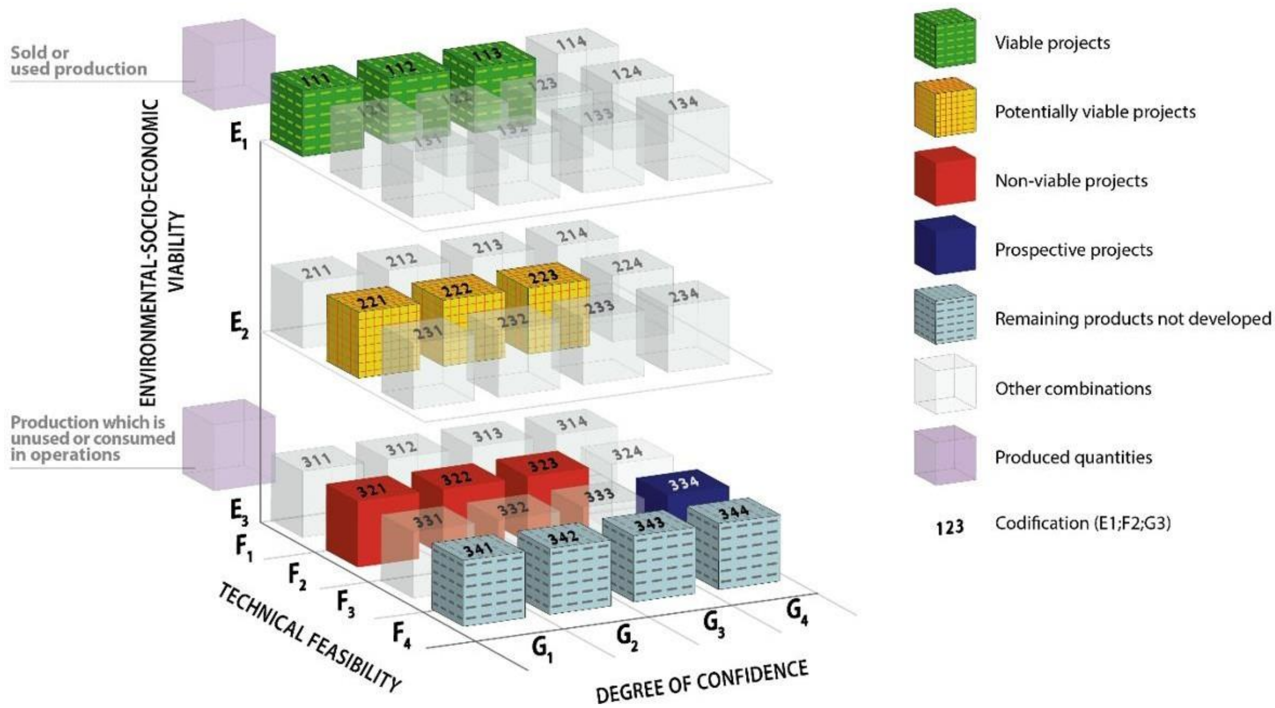

Figure 7. Full version of UNFC with main classes (Source: United Nations Economic Commission for Europe. "United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2019")

To simplify, and in the context of critical minerals, many governments desire safeguarding their critical minerals supply to attain a prosperous, sustainable, and carbon-neutral economy, which is achieved through their sustainable resource management. Moreover, the sustainable management of these minerals requires comprehensive decision-making, informed capital allocation, and the identification of strategic projects to the nation's best interest. In return, these requirements can only be realized when fed with consistent, coherent, real-time, transparent, and reliable information on critical minerals projects, which are well displayed through UNFC.

Figure 8. Roadmap to securing mineral supply using UNFC (Source: S. Solar, 2023, UNFC Basics, EIT Raw Materials and UNECE Workshop, RE-SOURCING Conference)

UNRMS emerges as a comprehensive solution meticulously designed to address the multifaceted challenges that require an integrated approach with social, environmental, and economic objectives. This is closely reflected in the 2030 Agenda for Sustainable Development. Developed by the **Expert Group on Resource Management (EGRM)**, UNRMS is akin to a "Swiss Army knife" for tackling sustainability and technology challenges, incorporating high-impact technologies and innovative methodologies.

UNRMS is thus a significant extension of UNFC, embodying a more comprehensive toolset for integrated and sustainable resource management. Complementary to UNFC, UNRMS is a principles-based framework envisioning resources as interconnected elements of a holistic industrial, social, and political ecosystem. Like UNFC, the system is also endorsed by the United Nations Economic and Social Council (ECOSOC). UNFC has been endorsed for global use by ECOSOC Decision (2021/250), and later UNRMS was endorsed for global use by ECOSOC Resolution E/RES/2023/19. In this *Policy Brief* on Transforming Extractive Industries for Sustainable Development, the UN Secretary-General addresses both tools saying that "*[they] implement a shared principles-based, integrated, sustainable resource management framework using tools such as the existing United Nations Framework Classification for Resources (UNFC) and the United Nations Resource Management System (UNRMS) under development*."

Over the last decade, significant pressure has been exerted on the mining industry to include social and environmental considerations in their activities as well as outline their principles and responsibilities with regards to sustainable operations. While previously the top risks in the mining industry were political instability and volatile markets, today this is environmental and social acceptance.[13] The voluntary principles and requirements established in UNRMS are key to the industry's maintaining its consumer base and the companies' competitive edge. Hence, UNRMS provides the industry with an international framework to demonstrate to stakeholders that its activities are not undesirable but are done with commitment to the environment and communities.

UNFC and UNRMS have a symbiotic relationship. As explained in its *overview document,* "UNRMS brings a holistic, programmatic, systems and life cycle view of resource management and plugs into the resource-specific and project-based classification of UNFC and implementation of the projects. UNFC enables resource accounting (present situation or current snapshot and provides information on project's maturity, while UNRMS works toward improving the project's maturity and addresses its holistic management." In simpler terms, UNFC provides information on the project's maturity, while UNRMS works toward improving the project's maturity.

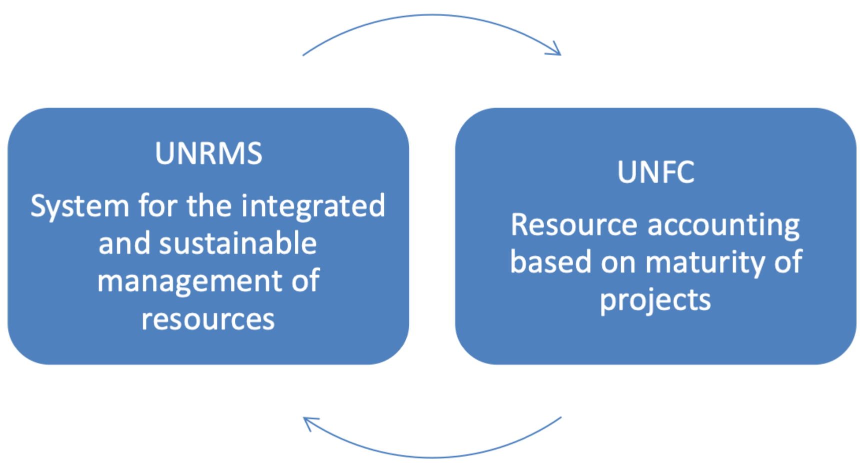

Figure 9. Schematic connection of UNRMS to UNFC and project-level implementation (Source: UNECE, "United Nations Resource Management System: An overview of concepts, objectives and requirements", United Nations, 2020)

In addition to UNFC, it is also worth mentioning the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) Template. The CRIRSCO family standards, an international reporting template, are mostly utilized to inform investment decision-making, and accepted for a number of stock exchanges around the world. This offers another perspective in resource classification, its integration and *bridging* with global standards like UNFC underscore the importance of universally accepted standards. It is not an alternative but a complementary framework, enriching the global discourse on resource management.

[13] Tulsidas, Harikrishnan. Interview. Conducted by Walker Darke, Mohammed Abdul Mujeeb Khan, and Alisa Reiner. 2 October 2023.

Case Study in UNFC/UNRMS Implementation

A real-world application of UNFC and UNRMS underscores their practicality, adaptability, and effectiveness. While voluntary tools, they are being increasingly accepted by countries and political entities. For example, in 2023, the European Union included UNFC as the cornerstone of the Critical Raw Materials Act.

Multiple case studies spanning various countries and resources highlight the increased adoption. Some of these include the application of UNFC to Rare Earth Elements and Thorium Comprehensive Resource Recovery Projects in Argentina, Phosphate Rock—Uranium Resources in Egypt, Uranium projects in Argentina, and many more.

Europe has been instrumental to the development of UNFC, emerging as the testing ground for UNFC, with many case studies examining both primary and secondary raw materials. These studies demonstrate the adaptable nature of UNFC across diverse conditions and help countries customize its application to their specific needs. The suitability of UNFC varies depending on factors such as the type of resources being assessed, classification methodologies, and project phases. To provide further insight, *several case studies* exemplifying successful applications of UNFC are outlined:

- United Nations Framework Classification for Resources Case Study from Austria – Sand and gravel resources in greenfield areas are the focus of the Austria pilot area east of Vienna.
- UNFC Case study – A case study on Graphite, Norway - This case study was done on flake graphite deposits and examines the Trælen deposit (active mine, Skaland Graphite AS) and the Bukkemoen deposit on Senja peninsula, in Troms County in Northern Norway. In addition, UNFC classification was applied to 24 graphite deposits.
- UNFC Case study – REE, Exploration Prospects and Secondary Resources in Sweden. Within the study following rare earth element (REE) sites were examined: the Olserum REE mineralization, the Norra Kärr REE deposit, and the Kiruna-Malmberget secondary resource deposit)
- United Nations Framework Classification for Resources Case Study from Germany – Tailings Storage Facility Bollrich – The tailings deposit Bollrich (Germany) was part of the Rammelsberg mining operation, which used to produce mainly Au, Ag, Pb, Cu, and Zn. The deposit is one of Germany's few possible critical raw materials (CRM) sources.

From a different perspective, the *UNFC case study on the Piampaludo titanium exploration project* in Italy, exemplifies the practical application of UNFC, by meticulously outlining the classification process. This study addresses the need for informed decision-making concerning resource management, particularly in the face of environmental and social constraints. Although constrained by data availability, this study provides a foundational classification adequate for local and national mineral inventories, serving as an educational paradigm for UNFC's application with solely publicly-accessible data i.e. no contact with the project owners. Despite its 'light' nature, this study serves as an educational example of UNFC application, with a focus on the importance of transparency and data availability for accurate resource classification. The main takeaway of this case study is that it underscores the potential benefits of UNFC for the inexperienced eye, which in return allows the user of the classification to make informed decisions.

Importantly, the role of youth is not peripheral but central in the implementation of resource management frameworks. Young people are not just passive recipients but active contributors, bringing innovation and dynamism essential for sustainable resource management. Hence, EGRM drives youth participation, recognizing the invaluable contributions young people can make to sustainabledevelopment.

The integration of UNFC and UNRMS is not optional but essential in navigating the intricate landscape of global resource management. These frameworks are unifying global standards guiding the world towards sustainable resource production and management and contextualizing the mining activities by giving the industry a “human face” amidst the complexities of balancing economic growth, environmental sustainability, and social equity.

Conclusion

The expected increase in production of critical energy transition minerals (CETMs) will not only play a vital role in enabling the clean energy transition but also holds promise for the social and economic development of many communities around the world.

The opportunities and challenges along the extractives sector value chain are issues of intergenerational equity, as this Guidebook has outlined. Long-term resilience is essential not only in ensuring the security of supply, as evident by the multiple global shocks we have seen over the past few years. Moreover, benefit-sharing is important given the existing cost-benefit skews to local mining communities; fostering economic diversification and producing in-country value add for producing countries and communities; and minimizing pollution, biodiversity loss, and ecological degradation, which inherently create further destructions to livelihoods. The extractive sector carries the shadows of a colonial past that cannot be repeated today or in the future.

Actors along the CETM value chain hold great responsibilities to ensure that products and technologies designed and used today leverage a circular model to reduce costs to people, communities, and the environment.

- **Industry** should consider and increase the R-imperatives such as repairability, remanufacturing, and refurbishment of the entire product lifecycle from the conceptualization of product planning and design. Doing so requires enhancing the efficiency with which we use materials (such as manufacturing efficiency, material reuse, repair) and ensuring that secondary materials are genuine substitutes for primary production so as to limit rebound effects. Importantly, industry should engage in meaningful social dialogues with mining and nearby communities, and Indigenous peoples and guarantee community benefits where possible.

- Within the industry**,** **producers**, in particular, can play a sizeable role in improving the sustainability and resilience of value chains by collaborating with suppliers, government entities, non-governmental organizations, and various stakeholders to *facilitate* knowledge exchange. This can include on improving robust sustainability reporting, on advancing *strategic investments* in technologies that promote resource-efficient production processes, on exploring innovative solutions that reduce waste, lower consumption, and minimize emissions. Producers grapple with multifaceted challenges, encompassing financial hurdles, unpredictable market dynamics, and intricate regulatory landscapes. However, by actively embedding sustainability into their operations, they stand to reap a myriad of benefits. These range from tapping into the burgeoning green financing sector and bolstering supply chain resilience, to cultivating enhanced brand trust and loyalty among discerning consumers and stakeholders. To truly harness these advantages, it is paramount for producers to spearhead efforts in innovation, foster collaborative partnerships across the value chain, and champion transparency in their operations, setting the stage for a balanced convergence of profitability and sustainability.

- **Research and Development** can improve and elevate the design and implementation of technologies, methods, and knowledge creation around CETMs. This can include more economical and resource efficiency recycling technologies, less intensive mining and processing methods, knowledge of global and regional stocks, and equitable market incentives and direct policy interventions. The development of coherent standards and frameworks with credible verification mechanisms underpin a more responsible mining sector. This should include economic and social safeguards to manage public and environmental health risks, gender and social equity, the rights of communities and countries to development, and the fundamental human right to a clean and healthy environment.

- **Governments and policymakers** should foster national and international collaboration in the global value chain such as through technology transfers and policies for in-country value-addition, while ensuring that social considerations are meaningfully embedded to maximize benefits to communities, workers, consumers, and value chain. This can include the integration of human rights and broader social due diligence at project conceptualization, extended producer responsibility, or providing guidance around social dialogues with communities. Governments need to consider how policy frameworks can be strengthened and harmonized to encourage responsible mining and sustainable and circular use of metals and minerals.

Overall, for the critical minerals value chain to impart generational benefits, the missing gap is the absence of coherent and holistic strategies to guide the capturing of critical mineral value chains for economic development, including the economic and social opportunities that can be derived from manufacturing products for clean energy generation, battery energy storage systems, EVs, amongst others. As mentioned, along the value chain, there is significant evidence of market concentration - the domination of a few particular countries - and an increasing trend in trade value further downstream the production process. From the extraction of raw materials to the manufacturing of EVs, each step adds more economic value, underscoring the importance of industrial and technological development for countries that endeavor to move into the processing and manufacturing stage of the value chain.

Intergenerational equity provides a moral compass for the care and use of Earth's natural resources. This is both consisting of a right, and responsibilities. Importantly, the temporal dimension of intergenerational equity also contains an *intra*-generational component, requiring **wealthier nations to support other developing communities' rights to benefit from Earth's resources and utilize them in a sustainable manner**. Today, while many industrialized countries have benefited from such extractions for their own social and economic development, the reality remains that many other industrializing economies can leverage their resource endowment and the energy transition in doing the same. Against the backdrop of climate change, we must consider what impact the decisions that we make today may have on the robustness and integrity of the environment that leave behind for future generations and future beings.

The development of coordinated, robust, and country-led critical minerals strategies and related action plans can necessitate and guide minerals-rich countries' in leveraging their endowment for the broader benefits of socio-economic development. Providing guidance in the responsible management of these resources while centering the collective relationship of past, present, and future generations and our dependency on Earth's natural systems is one step towards ensuring intergenerational equity in resource management.

ANNEX I

Canada:

Canada carries out criticality assessments through the Geological Survey of Canada (GSC) and Natural Resources Canada (NRCan). The GSC conducts research and data analysis to identify potential mineral resources and assess supply risks. On the other hand, NRCan focuses on developing and implementing policies to ensure secure and sustainable access to critical minerals. The main factors considered in these assessments include economic importance, supply risks, and geopolitical factors. The assessment also addresses the environmental and social impacts associated with mineral extraction. The purpose is to inform mineral policies, guide investment decisions,and promote responsible resource development, but the challenge is to balance economic development with environmental and social considerations (*Natural Resources Canada, 2022*).

European Union (EU):

The European Commission has been conducting a criticality assessment of raw materials since 2010. It is importantto mention that for the European Commission, the criticality assessment produces a list of "critical raw materials", rather than "critical minerals". This assessment method considers both the economic importance and supply risk of raw materials. Factors such as market concentration, governance issues, substitutability, recycling potential, and geopolitical risks are also taken into account (*Schrijvers et al., 2019*). This assessment aims primarily at upscaling and accelerating European critical raw materials production, monitoring criticality, prioritizing requirements and actions, diversifying the supply streams, informative policy making, and addressing trade alteration measures, while elevating the competitiveness of the EU economy. Following this method, the European Commission foresees risks related to supply disruption, lessened by substitution and recyclability. As of2023, the European Commission has proposed a Critical Raw Materials Act with defined benchmarks to strengthencritical raw materials supply chains in the EU, in which it further identifies a subgroup of critical raw materials, labeled as "*Strategic Raw Materials*". These raw materials are strategically important for the overall EU economy and are crucial for the green and digital transition.

United Kingdom:

The criticality assessment implemented in the UK was developed by the British Geological Survey (BGS). This methodology looks mainly at the supply risk relative to the chemical element in question, which results in a list ofcritical elements with economic value (*Hackenhaar et al., 2022*). The BGS method has an objective to update policymakers, industry, consumers, and other relevant stakeholders on the necessity of expanding supply channels, increasing recycling reliability, and responsible resource use. The anticipated risks of this criticality methodology include supply disruption caused by competition and demand from emerging economies, geopolitical factors, andexport restrictions (*Schrijvers et al., 2019*).

United States of America (U.S.A):

The US National Research Council (NRC) has developed a criticality study to identify critical and near-critical materials, geographically restricted to the U.S. The assessment method used by the NRC involves the evaluation of factors such as economic importance, supply risk, and susceptibility to supply disruption. The purpose of this assessment is to establish a concept of a general framework to assess material criticality in accordance with specific users and their own scenarios. Risks faced by the NRC include the unavailability of the materials, materialmarket prices, and the disruptions to economic activities (*Schrijvers et al., 2019*). On the other hand, the United States Geological Survey (USGS) adopts a method to identify critical minerals that are essential for the U.S. economy and national security. The assessment method used by the USGS includes the evaluation of factors suchas economic importance, supply risk, current production levels, and export dominance of specific countries. It evaluates the importance of materials for industrial sectors, national defense, and the technological innovation capacity of the country. The purpose of this assessment is to identify minerals that are of strategic relevance and could potentially face supply disruptions. Challenges faced by USGS include the lack of comprehensive data on critical mineral reserves and the identification of reliable indicators for supply risk (*Nassar and Fortier, 2021*).

Australia:

Being a major producer of critical minerals, Australia’s criticality assessment expands beyond the country and looks into positioning Australia globally, as a supplier of critical minerals. Yet, Australia's criticality assessments are conducted by Geoscience Australia and the Department of Industry, Science, Energy, and Resources. These assessments focus on evaluating the economic significance, supply risk, and potential impacts of critical minerals on Australia's economy and manufacturing sector. The factors considered include market concentration, global production, substitution potential, and future demand growth. The objective is to support policy development, resource exploration, and investment decisions (*Geoscience Australia, 2023*).

China:

The Ministry of Land and Resources of the People’s Republic of China carries out the criticality assessments in China. This assessment focuses on evaluating the strategic importance, supply risks, and potential impacts of critical minerals on China's industrial development and national security. Factors considered include economic importance, resource concentration, substitution potential, and protection of resource bases. The assessment aims to secure the supply of strategic resources by upscaling and amplifying production from the mining industry.This methodology foresees limitations in resource accessibility per capita, and potential hindering of the country’s sustainable development from a decrease in exploration investments (*Schrijvers et al., 2019*).

Japan:

Japan’s criticality assessment was overseen by the New Energy and Industrial Technology Development Organization (NEDO). This assessment evaluates several factors such as supply and demand risks, market prices and variations, recycling restrictions, and usage constraints related to minerals (*Hatayama & Tahara, 2015*). The purpose of the NEDO method is to determine the need for the development of substitutes, inform strategic decision-making, enhance mineral efficiency, and promote international collaboration for secure and sustainable resource supply. However, this criticality assessment anticipates risks related to mineral supply, price and demandperils, recycling constraints, and environmental implications (*Schrijvers et al., 2019*).

Critical Minerals for the Sustainable Energy Transition

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