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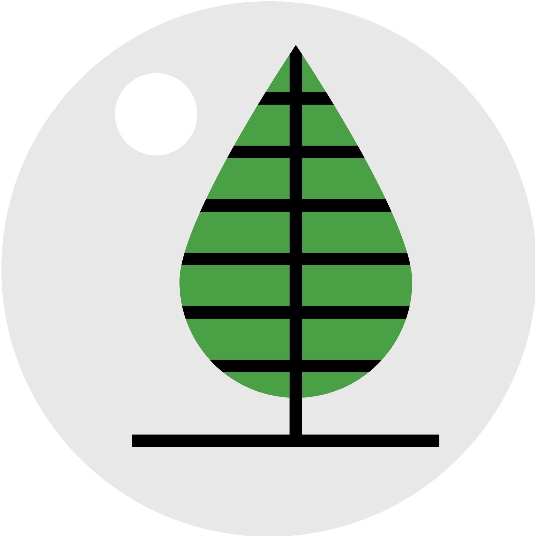
Critical Raw Materials Guide

Insights from an energy transition perspective

Securing the sustainable supply of critical raw materials is essential to deliver on the EU’s green policy ambitions and enhance the region’s resilience and autonomy. Arup can guide you.



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Relevance

This guide aims to provide an introduction on the utilisation, origin, (macro-) economics, and environmental issues of critical raw materials as defined by the EU, focusing specifically on those with a pivotal role in driving the global energy transition.

Introduction to the Critical Raw Materials Guide

Critical Raw Materials form the basis for many products relevant to advancement on current global challenges, such as the energy and digital transitions, and thus the future economy. Getting to grips with sourcing these materials is therefore important to stay ahead in providing top tier advice to our clients, specifically those operating in the energy transition space.

This guide is an objective perspective on origination and challenges of raw materials to a global energy transition, while using the EU definition in the Critical Raw Materials Act (CRMA) as the current market standard for what defines Critical Raw Materials.

In doing so, a concrete number of 34 Critical Raw Materials, and 17 Strategic Critical Raw Materials can be distinguished.

Of these, six Strategic Critical Raw Materials are identified as particularly relevant to the Energy Transition that will receive special attention in this guide; Cobalt, Copper, Lithium, Graphite, Nickel and Rare Earth Elements.

Definition & use

What are Critical Raw Materials?

Strategic Critical Raw Materials are essential to progress in the energy and digital transition sectors and have a high supply risk (from an EU perspective). This guide explores copper, nickel, graphite, cobalt, lithium and rare earths for their importance to the energy transition.

EU definition for Critical Raw Materials

Critical Raw Materials

The European Union (EU) has developed a definition of Critical Raw Materials (CRM), as part of their Critical Raw Materials Act (CRMA). It clearly outlines which materials are included and can be perceived as the market-standard definition

The EU has outlined 34 raw materials under the CRMA that are crucial for the EU's economy. They are classified as such for their economic importance and their supply risk, i.e. imbalances in global demand and supply and / or highly concentrated supply in one or several geographical areas.

Mining for CRM has many of the same potential economic, social and environmental consequences as other extractive industries, including fossil fuels. As demand for CRM increases, regulations are to be set by policy makers and responsible sourcing of materials is to be pursued by the supply chain.

Strategic Critical Raw Materials

17 of these are classified as "strategic", due to their criticality to strategic sectors for the EU that are vital for a sustainable and resilient future, such as; renewable energy generation, low-carbon (emission) alternatives (e.g. electric mobility) and digitisation:

A strategic critical raw material helps make Europe more independent in the production of strategic products, especially in green energy, digital technology and defence.

The list is subject to regular review and can be updated.

Critical Raw Materials in the energy transition

The 17 defined strategic CRMs are presented in the table adjacent. A selection of those critical to the energy transition (based on the International Energy Agency (IEA) report on critical minerals in the Energy Transition), and further analysed in this document are presented in bold.

1. Cobalt: Essential to the electrification of mobility and the electronics needed for smart devices
2. Copper: Electric conductivity fundamental to renewable energy infrastructure, storage systems and EVs
3. Graphite: Used as the dominant material in battery anodes for its energy density and cost-effectiveness
4. Lithium: Lithium batteries feature modularity, high energy density and high charging & discharging efficiency
5. Nickel: High energy density crucial in enhancing EV battery range. Also used in Alkaline Electrolysers
6. Rare Earth Elements: Critical to the energy transition through their use in permanent magnets.

Overview of the 17 defined strategic CRM in the Critical Raw Materials Act

Aluminium	Magnesium
Bismuth	Manganese
Boron	**Nickel**
Cobalt	Platinum Group Metals
Copper	**Rare Earth Elements (REE)**
Gallium	Silicon Metal
Germanium	Titanium Metal
Graphite	Tungsten
Lithium	

Source | European Commission, IEA

EU dependency

The EU is dependent on one or several countries for obtaining many of their CRMs. Current examples of this are:

China provides

100%

100% of the EU's supply of heavy Rare Earth Elements

Türkiye provides

98%

of the EU's supply of boron

South Africa provides

71%

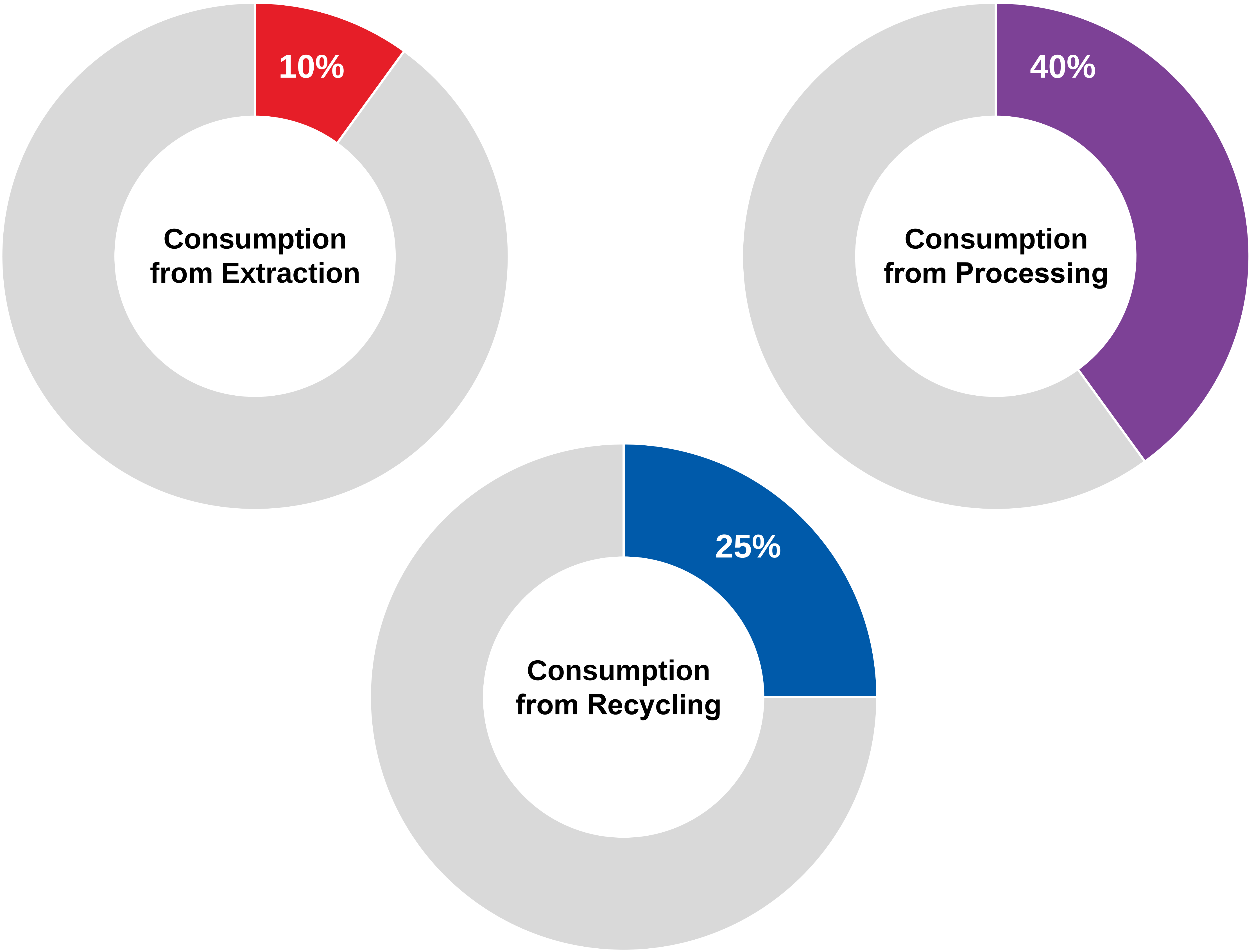
of the EU's needs for platinum

CRMA key characteristics

Key objectives: The CRMA is a regulation designed to address the strategic importance and supply chain vulnerabilities of critical raw materials for the EU's economy, by promoting their responsible sourcing, recycling, and substitution to ensure the resilience and competitiveness of the economy.

Quantitative goals: The Act sets these benchmarks along the strategic raw materials value chain and for the diversification of the EU supplies:

1. at least 10% of the EU's annual consumption from EU extraction;
2. at least 40% of the EU's annual consumption from EU processing;
3. at least 25% of the EU's annual consumption from recycling; and
4. no more than 65% of the EU's annual consumption of each strategic raw material at any relevant stage should come from a single third country by 2030.



Source | Council of the European Union

What are the key properties of CRMs?

This is a non-exhaustive overview of the 17 strategic critical raw materials mapped against key properties for their intended uses. Check marks indicate that this metal is commonly known to possess or used for possessing the respective property.

REE
The 17 rare earths are chemically similar to a degree that they are often collectively considered as one element. Although they do have their distinct properties that set them apart (e.g., they differ on electric conductivity and magnetic properties). In this table we display the properties that make (some of) the rare earths specifically useful.

Sources | Thysenkrupp, IRDS, All Metals Fabrication, Aria Manufacturing, Online MetalsThermtest, Wevolver, Xomertry

Key properties of the Strategic Critical Raw Materials (SCRM)

CRM	Light Weight	Corrosion Resistance	High Strength	Low Melting Point	Non-toxicity	Lubricating Properties	High Melting Point	Neutron Absorption	Deoxidizing Agent	Lumine-scent Properties	Catalytic Properties	Electro Chemical Properties	Electric Conductivity	Semi conductor Properties	Magnetic Properties	Thermal Conductivity
Aluminium	✓	✓							✓				✓			✓
Bismuth				✓		✓		✓								
Boron			✓					✓								
Cobalt		✓					✓				✓				✓	
Copper		✓											✓			✓
Gallium				✓										✓		
Germanium										✓				✓		
Graphite						✓										✓
Lithium												✓				
Magnesium	✓		✓		✓											
Manganese		✓	✓		✓				✓							
Nickel		✓					✓				✓				✓	
Platinum		✓					✓				✓					
REE										✓					✓	
Silicon														✓		✓
Titanium	✓	✓	✓		✓		✓				✓					
Tungsten			✓				✓									✓

Arup sees the six highlighted materials as crucial to the Energy Transition, based on the need for electric conductivity, magnets, semi-conductors and thermally dissipating/ stable material in Energy Transition assets.

How are Critical Raw Materials utilised?

Critical Raw Materials are key to building the assets required for the energy transition. Offshore and Onshore Wind require ca. 15.5 and 10.3 tons CRM per MW. Solar PV requires ca. 6.7 and alkaline electrolysers ca. 3.9 tons per MW. EVs require approximately 215 kg CRM per vehicle.

CRM | Importance to the energy transition

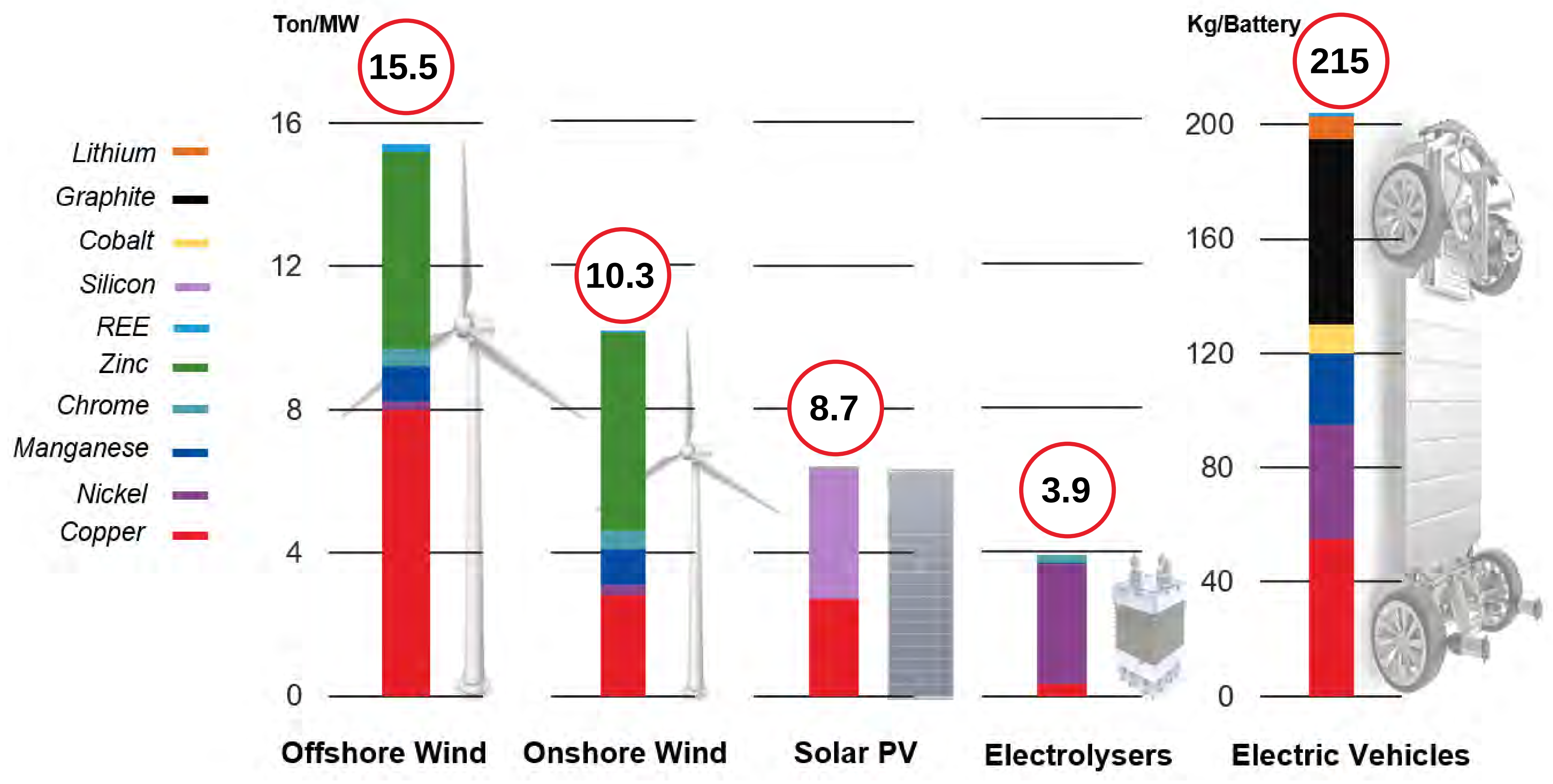
Many of the CRM are key to building the assets required for the energy transition. The charts opposite show the amount of CRM required for manufacturing of several important energy transition drivers.

1. Offshore and Onshore Wind Energy – top the list, requiring ca. 15.5 and 10.3 Ton / MW respectively. The bulk of this is copper used for generators, wiring, tubing, cables and step-up transformers, for its electric conductivity and heat dissipation capabilities. Next most required is zinc, mainly for the coating that must withstand harsh weather conditions, as it is highly resistant to corrosion. The rest is mostly made up of manganese, chromium, nickel, rare earth elements and molybdenum. Per MW, Offshore Wind requires about 2.5 times the amount of copper with respect to Onshore Wind. This is mainly electricity infrastructure needed due to the longer distances.
2. Solar Photovoltaic – requires ca. 6.7 Ton / MW, which is mostly silicon and copper. The copper is used for the same applications and reasons as with Wind Energy. The silicon is used as the outer layers of the solar cells, for its suitability as a semiconductor, its thermal conductivity and for being the second most abundant element in the earth’s crust, after oxygen. This makes it the cheapest alternative. The remaining parts consist of several metals, mostly zinc and nickel.
3. (Alkaline) Electrolysers – require ca. 3.9 ton / MW. The vast majority of this is nickel (about 85%), used in the electrodes. Nickel is used for its high conductivity, thermal stability, and good electrical properties. The rest usually comprises copper, chrome, zinc and REEs. Newer technologies (PEM, SOEC) rely also on cobalt.
4. Electric Vehicles – require a variety of CRM, mostly to manufacture the battery. Approximately 215kg are used per car. They require copper for batteries, inverters and wiring. Most cars have lithium-ion batteries with a cathode composed of nickel-manganese-cobalt (NMC). To enhance EV range, more nickel is added because of its high energy density. Graphite makes up 90-95% of the anode of lithium-ion batteries and ensures the battery remains stable during charge and discharge cycles.

Other materials

Apart from the CRM discussed here, several others play an important role that should be mentioned in relation to the Energy Transition but are not further investigated in this guide.

- Aluminium is classified as a CRM and often used in manufacturing EV batteries next to those mentioned
- PEM Electrolysers rely on the use of platinum (as cathode) and iridium (as anode), two very rare and expensive metals.
- Manganese appears because of its importance in various appliances. However, despite its criticality it is also relatively common, being one of the most abundant elements in the earth’s crust (varying accounts).
- Boron is crucial to nuclear plants for its for its tendency to absorb neutrons Boron and nuclear energy are not further investigated in this guide.



Sources used for this page: EBN, IEA, Aquametals, AFR, DNV, Visualcapitalist, Nickelinstitute, Rize, Royal Society of Chemistry

Graph Source: EBN

Origin

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Where do Critical Raw Materials come from?

The bulk of mineral extraction is largely concentrated in several countries. Global processing of minerals is even more concentrated. China dominates CRM processing, being the top supplier for 5 out of 6 of the selected CRM for the energy transition (REE and Graphite by respectively 89 and 100%).

Leading countries

Extraction

Extraction of selected CRM for the energy transition is dominated by a handful of larger countries, as the minerals are found largely concentrated in specific geographical areas.

1. **Cobalt:** Congo’s mining of cobalt is estimated at 0.14 MMT in 2023, accounting for 71% of world total.
2. **Copper:** Chile extracted 5 MMT of copper in 2023 (23% of world total), ranking above Peru with 2.6 MMT and Congo with 2.5 MMT (both at ca. 12%).
3. **Graphite:** China extracted 1.23 MMT of Graphite in 2023, accounting for 74% of the world total.
4. **Lithium:** Australia leads lithium extraction, as they account for about 43% of the world total with 0.09 MMT in 2023, whereas 2nd place Chile accounted for ca. 0.06 MMT (29%).
5. **Nickel:** Indonesia dominates nickel extraction, gathering 1.8 MMT in 2023 (47%), staying ahead of The Philippines (0.4 MMT, 12%) and Russia (0.2 MMT, 5%).
6. **Rare Earths:** China extracted 0.24 MMT Rare Earths in 2023 (68% of world total)

Processing

Processing of CRM is even more geographically concentrated, as China alone accounts for an average non-weighted 64% of processing (and therefore directly supplying) of selected 6 CRM.

1. **China:** processes 100% of graphite, 89% of Rare Earths and 75% of cobalt production. This is due to its proximity to extraction (in case of REE, Graphite), proximity to global value chains for renewable energy and digital products, ownership of mining supply chains, combined with relative affordability of processing due to low labour costs and government subsidies.
2. **Chile:** is the second largest processor, processing 33% of lithium and 12% of copper.
3. **The EU:** lacks presence, as only Finland processes an important amount of any of the selected CRM (10% of cobalt). It becomes clear that goals 2 and 4 of the CRMA (taking off 40% of CRM from domestic EU processing, and no more than 65% of one mineral supplied by a single third country), are far from reached.

Sources used for this page: Statista, EBN, IEA

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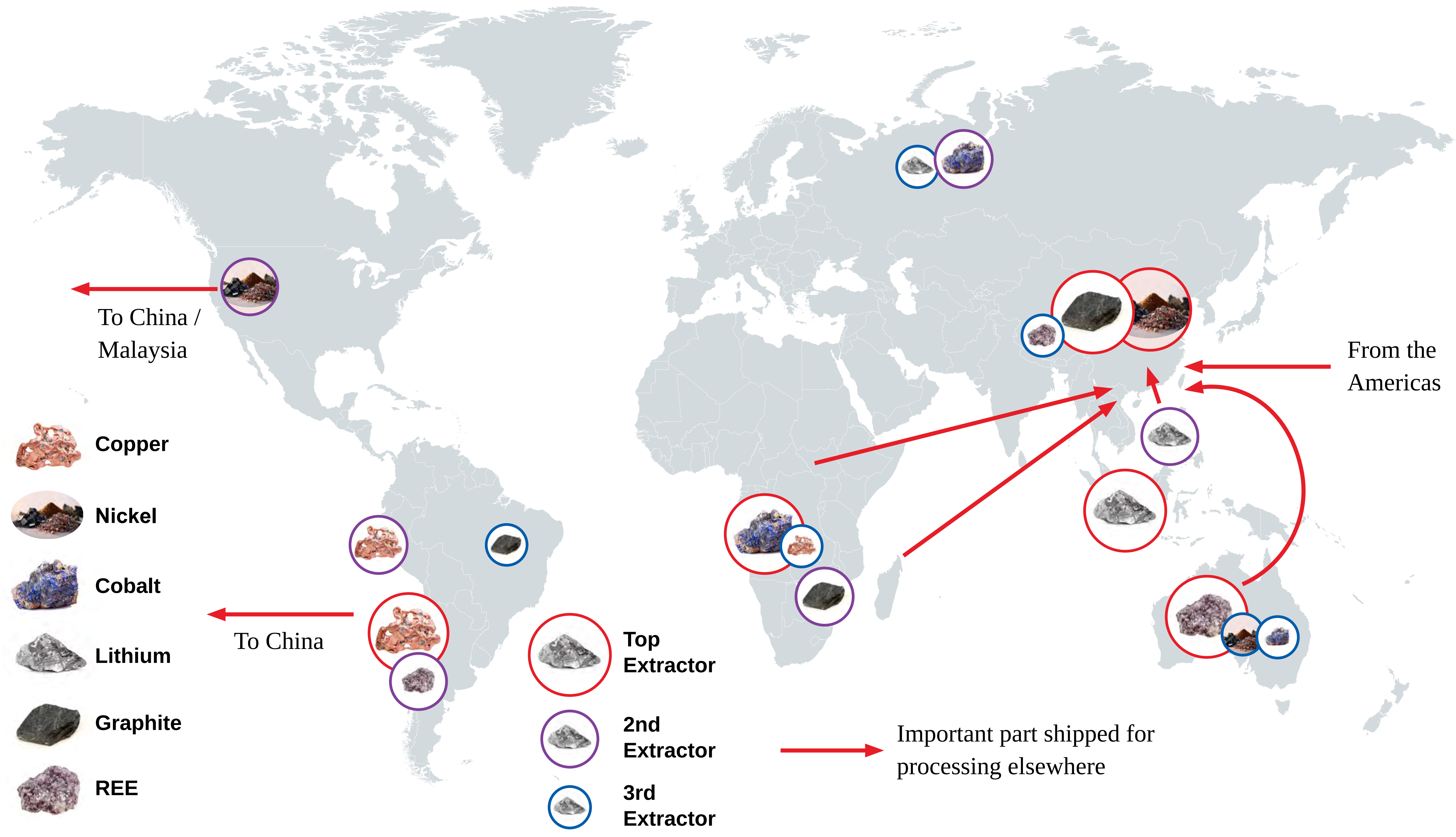

World map showing top 3 countries by amount of extraction of selected minerals. Arrows roughly indicate the global movement of materials based on where materials are processed (refined), as seen in the tables (right)
Source | Statista, EBN, IEA

Extraction

	Cobalt	Copper	Graphite	Lithium	Nickel	REE
1	Congo 71%	Chile 23%	China 74%	Australia 43%	Indonesia 47%	China 68%
2	Russia 5%	Peru 12%	Mozambique 6%	Chile 29%	Philippines 12%	US 12%
3	Australia 2%	Congo 12%	Brazil 6%	China 17%	Russia 5%	Australia 5%

Processing

	Cobalt	Copper	Graphite	Lithium	Nickel	REE
1	China 75%	China 41%	China 100%	China 63%	Indonesia 47%	China 89%
2	Finland 10%	Chile 12%	-	Chile 33%	Philippines 12%	Malaysia 10%
3	Canada 3%	Japan 5%	-	Argentina 4%	Russia 5%	Estonia 1%

Overview of top extractors and producers of selected minerals by country
Source: Statista, EBN, IEA

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How scarce are these Critical Raw Materials?

Considering the continuous exploration, technical advancements and the high recyclability of these critical raw materials, the risk of depletion is generally low. However, as demand growth outpaces extraction rate increases, supply constraints are expected in the coming years.

Reserves of selected CRM

According to the UK's centre for sustainable mineral development, "that part of a mineral resource, which has been fully evaluated and is deemed commercially viable to work, is called a mineral reserve." The evaluation process involves drilling and associated test work to prove that a deposit of sufficient quantity and quality is present. Importantly, this does not include whether legal access or valid planning permits have been obtained, which means that mineral reserves are not always extractable reserves, despite being identified as a commercially viable resource.

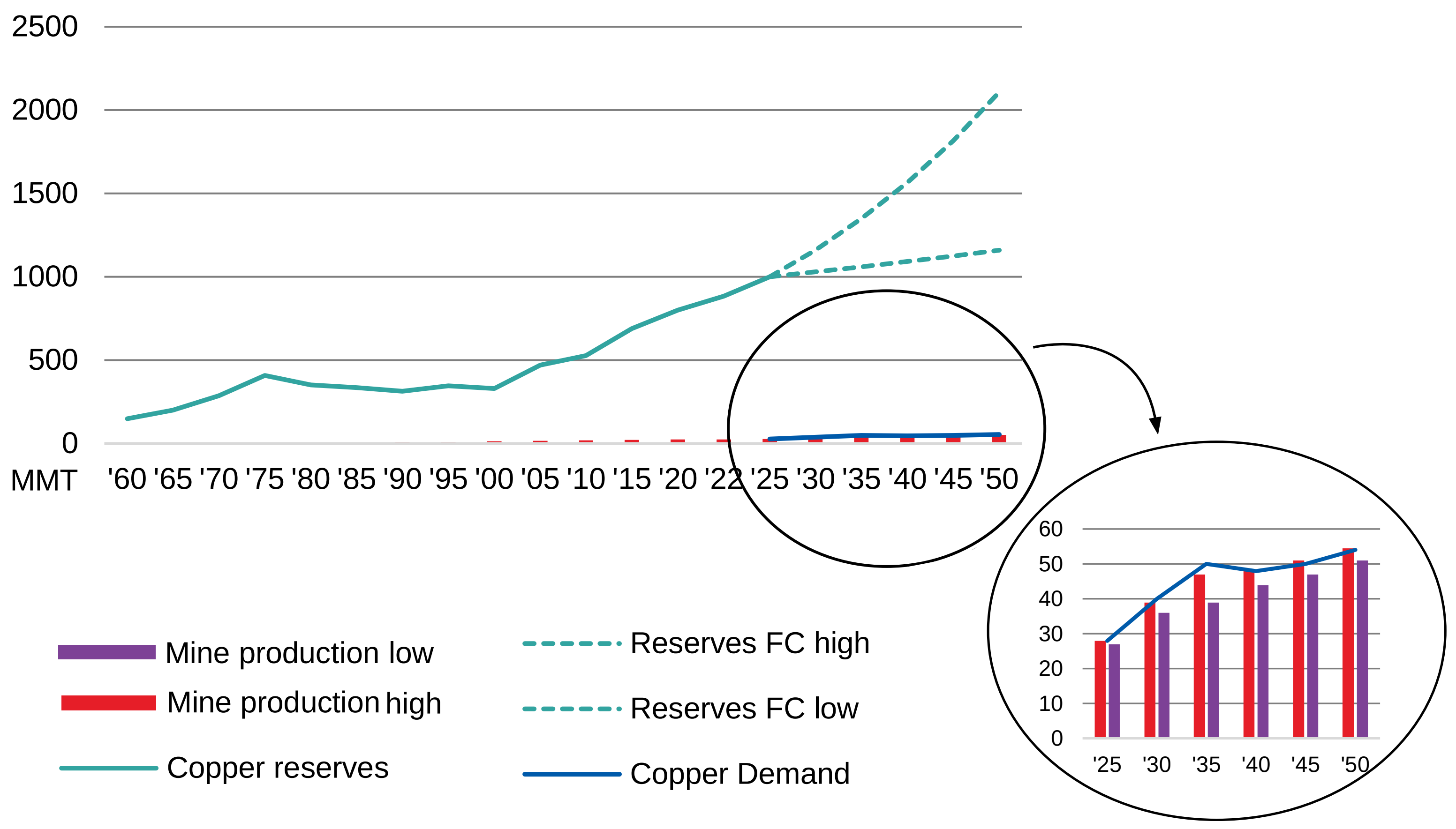
Scarcity

All selected CRM have sufficient reserves to keep supplying the yearly extracted amount for decades ahead. Considering the continuous exploration, technical advancements and the high recyclability, the risk of depletion is generally low for most.

Sources used for this page: Statista, Mckinsey, S&Pglobal, ICSG, Macquarie Research, UBS, CNBC, ING, IEA

1. Copper: Current copper reserves can hold the yearly extracted amount for about 37 years. Interestingly, this has been a similar number on average since 1960, which is due to exploration being funded as prices rise, through which a larger part of the copper resources are identified as commercially viable to extract. In the period 2000 – 2022, 396 MMT of copper has been mined, but reserves grew by 433 MMT (see chart opposite). However, global copper demand is expected to rise 2-3 fold by 2040. It is expected that global supply can increase from the current 24 MMT per year to 44-48 MMT in 2040. If demand will rise at this pace, exploration of commercially viable resources might not keep up, which would still result in a shortfall. There have already been copper supply deficits in recent years with the current rate of extraction.
2. Cobalt: Current reserves could hold 30 years at the current rate of extraction. The IEA predicts a 6-21 fold increase in demand for cobalt by 2040. Cobalt also saw supply surpluses after the deficit recorded in 2021.
3. Graphite: Current graphite reserves would hold 193 years at the current rate of extraction. However, demand rising 8-25 times by 2040 could lead to a supply deficit soon (expected by some sources already in 2025).
4. Lithium: Current reserves could hold 85 years at the current rate of extraction. The IEA predicts a 13-42 fold increase in demand for lithium by 2040. Deficit expected in 2025 by CNBC.
5. Nickel: Current reserves could hold 31 years at the current rate of extraction. The IEA predicts a 7-19 fold increase in demand for nickel by 2040. Nickel saw a supply deficit in 2021 and surpluses thereafter according to ING.
6. Rare Earths: Current reserves could hold 413 years at the current rate of extraction. The IEA predicts a 3-7 fold increase in demand for rare earth elements by 2040. BCG claims 20 new rare earths projects should be launched to avoid a shortfall by 2030.

Considering all factors, scarcity (i.e. supply difficulties) appears to develop for many of the selected CRM. However, this would not be due to the risk at depletion, but rather due to extraction rate not keeping up with increasing demand (see chart below). Investment in mining is expensive and risky due to high price volatilities. With regards to the minerals under review, uncertainty is also influenced by the extent to which they might prove substitutable as technology progresses. This is further explored in the chapter Volatility Drivers.



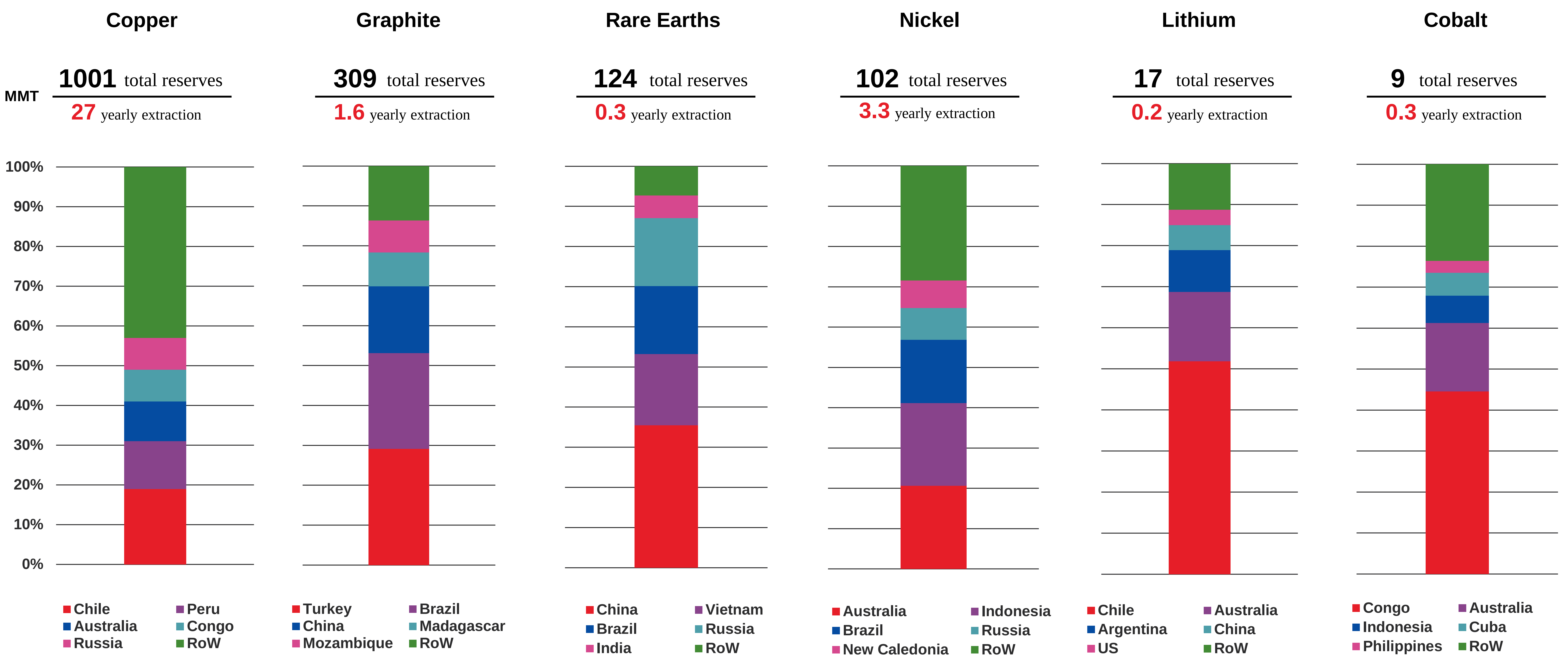
Historical copper reserves vs copper annual production, including forecast demand

Source | International Copper Association, S&P Global

Distribution of reserves

Considering the continuous exploration, technical advancements and the high recyclability of these critical raw materials, the risk of depletion is generally low. However, as demand growth outpaces extraction rates, supply constraints are expected in the coming years.

Reserves of selected CRM (cont.)



The distribution of reserves for selected CRM compared to global yearly extraction

Source | Statista

Sources used for this page: Statista, Mckinsey, S&Pglobal, ICSG, Macquarie Research, UBS, CNBC, ING

Key constraints

Several countries possess CRM reserves that do not match their global presence with regards to extraction. Amongst the most important explanations are the inaccessibility, lack of technical knowledge and skills, water supply issues, environmental concerns and demand uncertainty.

Reserves of selected CRM (cont.)

Constraints

It can be observed that several countries possess CRM reserves that do not match their presence with regards to extraction of that material. Several reasons can be identified, which we highlight adjacent.

Water supply issues

Australia's second place in copper reserves (around 13% of world total) surprisingly does not lead to significant extraction on world scale, rendering it only a 6th place (4%) in 2021. According to governmental channels, the ambition to scale-up is there, yet potentially unable to materialise "without a new water supply to the [respective] region". Water is used in mining operations for mineral processing, tailings and waste management. A medium-sized open pit mine may use and recycle 30 million litres of water per day. This leads to concerns of desertification and water competition, especially in dry, mineral rich areas such as Australia and Chile.

Inaccessible reserves

Brazil predominantly experiences inaccessibility of its large reserves of graphite, rare earths and nickel as they lie amid dense forests or lands appointed to the exclusive use of indigenous peoples. The Bolsonaro administration attempted to scale up the exploration within these areas. Along with the succession by Lula's administration, many mining requests have been revoked as of 2023, but tensions remain high on this important socio-economic issue in Brazil.

Demand uncertainty versus large and lengthy investments

The mining industry operates in a dynamic market environment, affected by technological developments, climate change and geopolitics. For example, the shift towards renewable energy sources is impacting the demand for certain minerals while creating opportunities for others. Additionally, technological advancements pose a threat of substitution. Mining companies find it difficult to adapt and forecast future needs effectively, as their investments take time to develop and will be locked in for a long time. Analysis of major mines that came online between 2010 and 2019 shows that it took, on average, over 16 years to develop projects from discovery to first production.

Environmental concerns

Apart from the physical difficulties and increased costs related to inaccessible reserves, there is considerable pressure from environmentalists to refrain from exploring mining opportunities in regions with natural significance (e.g. Brazil's part of the amazon basin and Indonesia's rain forests, but also the seabed in both national and unacclaimed marine territories). Aside from requiring a lot of water, mining releases toxic run-off in the natural environment, causes soil erosion, loss of biodiversity and habitats, among other concerns. These issues are further discussed under Sustainability.

Lack of (technical) knowledge

Türkiye is home to the world's largest reserves of graphite (about 90 million metric tons (MMT)). However, their yearly extraction is only a fraction of the global total output. The European Federation of Geologists argues that this is due to a lack of knowledge with respect to exploration and upgrading of ores. This relates to Türkiye's specific deposits exhibiting tiny flaked ores that are more costly and difficult to separate into the high-grade purified graphite that is currently in high demand.

Skills shortage

The skills shortage in mining is a worldwide phenomenon. Mining and metals companies face their most significant talent shortage after a massive wave of retirements and resignations. Replacing these workers and finding talent with critical skills will require a radical rethink of the sector's approach to attracting, retaining and nurturing talent.

The focus must be on an inclusive and open culture with solid career paths open to everyone. And this means improvement in working conditions, benefits, culture, and the opportunity for remote working and training.

Sources used for this page: Statista, IEA, Barrons, AFR, Australian Government, European Fed. Of Geologists, Stantec, Lusty & Gunn, Field Eagle

Mining

Mining for ores can be done in several ways. They vary by cost, damage done to the natural environment, corresponding safety hazards and waste streams generated.

After a mineral resource has been deemed commercially viable, companies can start extraction processes. The primary methods used to extract minerals are underground mining, surface (open pit) mining and placer mining. There is increasing attention for deep sea / seabed mining, but this is still in its infancy. According to the U.S. Geological Survey, the determining factors for selecting the method include the location and shape of the deposit, strength of the rock, ore grade, mining costs, and current market price of the commodity.

	Underground mining	Open pit mining	Placer mining	Seabed mining
Description	Used for higher grade, expensive metal ores or large, tabular shaped ore bodies. This method is relatively expensive due to its use of smaller machinery and having to reach areas that are difficult to access. It involves drilling and blasting the rock before moving it to the surface by truck, belt conveyor, or elevator. Once surfaced, the ore is separated from the waste rock in a mill.	This method is cheaper than underground mining as it can mine and separate large quantities. It is therefore used for lower grade metal ores and industrial minerals lower in value, which are the ones still found superficially. The method also involves drilling and blasting hard rock (except for some softer minerals that don't require blasting), after which they are separated.	Used to recover valuable minerals from sediments in present-day river channels, beach sands, or ancient stream deposits. In this case, the mined material is washed and sluiced to concentrate the heavier minerals. Due to this less complex practice compared to underground and open pit mining, placer mining is relatively cheaper.	Exploratory investigations have occurred, but commercial mining practices have not yet been undertaken. The method looks to collect mineral nodules from the ocean floor and the surface below, using vehicles effectively ploughing through the fields. There are large concerns that this method might destruct a natural environment that is largely unknown, both in its functioning and its importance to the wider global ecosystem.
Costs	High	Medium	Low	Unknown
Footprint land	Potential to displace large parts of surface area and some parts below the surface	Large (sub)surface area displaced	Surface area along waterways superficially disrupted	Natural habitat disruption
Tailing (waste rock)	Medium (due to higher grade ores)	High (due to lower grade ores)	Low (due to sifting, waste sediment is not displaced much)	Unknown
Safety concerns	Tunnel collapses, land subsidence	Exposure to radioactive elements and metallic dust	Safety concerns include exposure to heavy metals	Limited as most done robotically
Contamination	Toxic runoff into air and water can occur	Radioactive and toxic tailings can leak into bedrock	Direct metallic contamination of waterways can occur	Unknown

Sources used for this page: Statista, IEA, Barrons, AFR, Australian Government, European Fed. Of Geologists, Stantec

What are the key challenges?

Each CRM faces a different set of challenges in increasing mining activities. Novel solutions beyond the status quo are needed to help reduce supply challenges, especially where single-source dependency is not desired and environmental and social concerns are significant.

Below we set out some main identified challenges and potential solutions to increasing mining production of the six selected Energy Transition CRM.

CRM	Key challenges	Potential solutions
Cobalt	High reliance on the DRC for production and China for refining (both around 70%) set to persist, as only a few projects are under development outside these countries Significance on artisanal small-scale mining makes the supply vulnerable to social pressures New supply is subject to developments in nickel and copper markets as some 90% of cobalt is produced as a by-product of these minerals	Efforts to adopt processing methods that maximise cobalt recovery from copper and nickel mines can play an important role in mitigating risks.
Copper	Challenging to substitute due to its superior performance in electrical applications Mines currently in operation are nearing their peak due to declining ore quality and reserves exhaustion Declining ore quality exerts upward pressure on production costs, emissions and waste volumes Mines in South America and Australia are exposed to high levels of climate and water stress	New projects under development could bring a boost to near-term supply and investment has been picking up, but more is needed to support rising demand.
Graphite	Not all graphite is suited to meet the rising demand Expensive, energy intensive and dirty production process Dominance of China across the supply chain from mining to processing	Diversify access to graphite ore. Europe, for instance, has some sources of natural flake graphite close to or within its borders, with Norway and Ukraine as largest producers Creation a scale-up ecosystem outside of China. For example, The Bipartisan Infrastructure Deal under the Biden Administration is providing support for American companies involved in the production, sourcing and recycling of battery minerals and other materials.
Lithium	Possible bottleneck in lithium chemical production as many smaller producers are financially constrained after years of depressed prices Lithium chemical production is highly concentrated in a small number of regions, with China accounting for 60% of global production (over 80% for lithium hydroxide) Mines in South America and Australia are exposed to high levels of climate and water stress	New types of resources and technologies to recover lithium from unconventional resources may play an important role in the decade to come. For example, processing clay minerals is simpler and less energy-intensive than spodumene. Direct lithium extraction technologies are also on the horizon.
Nickel	Possible tightening of battery-grade Class 1 supply, with high reliance on the success of HPAL projects in Indonesia; HPAL projects have track records of delays and cost overruns Alternative Class 1 supply options are either cost-prohibitive or emissions-intensive Growing environmental concerns around higher CO2 emissions and tailings disposal	Some of the current Class 1 consumption in the non-battery sector could be switched to Class 2, freeing up Class 1 nickel supply for batteries. Increasing stainless steel production from scrap materials would make some Class 1 supply available Conventional oxide smelters, instead of HPAL, could produce Class 1 products from saprolite resources
RRE	Dominance of China across the value chain from mining to processing and magnet production Negative environmental credentials of processing operations Differences in demand outlooks for individual elements bring risk of price spikes for those in high demand (e.g. neodymium) and slumps for those in low demand (e.g. cerium)	New technologies could help unlock additional supply. For example, REEs could be recovered from the deposits of nuclear fuels. The US Department of Energy has funded several projects to develop commercially viable technologies to extract REEs from coal and coal by-product sources.

Urban mining

Urban mining provides opportunities for sustainable, secure CRM supply chains and value recovery, however its potential is limited by crude early market conditions, lack of infrastructure, technical innovation, cost and regulations.

Introduction

Not covered in typical CRM reserve estimates, the urban mining market aims to pull waste from landfills and reclaim non-renewable materials for recycling and reuse. As consumption grows, we are getting rid of electronics nearly just as fast as we produce them, filling landfills with an increasing amount of e-waste. Waste in cities can be seen as urban mines that can be exploited with the creation of new value.

Urban mining then requires a shift from the exploitation of natural stocks (virgin mining) to the exploitation of secondary raw materials from anthropogenic sources.

Market

According to the December 2022 publication 'Urban Mining – Global Outlook and Forecast 2022-2027' by Arizton:

– The global urban mining market is expected to grow at a compound annual growth rate (CAGR) of c. 13% during 2021-2027, from USD 18.1bn in 2021 to US 38.09bn in 2027.

– Electronics & electrical waste (e-waste), which dominates the market, is expected to grow at a CAGR of 13.65%.

– Precious metals is the largest commodity, expected to exceed USD 20.99 billion by 2027.

– Europe holds the largest urban mining market share globally and is expected to exceed USD 20.28bn by 2027.

– More recent market reports by Market Research (2023) and ISSUU (2024) support similar figures.

Major global urban mining market players have formed strategic partnerships with various industries that contribute significantly to waste generation activities for a competitive advantage, especially where they have developed their waste collection and separation infrastructure.

The success of collection efforts remains, dependent on the support of a committed and well-informed public.

Drivers

Urban mining appeal is based on some important foundations:

1. Reduction of greenhouse gas (GHG) emission, expressed in company targets and government regulations;
2. Awareness about recycling;
3. Value recovery;
4. The impact of depleting natural resources; and
5. The mitigation of potential environmental, and social impacts of waste generation through circularity-based alternatives to disposal.

An urban mining approach can then offer a range of benefits:

– Ensuring secure and sustainable supply chains;

– Increasing resource independence;

– Reducing transport costs;

– Increasing recovery and recycling rates reduces the strain on natural resource reserves; and

– Social benefits for local stakeholders.

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Introduction

Not covered in typical CRM reserve estimates, the urban mining market aims to pull waste from landfills and reclaim non-renewable materials for recycling and reuse. As consumption grows, we are getting rid of electronics nearly just as fast as we produce them, filling landfills with an increasing amount of e-waste. Waste in cities can be seen as urban mines that can be exploited with the creation of new value.

Urban mining then requires a shift from the exploitation of natural stocks (virgin mining) to the exploitation of secondary raw materials from anthropogenic sources.

Market

According to the December 2022 publication 'Urban Mining – Global Outlook and Forecast 2022-2027' by Arizton:

– The global urban mining market is expected to grow at a compound annual growth rate (CAGR) of c. 13% during 2021-2027, from USD 18.1bn in 2021 to US 38.09bn in 2027.

– Electronics & electrical waste (e-waste), which dominates the market, is expected to grow at a CAGR of 13.65%.

– Precious metals is the largest commodity, expected to exceed USD 20.99 billion by 2027.

– Europe holds the largest urban mining market share globally and is expected to exceed USD 20.28bn by 2027.

– More recent market reports by Market Research (2023) and ISSUU (2024) support similar figures.

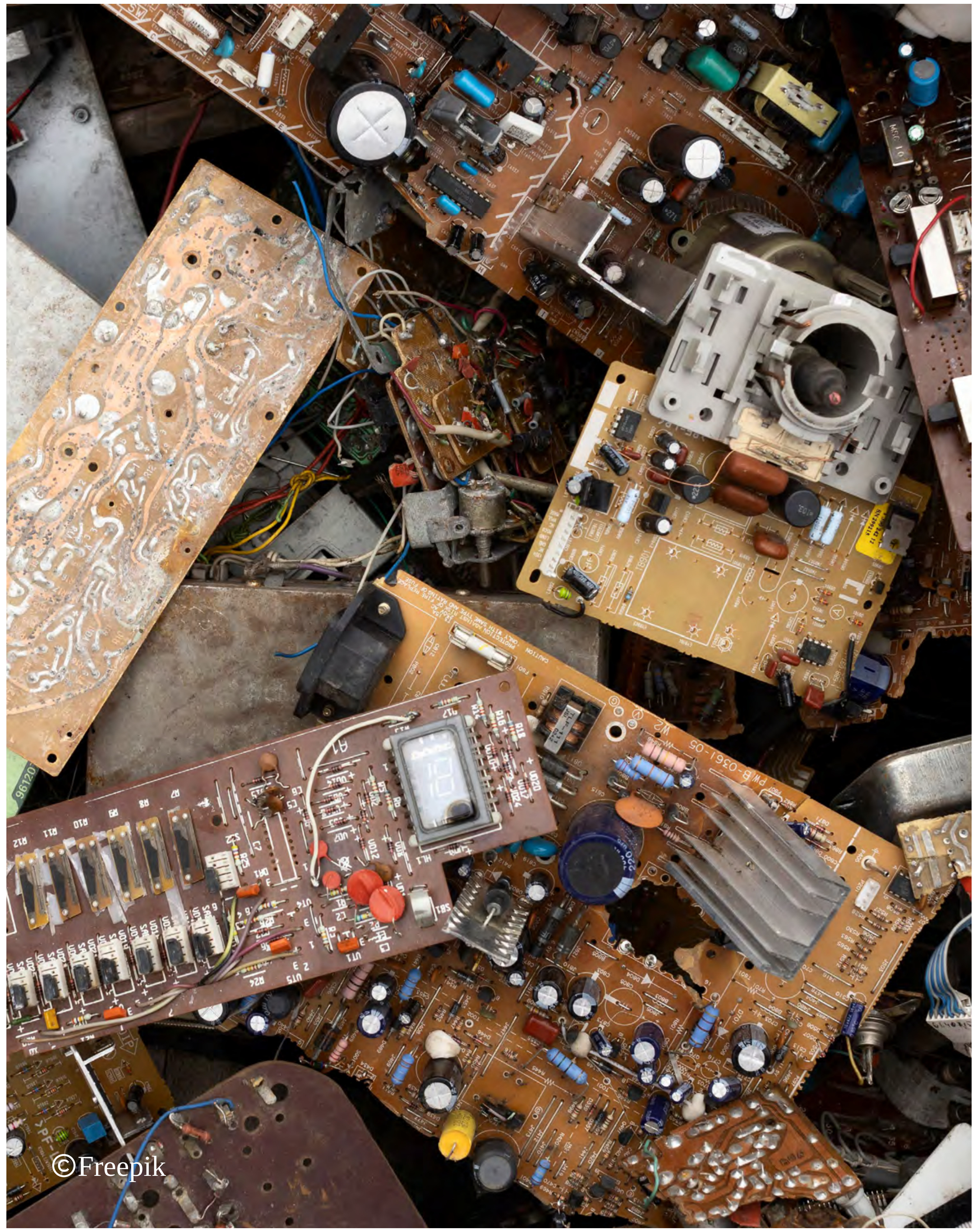
Major global urban mining market players have formed strategic partnerships with various industries that contribute significantly to waste generation activities for a competitive advantage, especially where they have developed their waste collection and separation infrastructure.

The success of collection efforts remains, dependent on the support of a committed and well-informed public.

Drivers

Urban mining appeal is based on some important foundations:

1. Reduction of greenhouse gas (GHG) emission, expressed in company targets and government regulations;
2. Awareness about recycling;
3. Value recovery;
4. The impact of depleting natural resources; and
5. The mitigation of potential environmental, and social impacts of waste generation through circularity-based alternatives to disposal.

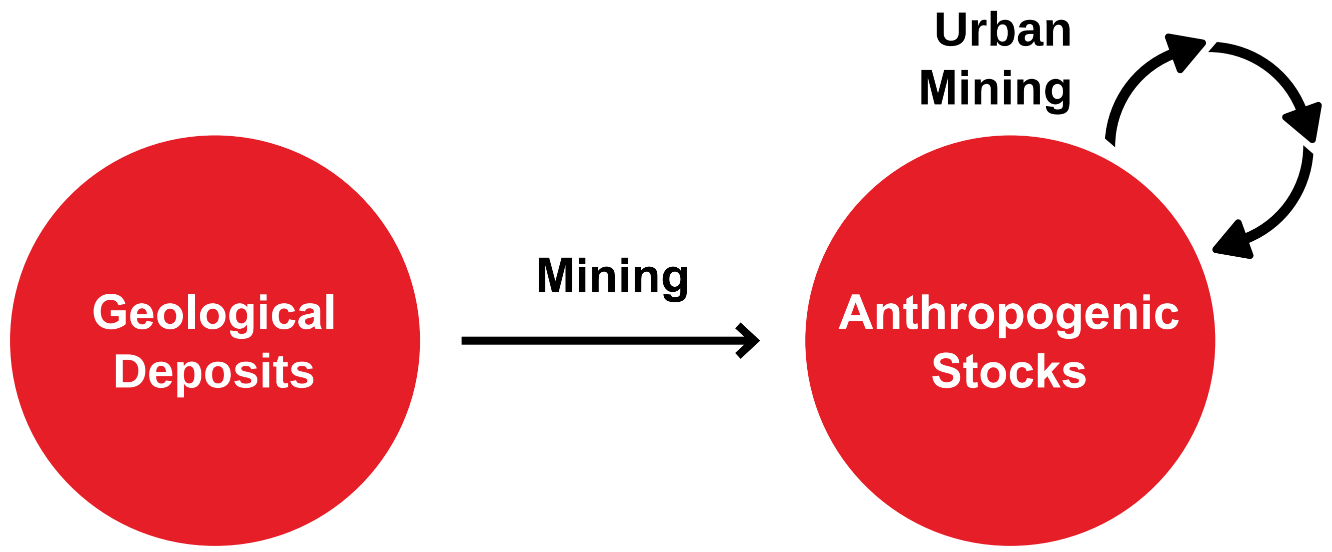


What are the key challenges?

All relevant aspects of a particular case for Urban Mining need to be considered, as challenges and concerns can outweigh its benefits over mining. Location, material flow, cost and value, acceptance, homo/heterogeneity and use especially need to be considered.

Mining vs Urban Mining

- Location/distribution: Mining is based on geological formations and Urban Mining on the anthroposphere. The spatial distribution of raw material sources is then different in principle for both.
- Material flow: Unlike mining, Urban Mining does not have the potential to increase the amount of materials included in the anthropogenic stock. Only the flow of discarded products and material recovered from landfills can be used. These do not lead to growth of the anthropogenic stock in total, but represent a shift in the distribution of the material to different life cycle stages (e.g., from scrap to finished product in use). Only conventional mining has the potential to increase the anthropogenic stock by extracting raw materials from geological sites.
- Use: The use of recycled materials is sometimes limited due to safety or environmental concerns such as reduced corrosion resistance or impurities that may wash out.
- Cost and value: The resources in the Urban Mine sometimes have a higher concentration and thus are more valuable than ores for conventional mining. The price for Urban Mining depends on the feedstock material and is not always advantageous. However, the recycling pathway is considerably more cost efficient than virgin mining for certain materials from secondary sources.
- Homo/Heterogeneity: Highly complex, diluted and heterogeneous waste streams that feed Urban Mining call for elaborate collection and recycling processes with environmental footprints approaching that of conventional mining. The worldwide distribution of the products and the need for economies of scale in their recycling brings large logistical and technical challenges, especially where materials are not easily separated.
- Acceptance: Both mining and Urban Mining require the acceptance of the population living near production sites. While the image of recycling/Urban Mining is less tainted by high-profile incidents and the use of natural resources and landscape changes inherent to mining, recycling facilities can also cause pollution and face challenges, albeit on a much smaller scale.



Mining

- Based on geological resources
- Requires exploration and characterization of resources; standards available
- Finite: Limited through availability of geological deposits
- Source of all metals in use
- Secures the majority of metal supply today
- Can expand to match increasing demand
- Can be strongly concentrated in few localities
- Significant environmental impact
- Difficult to secure support of the population
- Public not directly part of operations

Urban Mining

- Based on anthropogenic resources
- Requires exploration and characterization of resources; standards in demonstration
- Finite: Limited amount of materials in the anthroposphere
- Keeps metals in productive use longer
- Provides significant supply contributions for some metals
- Cannot match increasing demand
- Concentrated in urban areas (especially in industrialized countries)
- Often lower environmental impact
- Less difficult to secure support of the population
- Public essential contributor to collection

Comparing mining to Urban Mining

Source | Fraunhofer Institute, 'The promise and limits of Urban Mining' (2020)

Sources used for this page: Fraunhofer Institute, Xianlai et al. (2022)

Volatility Drivers

Six key price volatility drivers

Six price volatility drivers for CRM are identified; Product demand, Reserves and exploration, Political issues, Policies, Environmental and Social pressures and Climate risks. CRM prices are strongly affected on the demand (renewable energy growth) and supply side (continuous exploration).

Price development (1)

Introduction

The rise in demand for CRM requires that supply moves in parallel in a reliable manner. However, this is not evidenced in practice. Prices of most CRM are highly volatile. The charts opposite show the development of the copper, lithium, cobalt and nickel price over the last 5 years.

Six important price volatility drivers for CRM are identified, namely Product demand, Reserves and exploration, Political issues, Policies, Environmental and Social pressures and Climate risks.

1. Product demand

CRM classify as commodities, used to manufacture consumer products, which makes their pricing susceptible to consumer demands. Especially the minerals identified as critical to the energy transition have seen demand increase significantly since energy transition efforts grew, see opposite. According to the World Trade Organisation, annual trade in energy-related critical minerals has increased from $53 billion to $378 billion over the past 20 years.

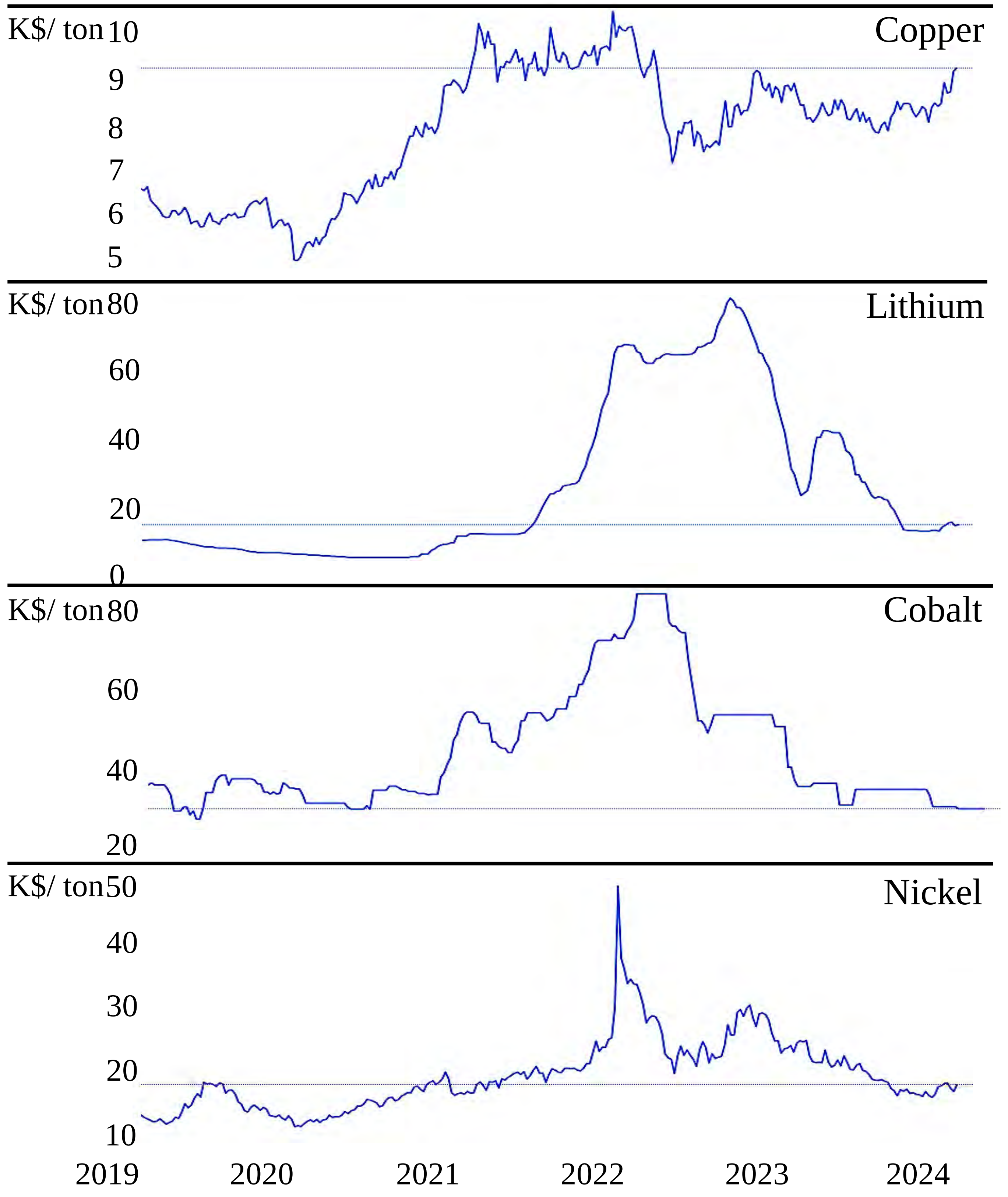
Inversely, their prices are affected by a drop in (expected) demand. For example, demand for nickel, cobalt and lithium is heavily connected to demand for Electric Vehicle (EV) batteries (see EV battery market case). The recently decreasing prices of these metals can be largely attributed to lower than expected EV battery demand.

Lithium, cobalt and nickel prices have developed relatively similar over the past 5 years, whereas copper's price development differs. This is due to copper being used more and in a wider array of appliances, making it less susceptible to volatility in demand of specific consumer products (copper's yearly extraction is about 100 times that of lithium or cobalt).

2. Reserves and exploration

As discussed, the term reserves implies viable commercial extractability, which means there are vast resources beyond what is currently identified as reserves. Therefore, in the standard price mechanism (as seen historically) exploration of newly identified reserves occurs continuously as demand rises and prices increase alongside it, which counteracts these price increases and establishes a balance.

However, contemporary forecasts for the next 10-15 years expect demand to rise at a rate that expected increases in supply cannot keep up with (i.e. too few projects are being executed to increase extraction at the same rate as demand for many critical raw materials, estimations for copper are given as an example (on slide 9). The chapter Reserves discusses how fast demand is expected to rise for the various selected CRM. Because of this, current forecasts also expect prices to rise considerably. CNBC (January 2024) expects prices for copper to increase with 75% to reach around $15k per tonne in 2025, fuelled in the background by global renewable energy targets.



Fluctuations of commodity prices of CRM

Source | Trading Economics

Sources used for this page: Trading Economics, AFR, Reuters, The Economist, The Oregon Group, WTO

The increasing value and highly concentrated origin of CRM makes the system vulnerable to political instability, geopolitical risks and possible competitive export restrictions, which can lead to lengthy processes, increased risk for investors and supply chain disruptions (affecting prices).

Price development (2)

3. Political issues

Today's production and processing operations for many energy transition minerals are highly concentrated in a small number of countries, making the system vulnerable to political instability, geopolitical risks and possible competitive export restrictions.

As the importance of CRM to the global economy grows, so does the degree to which they are used as leverage in political affairs. Their increasing value sparks conflict (armed or economic), increased protectionism and economic neo-colonial tendencies. Concurrently, the amount of CRM required to manufacture the products critical to the energy and digital transitions increases steadily, reinforcing the former. It is important to note here that the CRM miners and processers of tomorrow are likely to be the same as those of today.

Some examples:

The Democratic Republic of Congo is currently in an armed conflict in which mining of cobalt, coming almost exclusively from this region, allegedly takes centre stage. Apart from numerous human rights violations with respect to the mining itself (such as child labour, exposure to toxic elements), Amnesty International declares that forced evictions occur for the benefit of excavating new sites.

Chile's President Gabriel Boric is aiming to increase its grip on the country's lithium industry by taking a controlling stake in mining operations, to concurrently boost its economy and better protect its environment by mandating a different extraction technique (see – Do no significant harm).

Indonesia banned exports of nickel ore entirely in 2020, to encourage companies to process it onshore so more value accrues to Indonesia, instead of sticking entirely to the (mostly Chinese) mining companies. Since the policy, Indonesia attracted serious foreign direct investment, as factories were set up for mineral processing, followed by investments from the automotive industry.

Mexico's president signed a decree in 2023 handing over responsibility for lithium reserves to the energy ministry, after having already nationalised its lithium deposits.

Myanmar's military coup has raised concerns over supply disruption of heavy REEs, fuelling a surge in prices.

These political matters influence CRM prices in various ways:

1. Lengthy processes: Increased direct government influence in mining practices can be a concern for investors, as a major stakeholder with limited industry experience, could lengthen processes.
2. Increased contingencies: Unstable governments and unpredictable events require a need for investors to increase contingencies in their financial models.
3. Supply chain disruptions: Trade barriers, state aid and import / export regulations influence the development of global value chains and the flows of goods between countries / regions, because of direct price influences and potentially the relocation of facilities. The EU's Critical Raw Materials Act is an example of protective measures that will influence global value chains, albeit more consisting of goals than hard-lined regulations (such as the Nickel export ban in Indonesia). The US Inflation Reduction Act inclusions on EV mobility have created tensions with China who dominates some the CRM supply chain for EV batteries.

World Trade Organisation (WTO)

The WTO are responsible for resolving trade disputes and setting legal rules for trade. An important role in the face of increasing pressure on global value chains. A founding principle is its most-favoured-nation clause, which requires a country to extend the same trade terms to all trading partners.

- Import: The most-favoured-nation tariff applied to imports of critical minerals decreased from 5.4% to 3.7% in the period 2002 – 2022. This indicates that the global trend is that of a more lenient import policy towards CRM, benefitting global trade.
- Export: However, OECD data shows that export restrictions pertaining to critical minerals have increased from 396 to 502 in the period 2009 – 2021, reflective of a more protectionist trend among producing countries, such as Indonesia's ban on nickel export. This leads to upward pressure on prices and concerns about supply security among manufacturers. The WTO also points to the risk of competitive policy practices leading to upward spiralling export taxes, as the minerals come from a limited number of countries and alternative countries becoming the sole supplier might be tempted to follow the restrictive policies.

Sources used for this page: BNEF, Goldman Sachs, Trading Economics, WTO, Reuters

Many dynamic push and pull factors continuously influence CRM market prices, leading to high price volatility. In combination with the uncontrollable nature of government policies, in an era of ecological scrutiny, makes mining a difficult sector to invest in.

Price development (3)

4. Policies

Product demand, especially for Energy Transition products, moves with government policy implementation, as many CRM requiring assets are still highly subsidised or incentivised otherwise. Therefore, political statements, new regulations, subsidies and / or targets pertaining to the Energy Transition can directly influence CRM prices, specifically the six under review in this guide, through speculations of their impact on product demand.

5. Environmental and Social pressure

Pressure on improving environmental performance could put upward pressure on production costs of energy-intensive mining and processing operations. Due in part to declining resource quality, the production and processing of energy transition minerals are increasingly energy-intensive, involving higher emissions to produce the same quantity of product. Mining and processing companies face growing pressure to address these and other issues related to their social and environmental performance.

Sources used for this page: BNEF, Goldman Sachs, Trading Economics, WTO, Reuters, IEA

A growing number of consumers and investors are requesting companies to disclose targets and action plans on these issues. Tightening scrutiny of ESG issues could have an impact on costs and supply prospects.

There is also increasing pressure from consumers and human rights activists to demand a supply chain without human rights violations, leading companies to re-evaluate where they source their products, which in turn increases resource demanded from politically stable countries.

Prioritising environmental and social concerns could increase the costs of extraction. A lack of attention to environmental and social concerns, however, could also influence pricing due to consumer demands influencing company sourcing behaviour, just as with human rights issues.

6. Climate risks

A combination of more frequent drought events in major producing regions and higher water intensity in ore processing has brought the critical importance of sustainable water sourcing to attention. For example, in 2019 the worst drought in more than 60 years severely affected some operations in Chile, with similar events having occurred in Australia, Zambia and others. The El Teniente mine, the largest underground copper mine in Chile, implemented water rationing to deal with severe droughts.

Natural disasters have also become one of the most frequent causes of mineral supply disruption, third only to accidents and labour strikes.

Conclusion

It shows that many dynamic push and pull factors continuously influence CRM market prices, leading to high price volatility. In combination with the uncontrollable nature of government policies, in an era of ecological scrutiny, makes mining a difficult sector to invest in.

Case studies

Arup has presented case studies for two main use cased of CRM in the Energy Transition.

Electrolyser Market

If all electrolyser projects currently in the pipeline would be executed, an installed electrolyser capacity of ca. 300-400 GW would be reached by 2030. Many different forecasts exist on future electrolyser demand. According to the International Energy Agency (IEA), a net-zero scenario would require an estimated 3670 GW to be installed by 2050.

There are currently 3 main types of electrolysers of which at least 1 GW is being manufactured annually. These are alkaline, proton exchange membrane (PEM), and solid oxide electric cells (SOECs), from most to least common. As shown in the table below, they require varying (amounts of) materials to be manufactured.

The International Renewable Energy Agency (IRENA) and the IEA have separately estimated the material requirement for manufacturing the electrolyser capacity in a net-zero scenario (assuming 40-40-20% for Alkaline, PEM and SOEC respectively). When comparing these numbers against the estimated, cumulative production capacity of the metals required, there would likely be more than sufficient material. Even though platinum, palladium and iridium are relatively rare (<210 metric tons produced annually), this still seems sufficient to manufacture the estimated required installed capacity of PEM electrolysers by 2050.

However, adding up the estimated Fuel Cell requirement under the same guidelines (also requiring platinum), the production rate for this material is possibly insufficient for establishing a hydrogen economy that features both PEM and platinum Fuel Cells (noting that the reduction of platinum usage here is R&D priority).

	Material	Requirement in ton/GW
Alkaline	Nickel	800
	Zirconium	100
	Aluminium	500
PEM	Platinum	0.30
	Palladium	0.30
	Iridium	0.70
SOEC	Nickel	175
	Zirconium	40
	Lanthanum	20
	Yttrium	5
Fuel Cells	Platinum	0.29

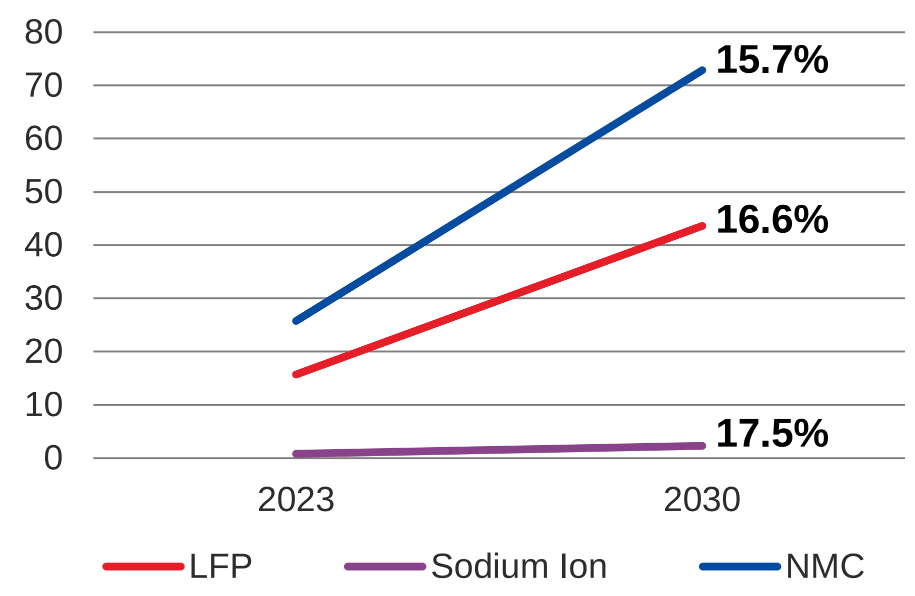
Headlines estimates for material requirement for various electrolyser technologies (dependent on supplier)
Source | IEA

EV Battery Market

The recently decreasing prices of lithium, nickel and cobalt can be largely attributed to lower than expect Electric Vehicle (EV) battery demand. An example of this is that the battery sector is responsible for 70 percent of the global demand for cobalt, according to the World Trade Organisation. Analysts from Goldman Sachs have connected the lagging demand to price competition among EV manufacturers and countries lowering their support schemes for EVs.

Even though this led the bank to lower its forecast growth in global battery demand in 2024 from 35% to 29%, it remains clear that demand is still expected to rise strongly. The EV market grew from ca. 1m global car sales in 2017 to 14m in 2023 and is forecast to grow to almost 27m in 2026 in a report issued by BNEF in 2023. It is questioned, however, for how long EVs will require the same materials to manufacture their batteries, as various battery technologies exist.

New sodium-ion batteries require no nickel, copper, cobalt or lithium. Lithium iron phosphate (LFP) are a type of Lithium-Ion batteries that do require lithium but do not require nickel or cobalt. If technological advancements would lead demand for either of these technologies to supersede the dominant Nickel Manganese Cobalt (NMC) type Lithium-Ion battery, demand for these metals could see strong declines. So far, upcoming technologies do not seem to slow down demand for the NMC type Lithium-Ion batteries. Instead, demand for all battery technologies are expected to rise until 2030, given their projected market value growth as shown in the graph below.



Expected market growth of various battery types, including averaged CAGRs
Source | insightaceanalytic, evmarketsreports, grandviewresearch, marketsandmarkets, prnewswire, precedenceresearch, gminsights

Sources used for this page: IEA, BNEF, Goldman Sachs, Trading Economics ,The Breakthrough Institute

Sustainability

Aligning CRM extraction with sustainable development

Mining for CRM has many of the same potential economic, social and environmental consequences as other extractive industries, including fossil fuels. As demand for CRM increases, regulations are to be set by policy makers and responsible sourcing of materials is to be pursued by the supply chain.

Introduction

A 2023 United Nations Energy (UN-Energy) brief on ‘Aligning Critical Raw Materials Development with sustainable development’ sets out a number of sustainability challenges with the unavoidable increase of supply of CRM.

Challenges

- Poorly managed CRM extraction, transport and processing development can have a range of negative impacts on the environment and society.
- The extraction and processing of natural resources currently account for approximately half of global GHG emissions. Metals and non-metal minerals are responsible for about 20% of this.
- Mining can also lead to environmental degradation, including water pollution and competition, the use of hazardous chemicals, loss of biodiversity and a change in land use. This degradation can further impact health, poverty, inequality and demographic imbalances.
- Declining mineral quality and resulting low-quality ore mining requires more energy and produces more waste and tailings, resulting in higher production costs and increased emissions.
- The rapid development of critical minerals mining is a particular challenge for many developing countries that have rich resources but weak governance. This challenge can be seen in areas such as environmental regulation, revenue management – including combatting corruption – and social development. Many of the countries that have the most significant CRM resources and/or the greatest potential for their extraction, are emerging and developing economies. These often require stronger resource governance and have a limited capacity to mitigate the economic and environmental consequences of increased extractive activities.
- Weaknesses in the legal and judicial systems may undermine a host governments’ capacity to detect and prevent corruption effectively, as well as its interest in doing so. At the same time, although allegations of corruption in the mining industry occur frequently, governance and corruption are not high on the agenda of consumer countries when they consider CRM supply chains.

ARUP

In order to align CRM extraction with sustainable development, the UN-Energy suggests a range of key actions across three main pillars i) messages to policy makers, ii) transparency along supply chains and iii) global supply chain cooperation.

Key messages to policy makers	Increase transparency along CRM supply chains	Enhance global supply chain cooperation
Promote the diversification of sources of CRM supply	Adopt a standardized and harmonized approach to public disclosure of the ESG performances of the mining companies	Coordinate global efforts to establish norms and arrangements that promote free markets for CRM
Promote the recycling and recovery of CRM		Coordinate efforts to establish international standards on green finance
Promote investment in innovation to reduce demand for CRM	Encourage governments and extractive industries to work together to eradicate illegal financial flows	Develop a global risk assessment programme for CRM and suppliers
Launch a global campaign to promote sustainable and responsible consumption of CRM		Establish relevant regional institutions to facilitate regional coordination, dialogue, and capacity building

UN-Energy recommendations to align the future development of CRM with the goals of sustainable development

Source: UN-Energy, 'Aligning Critical Raw Materials Development with sustainable development' (2023)

Sources used for this page: UN-Energy, University of Utrecht

ARUP

What are the environmental impacts?

Environmental effects of mining can occur at local, regional, and global scales through direct and indirect mining practices. Erosion, contamination and deforestation and biodiversity losses are common. Mining causes between 4-7% of global greenhouse gas emissions.

Environmental Impacts

Environmental impacts of mining can occur at local, regional, and global scales through direct and indirect mining practices. These impacts have been studied in detail.

Mining can cause erosion, sinkholes, loss of biodiversity, or the contamination of soil, groundwater, and surface water by chemicals emitted from mining processes. Land areas and surface and underground water bodies can be affected for years, decades to come. Mining processes also affect the atmosphere through carbon emissions which contributes to climate change.

Opposite, we discuss some of the main negative environmental impacts associated with (land based) mining. Mitigation technologies exist, but are expensive and not always well regulated or applied.

The environmental impacts from seabed mining are largely unknown and require significant further research. Environmental advocacy groups claim that seabed mining has the potential to damage deep sea ecosystems and spread pollution from heavy metal-laden plumes.

Environmental impacts vary from one mining operation to another, depending primarily on the materials being mined, and how mining waste is managed. Some mining methods (e.g. lithium mining, mountaintop removal mining) may have such significant environmental and public health effects that mining companies in some countries are required to follow strict environmental and rehabilitation codes to ensure that the mined area returns to its original state.

Impact	
Air pollution	The mining industry contributes between 4 and 7% of global greenhouse gas emissions, both directly and indirectly throughout the mining process and can have significant impacts on global climate change. Ozone and Nitric-oxides can affect metabolic functions of leaves.
Biodiversity losses	Mining impacts biodiversity across various spatial dimensions. Locally, the immediate effects are seen through direct habitat destruction at the mining sites. On a broader scale, mining activities contribute to significant environmental problems such as pollution and climate change, which have regional and global repercussions. Direct habitat is the main component of biodiversity losses, but contamination caused by mine-extracted material, and indirect poisoning through food and water can also affect animals, vegetation and microorganisms. Soil acidification through pH diminution by chemical contamination and temperature modification can also lead to a diminished species number in a wide area. Soil texture and water content can be negatively modified.
Deforestation	Both open cast mining and the frequently released amount of toxins, and heavy metals released during mining activities cause deforestation. Furthermore, when rainfall occurs the ashes and other materials are washed into streams that can hurt life in and around these streams and contaminate ground water. These impacts can still occur after the mining is closed, meaning restoration of the deforestation takes longer than usual because the quality of the land is degraded.
Erosion	Erosion is caused by physical disturbances applied in mining activities damaging plant and tree root systems, a crucial component in stabilising soil. Eroded materials are then often transported by runoff into nearby surface water, leading to a process known as sedimentation. Additionally, altered drainage patterns redirect water flows, intensifying erosion and sedimentation of nearby water bodies, cascading damages. The cumulative impact results in degraded water quality, loss of habitat, widespread pollution and long-lasting ecological damage.
Land contamination	Runoff, erosion, and waste such as tailings and spoil tips (often contain unnatural (amounts of) chemicals that lead to devastation of surrounding vegetation and contaminated and acidized soil.
Waste materials	Mining processes produce an excess of waste materials known as tailings. The materials that are left over after are a result of separating the valuable fraction from the uneconomic fraction of ore. Tailings have great potential to damage the environment by releasing toxic metals by acid mine drainage or by damaging aquatic wildlife. A spoil tip is a pile of accumulated overburden that was removed from a mine site during the extraction of coal or ore. These waste materials are composed of ordinary soil and rocks, with the potential to be contaminated with chemical waste.
Water pollution	Unnaturally high concentrations of chemicals, such as arsenic, sulphuric acid, and mercury can spread over a significant area of surface or ground water. This is exacerbated by the run-off and disposal of the large amounts of water used for mine drainage, mine cooling, aqueous extraction and other mining processes increases the potential for these chemicals to contaminate ground and surface water.
Water scarcity	Mines tend to use significant amounts of water that has to be sourced locally. This means that a mine often competes for water with the surrounding environment and flora and fauna therein, causing droughts.

Sources used for this page: IEA and European Parliament Social and Environmental impacts of mining activities in the EU ‘, wide range of academic papers

What are the social impacts?

Mining can provide various advantages to societies, yet it can also spark conflicts, particularly regarding land use both above and below the surface and wealth distribution. Responsible resourcing of CRM requires a people-centered approach focused on fair distribution of wealth.

Introduction

There is growing recognition that the energy transition must be people-centered and inclusive. Demand growth of CRM to support the energy transition can support economic development and reduce poverty, if properly managed. This means contributions to (local) public revenue and providing decent economic livelihoods, particularly if paired with strong ESG standards that ensure that workers and communities are protected from environmental and social harms.

The IEA Global Commission on People-Centred Clean Energy Transitions in October 2021 called for climate solutions not to come at the expense of injustices along mineral supply chains, and for policy makers to promote responsible mineral production and trade; essentially in line with the UN-Energy brief of 2023.

Impacts

Failure to address negative social impacts from CRM extraction and processing may reduce reliability of CRM supply chains, many of which come from high-risk areas. According to the IEA there are several social impact related failings that can adversely impact the energy transition:

1. Potential liabilities associated with poor performance on social impacts can deter investment, particularly for projects in high-risk areas. Rigid de-risking, whereby companies and financial institutions fully disengage or stay away from certain regions, is widespread.
2. Inability to identify and mitigate social harms can make it difficult to obtain and maintain a ‘social license to operate’, which can exacerbate and lead to community pressure, adverse publicity and regulatory issues. Failure to obtain community acceptance can threaten long-term investments and multiplies the risk of short-term supply disruptions.
3. Specific incidents may give rise to short-term supply disruptions. Safety failures can harm workers and lead to long-term interruptions to operations. In addition, corruption in the mining sector and a volatile business climate appear to be associated with periodic shut-downs, and shake-downs, of mine sites.
4. A large proportion of today’s lithium and copper production is concentrated in areas with high water stress, and use of scarce water should not go at the cost of the local population.
5. There does not appear to be broad recognition or understanding of the importance of managing risks associated with conflict-affected or high-risk areas in CRM supply chains. Many CRM supply chains have seen reports of serious governance incidents typically associated with conflict-affected and high-risk areas. As conflicts and areas of high risk are ever changing, where a particular geographic area does not carry a high risk today, it might tomorrow. These issues could lead to supply challenges down the road, even for supply chains that currently appear to be insulated.

Sources used for this page: IEA and European Parliament ‘Social and Environmental impacts of mining activities in the EU’

Solutions

Many of the above challenges stem from underlying governance issues that can limit the positive impacts that responsible investing could theoretically yield.

Governments and international organisations should ensure that future mining projects are developed in accordance with the highest possible social standards and establish clear incentives to reward producers that meet these standards.

Businesses and investors in CRM and downstream energy transition assets can make a positive contribution by addressing potential adverse impacts linked to their activities or supply chains by opting for responsible sourcing.

OECD standards on responsible business conduct (RBC) provide a proactive framework that can help businesses anticipate risks accordingly. In addition, all stakeholders should support efforts to improve governance, transparency and accountability of the extractive sector globally.

This should include at a minimum:

1. Technical assistance and capacity building for government agencies and administrations responsible for the oversight of mineral production, environmental protection and trade;
2. Support for broader uptake of transparency principles such as those set forth in the Extractives Industries Transparency Initiative;
3. A targeted and consistent effort to combat bribery and corruption throughout mineral supply chains;
4. Legal support and advice to enable development, holistic integration, implementation and enforcement of robust ESG standards and reporting frameworks at all levels, including robust legal frameworks to require companies to undertake supply chain due diligence to identify and mitigate salient risks in mineral supply chains.

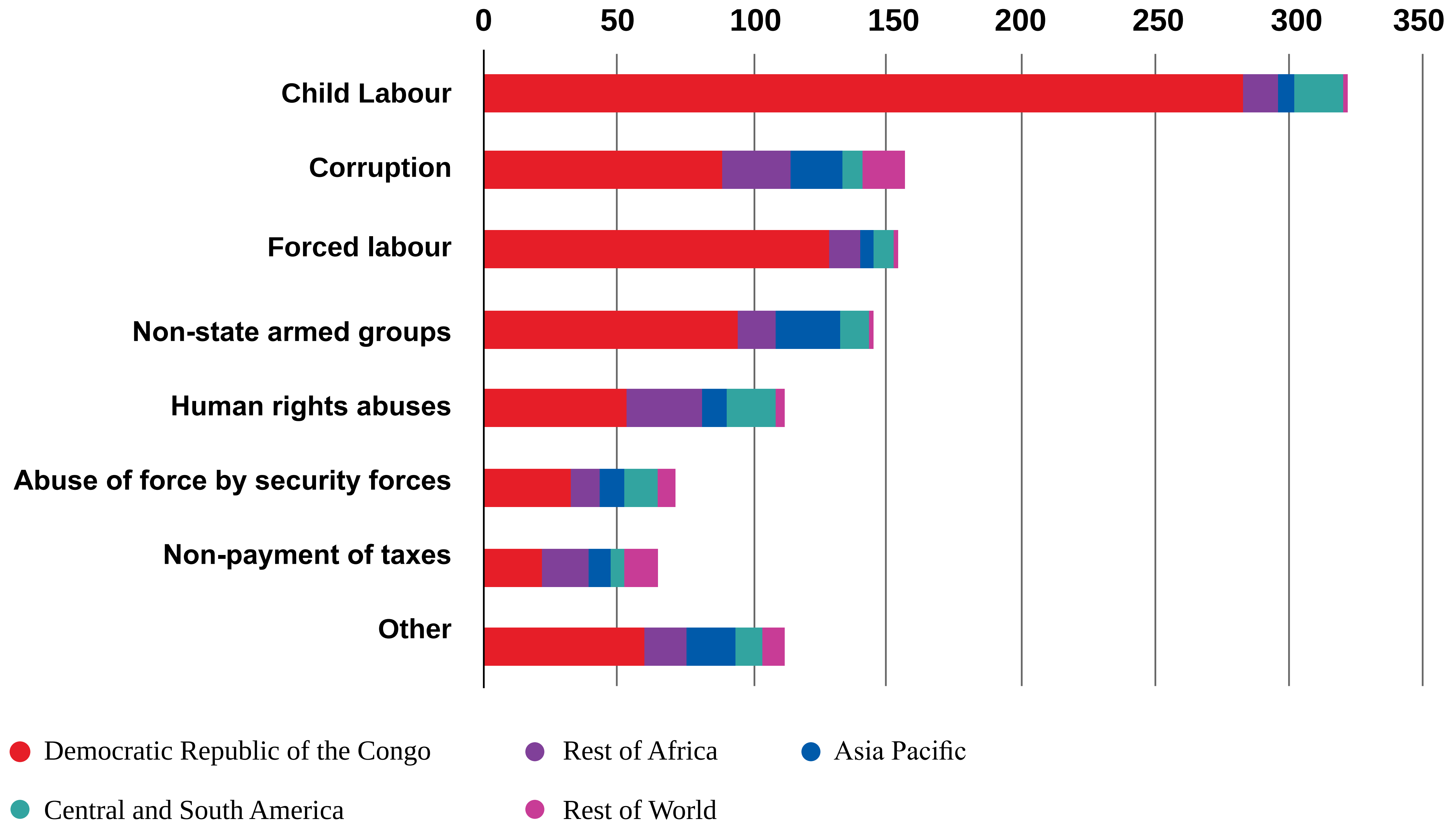
©Adobe stock

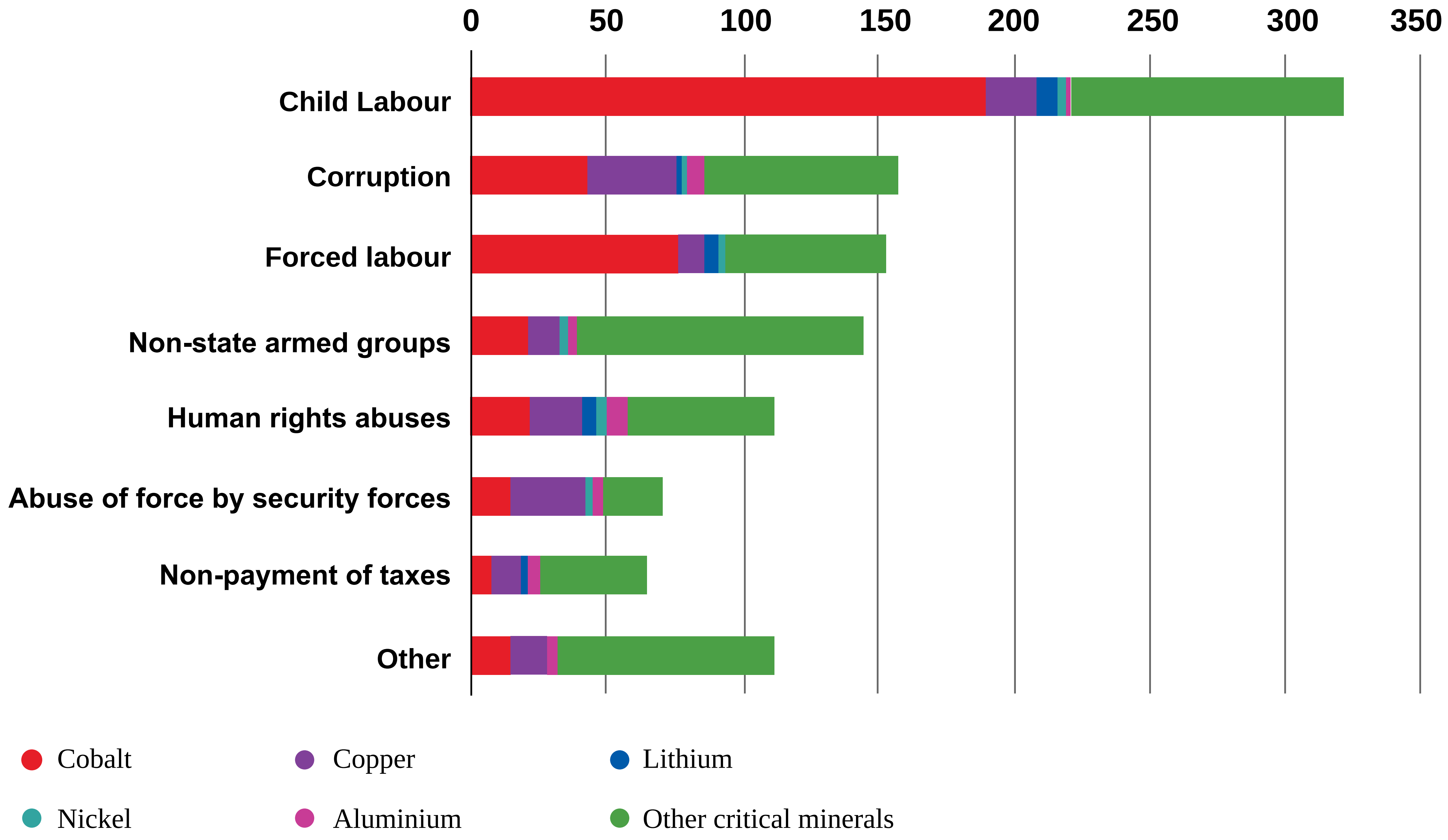
Sources used for this page: IEA and European Parliament 'Social and Environmental impacts of mining activities in the EU'

Although data sources are limited due to the inherent nature of the problems, the IEA has reported 2017-2019 governance related risks by region and mineral supply chains, showcasing the serious nature of social impacts.

Below we have presented some of the key reported (social) governance related risks in the period 2017-2019 in terms of number of reports. It has to be clearly understood that there is serious concern that not nearly all social impact risks are reported.

Of course, this is far from exhaustive and does not provide a relative representation per mine, country or CRM, however it does portray the seriousness of the matter.





Public reports of governance-related risks by country (left) and mineral supply chain (right), 2017-2019
Source: IEA

EU Taxonomy

Mining is not currently included as an eligible activity in the EU Taxonomy, but CRM sourcing may be indirectly impacted by downstream eligible activities, predominantly due to active reference made to circular nature of raw materials, and thus urban mining potential.

Introduction

The EU Taxonomy is a science-based classification system (a ‘dictionary’) establishing a list of environmentally sustainable economic activities (**eligible activities**) and related sustainability criteria, to facilitate investments that are aligned with **six objectives** for net-zero trajectory by 2050 and broader environmental goals:

1. Climate change mitigation (Paris Agreement)
2. Climate change adaptation
3. Sustainable use and protection of water and marine resources
4. Transition to a circular economy
5. Pollution and prevention control
6. Protection and restoration of biodiversity and ecosystems.

Technical Screening Criteria (TSC) then define the specific requirements and thresholds for an eligible activity to be considered as **substantially contributing** to one of the six sustainability objectives, and whether it **does no significant harm (DSNH)** to the other five sustainable objectives. These TSCs are elaborated in secondary legislation called **Delegated Acts (DAs)**.

The EU Taxonomy then serves as the foundation to judge sustainable activities under **disclosure regulations (CSRD and SFDR)**. For example, so-called ‘Article 8 funds’ are required to disclose information on how and to what extent their eligible activities are Taxonomy-aligned. ‘Article 9 funds’ must ensure that all the companies they invest in are fully Taxonomy-aligned. This means the activity is (i) making a substantial contribution to at least one of the six objectives, while (ii) also doing no significant harm to the remaining objectives and meeting **minimum social safeguards**.

An **EU Social Taxonomy** for socially sustainable activities with a similar structure is being drafted.

Direct implications for CRM

Extraction of CRM currently falls outside the scope of the EU Taxonomy Regulation, it is not included yet as an eligible activity. The European Commission (EC) confirmed that it would include mining as an eligible activity in the Taxonomy and it is the sustainable finance group of experts is evaluating.

Indirect implications for CRM

For each currently included downstream eligible activity, the TSC lay out contribution and DNSH criteria that may affect CRM sourcing. This means that, indirectly, there are some considerations relating to currently included eligible activities. We have set out some examples to the right, mostly focusing on circular economy.

Electric Vehicles	Renewable Hydrogen	Renewable Energy
Activity: Manufacture of automotive and mobility components Substantial contribution: manufactures, repairs, maintains, retrofits, repurposes and upgrades components that are essential for delivering and improving environmental performance	Activity: Manufacture of equipment for the production and use of hydrogen Substantial contribution: manufactures equipment for the production of EU taxonomy aligned hydrogen	Activity: Manufacture of renewable energy technologies Substantial contribution: manufactures renewable energy technologies (e.g. wind turbines and solar panels and related power management systems)

DNSH: Circular Economy > The activity assesses the availability of and, where feasible, adopts techniques that support:

- reuse and use of secondary raw materials and re-used components in products manufactured;
- design for high durability, recyclability, easy disassembly and adaptability of products manufactured;
- waste management that prioritises recycling over disposal, in the manufacturing process;
- information on and traceability of substances of concern throughout the life cycle of the manufactured products.

Implications for CRM lie predominantly in the circular economy push in the EU Taxonomy, with active reference made to the raw materials. High, Medium and Low Voltage Equipment and Other Low Carbon manufacturing have similar circular economy related DNSH criteria.

Downstream manufacturing activities included in the EU Taxonomy that may have an indirect impact for sourcing CRM

Source: EU Taxonomy

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