Zero Carbon Analytics

Briefing · July 2022

Minerals and Metals for the energy transition

Key points:

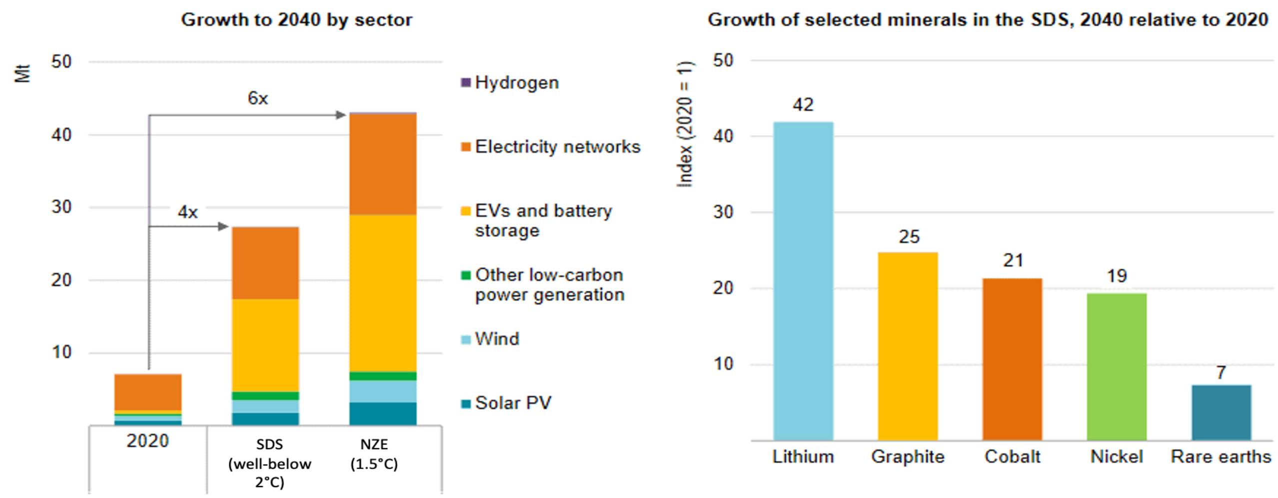
- Total availability is, broadly speaking, not an issue - there are enough mineral resources for the net-zero energy transition.
- However, production capacity is not scaling up fast enough, thus creating uncertainty, especially for battery metals and for copper.
- Despite high prices, investors seem reluctant to mobilise capital. They show a lack of confidence in governments' NZ pledges - policy signals such as gas being labeled as 'green energy' are clearly unhelpful.
- Investment is needed to avoid supply crunches for cobalt, lithium and copper, but demand forecasts have changed and will continue to do so. Substitution, mining innovation and recycling can curb demand and alleviate supply risks to some extent.
- Countries that want to position themselves as leaders in the energy transition in the next decade - especially EV battery production - need to invest now to scale up mineral production (as well as alternative technologies and recycling). Delaying investment will make the energy transition more expensive as prices are likely to rise, leading to more government subsidies.
- China is leading the race to scale up production, driving geopolitical concerns.
- Strong social and environmental standards urgently need to be managed by governments, communities, companies and civil society.
- For more detailed information, see this spreadsheet.

Which minerals are needed in the energy transition?

Clean energy technologies are, broadly, more material-intensive than fossil fuels or nuclear power. For instance, a typical electric car requires six times more metals and minerals than a car with a combustion engine.[1] Demand for energy transition minerals is also up front, rather than evenly distributed over time, which greatly contributes to the current concern over their scale-up - while the emissions savings from clean energy technologies such as wind turbines, solar panels and batteries accrue over time, demand for materials happens only during their construction phase (Fig. 1).

[1] **Minerals** are naturally occurring inorganic substances found in the Earth's crust. They have a certain chemical composition and crystal structure. **Metals** are elementary substances, such as gold, silver and copper. They are crystalline when solid and naturally occur in minerals. (Source). For simplicity, the term mineral will be used for both.

Fig. 1: Growth in mineral demand from clean energy technologies by scenario, 2020 compared to 2040



Source: IEA
Note: Includes chromium, copper, major battery metals (lithium, nickel, cobalt, manganese and graphite), molybdenum, platinum group metals, zinc, rare earth elements and others, but does not include steel and aluminium.

Table 1 shows selected key minerals and the energy-transition technology for which they are used. Cobalt, copper, lithium and nickel are the most important components of lithium-ion batteries. Rare earth elements (REE) are mainly needed for permanent magnets used in EVs but also hydrogen electrolysers.[2] Copper is widely used across all power generation and electrification technologies. It is also used for solar panels, together with silicon. While there is overall agreement that mineral demand will increase, analysis of scenarios by the World Bank shows that the future technology mix – and the resulting mineral demand – on the way to net zero can be very different depending on policy choices, technological innovation and market forces.

Table 1: Minerals used for transition technologies

Bauxite	Aluminium production, solar modules, concentrated solar power, electricity networks, EVs and battery storage
Chromium	Stainless steel, concentrated solar power, geothermal
Cobalt	Lithium-ion batteries
Copper	Electricity networks, wind turbines, lithium-ion batteries, solar panels
Graphite	Lithium-ion batteries, fuel cells
Lithium (LCE)	Lithium-ion batteries
Manganese	Steel, wind turbines, EVs
Molybdenum	Wind and geothermal power generation

[2] Rare earth elements (REE) are a relatively abundant group of 17 elements composed of scandium, yttrium, and the lanthanides.

Nickel	Stainless steel, geothermal, EVs and battery storage, hydrogen
Rare Earth Elements	Permanent-magnets (key to electrifying industry/transport), hydrogen electrolysers, catalysts, wind turbines, energy-efficient fluorescent lighting
Silicon	Solar modules
Zinc	Wind turbines

Is there enough mineral supply to meet rising demand from clean energy technology?

The issue of meeting rising demand from the energy transition is three-fold: How much minerals are needed? Are there enough minerals to meet these needs? And can supply scale up fast enough to meet rising demand?

1) How much minerals will we need?

If we set a Paris-compatible climate target, then six times more than today.

Total demand depends on how transformative the scenario is (e.g. 1.5°C compatible) and the mineral intensity of the technologies it relies on. Some scenarios rely more heavily on electrification and batteries while others rely on CCS or bioenergy, which are less mineral intensive (Figure 1). For example, **wind, solar and hydrogen require much smaller amounts of minerals than batteries**.

In 2020, clean energy technologies used approximately seven million tonnes (Mt) of minerals. Demand is set to increase dramatically, according to three IEA scenarios:

- If countries stick to their current targets, demand is predicted to **double** by 2040 (Stated Policies Scenario)
- Limiting temperature rise to well below 2°C and implementing development measures might raise demand **four times** by 2040 (Sustainable Development Scenario)
- If emissions are to be reduced to net zero by 2050 (1.5°C scenario), demand could grow **six times**, to 43 Mt (Net Zero Scenario).

2) Are there enough minerals?

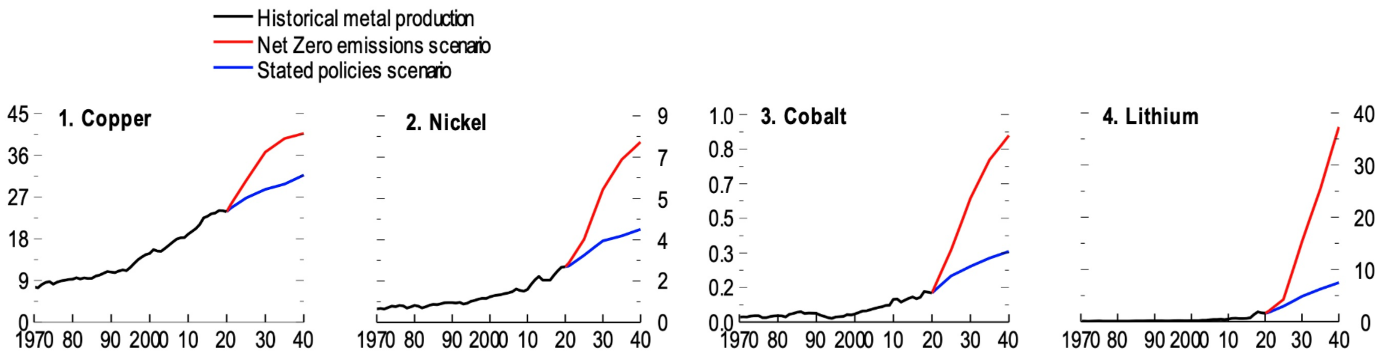
Yes, but with some caveats.

Sufficient reserves (those resources that can be extracted profitably; resources being the total stock - discovered and undiscovered - of a particular mineral) exist out to 2050 for most minerals needed for the energy transition. According to our own analysis, cobalt is the only mineral with insufficient reserves, which would only meet the demand of the IEA's Net Zero Scenario until 2039. However, according to S&P, cobalt exploration budgets rebounded in 2021 and increased by 27% to USD 70 million, which could change our forecast.

It's also important to bear in mind that some metals are produced as by-products of other metals, making supply dependent on the supply of the host metal. For example, cobalt is mined today as a by-product of nickel and copper. With higher demand driving prices up, pure-play mining of cobalt could occur, which would increase reserves.

Increasing supply depends, of course, on investment. However, many of the markets for these minerals are small and have not seen the interest or levels of investment needed to satisfy a net zero trajectory (see Fig. 2). With further investments and higher prices, resources turn into reserves. For instance, the increase in lithium reserves over the past ten years alone is sufficient to meet net zero demands until 2040. Policy commitments to ambitious climate targets are, therefore, key to attracting sufficient investment, according to the IEA.

Fig. 2: Historical metal production and IEA energy transition scenarios (million metric tonnes)



Source: IEA; Schwerhoff and Stuermer (2020); US Geological Survey; IMF staff calculations

3) Can supply scale up fast enough to meet rising demand?

Yes, for the majority of minerals, but there are noticeable exceptions.

The difficulty of scaling up a particular mineral depends on how large and established supply chains are today, and whether clean energy technologies represent a significant increase from the total demand from other uses. For instance, copper has an enormous market today and, while clean energy demand growth is sizable, supply chains only need to grow by 20% until 2050. A recent report by S&P, however, states that demand for refined copper will outpace supply up to 2035 due to an absence of investment.

On the other hand, lithium demand rises quickly in a Paris-compatible scenario to overtake all uses, growing the total market 40-fold. Current supply chains are unable to absorb this easily, as they can in the case of cobalt and nickel.

Lead times (from discovery to production) vary, but are generally much longer than for the construction times of factories for battery or other clean energy technologies, creating an important mismatch. **Copper, nickel and cobalt** come from mines that require intensive investment and take, on average, more than a decade from discovery to production. In contrast, because of a different extraction process, **lithium**'s lead times for new production is typically five years.

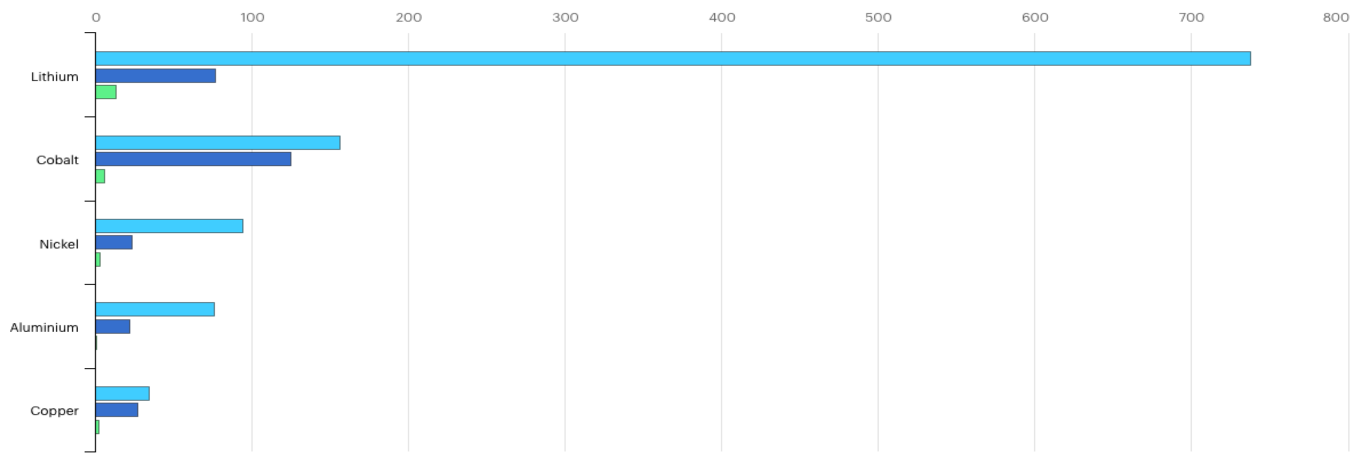
In summary, there are broadly enough key critical materials to cover demand in the medium term (10-15 years) for most net-zero scenarios. However, in the near-term, shortages could develop as supply struggles to meet rapidly-rising demand.

What does this imply for prices?

Prices of many minerals that are essential for clean energy technologies have recently soared due to a combination of rising demand and disrupted supply chains. For example, the prices of lithium and cobalt more than doubled in 2021, while those of copper, nickel and aluminium all rose by 25% to 40%.

In particular, the rapid increase in EV sales during the pandemic has tested the resilience of battery supply chains, and Russia's war in Ukraine has further exacerbated the challenge, since Russia supplies 20% of global high-purity nickel. Lithium is an extreme case - in May 2022, lithium prices were over seven times higher than at the start of 2021 (Fig. 3). Unprecedented battery demand and a lack of structural investment in new supply capacity are key causes.

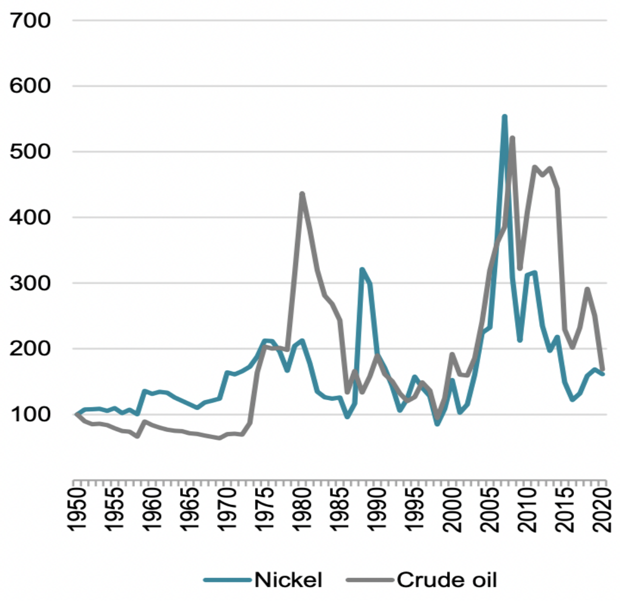
Fig. 3: Scale of price increase in 2021 for selected energy transition metals in %



Source: IEA

How this is likely to play out over the next decade is unclear. Goldman Sachs estimates that the current high prices for cobalt, nickel and lithium could decrease in the next two years as investor exuberance may lead to an oversupply. On the other hand, analysts say the supply of copper could be extremely tight in the next few years due to rising input costs, a lack of labour, long lead times and a lack of capital. Overall, analysts agree that the resulting higher prices are expected and needed to drive investment, which is lacking today.

Fig. 4: US price trends for crude oil and nickel in real terms, 1950-2020



Source: IEA and S&P

These higher prices are not factored into most scenarios, and mean that other measures, such as technology innovation, efficiency improvements and economies of scale, will have to overperform if cost trends are to be maintained (innovation and economies of scale have rapidly reduced the cost of key clean energy technologies over the past decade). For example, higher prices for cathode materials in

2021 pushed up lithium-ion battery pack costs by an estimated 5% from their 2020 levels. With the recent surge in lithium and other battery metal prices in early 2022, this figure is now around 20%. Prices for wind turbines and solar PV modules also increased, by 9% and 16% respectively.

This does not mean the cost and deployment trajectories of clean energy technologies are likely to be disrupted in the next decade – raw materials remain a small percentage of costs across almost all technologies. Rather, it means that high material prices put an additional pressure on innovation to seek further sources of cost reduction, on finding alternative technologies or material substitutes, and on increasing material reuse and recycling, and that extending government support for clean energy might be needed in certain areas.

What might prevent supply from keeping up with demand? Can these risks be mitigated?

There are six crucial aspects that will determine the risks around supply crunches and price spikes, and whether supply is able to keep pace with rising demand from clean energy technologies:

- Will investment flow quickly enough?
- How much demand can be mitigated through substituting critical minerals with other materials, recycling or circular economy approaches?
- How will the tension with high environmental and social standards be handled?
- To what extent will the mining sector innovate to shorten extraction times and reduce impacts?
- How will critical material geopolitics play out?

Timing and size of investment

Forecasts of the size of transition mineral markets vary - they rise to the value of today's coal industry according to the IEA, or today's oil industry according to the IMF, in a 1.5°C scenario. But the IEA says "today's supply and investment plans for many critical minerals fall well short of what is needed" to deploy green technology. Until now, the elevated prices have not been enough to attract the investment needed for an energy transition without supply crunches and sustained price spikes. According to several reports, a key issue is the **lack of reliable statements of policymakers on national energy transitions**. According to the IEA, "if companies do not have confidence in countries' energy and climate policies, they are likely to make investment decisions based on much more conservative expectations."

There are other issues that prevent capital from flowing at the pace needed. There is a strong conservatism in the mining industry, stemming from the deep downturn the industry underwent in the late 2000s following the global financial crisis. According to Goldman Sachs, investors are content with the current high returns they are getting from the mining industry. The minerals and metals industry is also struggling to attract young workers, creating a skills bottleneck in the industry.

Overall, analysts expect investment to continue to lag behind rising demand, leading to high prices over a prolonged period of time. The IMF, for instance, expects prices to remain at historic 2011 peak levels.

Material substitution

Sustained high prices, pressure to reduce costs, geopolitical issues or environmental and social concerns can accelerate the search for material alternatives that reduce pressure on supply, as can technological innovation.

For example, 40%-50% reductions in the use of silver and silicon in solar modules have decreased prices and enabled a spectacular rise in solar PV deployment. The thickness of silicon wafers used in solar panels has reduced greatly in the last two decades, reaching record levels and saving significant amounts of silicon. The same is true for silver demand for solar modules, where silver paste has been substituted by nickel-copper plating.

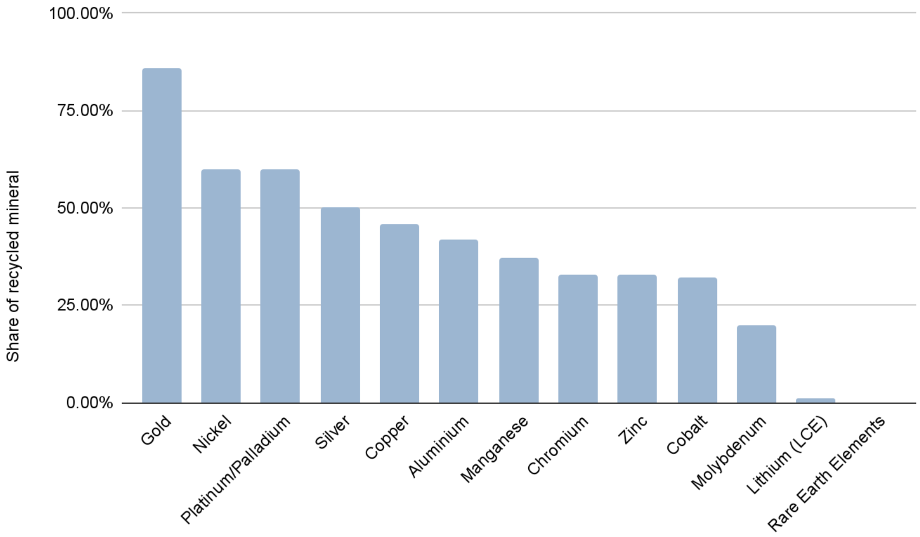
Battery technology, too, has shown innovation to reduce critical material inputs. Car producers were under pressure to reduce their reliance on cobalt mined under poor conditions (including child labour) in the DRC, which accelerated the development of NMC 811 batteries (80% of nickel, 10% of manganese and 10% of cobalt). Some lithium-ion batteries are also being substituted by lithium-iron batteries for grid-scale installations, particularly in China. These batteries use no cobalt or nickel and are safer, cheaper and offer lower cost and higher durability. Zinc-air batteries could also curb metals demand, although large-scale deployment is only likely to come after 2030. In order to further drive technological innovation, governments need policies promoting technological diversity.[3]

Material recycling

Minerals and metals can be reused and recycled continuously if the right infrastructure and technologies are available – a great advantage in comparison to fossil fuel infrastructure. However, the current evidence suggests the potential for reuse and recycling might be limited without enormous efforts to move towards a circular economy.

For many metals, such as copper and aluminium, recycled input rates have not changed much in recent years, meaning that recycling has only managed to keep up with growth in demand. The IEA estimates that, by 2040, recycled quantities of copper, lithium, nickel and cobalt from spent batteries could reduce combined supply requirements by 12%. However, even if we recycled 100% of minerals by 2050, we would still need considerable investment in mining.

Fig. 5: Recycling rates of selected minerals and metals



Source: IEA and USGS

Recycling can release pressure from suppliers. The first EV batteries will reach the end of their first lives around 2030. The necessary infrastructure and technology need to be in place by then to seize the potential of recycling. This is true particularly for lithium and rare earth metals, as their recycling rates are still negligible (see Fig. 5). By contrast, gold has recycling rates of over 85%, and nickel and palladium 60%.

[3] For more historical examples on how past price spikes have encouraged innovation and substitution, read this report.

According to the IEA, higher recycling rates demand "increased collection rates, developing knowledge of global and regional stocks, market incentives, and collaboration, often beyond country borders, to encourage secondary market development".

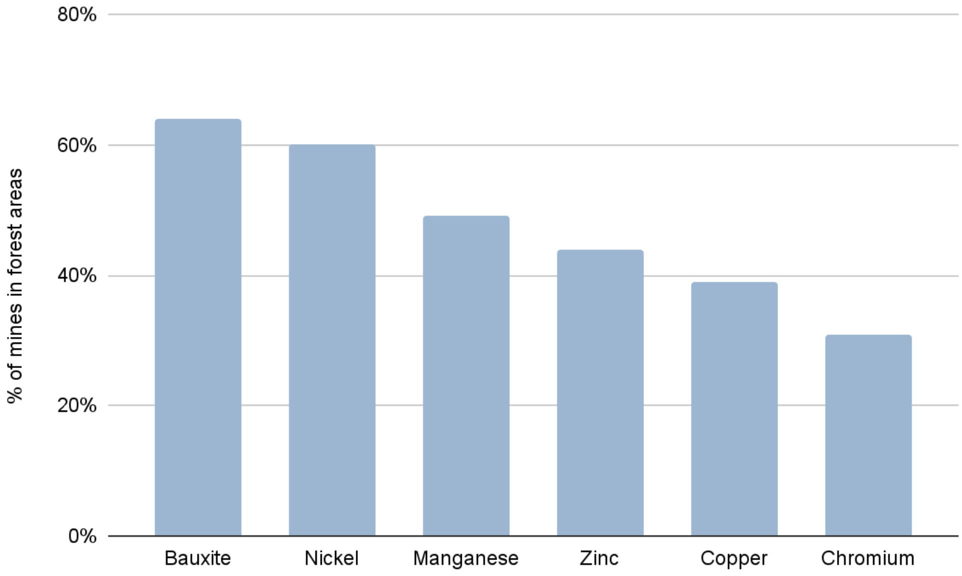
High environmental and social standards

Without additional measures, the energy transition can, paradoxically, be at odds with social and environmental efforts.

High environmental standards have increased lead development times for new mining projects. For example, during the rapid increase in copper demand in the 2000s due to the economic rise of China, an average copper mine would require six months of permitting time. Today, permitting times have risen to two to three years, largely due to ESG standards.

A survey conducted by Ernst &Young revealed that 25% of the surveyed global mining and metals executives saw environmental and social issues as the number one risk for their sector. Moreover, 91% of investors view non-financial performance as "pivotal" in their investment decisions. On the other hand, an analysis of 1,200 mining companies showed that those who raised their ESG ratings from 2018 to 2020 saw an **increase in debt and equity financing**.

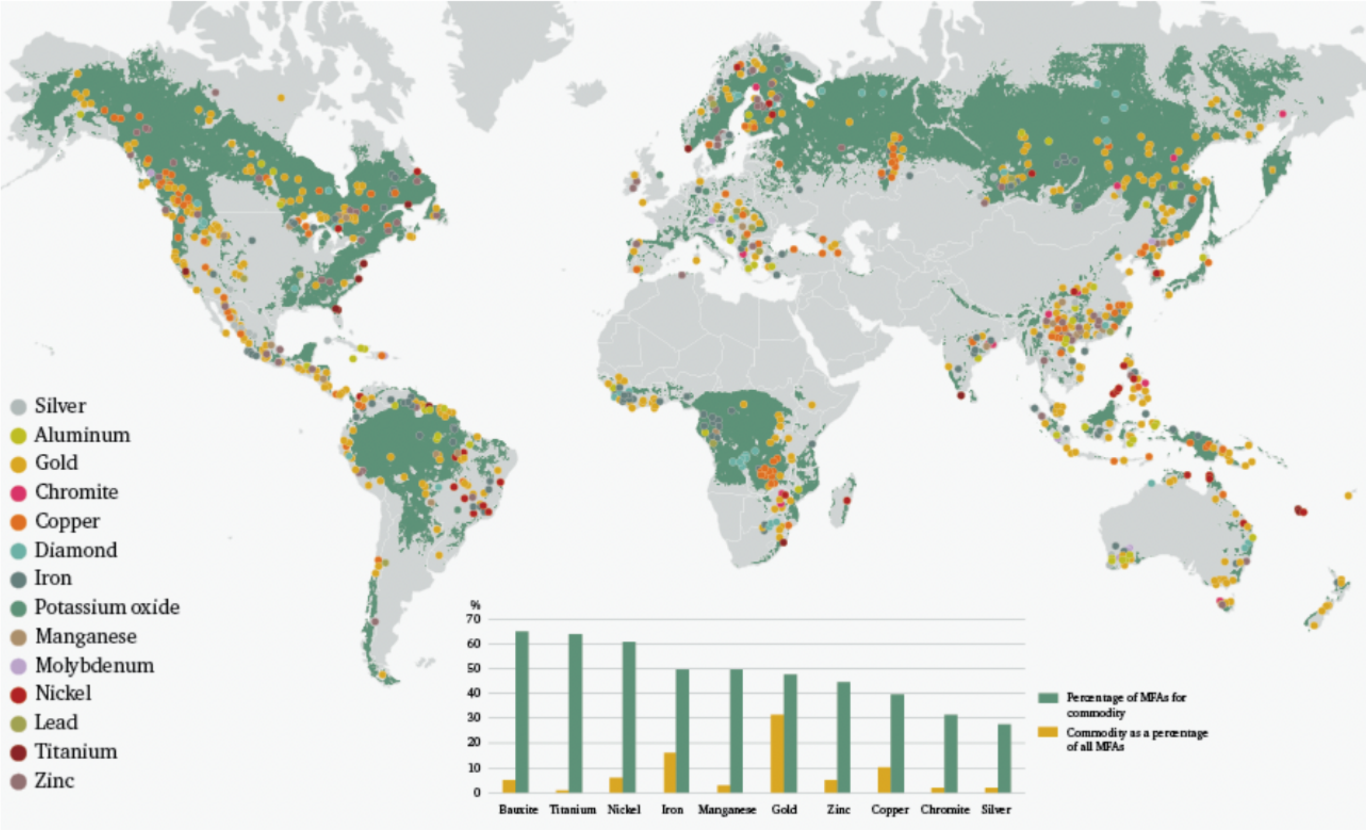
Fig. 4: Share of mines in forest areas for selected minerals



Source: World Bank & Profor (2019): Forest Smart Mining

Mining changes land use and can destroy biodiversity and undermine forest protection efforts that are essential for stabilising climate change - 7% of global deforestation is caused by mining, while in the Amazon, mining was responsible for 10% of forest loss between 2005 and 2015. Fig. 4 shows that the share of mines in forest areas is currently highest for bauxite and nickel, at around 60%, while manganese, zinc and copper are at around 40%. Over half of all existing forest mining occurs in lower or middle-income countries. However, most mines in development are in high-income countries (see Fig. 5). According to the World Bank, "much forest mining occurs in evergreen needle leaf forests from high latitudes, but 7 % of all forest mine operations are based in tropical rainforest biomes, the forest where biodiversity and carbon values are highest."

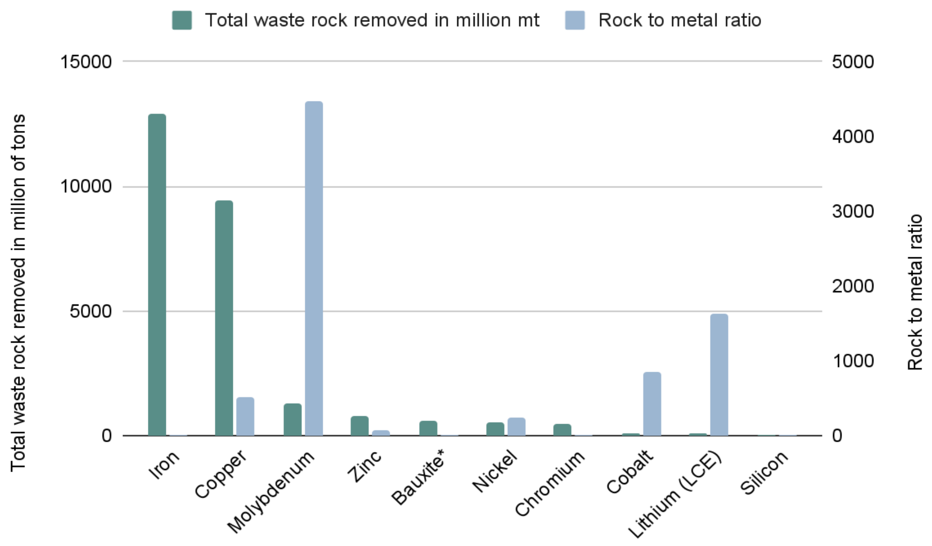
Fig. 5: Large-scale mines in forest areas (MFAs) by primary commodity



Source: [Chatham House]

New metrics are emerging to evaluate the environmental impact of mining on land-use change and help drive responsible investment. For instance total waste rock generated, as well as [rock-to-metal ratio] (the amount of waste rock dug up for each tonne of metal mined). Some metals, like iron and copper, produce a low amount of waste per tonne but are heavily mined. Lithium, however, despite being a small market today, is second in waste rock per tonne, generating 1,600 tonnes waste/tonne, which has important implications for scaling up production (Fig. 6.).

Fig. 6: Total waste rock removed in million mt and rock to metal ratio (2018)



Source: Nassar et al. (2022): Rock-to-metal ratio
*Aluminium is used for bauxite's rock to metal ratio,

Voluntary initiatives are emerging due to the lack of concerted regulatory action by governments. IRMA, the Initiative for Responsible Mining Assurance, for instance, offers a global standard for mining established by community representatives, civil society, labour unions and the private sector. However, voluntary initiatives should not delay or replace regulation. Non-profit organisations have developed a Mining Policy Framework for best social, economic and environmental practices, including taxation and environment management.

Empowering local communities to negotiate the terms and conditions of extraction is key to legitimising mining. Moreover, health and environmental risks emerging from artisanal and small-scale mining (ASM) need to be addressed to ensure a positive impact for those living from it.

Innovation for mining

A number of industry analysts claim innovation in mining can reduce the risk of supply chain crunches – however, the capacity of the mining industry to innovate appears to be limited.

The lead times of mines are currently very long - the average is 16 years for major mines that opened between 2010 and 2019. Such long lead times affect the feasibility of scaling up mineral supply quickly enough to meet demand. Nickel laterite even has a lead time of 20 years on average, which is problematic as cobalt emerges as a by-product of nickel and copper mining. In contrast, the latest Tesla battery gigafactory was built in under a year. According to the IEA, if companies wait for deficits to emerge before committing to new projects, this could lead to a prolonged period of short supply and price volatility.

In light of the high geographic concentrations of minerals, several countries aim to become less import-dependent and start onshoring mineral mining. The development of more profitable exploitation and processing methods is, therefore, necessary to compete with existing country or company monopolies.

Besides the increasing demand and the concentrated supply, declining ore grades, extreme weather conditions, deeper deposits, harder rock mass and high-stress environments represent major challenges for the mining sector. They are, however, surmountable, according to the IEA. The increased need for transition minerals requires innovation regarding the environmental and social impacts of mining. For example, according to IRENA, certain residue streams such as red mud (from aluminium production) contain significant amounts of REE that can be recovered. Waste rock from long-closed iron ore mines were found to potentially provide valuable REE in the US.

Digitisation to increase efficiency is also needed. One study highlighted that the level of digitisation of the industry remains low, indicating there is potential to be unlocked. A great deal more can also be done on sustainability, efficiency, reducing environmental footprints and enhancing the safety (e.g. in situ leaching). Innovation still requires R&D to ensure minimal side effects, as a study has shown that it often comes with negative repercussions for individual sustainable development goals.

Geopolitical constraints

The geographic concentration of mineral mines is greater than for fossil fuels. This allows individual countries and companies to abuse their market power and render access to important raw materials more difficult. Among our twelve selected minerals, six are mined mainly in China, while nine are predominantly processed there (table 2). The shares of Chinese dominance range from 35% in the case of zinc mining to 64% for graphite. In the case of mineral processing, this ranges from 40% for copper to 87% for REE (see Table 2). There are seven major processing plants for REE worldwide, six of which are in China.

China's dominance of materials supply is a result of its investment in large-scale production capacity over decades. For example, between 1990 and 2000, China's production of REE increased by 350% from 16,000 tonnes to 73,000 tonnes, while the production from other countries declined by almost

60%. China's investment in domestic mineral exploration and development increased nearly sixfold between 2000 to 2012.

China was also ahead of other countries in investing abroad. In 2000, China expanded overseas foreign direct investment for mineral resources and infrastructure in Africa and Asia, including signing a 2007 minerals-for-infrastructure agreement with the DRC. As a result, China's global production share has jumped from 2% (domestic production only) to 14%. It then expanded its domestic refinery capacity, producing 34 times more refined cobalt in 2016 than in 2000. This dominance raises security of supply concerns.

Can minerals be an opportunity for the Global South?

A concentrated supply of metals implies some top producers may benefit. Usually, countries with the largest output have the greatest reserves, and would likely be major prospective producers. The DRC, for example, accounts for about 70% of global cobalt output and half of the reserves. Other standouts include Chile for copper and lithium, along with Peru, Indonesia and South Africa. The IMF estimates that for transition metal-exporting countries, every 10% increase in global prices adds around an extra two-thirds of a percentage point to the pace of economic growth.

For countries with weaker governance structures, the risk of a resource curse - where countries rich in natural resources suffer poor economic growth - is real as the demand for minerals grows. This has been identified for the DRC, Chile, Cuba, Madagascar and Zambia. Concerted government action at the international level (e.g. through mechanisms against Tax Base Erosion and Profit Shifting (BEPS)) would be important to alleviate such risks. Moreover, high environmental and social standards as well as transparency need to be negotiated by local policymakers before extraction or exploration.

Countries that want to position themselves as leaders in the energy transition in the next decade - especially in EV battery production - need to invest now in scaling up mineral production, as well as in R&D for alternative battery technologies and recycling.

Due to environmental concerns and the long timeframes for their development, new mines outside of China are often disputed, which discourages new local exploration projects. For example, the development of one of the largest undeveloped rare earth deposits in the world was cancelled by Greenland's parliament last year. Diplomatic mechanisms also need to be developed to increase cross-country cooperation to push investment into supply chains.

Table 2: Top extracting and processing countries of selected minerals

Mineral/ Metal	Top extracting country	% of top extracting country	Top processing country	% of top processing country
Cobalt	DRC	69%	China	65%
Graphite	China	64%	Mozambique	79%
Silicon	China	64%	China	70%
Rare Earth Elements	China	60%	China	87%

Lithium (LCE)	China	52%	China	58%
Chromium	South Africa	43%	South Africa	43%
Molybdenum	China	43%	China	24%
Manganese	South Africa	37%	China	45%
Zinc	China	35%	China	34%
Nickel	Indonesia	33%	China	35%
Bauxite	Australia	29%	Australia	28%
Copper	Chile	28%	China	40%

Source: USGS, IEA

Annex: Climate-delaying narratives around critical materials

Delaying narratives have grown in the past year, leaning into the supply risks outlined above. These include:

- **Renewable energy deepens geopolitical dependence**
- **Governments fail to push local renewable energy production**
- **There are not enough reserves or supply chains to make net zero possible**
- **Climate advocates are downplaying or ignoring the negative impacts of mining**

Voices coming from think tanks supporting climate denial or delay are embracing narratives on minerals and metals to discredit renewable energy. Mark P. Mills from the Manhattan Institute states that "scaling up these [renewable] energy sources entails a radically heavier materials footprint than is associated with fossil fuels," a narrative pushed by Net Zero Watch, too.

Mills alarms the reader by neglecting to explain the difference between mineral resources and reserves: "The resulting demand [...] would exceed [...] known global **reserves** of those minerals." He also downplays the benefits of material substitution. To him, the alternative is to "adopt more moderate and longer-term deployment targets for solar, wind and battery hardware," as the current path "won't meet targets to reduce carbon dioxide emissions, but would cause massive collateral damage to economies and the environment."

Many analysts from said think tanks focus on the Biden administration's performance regarding the sourcing of critical minerals. Scott Lincicome from the Cato Institute criticises the US government for importing critical minerals from China and Australia instead of creating domestic supply. According to Lincicome, this is due to heavy regulations and environmental backlashes in the US that make it impossible to build mines quickly. There are no notions about short and long-term strategies in those analyses.

The increasing dependence on China is a major issue for Colin Dueck from the American Enterprise Institute: "The federal government ought to make it easier for US mining companies to open new production and refining facilities in this country, not less so. Defense contractors should not be permitted to buy rare earth-enabled products from China in the coming years. The Chinese must not be allowed to dominate international energy systems. This is a vital national interest." The Institute for Energy Research warns about outsourcing entire value chains to China's advantage: "But, eventually, the Biden people will likely say it is simpler to have China do it all as that country dominates the critical mineral industry either through having the resources or through processing the ores. As a result, the United States will send billions of more dollars to China to buy Chinese green technology systems. We already send billions annually." The article also falsely states that the US was ranked as the world's largest producer of REE until 1995, when China took its place. Similar narratives are also pushed by European climate denial think tanks such as the UK-based Global Warming Policy Foundation or Net Zero Watch.

The criticisms of the current US government also include plans for offshore wind farms. Jonathan A. Lesser from the Manhattan Institute characterises offshore wind proponents as rent-seekers: "They may believe that addressing climate change is important, but their primary interest is exploiting green energy mandates for their own financial gain." He also calls them "reckless climate advocates," for whom preventing that climate "catastrophe is more important than any other societal value, be it democracy, free speech, or existing laws... For this group, the extensive environmental damage caused by the mining and processing of rare-earth minerals, or the child and slave labor that is used to mine cobalt in the Congo, is irrelevant. Similarly irrelevant are concerns about adverse impacts on fisheries and endangered species, as well as higher energy costs and their impacts on the poor. This group is impervious to evaluating tradeoffs and, often, any rational argument." Adding to the environmental arguments, European climate crisis denial think tanks warn about an upcoming waste crisis from unrecycled solar panels or "discarded panel mountains leaking dangerous heavy metals." Human rights arguments are also pushed by Net Zero Watch, pointing at the production of solar panels by Uighur prisoners.

Lesser also stresses that supply is too short for the plans to become reality soon, labelling them "scarce resources." Moreover, he warns that such projects lead to higher electricity prices that "destroy far more jobs and investment than would be created by the massive subsidies the projects require." Finally, according to Lesser, wind turbines are generally outdated: "Wind power is an 18th-century solution to 21st-century energy challenges, out of time and place, best left to weekend sailors and readers of swashbuckling novels."