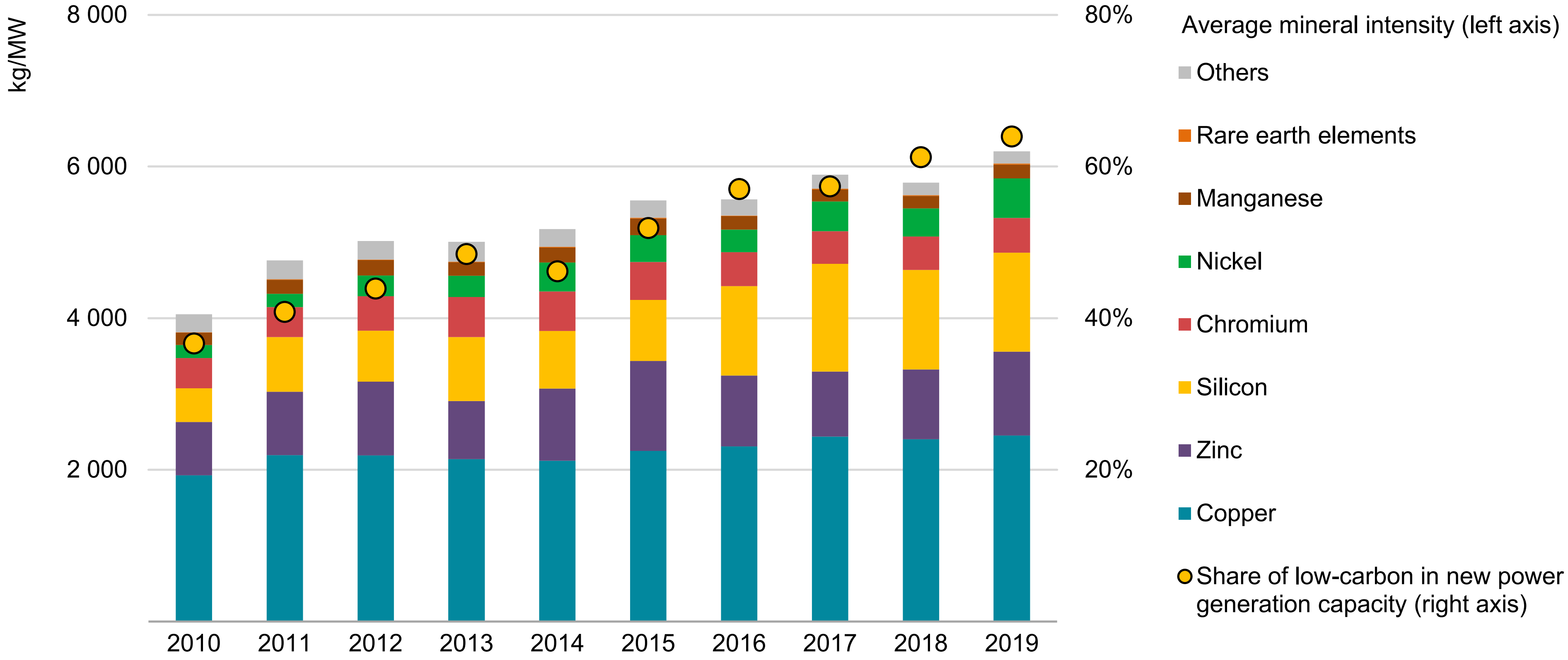
The mineral requirement for new power generation capacity has increased by 50% since 2010 as low-carbon technologies take a growing share of investment

Average mineral intensity of new power generation capacity



Note: Low-carbon technologies include renewables and nuclear.

The shift from a fuel-intensive to a material-intensive energy system

The Covid-19 pandemic and resulting economic crisis have had an impact on almost every aspect of the global energy system. However, while fossil fuel consumption was hit hard in 2020, clean energy technologies – most notably renewables and electric vehicles (EVs) – remained relatively resilient. As a result, our latest estimates suggest that global energy-related CO_2 emissions fell by 6% in 2020, more than the 4% fall in energy demand (IEA, 2021b).

Nonetheless, as things stand, the world is far from seeing a decisive downturn in emissions – CO_2 emissions in December 2020 were already higher than their pre-crisis level one year earlier. Putting emissions on a trajectory consistent with the Paris Agreement, as analysed in the *World Energy Outlook* Sustainable Development Scenario (SDS), requires a significant scale-up of clean energy deployment across the board. In the SDS, the annual installation of solar PV cells, wind turbines and electricity networks needs to expand threefold by 2040 from today's levels, and sales of electric cars need to grow 25-fold over the same period. Reaching net-zero emissions globally by 2050 would demand an even more dramatic increase in the deployment of clean energy technologies over the same timeframe.

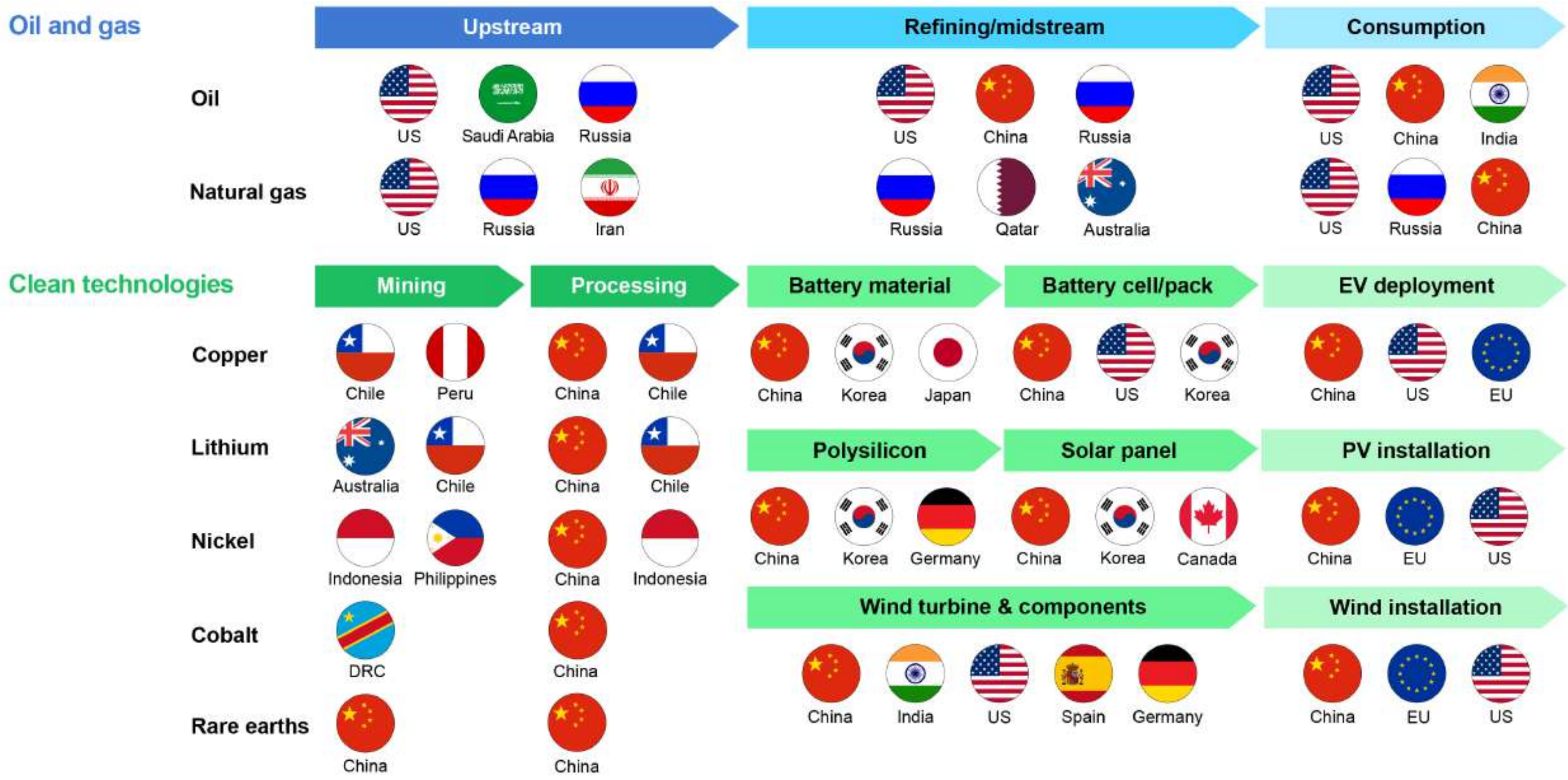
An energy system powered by clean energy technologies differs profoundly from one fuelled by traditional hydrocarbon resources. While solar PV plants and wind farms do not require fuels to operate, they generally require more materials than fossil fuel-based counterparts for construction. Minerals are a case in point. A typical electric car requires six times the mineral inputs of a conventional car and an onshore wind plant requires nine times more mineral resources than a gas-fired plant of the same capacity. Since 2010 the average amount of minerals needed for a new unit of power generation capacity has increased by 50% as renewables increase their share of total capacity additions. The transition to clean energy means a shift from a fuel-intensive to a material-intensive system.

The types of mineral resources used vary by technology. Lithium, cobalt and nickel play a central role in giving batteries greater performance, longevity and higher energy density. Rare earth elements are used to make powerful magnets that are vital for wind turbines and EVs. Electricity networks need a huge amount of copper and aluminium. Hydrogen electrolysers and fuel cells require nickel or platinum group metals depending on the technology type. Copper is an essential element for almost all electricity-related technologies.

These characteristics of a clean energy system imply a significant increase in demand for minerals as more batteries, solar panels, wind turbines and networks are deployed. It also means that the energy sector is set to emerge as a major force in driving demand growth for many minerals, highlighting the strengthening linkages between minerals and clean energy technologies.

The transition to a clean energy system brings new energy trade patterns, countries and geopolitical considerations into play

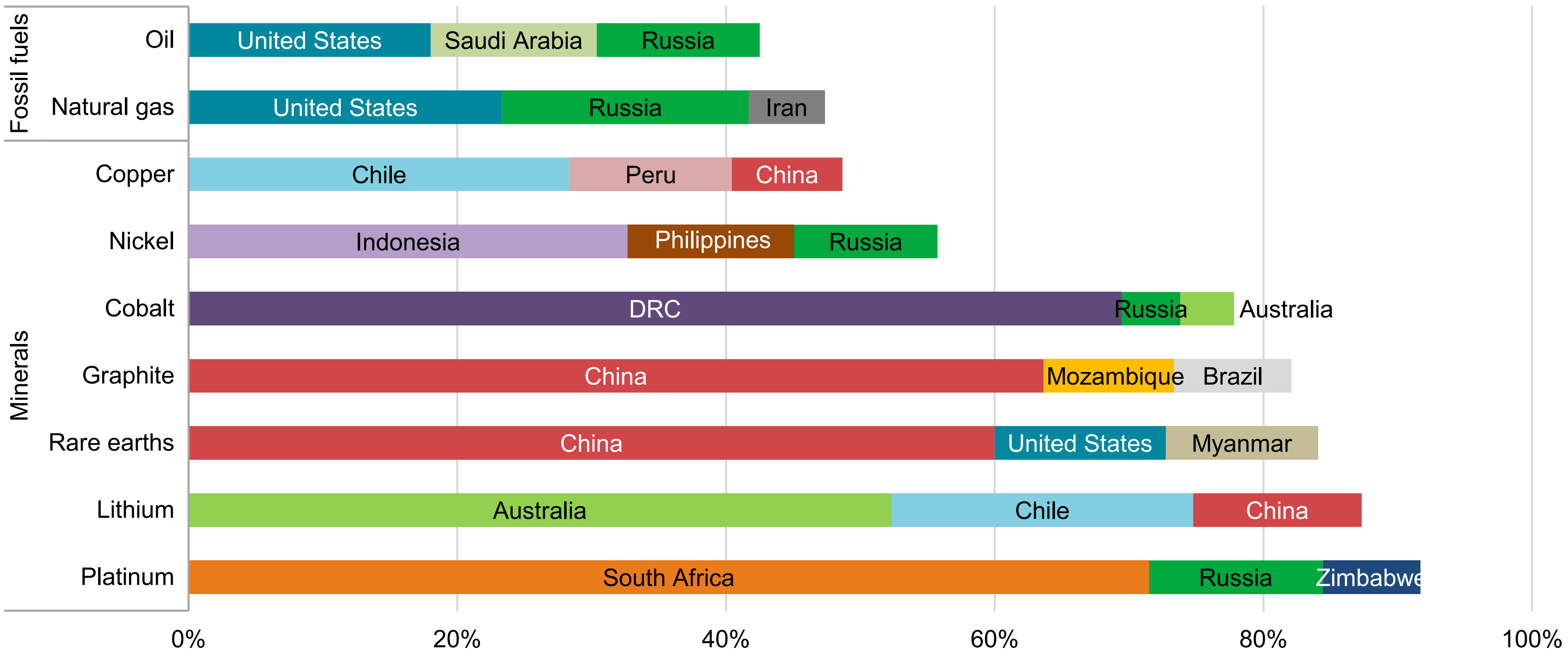
Indicative supply chains of oil and gas and selected clean energy technologies



Notes: DRC = Democratic Republic of the Congo; EU = European Union; US = United States; Russia = Russian Federation; China = People’s Republic of China. Largest producers and consumers are noted in each case to provide an indication, rather than a complete account.

Current production of many energy transition minerals is more geographically concentrated than that of oil or natural gas

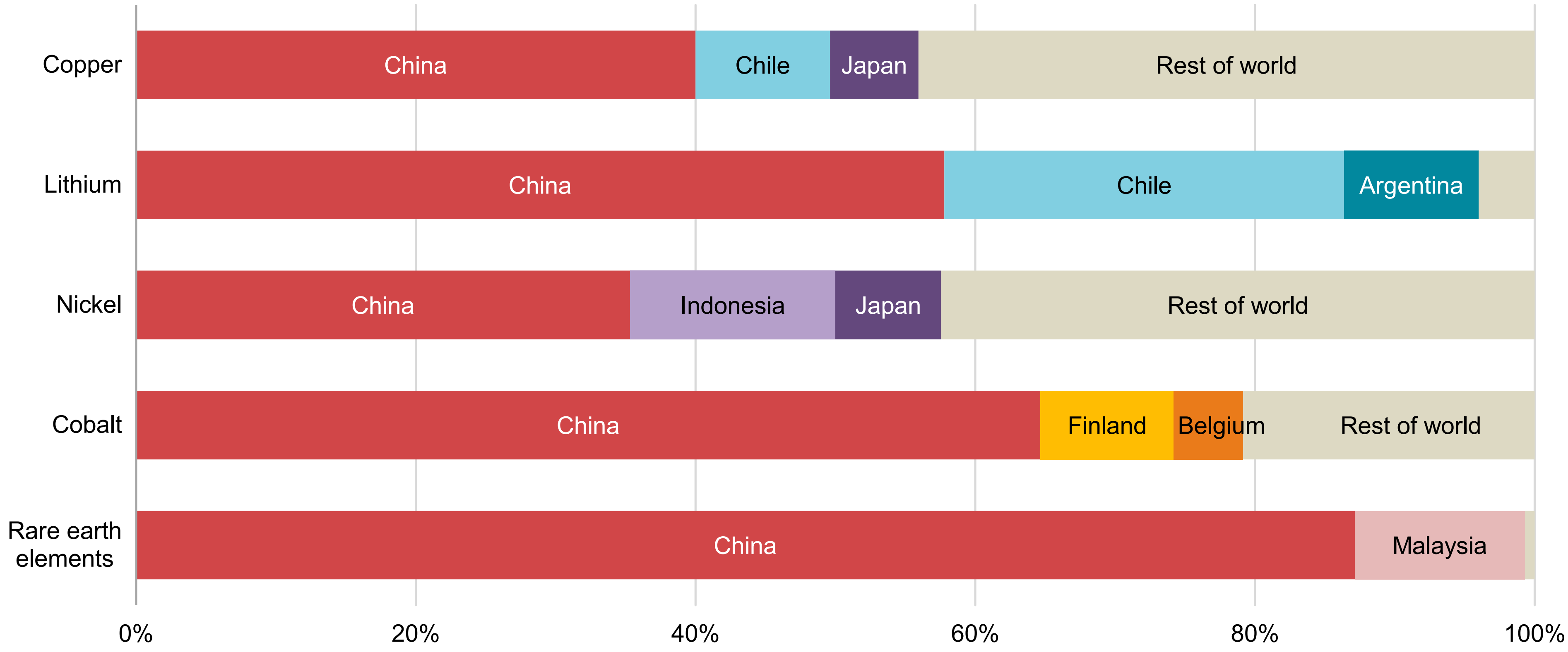
Share of top three producing countries in total production for selected minerals and fossil fuels, 2019



Sources: IEA (2020b); USGS (2021).

The level of concentration is similarly high for processing operations, with China's significant presence across the board

Share of processing volume by country for selected minerals, 2019



Note: The values for copper are for refining operations.
Sources: World Bureau of Metal Statistics (2020); Adamas Intelligence (2020) for rare earth elements.

Robust and resilient clean energy supply chains are essential, especially for critical minerals

Today's international energy security mechanisms are designed to provide some insurance against the risks of disruption, price spikes and geopolitical events in the supply of hydrocarbons, oil in particular. These concerns do not disappear during energy transitions as more solar panels, wind turbines and electric cars are deployed. However, alongside the many benefits of clean energy transitions, they also raise additional questions about the security and resilience of clean energy supply chains, which policy makers need to address.

Compared with fossil fuel supply, the supply chains for clean energy technologies can be even more complex (and in many instances, less transparent). In addition, the supply chain for many clean energy technologies and their raw materials is more geographically concentrated than that of oil or natural gas. This is especially the case for many of the minerals that are central to manufacturing clean energy technology equipment and infrastructure.

For lithium, cobalt and rare earth elements (REEs), the top three producing nations control well over three-quarters of global output. In some cases, a single country is responsible for around half of worldwide production. South Africa and the Democratic Republic of the Congo are responsible for some 70% of global production of platinum and cobalt respectively, and China accounted for 60% of global REE production in 2019 (albeit down from over 80% in the mid-2010s). The picture for copper and nickel is slightly more diverse, but still around half of global supply is concentrated in the top three producing countries.

The level of concentration is even higher for processing and refining operations. China has gained a strong presence across the board. China's share of refining is around 35% for nickel (the figure becomes higher when including the involvement of Chinese companies in Indonesian operations), 50-70% for lithium and cobalt, and as high as 90% for REE processing that converts mined output into oxides, metals and magnets.

This creates sources of concern for companies that produce solar panels, wind turbines, electric motors and batteries using imported minerals, as their supply chains can quickly be affected by regulatory changes, trade restrictions or political instability in a small number of countries. The Covid-19 pandemic already demonstrated the ripple effects that disruptions in one part of the supply chain can have on the supply of components and the completion of projects.

The implications of any potential supply disruptions are not as widespread as those for oil and gas (see Box 1.1). Nonetheless, trade patterns, producer country policies and geopolitical considerations remain crucial even in an electrified, renewables-rich energy system.

Box 1.1. Oil security vs mineral security

Minerals are increasingly recognised as essential to the good functioning of an evolving energy system, moving into a realm where oil has traditionally occupied a central role. There are similarities, in that threats to reliable supply can have far-reaching consequences throughout the energy system. So traditional concerns over oil security (e.g. unplanned supply disruption or price spikes) are relevant for minerals as well.

However, fundamental differences exist in the impacts that disruption may have. An oil supply crisis, when it happens, has broad repercussions for all vehicles that run on it. Consumers driving gasoline cars or diesel trucks are immediately affected by higher prices.

By contrast, a shortage or spike in the price of a mineral required for producing batteries and solar panels affects only the supply of new EVs or solar plants. Consumers driving existing EVs or using solar-powered electricity are not affected. The main threats from supply disruptions are delayed and more expensive energy transitions, rather than disturbed daily lives.

Notably, oil burns up when it is used, requiring continuous inputs to run assets. However, minerals are a component of infrastructure, with the potential to be recovered and recycled at the end of the infrastructure lifetime (Hastings-Simon and Bazilian, 2020).

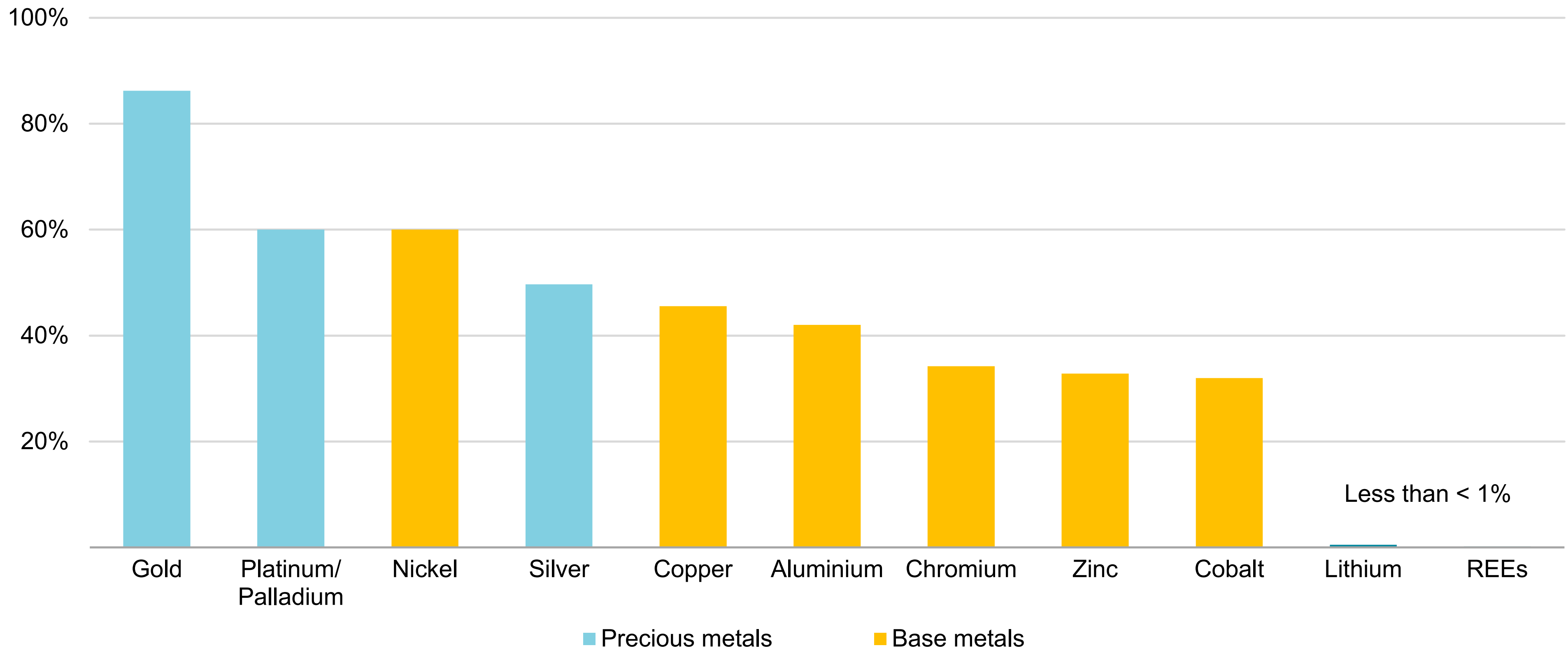
Moreover, while oil is a single commodity with a large, liquid global market, there are multiple minerals now in play for the energy sector, each with its own complexities and supply dynamics. Individual countries may have very different positions in the value chain for each of the minerals that are now rising in prominence in the global energy debate.

Despite these differences, the experience of oil markets may offer a number of lessons for an approach to mineral security. The approach to safeguarding oil security tended to focus on supply-side measures. Strategic stockholding has long been at the centre of the IEA's efforts to ensure oil market security. However, the framework for oil security has evolved over time to encompass demand and resilience aspects, including efforts to identify immediate areas of demand restraint, improve fuel efficiency and review countries' preparedness against potential disruption.

This range of responses and measures provides valuable context for the discussion on minerals security. While supply-side measures (e.g. ensuring adequate investment in production) remain crucial, these need to be accompanied by efforts to promote more efficient use of minerals, assess the resilience of supply chains, and encourage wider use of recycled materials, to be more effective.

Today's recycling rates vary by metal depending on the ease of collection, price levels and market maturity

End-of-life recycling rates for selected metals



Sources: Henckens (2021); UNEP (2011) for aluminium; Sverdrup and Ragnarsdottir (2016) for platinum and palladium; OECD (2019) for nickel and cobalt.

Scaling up recycling can bring significant security benefits, although the need for continued investment in primary supply remains

One of the major differences between oil and minerals lies in the way that they are used and recovered in the energy system. Unlike oil, which is combusted on an ongoing basis, minerals and metals are permanent materials that can be reused and recycled continuously with the right infrastructure and technologies in place. Compared with oil, this offers an additional lever to ensure reliable supplies of minerals by keeping them in circulation as long as possible.

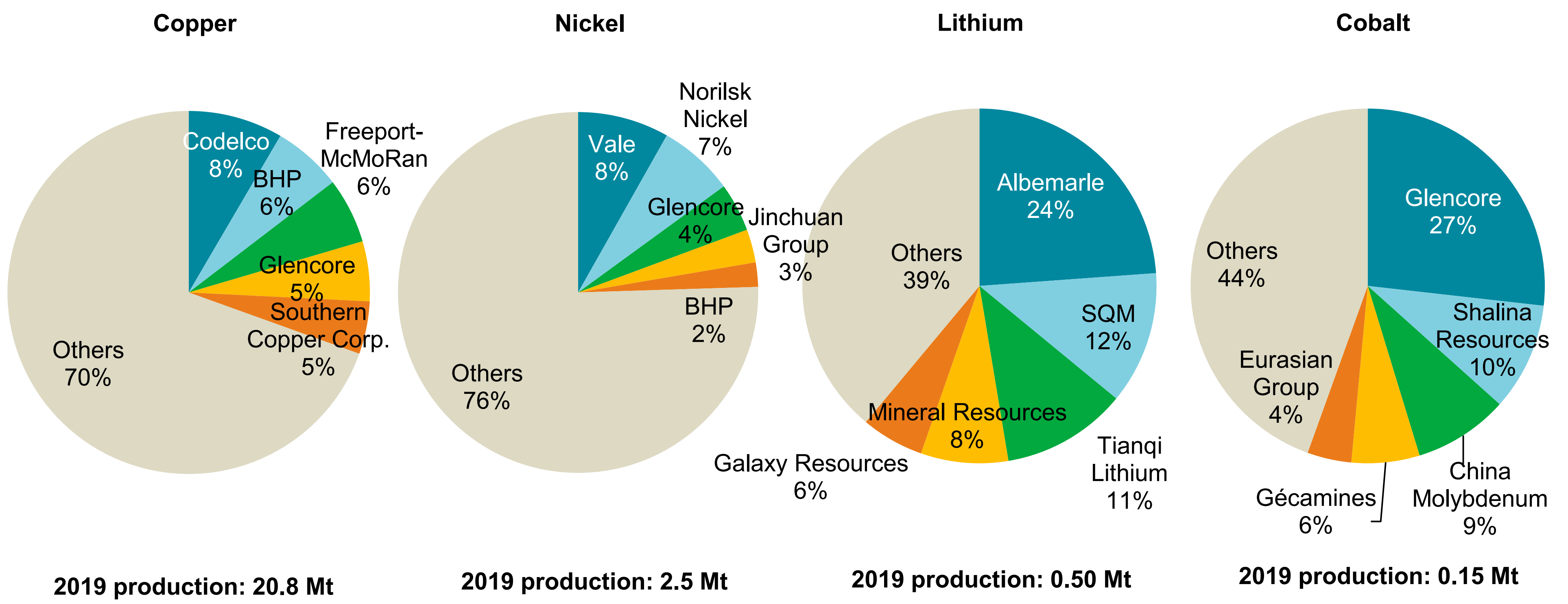
The level of recycling is typically measured by two indicators. End-of-life (EOL) recycling rates measure the share of material in waste flows that is actually recycled. Recycling input rates (also called recycled content rates) assess the share of secondary sources in total supply. EOL recycling rates differ substantially by metal. Base metals used in large volumes such as copper, nickel and aluminium have achieved high EOL recycling rates (Henckens, 2021). Precious metals such as platinum, palladium and gold have also achieved higher rates of recycling due to very high global prices encouraging both collection and product recycling. Lithium, however, has almost no global recycling capabilities due in part to limited collection and technical constraints (e.g. lithium reactivity in thermodynamic and metallurgic recycling), with a similar picture for REEs. There are also regional variances: around 50% of total base metal production in the European Union is supplied via secondary production, using recycled metals, as opposed to 18% in the rest of the world (Eurometaux, 2019).

Recycling does not eliminate the need for continued investment in primary supply of minerals. A World Bank study suggests that new investment in primary supply will still be needed even in the case that EOL recycling rates were to reach 100% by 2050. (World Bank, 2020). However, recycling can play an important role in relieving the burden on primary supply from virgin materials at a time when demand starts to surge. For example, the amount of spent EV batteries reaching the end of their first life is expected to grow exponentially after 2030 in the SDS, offering the potential to reduce the pressure on investment for primary supply (see Chapter 3).

Although various commercial and environmental challenges exist, the competitiveness of the recycling industry is set to improve over time with economies of scale and technology improvement as more players enter the field. Their relative advantages are likely to be further supported by potential upward pressure on production costs for virgin resources. Also, regions with greater deployment of clean energy technology stand to benefit from far greater economies of scale. This highlights the sizeable security benefit that recycling can bring to importing regions and underscores the need to incorporate a circular approach in the mineral security framework.

Companies that mine and process minerals have a major role to play in clean energy transitions

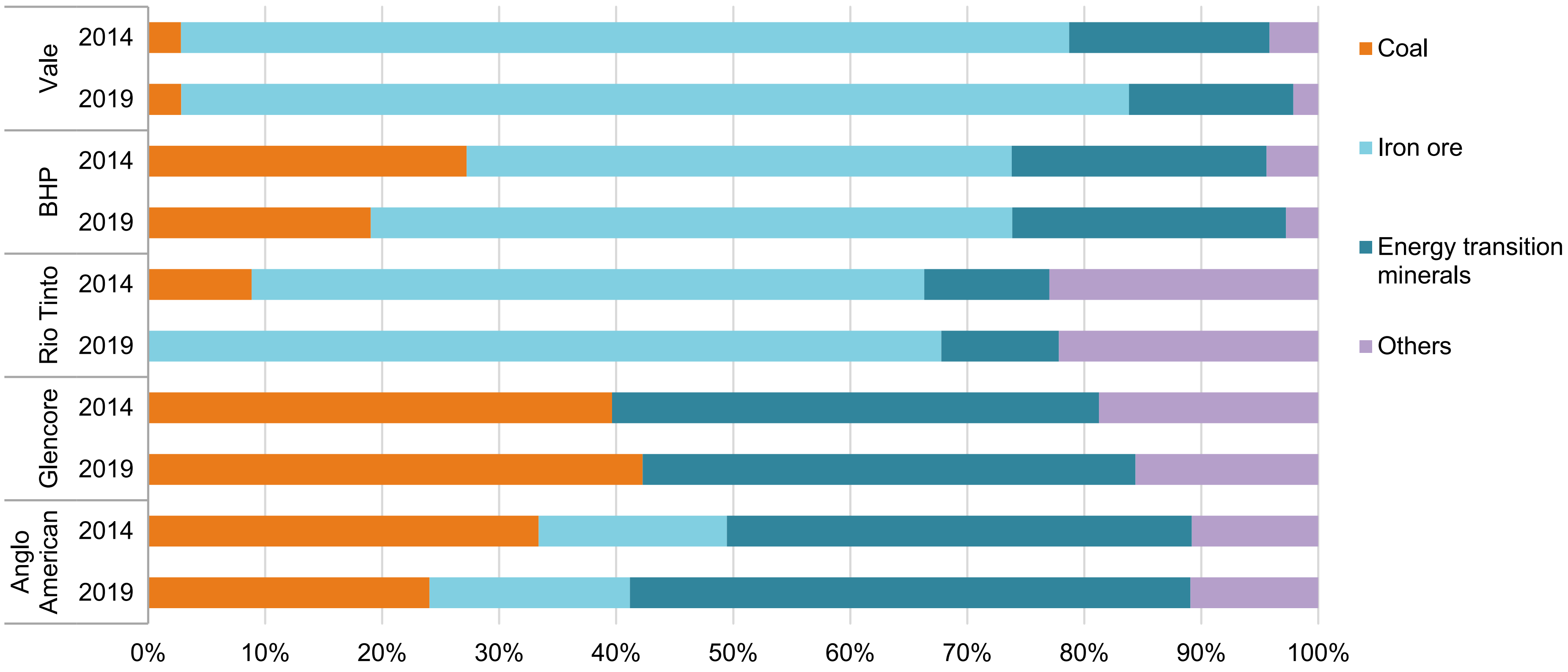
Major mining companies that produce selected energy transition minerals, 2019



Notes: Mt = million tonnes. Glencore's cobalt production volume includes output from Katanga Mining Ltd. Shalina Resources' cobalt production volume includes output of Chemaf. Lithium production volumes are denoted on a lithium carbonate-equivalent basis.
Source: S&P Global (2021).

Some mining majors have reduced coal exposure in recent years, although a decisive shift towards the minerals required for energy transitions is not yet visible

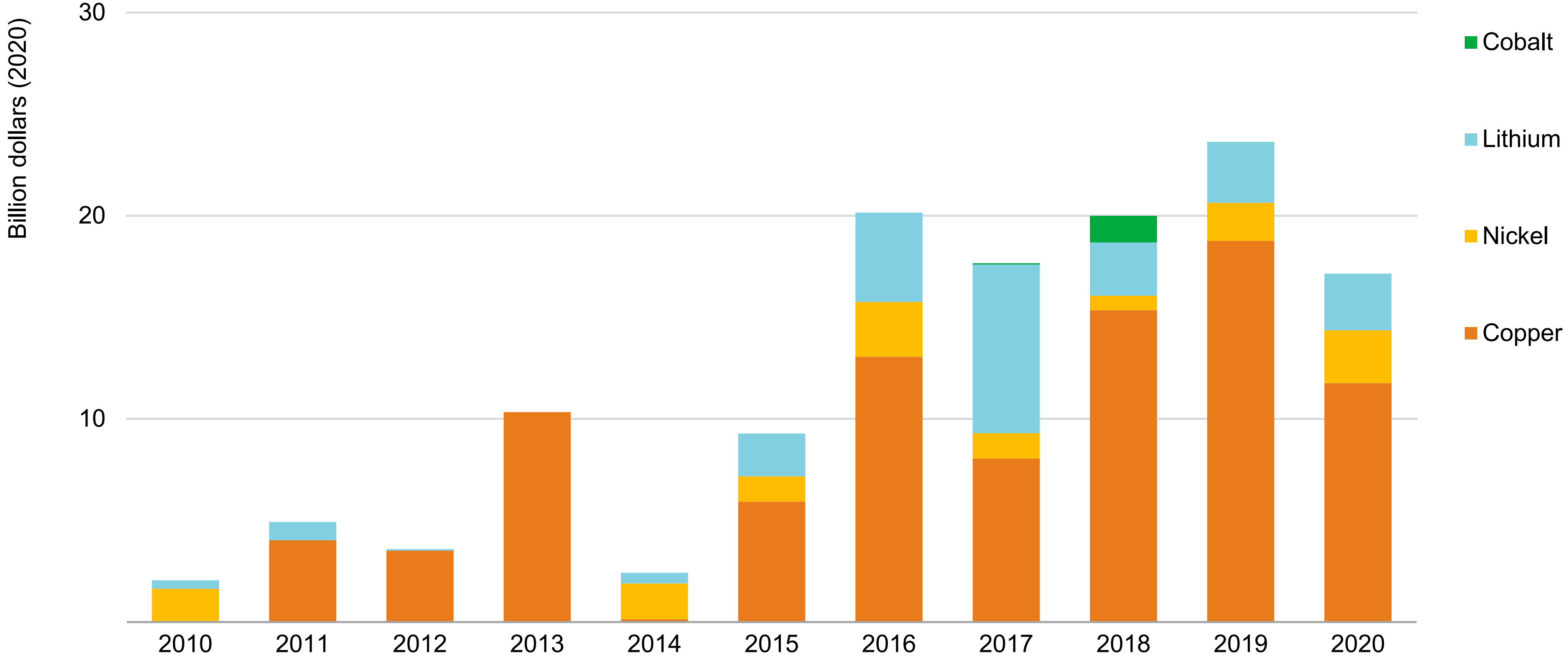
Production portfolio value of selected diversified major mining companies, 2014 and 2019



Notes: Energy transition minerals include copper, lithium, nickel, cobalt, manganese, molybdenum and platinum-group metals. The value of the 2014 production portfolio was estimated using 2019 prices to remove price effects.
Source: IEA analysis based on companies' annual reports and S&P Global (2021).

Investment in new mineral supply projects has been on an upward path…

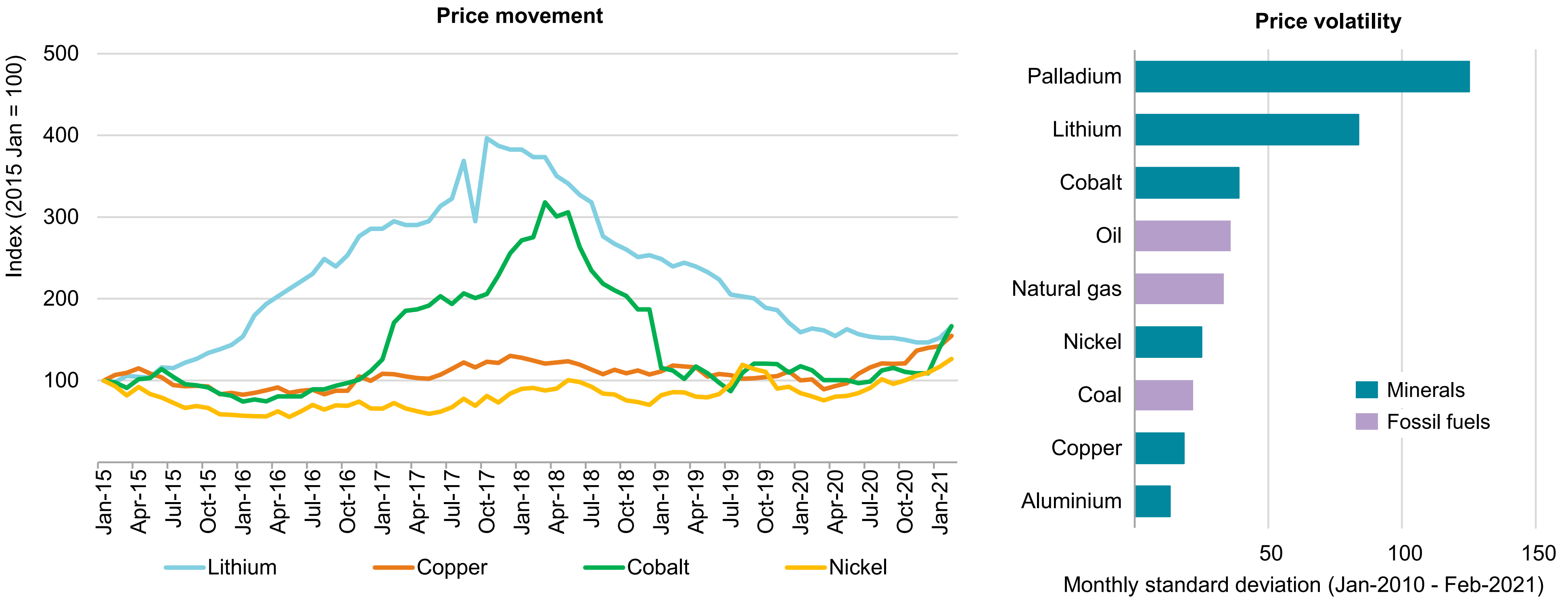
Announced capital cost for greenfield projects for selected minerals



Notes: Capital cost for cobalt includes only those projects whose primary commodity is cobalt. The figures do not include sustaining capital expenditure.
Source: S&P Global (2021).

…but continued investment is needed to manage new price cycles and volatility

Price movement and volatility of selected minerals



Notes: Assessment based on Lithium Carbonate CIF Asia, LME Copper Grade A Cash, LME Cobalt Cash and LME Nickel Cash prices.
Source: IEA (2020a), S&P Global (2021).

Exploitation of mineral resources gives rise to a variety of environmental and social implications that must be carefully managed to ensure reliable supplies

Selected environmental and social challenges related to energy transition minerals

Areas of risks		Description
Environment	**Climate change**	• With higher greenhouse gas emission intensities than bulk metals, production of energy transition minerals can be a significant source of emissions as demand rises • Changing patterns of demand and types of resource targeted for development pose upward pressure
	Land use	• Mining brings major changes in land cover that can have adverse impacts on biodiversity • Changes in land use can result in the displacement of communities and the loss of habitats that are home to endangered species
	Water management	• Mining and mineral processing require large volumes of water for their operations and pose contamination risks through acid mine drainage, wastewater discharge and the disposal of tailings • Water scarcity is a major barrier to the development of mineral resources: around half of global lithium and copper production are concentrated in areas of high water stress
	Waste	• Declining ore quality can lead to a major increase in mining waste (e.g. tailings, waste rocks); tailings dam failure can cause large-scale environmental disasters (e.g. Brumadinho dam collapse in Brazil) • Mining and mineral processing generate hazardous waste (e.g. heavy metals, radioactive material)
Social	**Governance**	• Mineral revenues in resource-rich countries have not always been used to support economic and industrial growth and are often diverted to finance armed conflict or for private gain • Corruption and bribery pose major liability risks for companies
	Health and safety	• Workers face poor working conditions and workplace hazards (e.g. accidents, exposure to toxic chemicals) • Workers at artisanal and small-scale mine (ASM) sites often work in unstable underground mines without access to safety equipment
	Human rights	• Mineral exploitation may lead to adverse impacts on the local population such as child or forced labour (e.g. children have been found to be present at about 30% of cobalt ASM sites in the DRC) • Changes in the community associated with mining may also have an unequal impact on women

Clean energy transitions offer opportunities and challenges for companies

As the world moves from fuel-intensive systems to more material-intensive systems, companies that produce minerals and metals provide an essential bridge between resources in the ground and the energy technologies that consumers need. As such, there is large scope for mining and refining companies to contribute to orderly clean energy transitions by ensuring adequate supply of minerals. These projects will inevitably be subject to strong scrutiny of their social and environmental performance.

Many of the large mining companies are already involved in the energy sector, as producers of coal. Energy transitions therefore present a challenge, as well as an opportunity, as companies respond to rising stakeholder pressure to clarify the implications of energy transitions for their operations and business models. Some of these companies are already moving away from coal. Rio Tinto entirely exited the coal business in recent years and other companies are heading in a similar direction, largely through reducing thermal coal production. Although there has been growing participation in copper production in recent years, they have yet to make a concerted move into energy transition minerals.

Despite the prospects offered by energy transitions, until recently companies were quite cautious about committing significant capital to new projects; this is largely because of uncertainties over the timing and extent of demand growth (linked to questions about the real commitment of countries to their climate ambitions) as well as the complexities involved in developing high-quality projects.

The picture is starting to change, as countries have sent stronger signals about their net-zero ambitions, and price signals for some minerals in 2017-2018 offered greater encouragement. Investment in new projects picked up in the latter part of the 2010s (although there was a Covid-induced fall in 2020). This trend would need to be sustained in order to support ample supply, although the risk of boom and bust cycles is ever-present for commodities that feature long lead-times from project planning to production (see Chapter 3).

Prices for minerals tend to be volatile, often more so than for traditional hydrocarbons, due to the mismatch between the pace of changes in demand patterns and that of new project development, and also to the opacity of supply chains. In the late 2010s, prices for minerals with relatively smaller markets – such as lithium and cobalt – recorded a dramatic increase in a short time as the adoption of EVs started to grow in earnest. Although prices have since dropped, as higher prices triggered a swathe of supply expansions (in the form of ASMs for cobalt), this has been a wake-up call about possible strains on supply and market balance. This provides additional reasons for policy makers to be vigilant about this critical aspect of a clean energy future.

Mineral requirements for clean energy transitions

Introduction

Minerals and metals[1] have played a critical role in the rise of many of the clean energy technologies that are widely used today – from wind turbines and solar panels to electric vehicles and battery storage. As the deployment of clean energy technology rises, the energy sector is also becoming a vital part of the minerals and metals industry. With clean energy transitions, the linkages between minerals and energy are set to strengthen.

However, this raises the question: will sufficient sustainable and responsibly sourced mineral supplies be available to support the acceleration of energy transitions? The first step to address this is to understand the potential requirements for minerals arising from clean energy transitions.

The type and volume of mineral needs vary widely across the spectrum of clean energy technologies, and even within a certain technology (e.g. wind turbine technologies; EV battery chemistries). In this chapter we assess the aggregate mineral demand from a wide range of clean energy technologies – low-carbon power generation (renewables and nuclear), electricity networks, electric vehicles (EVs), battery storage and hydrogen (electrolysers and fuel cells) – under two main IEA scenarios: the Stated Policies Scenario (STEPS) and the Sustainable Development Scenario (SDS).

For each of the clean energy technologies, we estimate overall mineral demand using four main variables: clean energy deployment trends under different scenarios; sub-technology shares within each technology area; mineral intensity of each sub-technology; and mineral intensity improvements.[2] The first two variables were taken from the projections in the *World Energy Outlook 2020*, complemented by the results in the *Energy Technology Perspectives 2020*.

We compiled the mineral intensity assumptions through extensive literature review, and expert and industry consultations, including with IEA Technology Collaboration Programmes. The pace of mineral intensity improvements varies by scenario, with the STEPS generally seeing minimal improvement over time as compared to modest improvement (around 10% in the longer term) assumed in the SDS. In areas that may particularly benefit from economies of scale or technology improvement (e.g. silicon and silver use in solar photovoltaic [PV], platinum loading in fuel cells, rare earth element

[1] This report considers a wide range of minerals and metals used in clean energy technologies, including chromium, copper, major battery metals (lithium, nickel, cobalt, manganese and graphite), molybdenum, platinum group metals, zinc, rare earth elements and others (see Annex for the complete list). Steel and aluminium are not included in the scope for demand assessment, but aluminium use in electricity networks is exceptionally assessed given that the outlook for copper is closely linked with aluminium use in grid lines (see Introduction).

[2] See Annex for methodologies and data sources.

[REE] use in wind turbines), we applied specific improvement rates based on the review of underlying drivers.

Projected mineral demand is subject to considerable uncertainty. It is highly dependent on the stringency of climate policies (reflected in the difference between the STEPS and SDS), but also on different technology development pathways. As such, in addition to our base assumptions for technology development pathways ("base case") in both the STEPS and SDS, we identified key variables for each technology that could drive mineral demand in different directions. We then built 11 alternative cases under both scenarios to quantify the impacts of varying technology evolution trends.

Alternative technology evolution pathways explored

Technology	Alternative cases
Solar PV	• Comeback of high cadmium telluride • Faster adoption of perovskite solar cells • Wider adoption of gallium arsenide technology
Wind	• Constrained REE supply
Electricity networks	• Increased use of aluminium in underground cables • Wider adoption of direct-current systems
EVs	• Delayed shift to nickel-rich cathodes • More rapid move towards a silicon-rich anode • Faster uptake of lithium metal anode all-solid-state batteries
Battery storage	• Rapid adoption of home energy storage • Early commercialisation of vanadium flow batteries

While our report focuses on projecting mineral requirements for clean energy technologies, for the five focus minerals – copper, lithium, nickel, cobalt and neodymium (as a representative for REEs) – it also assesses demand from other sectors. This is to understand the contribution of clean energy technologies to overall demand and better assess supply-side challenges. We projected mineral demand for other sectors using historical consumption by end-use applications, relevant activity drivers (e.g. GDP, industry value added, vehicle activities, steel production) and material intensities (see Annex: Scope and methodology).

Mineral needs vary widely across clean energy technologies

Critical mineral needs for clean energy technologies

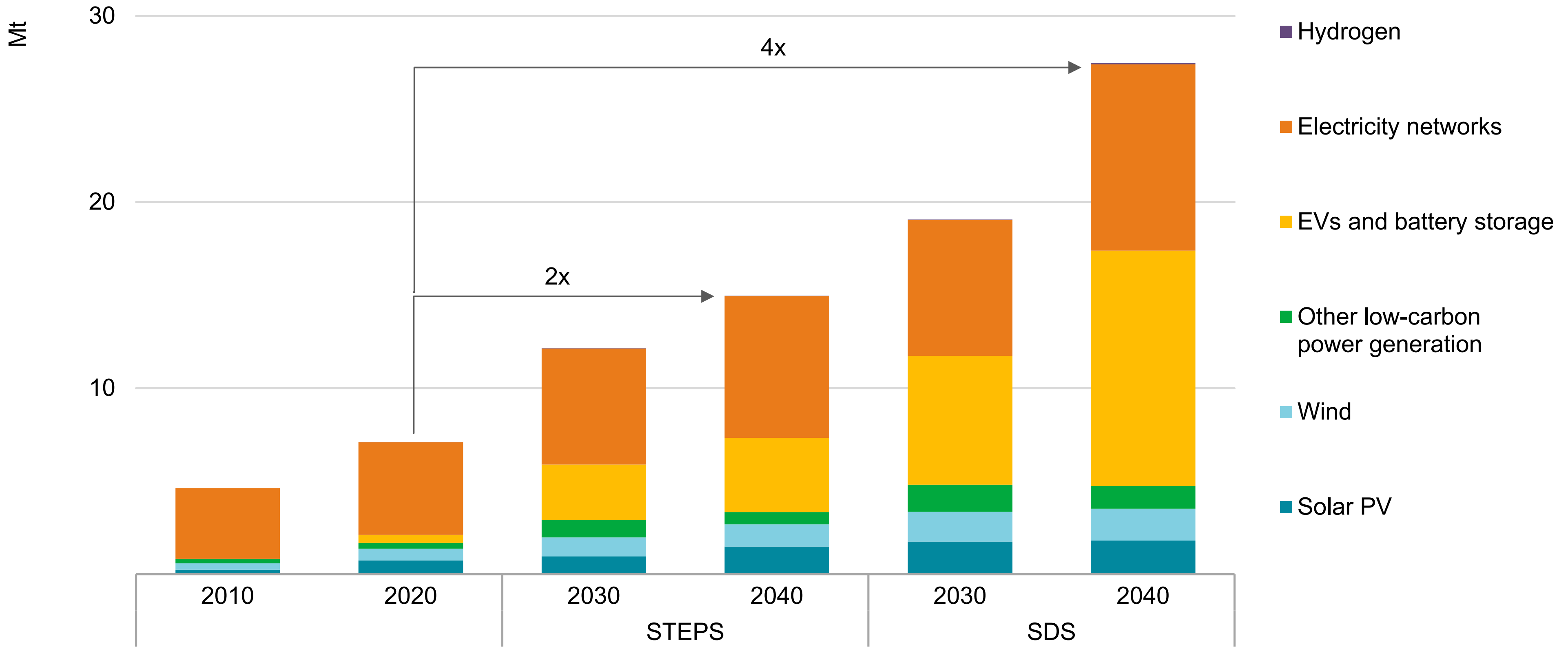
	Copper	Cobalt	Nickel	Lithium	REEs	Chromium	Zinc	PGMs	Aluminium*
Solar PV	●	○	○	○	○	○	○	○	●
Wind	●	○	◍	○	●	◍	●	○	◍
Hydro	◍	○	○	○	○	◍	◍	○	◍
CSP	◍	○	◍	○	○	●	◍	○	●
Bioenergy	●	○	○	○	○	○	◍	○	◍
Geothermal	○	○	●	○	○	●	○	○	○
Nuclear	◍	○	◍	○	○	◍	○	○	○
Electricity networks	●	○	○	○	○	○	○	○	●
EVs and battery storage	●	●	●	●	●	○	○	○	●
Hydrogen	○	○	●	○	◍	○	○	●	◍

Notes: Shading indicates the relative importance of minerals for a particular clean energy technology (● = high; ◍ = moderate; ○ = low), which are discussed in their respective sections in this chapter. CSP = concentrating solar power; PGM = platinum group metals.

* In this report, aluminium demand is assessed for electricity networks only and is not included in the aggregate demand projections.

Total mineral demand from clean energy technologies is set to double in the STEPS and quadruple in the SDS by 2040

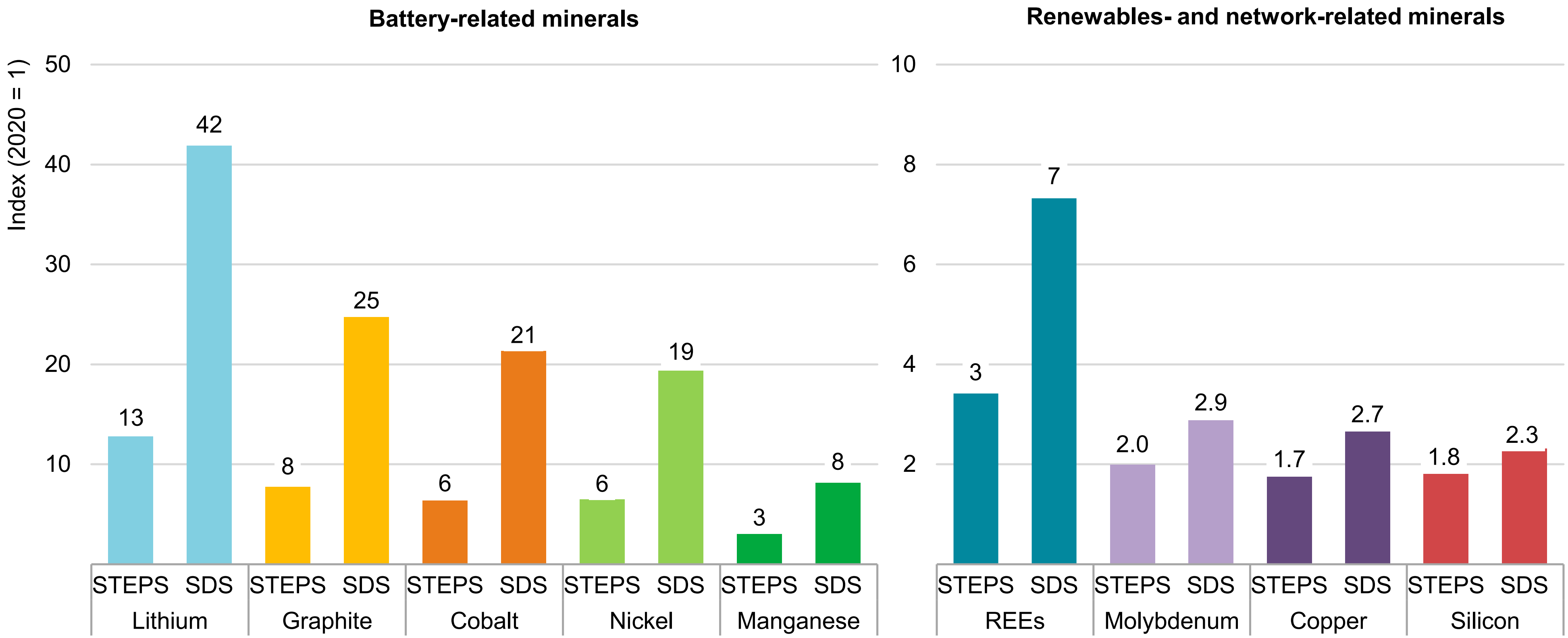
Total mineral demand for clean energy technologies by scenario



Notes: Includes all minerals in the scope of this report, including chromium, copper, major battery metals (lithium, nickel, cobalt, manganese and graphite), molybdenum, platinum group metals, zinc, REEs and others, but does not include steel and aluminium (see Annex for a full list of minerals). Mt = million tonnes.

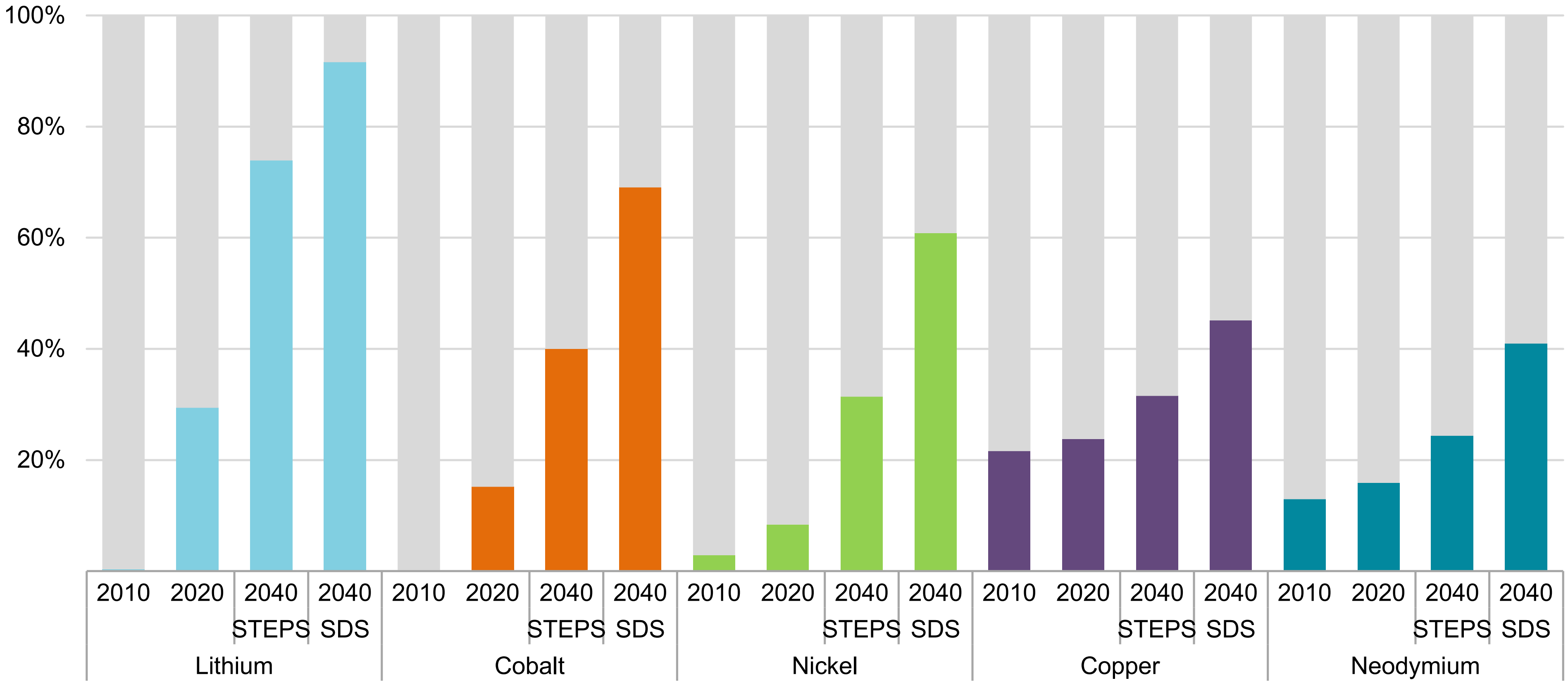
The relative demand growth is particularly high for battery-related minerals

Growth in demand for selected minerals from clean energy technologies in 2040 relative to 2020 levels



Clean energy technologies are set to emerge as a major force in driving demand growth for critical minerals

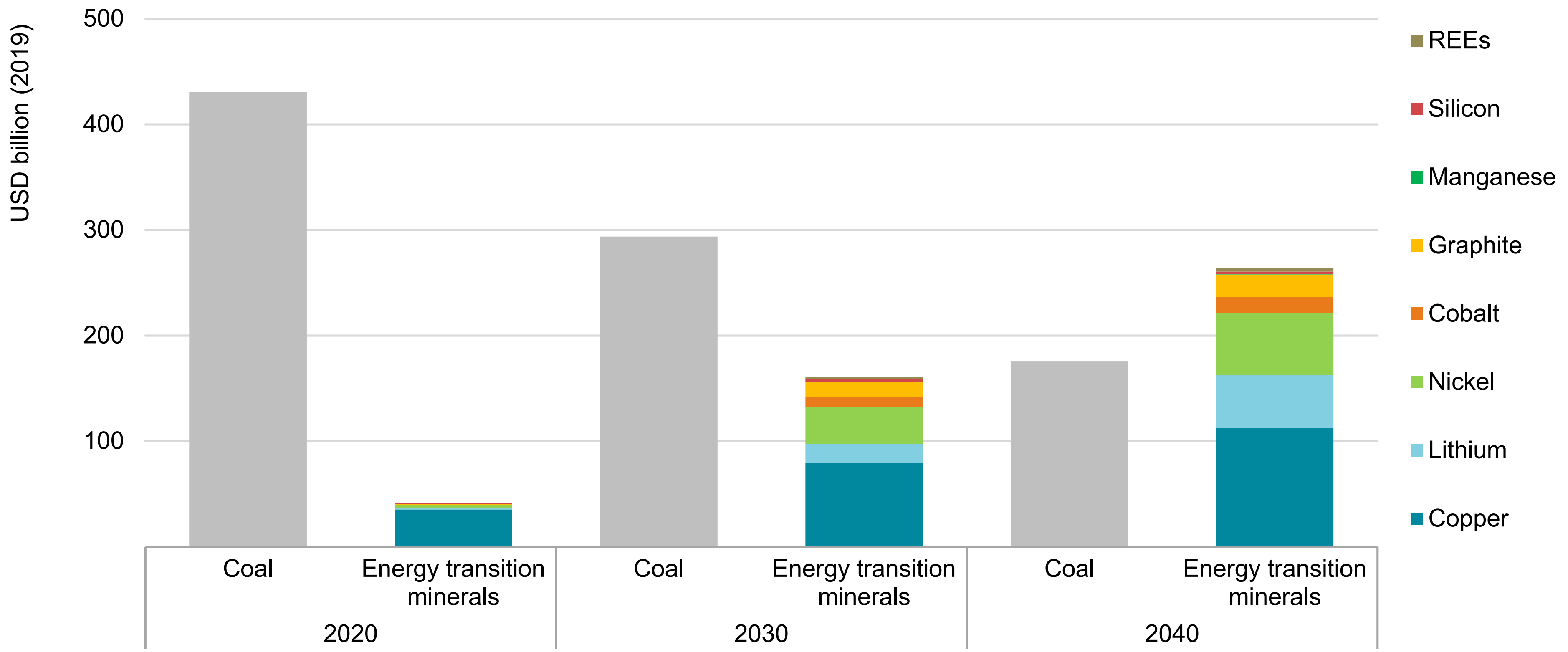
Share of clean energy technologies in total demand for selected minerals



Note: Demand from other sectors was assessed using historical consumption, relevant activity drivers and the derived material intensity.

Changing fortunes: Coal vs energy transition minerals

Revenue from production of coal and selected energy transition minerals in the SDS



Notes: Revenue for energy transition minerals includes only the volume consumed in clean energy technologies, not total demand. Future prices for coal are projected equilibrium prices in *WEO 2020* SDS. Prices for energy transition minerals are based on conservative assumptions about future price trends (moderate growth of around 10-20% from today's levels).

Rising deployment of clean energy technologies is set to supercharge demand for critical minerals

The global clean energy transitions will have far-reaching consequences for mineral demand over the next 20 years. By 2040 total mineral demand from clean energy technologies double in the STEPS and quadruple in the SDS.

EVs and battery storage account for about half of the mineral demand growth from clean energy technologies over the next two decades, spurred by surging demand for battery materials. Mineral demand for use in EVs and battery storage grows nearly tenfold in the STEPS and around 30 times in the SDS over the period to 2040. By weight, mineral demand in 2040 is dominated by copper, graphite and nickel. Lithium sees the fastest growth rate, with demand growing by over 40 times in the SDS. The shift towards lower cobalt chemistries for batteries helps to limit growth in cobalt, displaced by growth in nickel.

Electricity networks are another major driving force. They account for 70% of today's mineral demand from the energy technologies considered in this study, although their share continues to fall as other technologies – most notably EVs and storage – register rapid growth.

Mineral demand from low-carbon power generation grows rapidly, doubling in the STEPS and nearly tripling in the SDS over the period to 2040. Wind power plays a leading role in driving demand growth due to a combination of large-scale capacity additions and higher mineral intensity (especially with growing contributions from mineral-intensive offshore wind). Solar PV follows closely, with its unmatched scale of capacity additions among the low-carbon power generation technologies. Hydropower, biomass and nuclear make only minor contributions given their comparatively low mineral requirements and modest capacity additions.

The rapid growth of hydrogen use in the SDS underpins major growth in demand for nickel and zirconium for use in electrolysers, and for copper and platinum-group metals for use in fuel cell electric vehicles (FCEVs). Despite the rapid rise in FCEVs and the decline in catalytic converters in gasoline and diesel cars, demand for platinum-group metals in internal combustion engine cars remains higher than in FCEVs in the SDS in 2040.

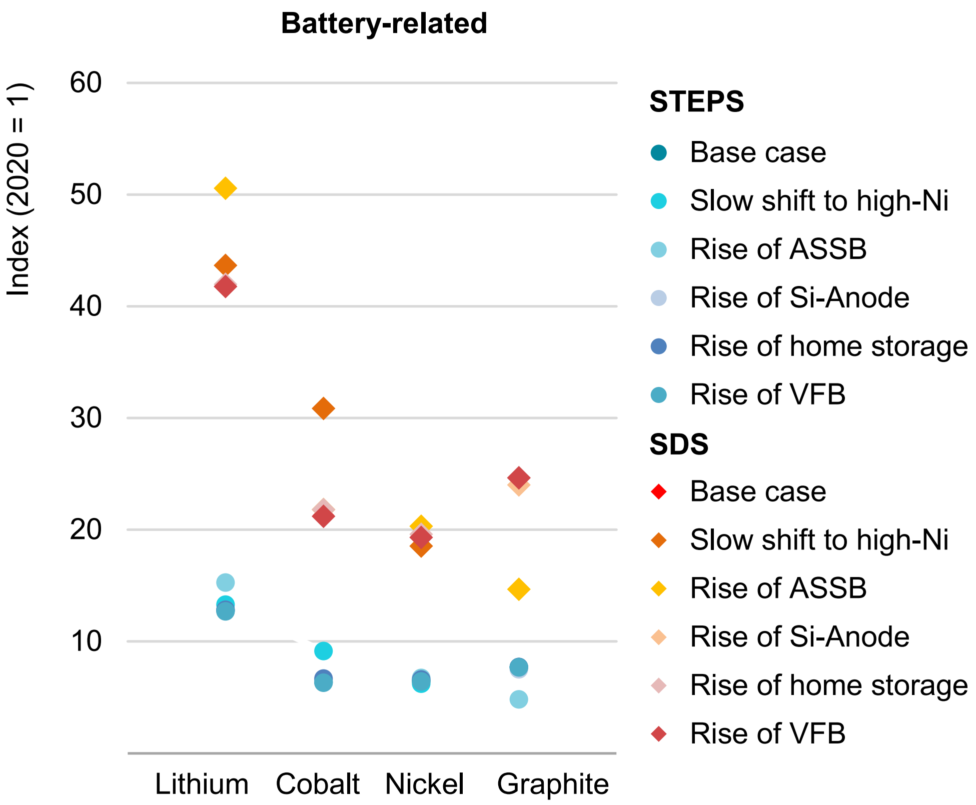
Demand for REEs – primarily for EV motors and wind turbines – grows threefold in the STEPS and around sevenfold in the SDS by 2040.

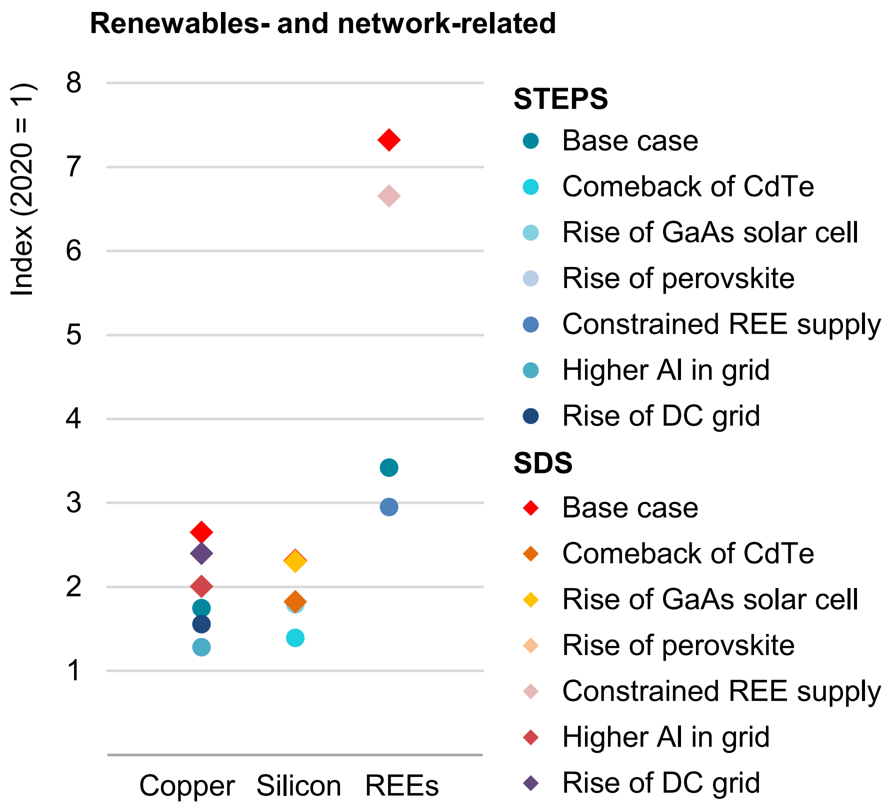
For most minerals, the share of clean energy technologies in total demand was minuscule until the mid-2010s, but the picture is rapidly changing. Energy transitions are already the major driving force for total demand growth for some minerals. Since 2015 EVs and battery storage have surpassed consumer electronics to become the largest consumers of lithium, together accounting for 30% of total current demand. This trend is set to accelerate as countries step up their climate ambitions. Clean energy technologies become the fastest-growing segment of demand for most minerals, and their share of total demand edges up to over 40% for copper and REEs, 60-70% for nickel and cobalt and almost 90% for lithium by 2040 in the SDS.

Assessments based on total mineral weights often do not adequately account for the significance of certain minerals. It is also useful to consider the revenue generated from producing the minerals, as there is a wide range in monetary value between minerals. Coal is currently the largest source of revenue for mining companies by a wide margin. Revenues from coal production are about ten times larger than those from producing minerals used in clean energy technologies. However, accelerating clean energy transitions are set to change this picture radically. In the SDS, coal's stronghold on the energy system is increasingly challenged by phase-out policies in many countries and also by the rise of renewables. By contrast, many energy transition minerals are likely to face a tailwind from growing demand and upward pressure on prices. This underpins a sharp reversal of fortunes between coal and energy transition minerals. In the SDS, the combined revenue from energy transition minerals (including only the volume used in the clean energy sector) overtakes that of coal by 2040.

A wide range of futures are possible, mainly related to level of climate ambition and action, as well as technology uncertainties

Mineral demand from clean energy technologies in 2040 relative to 2020 under different scenarios and technology evolution trends





Notes: Al = aluminium; ASSB = all-solid-state batteries; CdTe = cadmium telluride; DC = direct current; GaAs = gallium arsenide; Ni = nickel; Si = silicon; VFB = vanadium redox flow batteries.

Strong climate ambitions can reduce uncertainties around demand evolution, thereby stimulating investment and reducing security risks

Demand projections are subject to large variations, which lead to a wide range of possible futures. According to our analysis of the scenarios and alternative cases, lithium demand in 2040 may be 13 times higher (if vanadium redox flow batteries rapidly penetrate the market in the STEPS) or 51 times higher (if all-solid-state batteries commercialise faster than expected in the SDS) than today's levels. Likewise, cobalt and graphite may see 6- to 30-times higher demand than today depending on the scenario that unfolds. Among non-battery materials, demand for REEs grows by seven times in the SDS, but growth may be as low as three times today's levels should wind companies tilt more towards turbines that do not use permanent magnets in the STEPS context.

These large uncertainties around possible futures may act as a factor that hampers companies' investment decisions, which could in turn cause supply-demand imbalances in the years ahead. Despite the promise of massive demand growth, mining and processing companies may be reluctant to commit large-scale investment given the wide range of possible demand trajectories.

However, the biggest source of demand variance does not come from technology. It comes instead from the uncertainty surrounding announced and expected climate ambitions – in other words, whether clean energy deployment and resulting mineral demand follows STEPS or SDS trajectories.

Here, governments have a key role to play in reducing uncertainty by sending strong and consistent signals about their climate ambitions and implementing specific policies to fulfil these long-term goals. The recent pickup in new project investments reflects the way that government climate commitments provide market signals for investments, which could help ensure reliable supply of minerals to support an orderly energy transition. The efforts also need to be accompanied by a range of measures to dampen the rapid growth in primary supply requirements such as promoting technology innovation for material efficiency or substitution, scaling up recycling and extending the lifetime of existing assets through better maintenance (see Chapter 3).

In the following sections we explore the mineral requirements for each clean energy technology under different scenarios and with varying trends in technology evolution.

Low-carbon power generation