Harnessing the Potential of Critical Minerals for Sustainable Development

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Introduction

Rapidly reducing dependence on fossil fuels and accelerating the transition to renewable energy remains the most viable pathway to a net-zero world, essential for tackling climate change and securing a liveable future for all. However, the energy transition will require vast amounts of metals and minerals—dubbed "critical minerals" because they are indispensable for renewable energy technologies. Achieving net-zero carbon dioxide (CO_2) emissions by 2050 will require the rapid and widespread adoption of low-emission renewable technologies and securing universal access to energy services.

The exploration, extraction, processing, and use of critical minerals is fraught with complex economic, social, and environmental challenges, which can be exacerbated by limited international cooperation and the absence of robust multilateral frameworks. Managing the complex supply chains of these resources requires Governments to consider intricate relationships and potential trade-offs between trade, climate, sustainable development, and energy security objectives. Trade barriers, whether driven by energy security concerns, geopolitical competition, or protectionist policies, risk fragmenting markets, driving up costs, reducing investments, and slowing down the pace of the energy transition.

For developing countries with extractable reserves of critical minerals, the increasing demand presents a significant opportunity to drive economic growth and advance sustainable development, provided they can capture the gains from value addition and ensure that social and environmental objectives are also advanced. Otherwise, as has been the case with mineral-driven growth in the past, there can be substantial macroeconomic and developmental risks, including corruption, elite capture, increasing inequality, environmental degradation, and conflict. Learning from these mistakes can help nations make the most of the opportunities and avoid the so-called resource curse.

The present document examines the potential of critical minerals from a development perspective and includes actionable recommendations to mitigate challenges. Unlocking their benefits will require the development of strategic and coordinated national policies as policymakers navigate complex economic, environmental, social, and geopolitical challenges. Strong international collaboration will also be essential to ensure a rapid, fair, and equitable energy transition aligned with the Sustainable Development Goals (SDGs) and the key principle of "leaving no one behind".

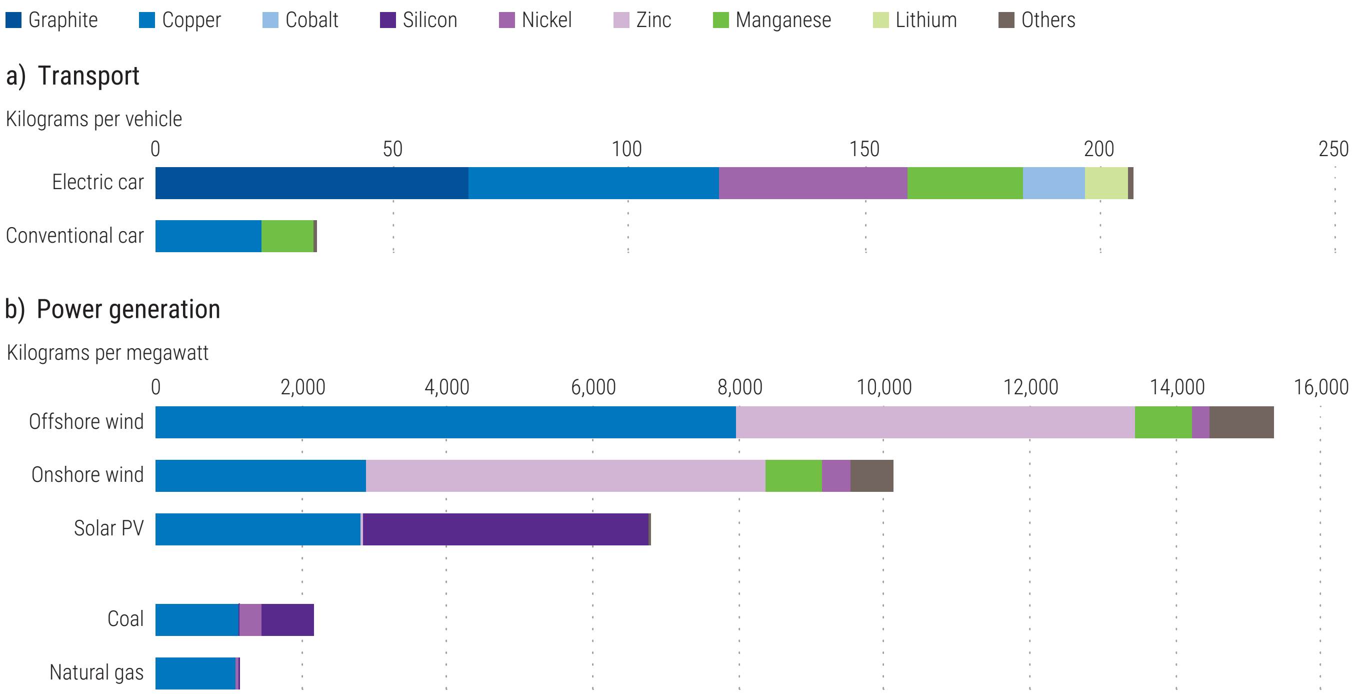
The state of play in the critical minerals sector

Critical minerals are indispensable for the energy transition

Rapidly adopting renewable energy technologies and phasing out fossil fuels are crucial for combating climate change. Achieving net-zero CO_2 emissions by 2050 will require a much faster deployment of clean energy technologies, from wind turbines and solar panels to electric vehicles and battery storage. The timely adoption of these clean energy technologies—as developing countries strive to achieve universal energy access and diversify their economies—is driving demand growth for many minerals, including copper, cobalt, lithium, nickel, and rare earth elements. An onshore wind power plant, for instance, requires mineral inputs nine times greater than those needed for a gas-fired plant of the same capacity, while an electric vehicle (EV) requires six times more minerals than a conventional car (see figure 1). The average mineral requirement for new power generation capacity rose by 50 per cent in the 2010s as the share of renewables in total capacity additions increased (IEA, 2022) (see figure 2).

Figure 1

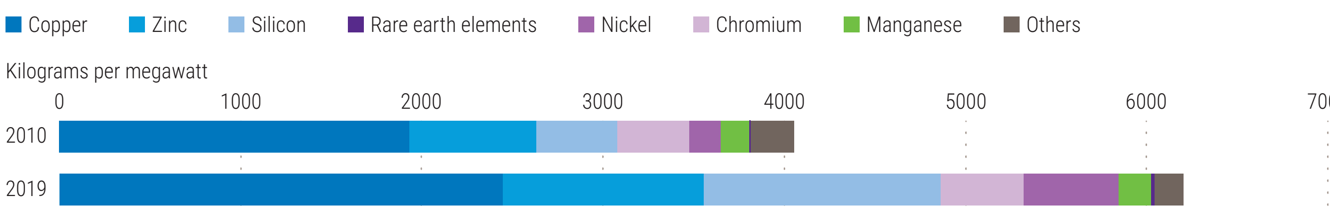
Critical minerals used in selected clean energy technologies and traditional energy technologies



Source: UN DESA, based on data from IEA.

Figure 2

Average critical mineral intensity of new power generation capacity



Source: UN DESA, based on data from IEA.

Figure 3

Selected materials critical for energy transition, by technology type

■ Alkali metals ■ Transition metals ■ Lanthanides ■ Other metals ■ Metalloids ■ Non-metals

	EV batteries	EV motors	EV body	Battery storage	Bioenergy	Electricity grid	Solar PV	Concentrated solar power	Geothermal	Hydropower	Wind power	Hydrogen
13 Al Aluminium	✔		✔		✔	✔	✔	✔		✔	✔	✔
27 Co Cobalt	✔			✔	✔							✔
29 Cu Copper	✔	✔		✔	✔	✔	✔	✔	✔	✔	✔	✔
66 Dy Dysprosium		✔									✔	
6 C Graphite	✔			✔								✔
3 Li Lithium	✔			✔								
25 Mn Manganese	✔			✔				✔	✔	✔	✔	
60 Nd Neodymium		✔									✔	
28 Ni Nickel	✔			✔	✔		✔	✔	✔	✔	✔	✔
15 P Phosphate	✔											
78 Pt Platinum												✔
14 Si Silicon	✔	✔					✔					
30 Zn Zinc					✔		✔	✔		✔	✔	

Source: UN DESA, based on Van de Graaf and others (2023), Azevedo (2022) and United States Geological Survey (2022).

The choice of clean technologies will determine the demand for different critical minerals in the coming years (see figure 3). Some minerals are essential for specific technologies, such as cobalt and lithium for batteries, while others, such as aluminium and copper, are widely needed across various applications. As countries intensify their energy transition efforts, there will be significant shifts in the demand patterns for critical minerals.

Many countries have identified minerals essential for industrial production, modern technology, and clean energy as "critical minerals", "strategic minerals", or "energy transition minerals" (hereinafter referred to as "critical minerals"). Among the Group of Twenty (G20), at least 16 economies have critical minerals lists comprising anywhere from 20 to more than 60 minerals;[1] they generally include cobalt, lithium, graphite, and nickel, among others (see table 1). The lists of critical minerals are specific to each country. For developed economies, the importance of these minerals to national security, their relevance to modern technologies, relationships with trading partners, vulnerability to supply chain disruptions, and the availability of substitutes are key considerations. In contrast, developing countries prioritize the significance of these minerals for their low-carbon transitions, the growth of emerging and high-tech industries, enhancing their comparative trade advantages, and addressing broader development challenges. Country lists of critical minerals have evolved over time, reflecting technological advancements, changing supply and demand dynamics, and shifting societal needs. For example, in 2023 the United States of America published a list of 50 critical minerals, up from 35 in 2018 (Rowan, 2024).

Table 1

Minerals classified as critical by at least ten Group of Twenty economies

Critical minerals	Number of G20 economies identifying minerals as critical
Cobalt, lithium	16
Graphite, nickel, tungsten, vanadium	15
Antimony, niobium, platinum group metals, tantalum	14
Gallium, rare earth elements, titanium	13
Copper, manganese, silicon	12
Bismuth, chromium, germanium, indium, molybdenum, tin	11
Beryllium, magnesium, zirconium	10

Source: UN DESA, based on national sources.
Note: The table reflects metals and minerals classified as critical by the members of the Group of Twenty economies according to their national definitions, which go beyond those solely needed for the energy transition.

Critical minerals markets reflect shifting dynamics

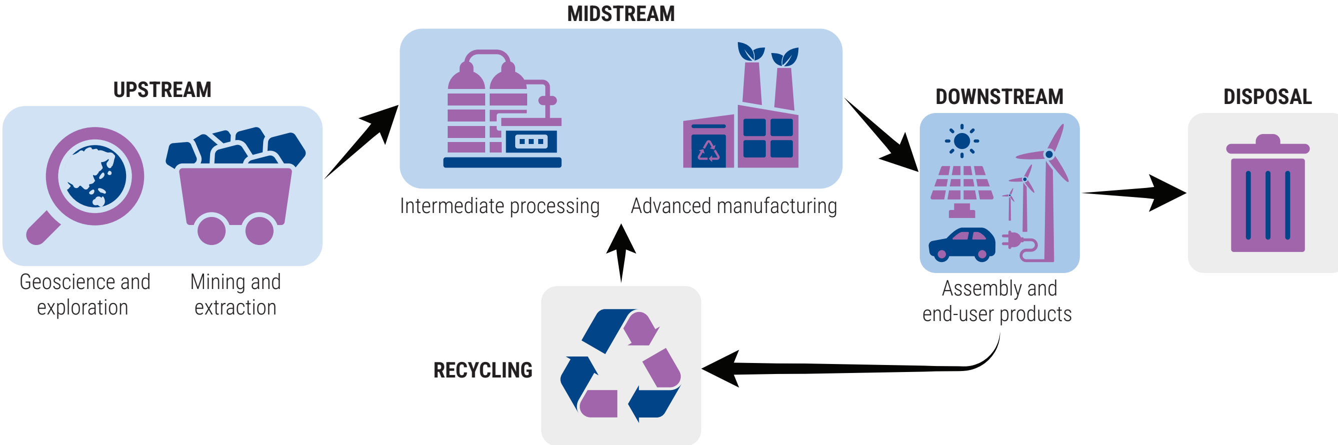
The critical minerals value chain encompasses exploration, extraction, processing, refining, manufacturing, recycling, and disposal (see figure 4). The extraction of critical minerals shares several characteristics with the mining of traditional minerals.[2] For instance, both are capital-intensive, with long lead times before generating revenue for the mining company. Most mining companies are price takers, making them vulnerable to highly volatile prices, rapid changes in global economic conditions, and policy shifts that affect demand, coupled with the slow adjustment of supply (Daly and others, 2022). Similar to traditional mining, the extraction and processing of critical minerals have significant local impacts, including social and community disruptions, as well as environmental consequences such as soil erosion, water contamination, and ecosystem damage.

At the same time, critical minerals possess distinct features that set them apart from traditional minerals. First, many critical minerals are by-products or co-products of mining other minerals. For example, antimony can be

1 As at August 2024.
2 Excluding oil and gas, mining as an industry accounts for approximately 3.7 per cent of global GDP. In 2023, global exports of copper and nickel ores—the critical minerals with the largest markets—totalled $57 billion, while oil and gas exports surpassed $1.8 trillion (United Nations Comtrade database). As at September 2024, the combined market capitalization of the top five mining companies was $493 billion, compared with $2.9 trillion for the top five oil and gas companies.

Figure 4

Illustration of the critical minerals value chain



Source: UN DESA.

a by-product of gold or lead mining; copper deposits often host cobalt, bismuth and tin; and nearly all indium is a by-product of zinc mining (Nassar, Graedel and Harper, 2015). Second, estimating global resources of critical minerals is particularly challenging.[3] Mineral deposits are not evenly distributed worldwide, not all ore deposits contain critical minerals by-products, and processing capabilities vary significantly across countries (McNulty and Jowitt, 2021). Third, the market size of critical minerals remains relatively small compared to that of other resources. In 2023, the market size of key energy transition minerals was $325 billion, roughly equivalent to that of iron ore and only about 5 per cent of the oil and gas market (IEA, 2024; Kings Research, 2024). However, market sizes of individual critical minerals vary significantly; for instance, in 2022, the market size of copper was over $180 billion, whereas that of lead was below $10 billion (Bhutada, 2023).

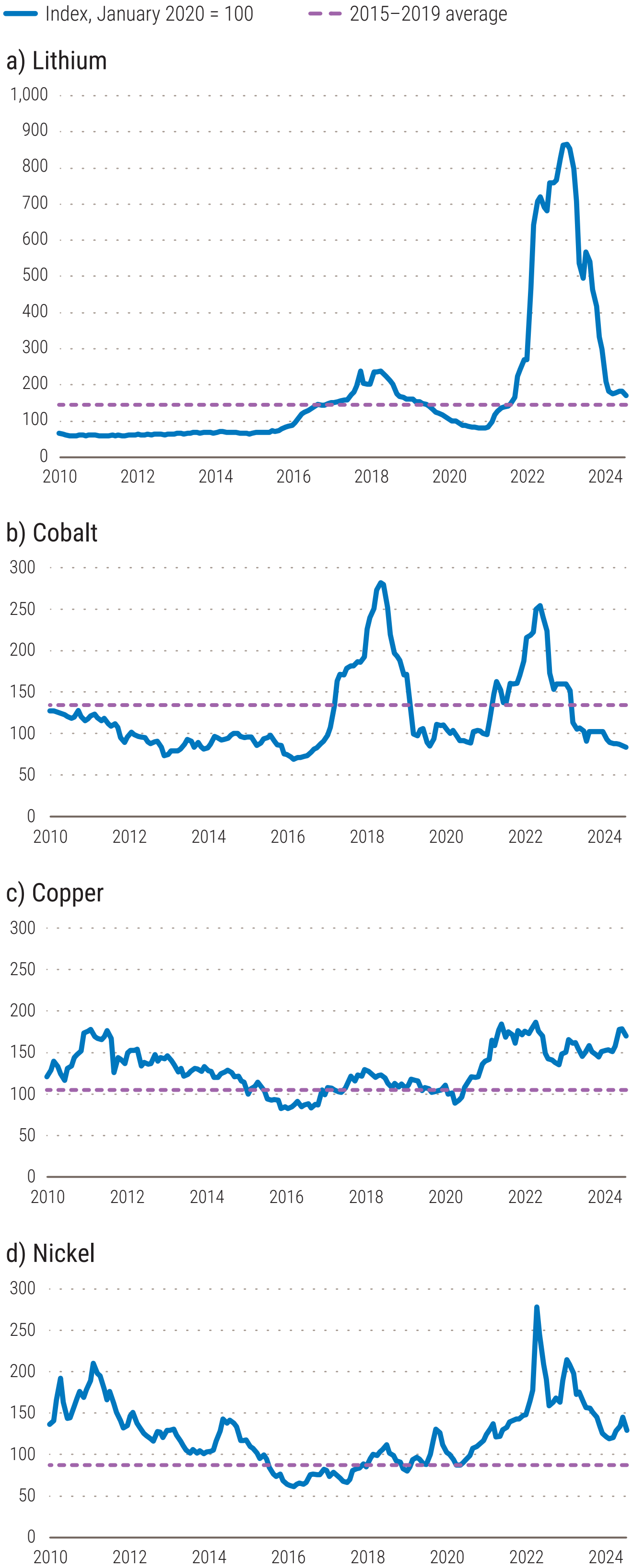
In recent years, significant price volatility has become a defining characteristic of several critical minerals markets, especially for those essential for manufacturing electric vehicles (EVs). Lithium prices, for example, have experienced substantial fluctuations. Similarly, cobalt prices surged by over 100 per cent in 2021, only to fall by 30–40 per cent in both 2022 and 2023 (see figure 5). Historical data indicate that large price swings for critical minerals have been more frequent than for basic metals such as iron and steel, with lithium and cobalt showing particularly high volatility (see figure 6).

The recent price fluctuations—particularly for cobalt, lithium, and nickel—reflect shifting supply and demand dynamics in the EV sector, where these minerals are primarily used for manufacturing batteries. As countries emerged from pandemic lockdowns, demand for various products and minerals surged, while supply chains remained disrupted. However, demand for EVs has fallen short of expectations since 2023 amid aggressive monetary tightening, weaker than expected demand growth in major markets, and concerns over potential trade tensions between major developed economies and China. Nickel and cobalt prices have also declined due to increased production and uncertainties about the pace of the transition to EVs. In contrast, demand for copper—widely used across multiple clean energy technologies such as solar photovoltaic (PV), hydropower and geothermal, as well as more broadly in construction and manufacturing—has remained robust, keeping its price elevated.

3 A mineral resource refers to a natural occurrence or concentration of solid material that has economic value, whereas a mineral reserve is the portion of a mineral resource that is economically viable to mine (CIM Standing Committee on Reserve Definitions, 2014). All reserves are resources, but not all resources are reserves.

Figure 5

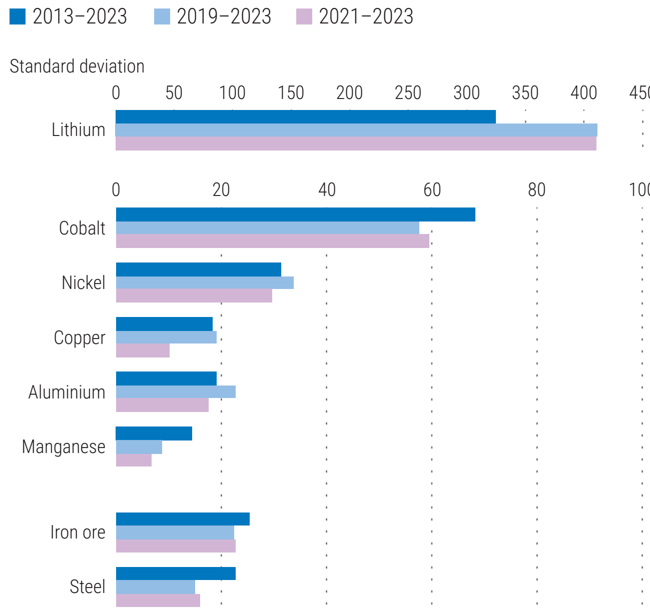
Monthly average prices of selected critical minerals



Source: UN DESA, based on data from S&P Global Market Intelligence (2024).

Figure 6

Standard deviation of prices for selected minerals



Source: UN DESA, based on data from S&P Global Market Intelligence (2024) and Trading Economics.
Notes: Prices are standardized by assigning the prices on the first trading day in 2013 a value of 100. Global average lithium carbonate prices are used for lithium; prices of steel rebar are used to reflect steel prices.

High volatility in the price of lithium is also attributed to its market immaturity and low liquidity in comparison with base metals and other commodities. While lithium prices rose with increasing EV demand between 2015 and 2019, volatility remained limited due to lithium being a small niche market where prices were fixed for long periods. During the pandemic, a surge in demand met a shallow market with limited suppliers, causing lithium spot prices to spike (Mehdi, 2024). It is worth noting that the prices of by-product minerals and metals such as cobalt tend to be more volatile than the prices of primary products. Research on 36 minerals shows that by-products exhibit, on average, about 50 per cent higher price volatility than main products, likely due to the inelastic nature of their supply (Redlinger and Eggert, 2016).

Price volatility is also associated with imbalances in supply-demand dynamics. The surge in the supply of cobalt, lithium, and nickel—driven by price spikes that prompted battery manufacturers

Figure 7

Projected supply of and demand for selected critical minerals

Source: UN DESA, based on data from the IEA Critical Mineral Data Explorer.
Notes: The scenarios for demand projections align with the IEA definitions. The Stated Policies Scenario is based on policy settings as at August 2023, associated with a temperature rise of no more than 2.4°C by 2100; the Announced Pledges Scenario assumes that Governments will meet all the climate-related commitments announced as at August 2023, including the targets and pledges in nationally determined contributions, and is associated with limiting the rise in temperature to no more than 1.7°C by 2100; and the Net Zero Emissions Scenario charts a pathway for the global energy sector to achieve net zero CO_2 emissions by 2050 and limit the global temperature rise to 1.5°C above pre-industrial levels by 2100. The supply projections are based on announced project pipelines for mining and refining, with modelled mineral recycling.

and original equipment manufacturers to invest in upstream mining—may diminish in the coming years. Recent price drops have deterred investors and made it harder for mining companies to secure traditional funding, forcing some, particularly junior firms,[4] to cut production or shut down operations (Biesheuvel, 2024). Such disruptions could have lasting effects, as stalled projects are often difficult to restart.

The demand for critical minerals is expected to rise sharply over the coming decades due to their essential role in the energy transition. While the current excess of supply over demand is likely to balance out by 2030, a persistent supply shortage is anticipated thereafter (see figure 7). These projections, however, are subject to a range of factors (see box 1). Policy directions will remain crucial; if countries do not credibly commit to

4 Junior firms are small, early-stage companies focused on the exploration and development of mineral deposits.

achieving net-zero emissions by 2050, including through the phasing out of fossil fuels, the demand for critical minerals may not increase as expected, further discouraging investment.

Critical mineral supply chains are characterized by a high degree of geographic concentration. In 2023, the top three producers accounted for 50–90 per cent of the global production of copper, cobalt, lithium, nickel, graphite, and rare earth elements. For example, the Democratic Republic of the Congo was responsible for over 60 per cent of global cobalt extraction, China for 80 per cent of graphite and 60 per cent of rare earth element extraction, and Indonesia for more than 50 per cent of nickel extraction (see figure 8a). Based on the current pipeline of projects, this concentration is unlikely to change significantly before 2040 (IEA, 2024). The concentration is even more pronounced at the processing and refining stage; for cobalt, lithium, graphite, and rare earth elements, the top three

Box 1

Uncertainties in forecasting supply and demand in the critical minerals sector

The use of critical minerals is expected to surge as the energy transition accelerates. Although many projections of supply and demand have been issued, estimates vary considerably.

While there is broad consensus that demand will rise significantly by mid-century, studies vary in their estimates of the scale and timing of this demand growth. Calderon and others (2024) relate that among the 38 publications they reviewed, annual projections for lithium demand in 2050 range from 146 to 6,800 kilotons, and the corresponding range for cobalt is 6 to 3,600 kilotons (see figure 1.1a). Supply projections also vary. Forecasts from a cross-section of about 20 reports from international organizations, academics, and industry over the past five years place the supply of lithium in 2030 at anywhere between 450 and 3,600 kilotons and the supply of cobalt at between 185 and 330 kilotons (see figure 1.1b).

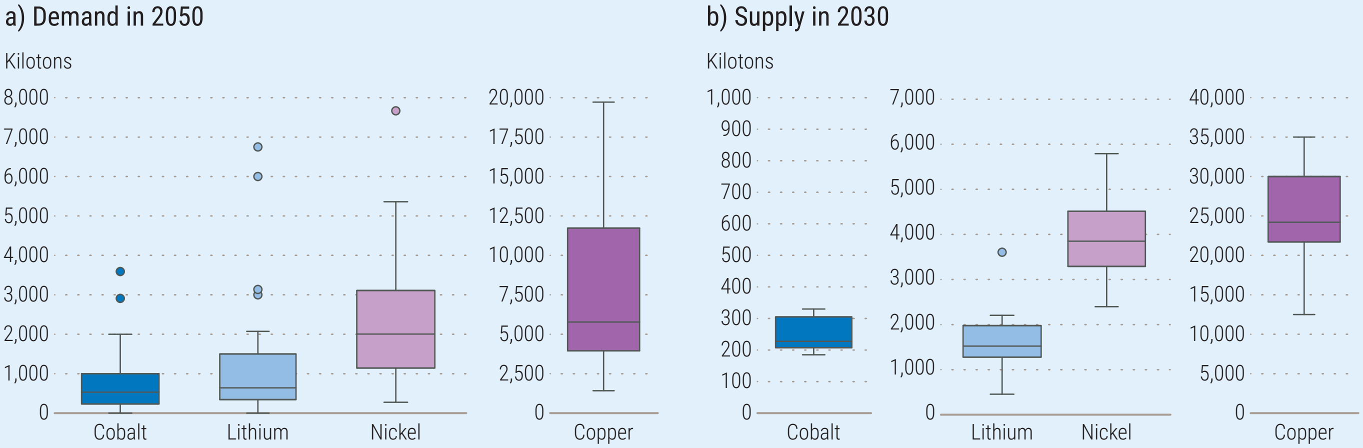
The significant disparities in these results are due to variations in model assumptions. Many mineral demand models start with an estimated future energy demand, including renewables, based on projected socioeconomic indicators (such as population growth or economic trends) or future renewable energy deployment under different policy scenarios. In addition, the models make assumptions about the composition of renewables, including solar, wind, and nuclear energy; electric vehicles (EVs); and the associated technologies and necessary infrastructure.

Different technologies require different sets of critical minerals. For example, EV lithium-ion batteries with nickel-manganese-cobalt cathodes usually require eight times more cobalt than do those with nickel-cobalt-aluminium-oxide cathodes. Lithium-iron-phosphate batteries require about 50 per cent more copper than do nickel-manganese-cobalt batteries but do not require cobalt, nickel, or manganese (IEA, 2022). The material use efficiency in different technologies, mineral recycling rates, and national policy directions (such as the endorsement of specific technologies) are also predetermined in various models. Some models exclude certain factors and constraints that could later turn out to be significant (Calderon and others, 2024).

Meanwhile, supply projections tend to cover a shorter time horizon than demand predictions and vary to a lesser extent. This is because supply is often forecast based on existing mining operations, announced projects, and pipeline projects.[a] Some projections specify that they do not consider unannounced mine life extensions, tailings processing, or reserve and resource updates (Soares, 2021), while others introduce scenarios based on the operational capacity of mines (Lazzaro, 2022). Assumptions are also made regarding extraction technologies and recycling (Jones and others, 2021). Calculations are often based on assumptions that mining projects will progress as planned. However, many factors can affect operations, including the stability of the water and energy supply, weather and climate conditions or events, the licensing process, ESG requirements, the geopolitical situation, and local community response. Stable critical minerals prices are particularly important for securing funding for project development; boom-bust cycles generate risks and uncertainties for investors.

Figure 1.1

Projected supply and demand ranges for selected minerals



Sources: a) Calderon and others (2024); b) UN DESA, based on Singh and Unzueta (2021); Benchmark Mineral Intelligence Limited (2022 and 2023); Jones and others (2021); Emmanuel (2020); IEA (2022 and 2024); L (2024); Kettle (2021); Sadow (2022); Lazzaro (2022); Lu and Frith (2019); Mandaokar (2023); Olander (2021); Soares (2021); Sun (2022); Trafigura (2022); Tuomela, Törmänen and Michaux (2021).
Note: The box plots show projected demand and supply in their lower quartile values, median values, upper quartile values, and outliers (dots).

As illustrated here, supply and demand projections for critical minerals are characterized by significant uncertainties. Historically, energy forecasts "show a remarkable extent of individual and collective failure in predicting actual developments" (Smil, 2000). However, Box (1976) observes that while "all models are wrong, some are useful". In any case, projections are valuable for presenting a range of demand and supply projections based on different assumptions and scenarios, which can help guide public policy design and strategic planning by firms.

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a "Probable mining projects" typically refer to mining endeavours that have been evaluated and have a reasonably high likelihood of being developed based on available geological, technical, and economic assessments. "Possible mining projects", in contrast, refer to mining endeavours that are still in the early stages of assessment and have not yet been thoroughly evaluated for feasibility.

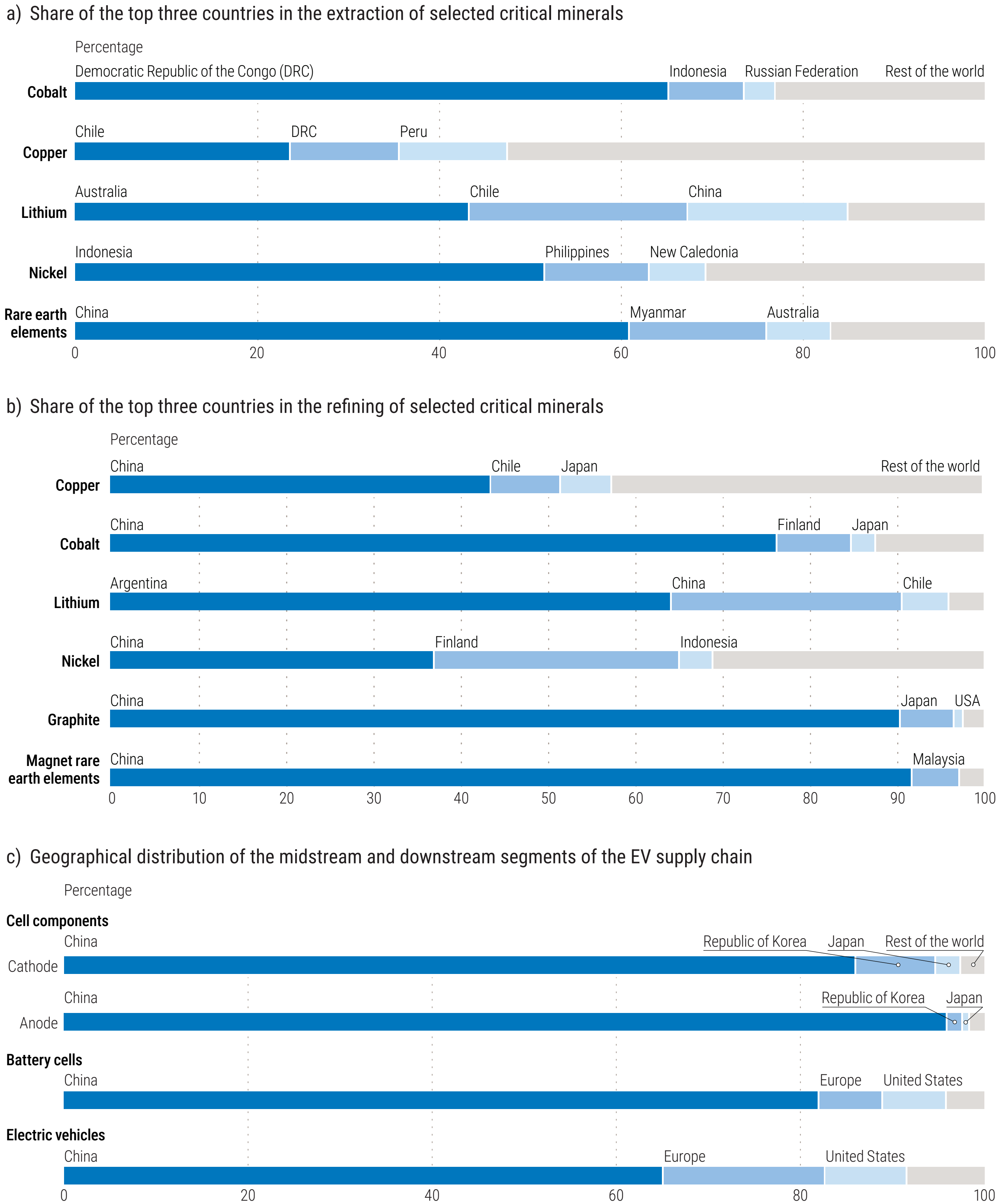
countries account for over 80 per cent of refined outputs (see figure 8b). In addition, the mining and processing of critical minerals are typically dominated by a few firms.[5]

The high geographic concentration of critical minerals supply chains indicates heavy reliance on a limited number of sources. Disruptions in any one supplier or country—whether due to natural disasters, conflict, trade disputes, or regulatory changes—could result in shortages or delays in the supply of these minerals. Such disruptions can lead to sudden price spikes and significantly impact midstream and downstream industries that depend on these critical inputs. China, the United States, Japan, and the Republic of Korea have leading positions in the midstream and downstream segments of the battery and EV supply chain, including processing critical minerals, producing cathode and anode materials, and manufacturing battery cells and EVs (see figures 8b and c).

5 Firm level data also suggest a high degree of concentration in extraction, particularly for cobalt, lithium, and rare earth elements (see figure 21 in the section on industrial policies).

Figure 8

Geographic concentration of critical minerals supply chains in 2023



Source: UN DESA, based on data from IEA (2024) and the IEA Critical Mineral Data Explorer.

National policies around critical minerals are growing

As Governments have increasingly acknowledged the strategic importance of critical minerals, they have introduced a growing array of related policies (UN DESA, 2024). Many of these policies are aimed at securing access to critical minerals and strengthening supply chain resilience against a backdrop of strategic competition between major economies. The policies are geared towards promoting exploration, offering financial support, encouraging sustainable and responsible practices, and facilitating bilateral and regional cooperation. Notable examples include the United States Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals (prepared by the Secretary of Commerce and heads of selected branch agencies and offices in response to an Executive Order issued in 2017), the European Union critical raw materials act (which entered into force in May 2024),[6] and, in China, the Five-Year Plan for Raw Material Industry Development (published by the Ministry of Industry and Information Technology, Ministry of Science and Technology, and Ministry of Natural Resources in 2021). Many other economies are also formulating industrial policies for critical minerals in order to maximize their returns (see the section on industrial policy).

The extraction and processing of critical minerals are also increasingly being influenced by broader green and industrial policy initiatives. Examples include the United States Inflation Reduction Act of 2022, the aforementioned European critical raw materials act, and the New Energy Vehicle Industry Development Plan (2021–2035) in China. The Inflation Reduction Act, for example, offers government support—such as tax credits, grants, and loan guarantees—to promote the production of EVs, offshore wind turbines, and other green technologies, which can contribute significantly to strengthening and potentially realigning critical minerals supply chains. Under these provisions, United States firms sourcing critical minerals from countries that have free trade agreements with the United States are eligible for these benefits. More broadly, critical minerals feature in national policies seeking to achieve a range of objectives related to climate, industrial development, national security, market access, and strategic dominance. Inherent tensions across these objectives, along with individual country interests, highlight the complexity of governing critical minerals in a rapidly changing global landscape (see the section on global cooperation).

Leveraging critical minerals for the Sustainable Development Goals

Accelerating SDG gains and avoiding pitfalls

Countries rich in critical minerals resources can derive substantial development gains from their endowments. These minerals have the potential to attract foreign and domestic investment, create jobs, and boost fiscal revenues, exports, and growth. Quantifying the economic scale of the mining industry can be challenging, especially since valuations vary in tandem with fluctuations in mineral prices. Yet mining serves as a major growth engine for many developing economies. In twelve developing economies, for example, mining accounts for 56 per cent or more of total exports and in some cases exceeds 80 per cent (see table 2). Mining represents, on average, 15.4 per cent of gross domestic product (GDP) in these economies, which is even higher if value added through backward and forward linkages[7] is taken

6 Informally known as the critical raw materials act, this instrument is officially designated Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020.

7 Backward linkages refer to the industries that supply the inputs required for exploring, extracting, and processing critical minerals (machinery, technology, chemicals and services). Forward linkages involve the industries that use these critical minerals to produce value-added goods such as batteries, electric vehicles, semiconductors, and renewable energy systems.

Table 2

Mining indicators for economies with the largest share of mining exports

Percentage

Countries	Mining exports as a share of total exports (Average 2019-2021)	Mineral rents as a share of GDP (2021 or latest available)	Mining GDP as a share of total GDP (2023 or latest available)	Mining contribution to total employment (2023 or latest available)	Mining contribution to fiscal revenues (2022 or latest available)
Botswana	91.6	0.2	25.0	..	33.0
Guinea	87.2	8.2	21.0	..	24.0[a]
Mali	85.4	16.2	7.0	1.5	30.0
Burkina Faso	84.1	15.5	14.3	7.8	19.3[a]
Zambia	78.7	28.2	10.5	3.4	44.0
Democratic Republic of the Congo	77.0	28.8	13.8	0.7	46.0[a]
Mauritania	66.1	9.6	23.8	2.3	29.8[a]
Namibia	61.3	3.2	11.9	2.6	9.0
Peru	60.6	12.1	15.0	1.7	14.0
Chile	58.7	16.2	11.9	4.0	18.9
Sierra Leone	57.0	0.2	1.0	6.4	11.0
Mongolia	56.4	26.6	30.0	9.0	32.0

Sources: UN DESA, based on data from UNCTAD (2023a) (mining exports); the World Bank World Development Indicators database (mineral rents); Extractive Industries Transparency Initiative (EITI) country reports; official sources; and ILO (mining GDP and the contribution of mining to employment and fiscal revenues).
Notes: Mining exports correspond to exports of ores, metals, precious stones, and non-monetary gold as a share of total exports for 2019-2021 (average). Mineral rents represent the difference between the value of production for a stock of minerals at world prices and the costs of production for tin, gold, lead, zinc, iron, copper, nickel, silver, bauxite, and phosphate.
a Data correspond to extractive industries.

into account.[8] In some economies, mining is also a key source of government finance, accounting for more than 30 per cent of total fiscal revenues in countries such as the Democratic Republic of the Congo, Mongolia, and Zambia, and therefore represents a vital resource for SDG-related public expenditures.

The potential for increased extraction and processing of critical minerals extends beyond traditional mining-dependent economies to those with substantial untapped reserves of critical minerals. Countries such as Brazil (rare earth elements and nickel), Viet Nam (bauxite and rare earth elements), United Republic of Tanzania (graphite), Mexico (copper), and India (rare earth elements) possess vast reserves of critical minerals, yet they currently account for only a small share of global production (see figure 9). Mining-dependent economies and those countries with large reserves of critical minerals—many of which are in Africa—are in a favourable position to leverage these resources to place progress towards achieving the SDGs on more robust footing.[9]

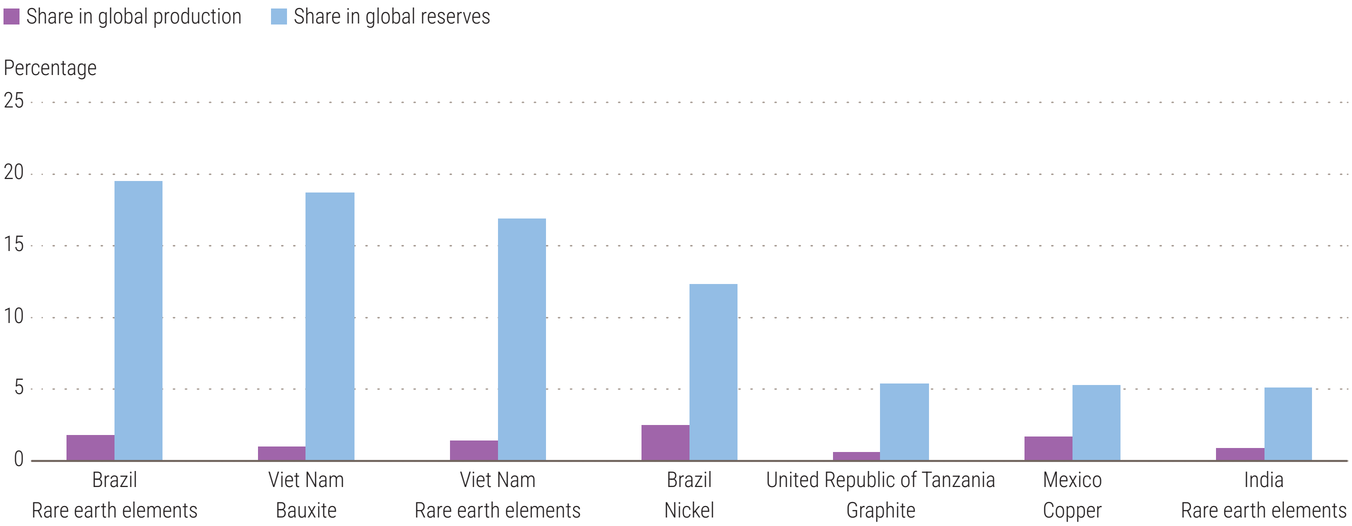
Although the mining industry is capital-intensive, the expansion of the critical minerals sector is generating—and will continue to generate—numerous direct and indirect job opportunities. Between 2019 and 2022, the global mining workforce for critical minerals, especially in copper and cobalt operations, expanded by an average of 8 per cent per year, and it could double by 2030 (IEA, 2023d). While many of these new jobs will require high-skilled labour—such

8 However, mining typically functions in relative isolation from the rest of the economy, and the indirect effects are often moderate (Stilwell and others, 2000; Castaño, Lufin and Atienza, 2019; Aguirre Unceta, 2021).

9 Depending on the preparedness of countries to tap into these opportunities (and the pace of the energy transition itself), benefits from critical minerals would accrue within and beyond the 2015–2030 SDG timeline.

Figure 9

Share in global production and reserves for selected countries and critical minerals



Source: UN DESA, based on data from United States Geological Survey (2024).

as engineers, data analysts, and environmental specialists—the employment impact will vary from one country to another. In developed economies such as Australia and in developing economies such as Brazil, Chile, and South Africa, there is a trend towards reduced demand for routine manual work and increased demand for cognitive, non-routine jobs performed by high-skilled labour (EY, 2019). This reflects an increasing focus on automation, digitalization, and advanced technologies in mining and other sectors of the economy. Some mining companies are even investing in university programmes to develop and secure high-skilled human capital (Daly and others, 2022). In certain developing economies, especially those on the lower end of the income scale, the demand for low-skilled labour and even informal or artisanal mining may also increase. While often providing much-needed income and livelihoods, informal and artisanal mining pose significant challenges related to working conditions and safety, necessitating the formalization of artisanal mining operations and the implementation of minimum labour standards. The development of the critical minerals sector can also create engagement opportunities for local firms and entrepreneurs in areas such as business services, transportation, and equipment manufacturing (Moritz and others, 2017). According to Born, Heerwig and Steel (2023), additional government revenues from critical minerals could range between $5 billion and $25 billion annually by 2040. Relative to the size of their regional economies, Latin America and the Caribbean and sub-Saharan Africa could be the largest beneficiaries of additional gross revenues per year, on average representing 1.2 and 0.76 per cent of regional GDP, respectively.

To fully harness the development potential of critical minerals, it is crucial for resource-rich economies to advance productive linkages and promote midstream and downstream economic activities, including processing and manufacturing. Moving into downstream activities along the critical minerals value chain or entering different value chains (such as EV battery production or PV manufacturing) presents a significant opportunity for some countries to diversify and upgrade economic activities, enhance value-added production, and strengthen technological capabilities. The unit prices of processed lithium, graphite and cobalt are about three to four times the prices of the raw materials, with processed nickel commanding an even larger markup (see table 3). The total

Table 3

Added value from extracting to processing selected critical minerals, 2022

	Weighted average unit price (United States dollars per kilogram)		Total value of exports (Billions of United States dollars)		
	Raw materials	Processed materials	Raw materials	Processed materials	Battery materials
Cobalt	6.6	20.8	0.2	9.9	10.5
Graphite	0.7	3.3	6.6	2.4	3.7
Lithium	1.7	5.7	20.0	7.3	51
Nickel	0.1	14.7	4.1	10.4	2.8

Source: UN DESA, based on data from the United Nations Comtrade database and UNCTAD (2023b).

trade value of more processed and battery materials is also generally higher than for raw materials.[10] Advancing backward and forward linkages offers clear benefits but is challenging in many developing economies due to the lack of productive and technological capacities, insufficient infrastructure, and market access limitations linked to the dominance of a few countries in the key stages of processing and manufacturing.

As countries seek to expand their involvement in this sector, they must consciously avoid risks that could limit, offset, or even negate the potential short- and medium-term benefits associated with critical minerals. These risks are tied to the “resource curse”, a situation in which, paradoxically, countries rich in natural resources can end up experiencing poorer development outcomes than those with fewer resources. Such negative impacts can include excessive dependence on mining and the lack of economic diversification, low productivity and slower economic growth, increased inequality, environmental degradation, and the heightened risk of conflict. Poor governance can exacerbate these issues, creating a cycle of instability and underdevelopment (Auty, 1993; Sachs and Warner, 1998).

Negative outcomes can occur at many levels and through multiple channels (Van der Ploeg, 2011). First, a booming extractive sector, coupled with exchange rate appreciation, can crowd out other industries with better medium-term growth prospects (Dutch disease). Second, dependence on primary sectors makes economies vulnerable to volatile commodity prices. Third, resource windfalls from boom periods can trigger rent-seeking, corruption, and conflict, and in such situations poverty and inequality may deepen, in part because the higher profits are not channelled towards increased public expenditures on health, education and other services aimed at improving people’s well-being. These impacts often manifest themselves in domestic currency appreciation, higher and mismanaged government spending, and high inflation. Robust, inclusive institutions and governance frameworks are crucial for translating resources into positive development outcomes.

A number of examples illustrate negative impacts in areas linked to particular sustainable development objectives. In the 1980s, for instance, falling oil prices induced a severe downturn, high inflation, and debt escalation in Nigeria, with the deteriorating economic conditions leading to significant development setbacks, including a rise in poverty (SDG 1) (Sala-i-Martin and Subramanian, 2003). Despite their vast oil resources, Angola and Equatorial Guinea have struggled with high poverty (SDG 1), inequality (SDG 10), and underdeveloped social services (SDGs 3 and 4). In Angola, oil revenues have translated into higher GDP growth rates,

10 Critical minerals have become increasingly important for international trade, with the annual traded value of energy-related minerals surging from $53 billion to $378 billion over the past two decades (Snoussi-Mimouni and Avérous, 2024).

but structural issues persist, including elevated inequality (SDG 10) and a lack of innovation and economic diversification (SDG 9) (Musacchio, Werker and Schlefer, 2010).

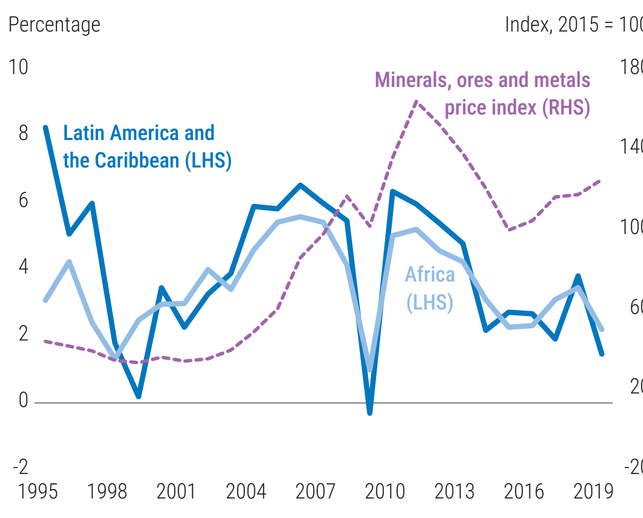
Conversely, many countries have achieved positive sustainable development outcomes from effective resource management. Botswana and Chile, for example, have leveraged their mineral resources to improve living standards (Havro and Santiso, 2008). Chile has used copper revenues to support social programmes and build fiscal stability, contributing to poverty reduction (SDG 1) and improved health services (SDG 3). Similarly, Botswana has invested diamond revenues in healthcare (SDG 3), education (SDG 4), and governance (SDG 16) (Lewin, 2011). The mining sector in Namibia has been important for creating job opportunities (SDG 8) and enhancing living conditions in local communities (SDG 11) (Nambinga and Mubita, 2021). Recent evidence shows that in Peru, the mining of copper has contributed to reducing poverty (SDG 1) (Chavez, 2023). These examples highlight how good governance, together with adequate national policies, can maximize the benefits of mining, ensuring long-term development progress.

As these examples illustrate, critical minerals can play a crucial role in accelerating progress towards the SDGs in developing economies in Africa, Asia, and Latin America and the Caribbean (see table 4). In African economies, for example, critical minerals can play a key role in reducing poverty and hunger (SDGs 1 and 2), enhancing health and education (SDGs 3 and 4), improving economic and employment prospects (SDG 8), and strengthening institutional capacity-building and governance (SDG 16). In Latin America, they can enhance economic prospects (SDG 8), support the building of technological capacities and innovation (SDG 9), and foster global partnerships (SDG 17). Critical minerals, by definition, are essential for renewable energy technologies, directly contributing to SDG 7 (affordable and clean energy) and SDG 13 (climate action) in many economies. However, ensuring that countries have the capacity to leverage critical minerals to accelerate progress towards the SDGs and limit the adverse environmental and social impacts requires effective national policies and institutions coupled with supportive multilateral frameworks.

Even if countries avoid the full extent of the resource curse, they risk the "reprimarization" of their economies, where they increasingly specialize in the extraction of raw materials. The experience of mineral-dependent economies in Latin America and Africa during the commodity boom between 2003 and 2015 is a cautionary tale. These economies experienced accelerated growth during the boom, with higher investment rates and profitability in the commodities sector, further entrenching their specialization in primary industries (ECLAC, 2012). However, growth rates slowed sharply in countries such as Chile, Namibia, Peru, and Zambia when commodity prices fell amid the absence of new activities or sectors driving growth (see figure 10). Relying solely on natural resource extraction is inadvisable, as there are inherent constraints linked to lower productivity gains and limited technological spillovers (Cimoli and Porcile, 2014).

Figure 10

Growth in mineral-dependent economies and mineral prices



Source: UN DESA, based on data from the World Economic Forecasting Model and UNCTADstat.
Note: LHS = left-hand scale; RHS = right-hand scale.

Table 4

Potential SDG gains from critical minerals in selected developing economies

Region	Country	Critical mineral	Share of reserves	Share of production	Main potential SDG gains
Africa	Democratic Republic of the Congo	Cobalt	54.5	73.9	1 No poverty; 2 Zero hunger; 3 Good health and well-being; 4 Quality education; 7 Affordable and clean energy; 8 Decent work and economic growth; 9 Industry, innovation and infrastructure; 16 Peace, justice and strong institutions
		Tantalum	..	40.8	
		Copper	8.0	11.4	
	Gabon	Manganese	3.2	23.0	
	Madagascar	Titanium	3.9	3.7	
		Cobalt	0.9	1.7	
	Mozambique	Titanium	3.2	18.6	
		Beryllium	0.0	7.3	
	South Africa	Platinum	88.7	66.7	
		Chromium	35.7	43.9	
		Manganese	31.6	36.0	
	Zambia	Copper	2.1	3.5	
	Zimbabwe	Platinum	1.7	10.6	
		Palladium	..	7.1	
Asia	China	Graphite	27.9	76.9	7 Affordable and clean energy; 8 Decent work and economic growth; 9 Industry, innovation and infrastructure; 10 Reduced inequalities; 12 Responsible consumption and production; 13 Climate action
		Cobalt	..	76.0[b]	
		Rare earth elements	40.0	68.6	
	Indonesia	Nickel	42.3	50.0	
		Cobalt	4.6	7.4	
	Philippines	Nickel	3.7	11.1	
		Cobalt	2.4	1.7	
Latin America and the Caribbean	Bolivia (Plurinational State of)	Lithium	23.0[a]	0.0	8 Decent work and economic growth; 9 Industry, innovation and infrastructure; 10 Reduced inequalities; 12 Responsible consumption and production; 13 Climate action; 15 Life on land; 17 Partnerships for the goals
	Brazil	Graphite	26.4	4.6	
		Manganese	14.2	3.1	
		Rare earth elements	19.1	0.0	
	Chile	Lithium	33.2	24.4	
		Copper	19.0	22.7	
	Argentina	Lithium	12.9	5.3	
	Peru	Molybdenum	10.7	14.2	
		Copper	12.0	11.8	

Source: UN DESA, based on data from United States Geological Survey (2024).
Notes: The SDG gains presented are not intended to be exhaustive but are provided to illustrate specific areas of potential improvement.
a Share of global resources.
b Share of refined cobalt production.

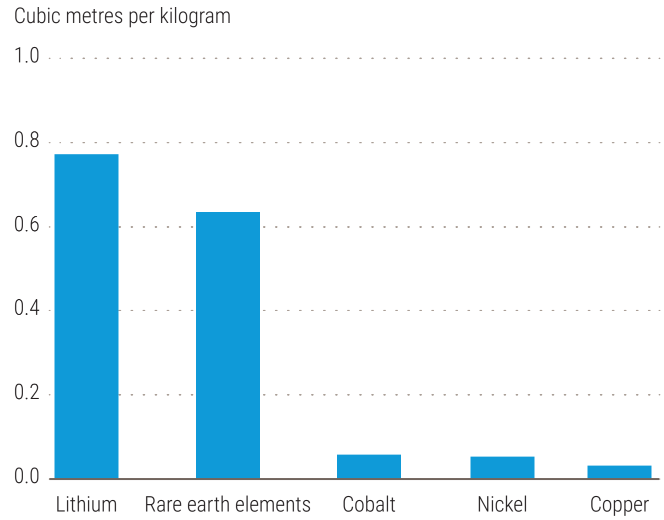
Environmental and ecological damage and adverse social impacts can offset the economic gains from critical minerals. Extraction activities involve extensive material movement, resulting in land disturbance and waste accumulation, which can seriously damage biodiversity and ecosystems. Tailings facilities, waste rock dumps, and mining voids often cover large areas, and waste facilities can contribute to pollution through dust dispersion or acid drainage.[11]

11 According to estimates, the amount of waste generated per unit of mineral produced increased by more than 20 per cent between 2019 and 2022 (IEA, 2024).

According to the United Nations Environment Programme (UNEP IRP, 2024), more than 90 per cent of global water shortages and land-related biodiversity loss is caused by extractive industries, and the operations required for bauxite in Australia, iron in Brazil, and copper and lithium in Chile have a high biodiversity impact. Water use is also an increasing concern, as mining critical minerals—particularly lithium—is highly water-intensive (see figure 11). Estimates show that 16 per cent of the world's land-based critical minerals mines and deposits are in areas dealing with high levels of water stress (Lakshman, 2024).[12] Meanwhile, insufficient regulatory protection can lead to exploitative labour practices, including unsafe working conditions and the use of child labour. Indigenous communities often face disproportionate impacts from mining due to their greater vulnerability and strong economic, social, and cultural connections to their lands. Around 54 per cent of critical minerals are located in or near Indigenous lands and territories (Bernal, Husar and Bracht, 2023).

Figure 11

Water use for selected critical minerals



Source: UN DESA, based on data from IEA (2021).

Illicit financial flows—linked, for example, to tax evasion, transfer mispricing, corruption, or illegal capital flight—can siphon resources out of a country and diminish the funds available for public investment and social services.[13] Illicit financial flows are a product of and contribute to corruption and rent-seeking behaviour (Reed and Fontana, 2011). It is estimated that Africa loses between $80 billion and $100 billion annually as a result of such flows,[14] which represents around 3.7 per cent of its GDP (UNCTAD, 2020; Signé, Sow and Madden, 2020). In addition, illicit financial flows can contribute to instability and conflict, as seen in West African countries such as Ghana and Liberia, where artisanal and small-scale mining are vulnerable to exploitation by criminal networks (Hunter, 2020). Illicit financial flows are also often linked to illegal mining activities that circumvent environmental regulations, causing unchecked ecological degradation in areas such as Amazonia (Gonzalez, Cole and Geary, 2023). Developing and developed countries must work together to curb illicit financial flows in order to fully realize the sustainable development potential of critical minerals. Strengthened collaboration between countries is essential to establish global standards and regulate the practices that enable illicit financial flows. As part of these efforts, robust legal frameworks must be implemented to monitor and guide the operations of multinational corporations.

Macroeconomic policies for maximizing SDG gains

Macroeconomic policies in resource-rich countries can play a critical role in maximizing economic and development benefits from those resources, including critical minerals. An integrated approach

12 For example, in Salar de Atacama, a major mining region in Chile, lithium and copper extraction consumes over 65 per cent of the local water supply, worsening drought conditions and causing environmental degradation and social challenges. Similar problems have been reported in connection with cobalt operations in the Democratic Republic of the Congo and graphite operations in China (Lakshman, 2024).

13 While there is no universally agreed definition, illicit financial flows are essentially "financial flows that are illicit in origin, transfer or use, that reflect an exchange of value and that cross country borders" (UNCTAD and UNODC, 2020).

14 According to some estimates, trade mispricing is responsible for approximately 50 per cent of illicit financial flows from Africa, with more than half of these trade-related flows originating from the extractive sector (ECA and African Minerals Development Center, 2017).

that combines fiscal and monetary policies is necessary to ensure stability, reduce volatility, and foster an equitable distribution of benefits.

Fiscal policy must create equitable frameworks for capturing economic rents through effective tax regimes that prevent tax evasion and illicit financial flows and for directing public expenditures towards programmes that provide long-term benefits for human development and social protection and ensure that no one is left behind. Countries can also adopt specific fiscal rules and establish stabilization funds to manage and save excess revenues during boom periods to promote fiscal discipline, countercyclical policy measures, and intergenerational equity. In addition, countries can establish funds that combine elements of stabilization with long-term savings, including for pension purposes. For example, the Government Pension Fund Global in Norway serves as both a stabilization mechanism and a pension fund, set up to strengthen intergenerational equity.

In recent decades, several resource-rich economies have adopted fiscal rules to address multiple challenges, including smoothing economic cycles, preventing exchange rate appreciation, and managing public debt (Apeti, Basdevant and Salins, 2023). Fiscal rules are often defined by fiscal indicators such as budget balance rules (Chile, Nigeria, Norway), expenditure rules (Ecuador, Mongolia, Peru), debt-level rules (Botswana, Liberia) or revenue rules (Niger, Timor-Leste). Most economies adopt a combination of these, with the most common being a mix of debt rules and operational limits on government expenditure or budget balance (Eyraud, Gbohoui and Medas, 2023). For example, Mongolia and Peru use expenditure rules that set ceilings on government spending growth to maintain fiscal discipline. In Chile, a structural balance rule that adjusts government spending based on long-term copper prices has been effective in smoothing public expenditures over price cycles (Marcel, 2013). Fiscal rules can restrict the ability of Governments to respond to crises; however, some Governments have integrated adaptability provisions that allow a degree of flexibility in the implementation of these rules. In Colombia, for example, the incorporation of escape clauses provides the Government with the manoeuverability it needs to respond to adverse shocks within a well-defined fiscal framework (Davoodi and others, 2022).

The establishment of sovereign wealth funds can help manage revenue volatility from critical minerals, enhance resilience to shocks, and provide savings for future generations. Some resource-rich countries, including Botswana, Guyana, and Timor-Leste, have shown that when these funds are well-integrated into broader fiscal frameworks, they can provide a buffer against commodity price swings and support countercyclical policies (Sugawara, 2014). Botswana uses its Pula Fund to accumulate savings from diamond revenues, ensuring that these are invested in diversified assets and used for long-term development needs. The Petroleum Fund of Timor-Leste, modelled on the aforementioned Government Pension Fund Global in Norway, aims to ensure that anticipated oil revenues over the coming two to three decades are utilized prudently, focusing on promoting the country's long-term economic growth and development. Guyana recently established the Natural Resource Fund to manage its growing oil revenues. The Fund has accumulated significant savings, and it currently faces the challenge of balancing withdrawals for infrastructure development with medium-term fiscal sustainability (Bhattacharya and Park, 2024). The success of a sovereign wealth fund depends on clear governance frameworks and alignment with national development objectives.

Monetary policy allows resource-rich economies to guard against some of the symptoms of the resource curse. Central banks need to use the tools at their disposal to achieve multiple objectives, including controlling inflation, maintaining a competitive exchange rate throughout commodity boom-and-bust cycles, supporting financial stability, and maintaining a conducive monetary environment for growth. In addition to interest rates, central banks have a range of tools to manage exchange rates and support financial stability. For instance, sterilized interventions[15] in the foreign exchange market can help prevent excessive currency fluctuations (Frankel, 2010; Aliyev, 2012). Additionally, macroprudential policies such as reserve requirements and capital controls can be used to manage capital flows and reduce financial risks. These tools are crucial for preventing the adverse effects of large capital inflows during boom periods.

Effective macroeconomic management in resource-rich economies requires strong coordination between fiscal and monetary policies. For instance, sovereign wealth funds can help sterilize excess revenues during booms, thereby reducing inflationary pressures and supporting exchange rate stability. In Chile, the combination of a structural fiscal balance rule with an inflation-targeting monetary framework and a flexible exchange rate has been effective in maintaining macroeconomic and financial stability. Botswana has effectively managed its resource wealth through a combination of prudent fiscal policy and a crawling peg exchange rate regime, allowing the country to maintain a relatively stable and competitive exchange rate (Adhikari and others, 2023).

Inclusive governance for sustainable development

In addition to macroeconomic policies, good governance is essential for converting critical minerals reserves into sustainable development gains. A growing number of resource-rich economies are adopting environmental, social, and governance (ESG) standards[16] to mitigate the adverse effects of mining operations while also aiming to maintain competitiveness and attract new foreign investments. As part of this trend, countries are increasingly integrating due diligence requirements into regulatory frameworks to promote more sustainable mining practices.

Governance and anti-corruption measures

Improving governance and combating corruption require the implementation of policies focused on transparency and accountability in the critical minerals sector. Policies can mandate transparency in licensing and concession processes, revenue reporting, and contracts, helping to minimize corrupt practices and illicit financial flows. Ensuring transparency requires the comprehensive monitoring and auditing of mining contracts and revenue streams.

For many resource-rich developing economies, particularly low-income economies, building robust institutional capacity is essential for establishing strong governance structures and enabling effective oversight of the critical minerals sector. Building institutional capacity through the establishment or strengthening of anti-corruption agencies and independent monitoring bodies is crucial for ensuring transparency and accountability.

Enhanced governance plays a vital role in combating illicit financial flows. This entails identifying and closing regulation gaps while enhancing coordination among authorities tasked with detecting illegal activities and their associated financial flows and prosecuting those responsible. Tackling illicit financial flows requires effective international collaboration, including the sharing of information and best practices, the harmonization of regulatory standards, and participation in joint investigations (see the section on global cooperation). Concerted efforts are being made at the global level—through, for example, the OECD Global Forum on Transparency and Exchange of Information for Tax Purposes and the Extractive Industries Transparency Initiative—to combat different types of illicit financial flows (see the section on global cooperation).

15 Sterilized interventions are central bank operations through which purchases or sales of foreign exchange are offset by corresponding transactions in domestic financial markets to neutralize their impact on the money supply.

16 According to the IEA, the cumulative number of transparency, environmental, and social standards policies at the domestic and international levels has grown significantly, increasing from 50 policies in 2015 to 108 in 2023 (IEA, 2023a).

Social responsibility and community engagement

The sustainable development impacts of mining crucially depend on the extent to which social sustainability standards are met. Local, regional, and national communities have become increasingly aware of this dynamic and are demanding greater accountability from mining firms. In 2018, almost half of the large mining firms in Chile identified the "social licence" as the most critical aspect of mining operations (Consejo Minero, 2018). Policies that promote social responsibility and community engagement, particularly as these relate to Indigenous communities, are essential to ensure that local voices are heard and rights are respected (Lèbre and others, 2020).

National policies need to require mining companies to conduct meaningful consultations with and obtain consent from local communities. Many developing economies have taken steps to implement free, prior and informed consent principles in mining projects; a notable example is the Escazú Agreement,[17] signed by 25 countries in Latin America and the Caribbean, which emphasizes public participation and access to environmental information (IEA, 2023b). Formal agreements can effectively ensure that local communities share in the benefits of commercial mining ventures through infrastructure development, job opportunities, contracts with Indigenous-owned businesses, and revenue-sharing. In Madagascar, for example, certain mining projects have included agreements to provide local communities with access to healthcare, education, and water infrastructure, helping to address long-standing development gaps while garnering local support (Dentons, 2024). In Canada, the mining sector fosters Indigenous participation by providing training, promoting business development, and creating employment opportunities (Marshall, 2020).

Human rights and labour standards

Countries with an abundance of critical minerals must adopt policies that uphold human rights and labour standards. It is essential that labour rights be enforced through the implementation of standards that protect workers, ensuring fair wages, safe working conditions, and the right to organize. In addition, mining companies should be required to conduct due diligence to identify, prevent, and mitigate potential human rights risks associated with their operations. Stringent regulations and monitoring systems are needed to combat child labour, particularly in artisanal and small-scale mining operations, which often face more serious environmental and safety challenges. In low-income countries, building institutional capacity is crucial for the effective implementation and enforcement of these standards. The ILO (2019) emphasizes the importance of a coordinated approach to eliminating child labour in hazardous mining activities, stressing the need to engage with communities and offer alternative opportunities for young children, particularly through access to education.

Environmental protection and sustainability policies

National-level regulations, especially in developing countries, have often been inadequate and ineffective in addressing the overexploitation of natural resources, displacement, and environmental and biodiversity degradation. In recent years, however, growing national and international pressure has emphasized the need to prevent environmental degradation and disasters and to decarbonize mining operations through effective waste and water management and reductions in greenhouse gas emissions (Navas-Aleman and Bazan, 2021). Mexico has responded by establishing official guidelines for mining waste management plans, while Brazil has taken steps towards mandating environmental

17 Formally known as the Regional Agreement on Access to Information, Public Participation and Justice in Environmental Matters in Latin America and the Caribbean, adopted on 4 March 2018.

impact assessments and conservation strategies for mining firms. South Africa has introduced regulations requiring mining companies to develop closure plans and manage waste more effectively, and Namibia has integrated environmental standards in their mining operations to mitigate ecological degradation (Environmental Compliance Consultancy, 2019). For many low-income countries, enforcing and monitoring these environmental protections effectively will require the strengthening of institutional capabilities. On the innovation front, one positive trend in recent years has been the sharp increase in patents relating to wastewater treatment, soil remediation, and eco-friendly technologies for mineral processing (Pietrobelli and others, 2024).

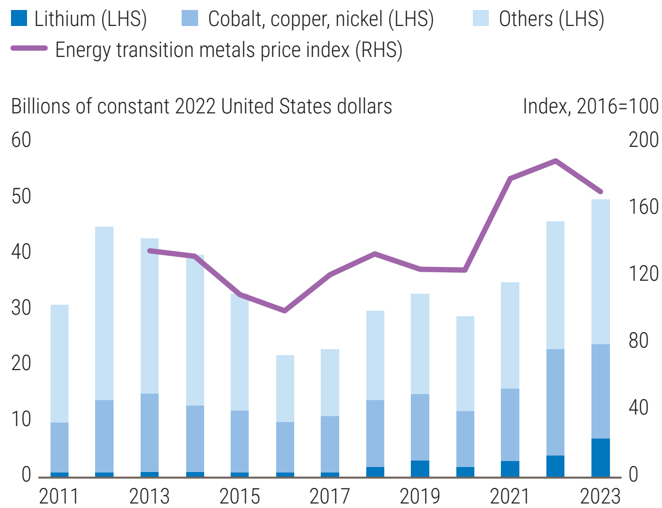
Investment in critical minerals

The state of investments

Mining investments are typically driven by mineral prices and can exhibit cyclicality. During the 2000s, rising mineral prices and increasing demand, particularly from China, led to a surge in mining investments. However, from 2011 to 2016, declining prices resulted in a slowdown in new investments in this sector. Among the largest mining firms, capital expenditures as a share of profits declined from over 60 per cent between 2013 and 2015 to about 25 per cent in 2021 and 2022 (*The Economist*, 2024). For critical minerals, however, there has been an upward trend driven by growing demand from the energy sector. Since 2020, annual investments in critical minerals production have expanded by an average of 20 per cent; investment growth has been strongest for lithium but has also been significant for cobalt, copper, and nickel (see figure 12). The United Nations Conference on Trade and Development reports that in 2022 there were 110 new critical minerals projects worldwide valued at a total of $39 billion (UNCTAD, 2024a). About 55 per cent of this investment was directed towards 60 critical mining projects in developing economies.

Figure 12

Investment in critical minerals production, by type



Source: UN DESA, based on data from IEA (2024) and IMF Primary Commodity Price System.
Notes: LHS = left-hand scale; RHS = right-hand scale. Investment refers to capital expenditure by 25 major mining firms. The "others" category includes cobalt, lead, magnesium, platinum group metals, tin, zinc, and others. The IMF annual energy transition metals price index shows the prices for the month of December; it covers prices of aluminium, chromium, cobalt, copper, lead, lithium, manganese, molybdenum, nickel, palladium, platinum, rare earth metals, silicon, silver, vanadium, and zinc.

Foreign direct investment (FDI) plays a major role in the critical minerals sector. In recent years, FDI in mining has trended upward, with the total value increasing from $13.1 billion in 2021 to $30.3 billion in 2022 and $57.9 billion in 2023. The number of announced FDI greenfield projects[18] in the critical minerals industry (including processing) also surged, increasing from 14 in 2016 to 114 in 2023 (UNCTAD, 2024b). Developing economies accounted for three quarters of these projects, and half were in processing. In 2023, one third of the announced greenfield projects in critical minerals were invested in by Chinese firms. In the mining sector as a whole, mergers and acquisitions increased from an average of

18 Greenfield FDI refers to investment in new production facilities, offices, or plants, as well as the creation of new jobs and infrastructure; with brownfield FDI, existing facilities or operations are acquired or form part of a merger.

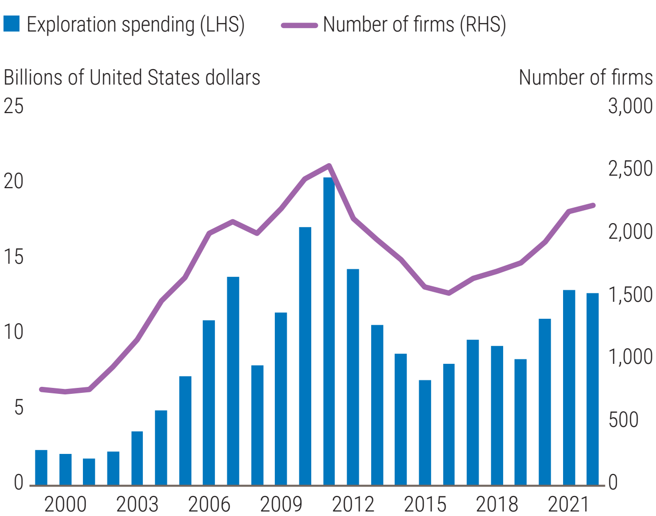
$66 billion between 2019 and 2020 to $95 billion between 2022 and 2023 (Sen, 2024).

One crucial aspect of mining investment relates to exploration activity. Exploration of new mines is essential to build a more resilient critical minerals supply chain, meet projected demand for the green transition, and ensure that developing economies benefit from their resources. Yet exploration is the riskiest part of the mining cycle, as determining the geological potential of an area is a complex process and requires high up-front costs without any guarantee of success (Born, Heerwig and Steel, 2023). It has been estimated that for every mine opened, there have been more than 100 unsuccessful exploration projects (MICA, 2020).

Over the past two decades, exploration spending has exhibited a cyclical pattern similar to that of mining investments (see figure 13). Although exploration spending has increased significantly since 2016, driven by rising prices for critical minerals, it remained much lower in 2023 than in the early 2010s, when it was at its peak. When adjusted for inflation, the gap is even more

Figure 13

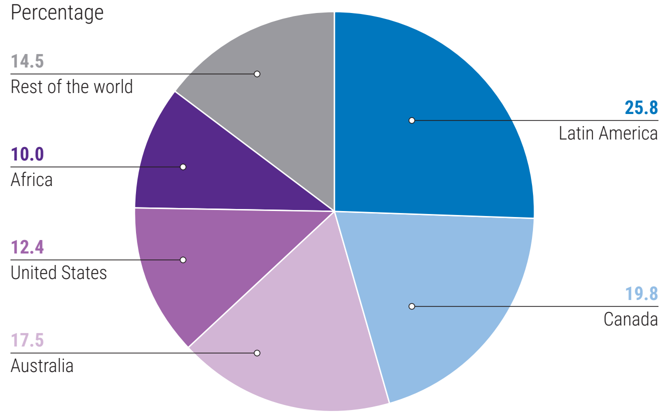
Exploration-related spending on critical minerals



Source: UN DESA, based on data from S&P Global Market Intelligence (2024).
Notes: LHS = left-hand scale, RHS = right-hand scale. Data are for the exploration of copper, nickel, lithium, zinc, and rare earth elements, as well as for non-ferrous metals such as gold and silver.

Figure 14

Regional distribution of exploration spending for selected critical minerals, 2022 and 2023



Source: UN DESA, based on data from S&P Global Market Intelligence (2024).
Notes: Data are for the exploration of copper, nickel, lithium, zinc, and rare earth elements, as well as for non-ferrous metals such as gold and silver.

pronounced, indicating a significant decline in real terms. The recent increase in exploration has been less pronounced than the growth in mining investments, and in 2023, exploration spending actually decreased slightly in comparison with the previous year. In 2024, copper, lithium, nickel, and rare earth elements together represented 37 per cent of exploration spending, with copper accounting for 24 per cent (S&P Global Market Intelligence, 2024). The modest increases in recent years have largely been driven by lithium exploration, which reached a record $830 million in 2023, making it the third most explored commodity. Latin America accounted for the largest share of exploration expenditure, accounting for a quarter of global spending in 2022 and 2023 (see figure 14). Africa—in spite its vast resource potential—attracted only 10 per cent of the overall exploration budget.

Several factors constrain investment in the exploration of critical minerals. One key limitation is the relative lack of geological knowledge about these minerals. Another is the absence of exploration techniques specifically geared towards critical minerals; most of the methods currently used have been developed for major minerals (González-Álvarez and others, 2021; Eggert, 2023). Research by Castillo, del Real and Roa (2024) indicates that firms investing in critical minerals such as cobalt, lithium, and rare earth elements tend to allocate a smaller portion of their budget to exploration than do those focusing on major minerals such as copper, gold, lead, nickel, or zinc. The same researchers assert that exploration spending on critical minerals is more sensitive to price fluctuations. In the current environment of relatively low prices for many critical minerals, exploration investments could be significantly affected. Overall, exploration for critical minerals generally attracts less investment than exploration for major minerals, posing a risk to the stable supply of critical minerals in the medium term.

Deep-sea mining (200 metres or more beneath the surface) could be given more serious consideration in the coming years as it offers access to vast untapped resources. Interest in extracting desirable deposits has been growing (UNEP FI, 2022), but commercial extraction remains subject to controversy due to the potential damage to marine ecosystems. Environmental concerns notwithstanding, decisions might be made to pursue deep-sea mining to meet the rising demand for metals and minerals as terrestrial sources become more scarce or difficult to access (Ashford and others, 2024). Nations with access to deep-sea resources anticipate significant revenues. The International Seabed Authority has issued 31 contracts for mineral exploration to 21 firms from 20 countries (ISA, 2024). While commercial mining in international waters has not yet commenced, pending the expected finalization of an international code for deep-sea mining by the International Seabed Authority in 2025, countries can still pursue deep-sea mining within their own territorial waters (or "exclusive economic zones"). Even after the international code is in place, those engaged in deep-sea mining will continue to face major challenges due to high capital requirements and operational costs (relative to conventional mining) and the enormous technical uncertainties associated with the unique problems surrounding mining on the ocean floor (Sumaila and others, 2023). Further compounding these challenges, recent reports suggest that the cost of ecosystem restoration will be twice as much as the cost of extraction (Amadi and Mosnier, 2023).

Investment needs and the financing gap

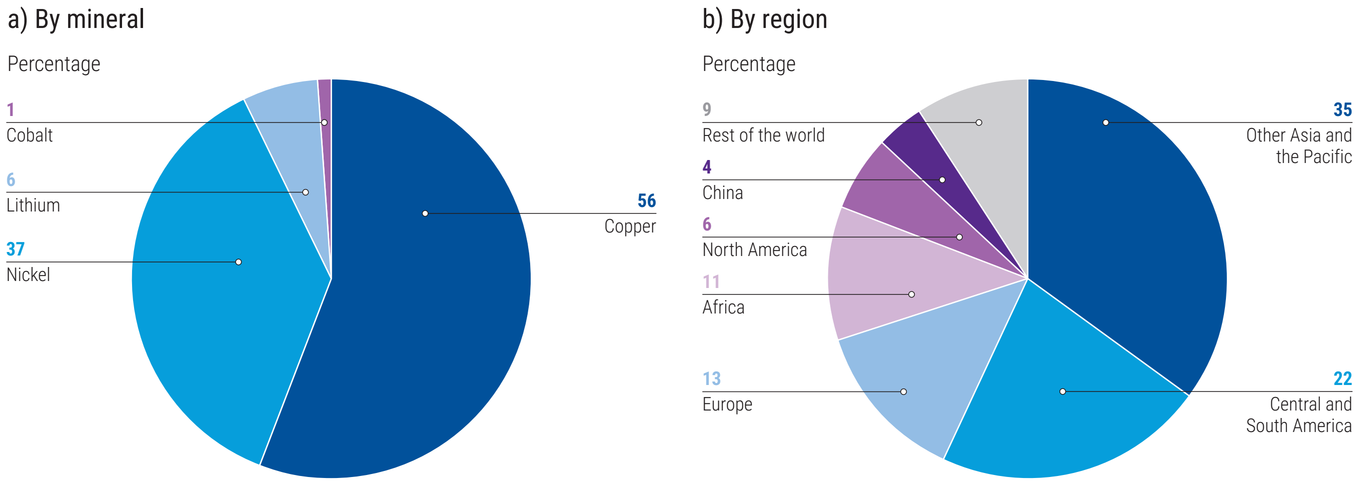
Given the projected increase in demand for critical minerals, the current level of investment falls short of what is needed to achieve net-zero emissions targets. A substantial scaling up of investment in critical minerals is essential. According to the IEA (2023c), a total of $360 billion to $450 billion (in real 2021 dollars), or an annual average of $40 billion to $50 billion, is needed between 2022 and 2030 to achieve the levels of lithium, nickel, copper, and cobalt production required to limit the global temperature increase to 1.5°C, as outlined in the Paris Agreement. Other studies present figures consistent with these but with varying timelines, mineral coverage, and scenarios (ETC, 2023; Kettle, Barnes and Sum, 2024).

Currently announced mining projects are expected to cover only half of the total investment needed by 2030, resulting in an investment gap of around $180 billion to $230 billion (IEA, 2023d). The shortfall is particularly pronounced for copper and nickel, which account for about 60 per cent of the required investments. Although the gaps for lithium and cobalt are smaller, significant new mining investments will still be necessary. Additionally, since 98 per cent of cobalt is produced as a by-product of copper and nickel mining (Gielen, 2021), establishing dedicated cobalt mines will be crucial for meeting rising demand. Geographically, 22 per cent of the expected investment in critical minerals in the coming years will likely be in Central and South America, while investment in Africa is projected to account for only 11 per cent of the total (see figure 15).

To meet projected demand, between $90 billion and $210 billion is needed for the processing segment during the period 2022–2030, yet

Figure 15

Expected investment in critical minerals, 2022–2030



Source: UN DESA, based on data from IEA (2023b).
Notes: The figure shows expected investments in four critical minerals (lithium, nickel, copper, and cobalt). Country groupings differ from the *World Economic Situation and Prospects 2025* groupings.

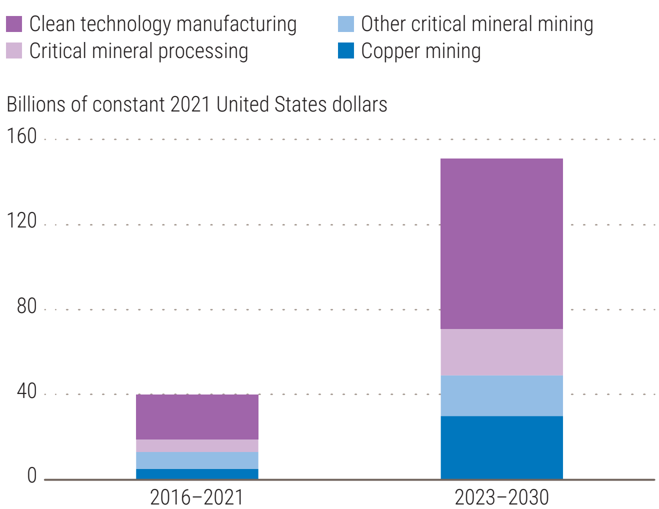
$70 billion to $160 billion in investment is expected (Bernal, Husar and Bracht, 2023). It is projected that approximately 70 per cent of the anticipated investment will be in China, with about 15 per cent going to other countries in the Asia-Pacific region. Among the critical minerals, polysilicon is the only material for which current investment plans align with the projected increase in demand needed to meet net-zero emissions targets, while nickel requires the most substantial additional investment (IEA, 2023b). In order to reach the necessary capacity by 2030, the average annual investment required for the mining and production of critical minerals and for the manufacturing of clean technologies is nearly four times the investment levels recorded between 2016 and 2021 (see figure 16).

What is deterring investment in critical minerals?

Despite the significant projected rise in demand for critical minerals, investment levels remain subdued. Several factors contribute to this. First, mining firms face volatile valuations, and projects require substantial up-front capital for exploration, feasibility studies, and infrastructure. Timelines from exploration to production can be lengthy—often extending beyond a decade—because of regulatory approval requirements, environmental assessments, and construction phases. This protracted process exposes projects to market fluctuations and regulatory changes. The lead time for mines is trending upward, averaging 17.9 years for those that began operations between 2020 and 2023, compared to 12.7 years for mines that started operations in 2005 (S&P Global Market Intelligence, 2024). Key reasons for this include longer exploration, permitting, and studies phases, as well as prolonged timelines for securing financing and obtaining construction permits. Second, mining firms, especially those in developing economies, often struggle to access capital markets due to political uncertainty and instability, weaker legal frameworks, and higher country risks. Shifts such as changes in mining laws or sudden tax increases can undermine financial viability and limit the ability of firms to secure financing on favourable terms (IEA, 2023b). Third, there is significant technological uncertainty; existing technologies used for the exploration, extraction or processing of critical minerals could be rendered obsolete if new technologies reduce or eliminate the need for them. The potential emergence of substitutes, more cost-efficient end-use, and alternative technologies for renewables could all introduce additional uncertainty and the risk of stranded assets for some minerals. Advances in battery technology, including the development of sodium-based or low-cobalt alternatives, could drastically change the demand for certain minerals (Majkut and others, 2023), as has already occurred in the past decade (Van de Graaf and others, 2023). Finally, high price volatility remains a major deterrent, as drastic price swings create an unstable market, making it difficult for mining companies to secure financing and plan long-term projects. As discussed in the first section, many critical minerals tend to experience a greater price volatility than do base metals.

Figure 16

Average annual investment needs for critical minerals and the manufacturing of clean energy technologies



Source: IEA (2023b).
Notes: “Other critical mineral mining” refers to the mining of bauxite, lithium, neodymium oxide, nickel, and cobalt. “Critical mineral processing” refers to the production of materials from these critical minerals. “Clean technology manufacturing” refers to the final stage of creating and installing products such as heat pumps, batteries, and solar cells.

Industrial policy to maximize the benefits of critical minerals

Technology access remains a challenge

Innovations in mining technology improve the efficiency of extraction and production processes and minimize environmental impacts. They can also promote value addition and foster backward and forward linkages. Over the past two decades there has been a surge in technological advancements (Clifford and others, 2018).[19] More patent applications for mining-related inventions were submitted between 2017 and 2021 than during the period 1970–2000 (Daly and others, 2022). Large multinational firms are the primary drivers of mining innovation, accounting for about 60 per cent of patent requests (Casella and Formenti, 2022).[20]

Resource-rich developing economies must improve their access to key technologies—across all phases of mining—by attracting multinational firms with advanced expertise and capabilities and promoting the transfer of these technologies to domestic firms. At the same time, it is crucial to strengthen local innovation ecosystems to enable domestic firms to adapt these technologies to local contexts, develop their own targeted technologies, and participate in domestic technology networking and exchange. However, these countries cannot achieve this alone. Given that such technologies directly or indirectly impact the transition to renewables and net-zero goals, international action is needed to facilitate access to technology on affordable terms for developing nations.

For exploration, countries need to increase their reliance on geological survey technologies such as satellite imaging, drone-based surveying, and 3D geological modelling to help them identify

19 Technological progress has been crucial for the exploitation of new mines in complex scenarios, including lower ore grades, extreme weather conditions, deeper deposits, harder rock mass, and high-stress environments (Sánchez and Hartlieb, 2020).
20 Australia, Canada, China, Europe, Japan, and the United States account for the largest share of global mining innovations, as evidenced by R&D investments and the number of mining technologies reflected in patent data (Daly and others, 2022).

deposits more quickly and effectively (Iizuka, Pietrobelli and Vargas, 2022). For extraction, greater access to automation and robotics—including automated drilling, blasting, and haulage systems—is essential. The use of in-situ leaching, heap leaching, and bioleaching techniques enables the selective dissolution of minerals without extensive surface excavation, reducing the environmental impact and energy consumption. Digitalization and data analytics can improve decision-making by enabling the real-time monitoring and optimization of mining operations, reducing costs and enhancing productivity.

Countries need to strengthen hydrometallurgical and pyrometallurgical capacities to expand processing and refining. This is vital for processing lower-grade ores and improving mineral recovery rates, especially as ore quality declines globally. Advanced metallurgical technologies and recycling methods can produce higher-purity metals while also promoting sustainable practices by minimizing waste and reducing energy consumption. Innovations in automation, such as remote-controlled equipment and real-time monitoring, optimize refining processes, reduce labour costs, and improve safety. However, adopting these technologies requires significant investment, particularly in machinery, equipment acquisition, and workforce training (Blundi and others, 2022).

Against this backdrop, strategic industrial policies are crucial for enhancing access to, and the development of, relevant new technologies that can help strengthen and expand the critical minerals sector.[21] These policies can play a key role in attracting foreign investments and financing for new projects, fostering technology transfers and innovation, and building technological capacities (Cimoli, Dosi and Stiglitz, 2009). In countries such as Canada and Australia, innovation policies have played a major role in the acquisition and absorption of technological innovations and have helped foster diversification and strengthen local capabilities in the mining industry (Daly and others, 2022; Anzolin and Pietrobelli, 2021). At the same time, the Chilean experience with copper exemplifies the limitations of relying solely on market forces to advance downstream activities and promote forward and backward linkages (Lebdioui, 2020). Despite being one of the world's largest copper producers, Chile has struggled to move beyond extraction into higher-value activities, underscoring the need for a more active policy approach.

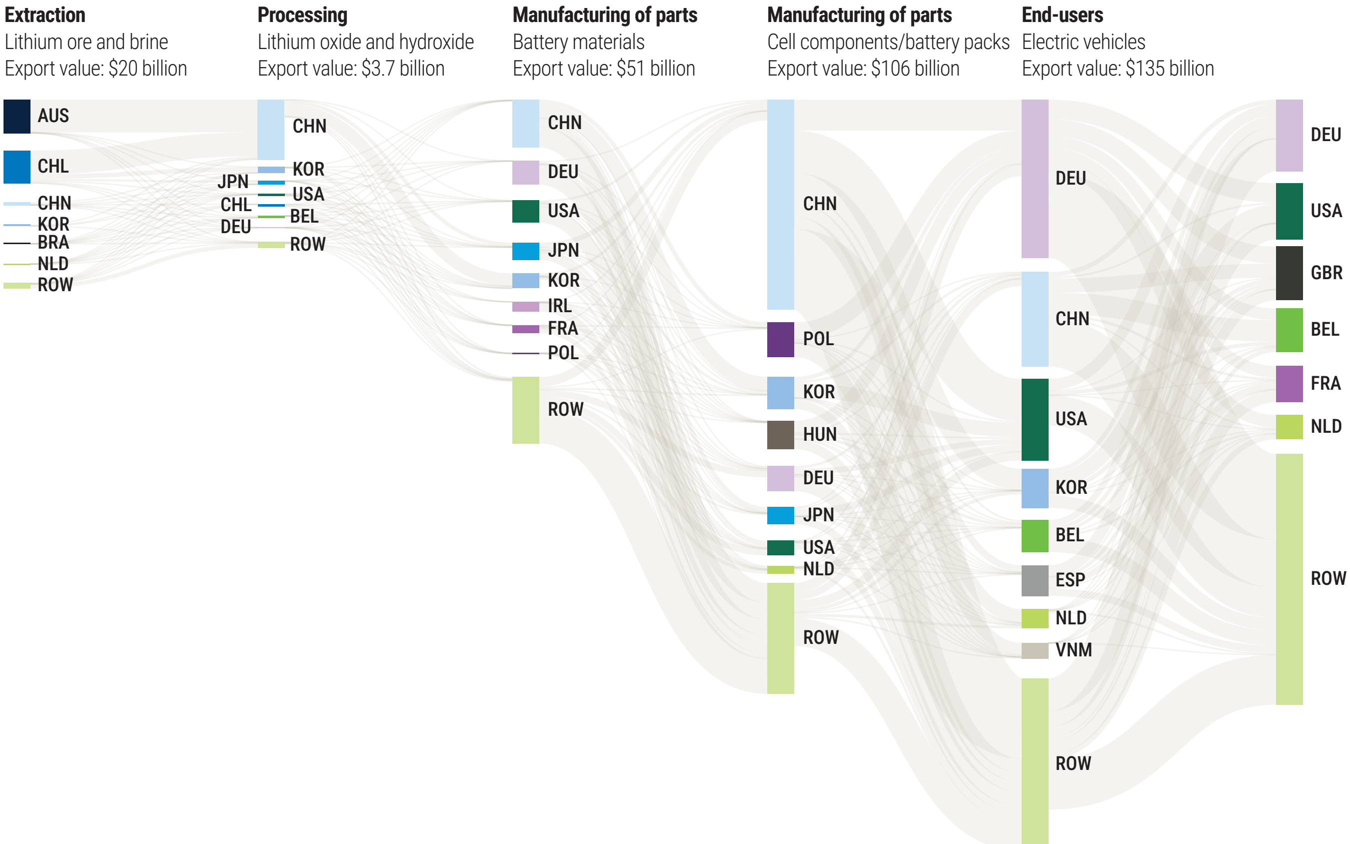
Policymakers have a range of industrial and innovation policy tools at their disposal, including tax incentives, subsidies, export restrictions, local content requirements, supplier development programmes, research and development (R&D) support, public-private partnerships, and labour market and skills development initiatives. A crucial question for countries is deciding which diversification strategy to pursue. Opportunities for upstream diversification through backward linkages may exist in the mining equipment, technology, and services sector; midstream opportunities—centring around the smelting, refining, and production of intermediate products—can be explored; and for a few countries, downstream activities might include the production of components for renewable energy, electronics, high-tech manufacturing, or electric vehicles.

These opportunities can entail product and process upgrading in the same stage of the value chain, upgrading to a higher value-added position in the value chain (intra-chain upgrading), or moving into a different value-chain (inter-chain upgrading) (Gereffi and others, 2001). Figure 17 illustrates the total value of exports for the lithium-ion battery value chain (inter-chain upgrading).

21 Industrial policies are aimed at changing the structure or sectoral composition of the economy in line with strategic and medium-term goals such as export diversification, technology upgrading, and industrialization. These policies address a broad range of industrial development priorities, including support for infant industries, trade and foreign direct investment, intellectual property rights, public procurement, the allocation of financial resources, and science, technology and innovation.

Figure 17

Total value of exports for the lithium-ion battery/EV value chain, by country, 2022



Source: UN DESA, based on data from the United Nations Comtrade database.
Notes: The country codes used are consistent with the International Standards Organization (ISO) alpha-3 codes. ROW = Rest of the world. The left side of the bars reflects the value of imports, while the right side reflects the value of exports; the two values may not be equal, as countries may import materials for domestic use or use domestic materials for exports.

Resource-rich developing economies face unique and multifaceted challenges in accessing advanced technologies. Addressing these challenges requires coordinated efforts to build local capacity, stimulate innovation, and create an environment conducive to attracting both public and private investments. This calls for well-designed industrial and innovation policies aligned with each country's specific diversification objectives. To provide a better understanding of these dynamics, the next section provides an overview of the current policy landscape, as many economies are increasingly adopting industrial and innovation policies to optimize the benefits of their critical minerals resources.

A proactive but heterogeneous policy landscape

Saddled with weak innovation ecosystems, most developing economies have implemented mining innovation policies that are narrow in scope and scale (Pamplona and Penha, 2019; Lebdioui, 2019). Moreover, as evidenced in Argentina, Brazil, and Peru, there has been a lack of sufficient incentives for domestic firms to acquire technology and build supplier capabilities (Pietrobelli and others, 2024). Consequently, it is not surprising that upgrading within value chains has been challenging for domestic suppliers, with innovative opportunities being seized by only a small number of firms, including some in Latin America (Iizuka, Pietrobelli and Vargas, 2022). In recent years, however, some developing economies—such as Brazil, Chile and South Africa—have gradually begun scaling up mining innovation policies.[22]

The experiences of some developed economies illustrate the broader scale and scope of their policy approaches. In Australia, for example, the Government has played a key role in promoting innovation and strengthening the capabilities of domestic suppliers through long-term initiatives and local content policies (Amburle and others, 2022). This has included a mix of employment and sourcing policy instruments, together with initiatives supporting technology transfers, R&D investments, and supplier development (Anzolin and Pietrobelli, 2021). Currently, the strategy prioritizes promoting forward linkages by attracting leading multinational firms, providing low-interest loans to mining and processing firms, and supporting the transfer of technology to engage in the production of intermediate and final products in the lithium-ion battery chain (Poveda Bonilla, 2021).

To enhance value addition and promote downstream activities, policymakers in a growing number of developing countries have implemented export restrictions and local content policies. In 2014, Indonesia introduced an export ban on nickel ore along with a local-content clause for firms investing in smelters. This export ban complemented a broader collaboration between China and Indonesia that included financing, project facilitation, and the establishment of special industrial zones. Since 2020, this strategy has resulted in significant investment in pyrometallurgy and hydrometallurgy smelters, which has, in turn, led to a surge in stainless steel exports from Indonesia (see figure 18) (Tritto, 2023).[23]

The current strategy in Indonesia—supported by tax incentives, import-duty exemptions, infrastructure development, and R&D subsidies—is aimed at developing the entire EV supply chain, from precursor materials to battery cells, battery packs, and electric vehicles. In recent years, over $20 billion in investments have been made by EV battery producers in various industrial parks. As a result, Indonesia has become the world's largest nickel producer, with nickel-related export revenues increasing from $1 billion in 2015 to $20.9 billion in 2021 (Tritto, 2023). The Democratic Republic of the Congo, Ghana, Malaysia, and Namibia have recently implemented similar export bans on several critical minerals, aiming to increase local value added through the processing and refining of these minerals.

Some countries have set up special economic zones to promote productive linkages and benefit from economies of scale. The Democratic Republic of the Congo and Zambia have established special economic zones offering tax breaks and other incentives for the production of sulphates and battery precursors, creating opportunities for foreign investors. However, the two countries have pursued different strategies for their copper sectors. Zambia has focused primarily on extraction rather than refining due to infrastructure gaps and the lack of policy incentives. In contrast, the Democratic Republic of the Congo has implemented explicit policies, including export bans, to promote local value addition. Consequently, refined copper accounts for about 83 per cent of the total copper exports from the Democratic Republic of the Congo, compared with only 26 per cent from Zambia.

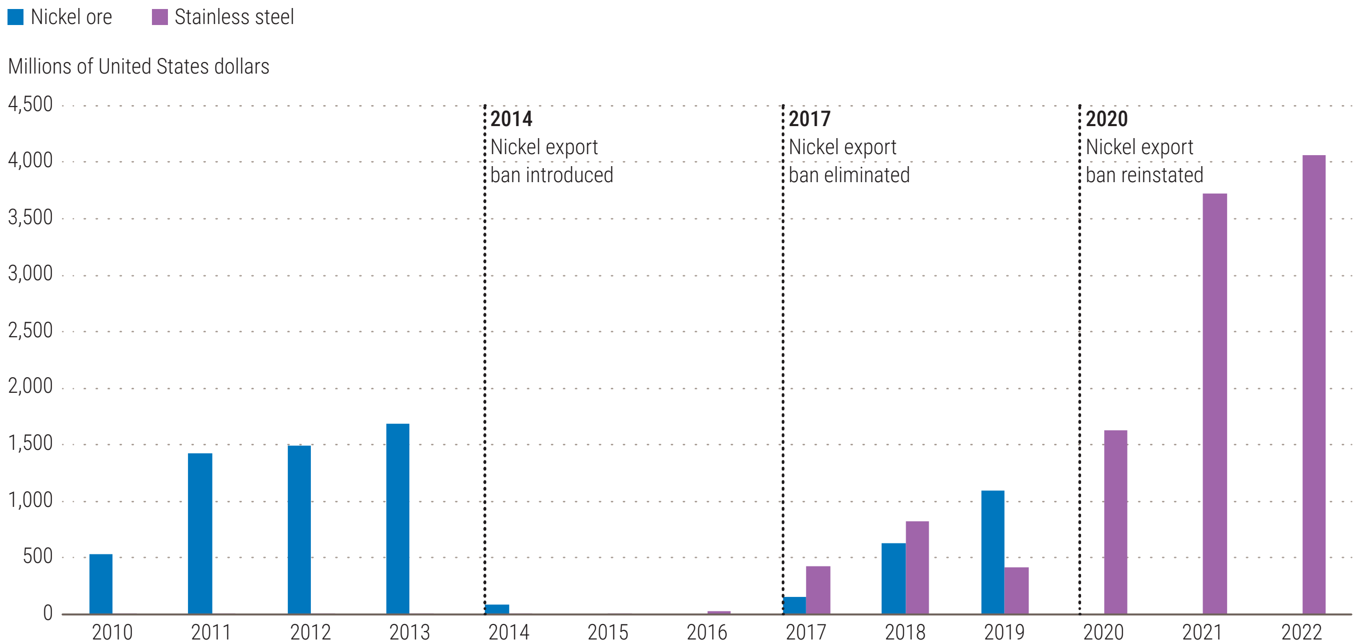
Argentina, the Plurinational State of Bolivia, and Chile—the countries that make up the "lithium triangle"—are pursuing different strategies for lithium development. Chile prioritizes the role of the State, employing a flexible approach to maximize State benefits. Lithium deposits are owned by the State, and the National Lithium

22 Several initiatives in South Africa are promoting technology transfer, R&D investment, and mining innovation. In Brazil, the Science, Technology, and Innovation Action Plan for Strategic Minerals sets out concrete actions to promote R&D investment. In Chile, there has been increased recognition of the need for more active mining policies in recent years, leading to a more proactive policy approach.

23 After the nickel export ban was imposed, the European Union initiated a WTO dispute against Indonesia. In 2022, the European Union won the dispute and imposed anti-dumping and anti-subsidies duties on Indonesian steel. In 2023, Indonesia filed a WTO case against these duties.

Figure 18

Indonesian exports of nickel ore and stainless steel



Source: UN DESA, with data compiled by its Statistics Division.

Strategy mandates that the exploitation of larger and more strategic salt flats be led by public-private partnerships, with the State holding a majority stake. For medium- and small-sized salt flats, operations can be led by either State enterprises or private firms. In contrast, the Plurinational State of Bolivia emphasizes strong State control across the entire value chain. The high level of State involvement, along with infrastructure deficiencies and geological challenges, has hindered lithium extraction in the country in recent years. However, a new joint venture between State-owned Yacimientos de Litio Bolivianos and Chinese battery manufacturer Contemporary Amperex Technology Co., Limited, plans to invest $1.4 billion in two lithium processing plants to kickstart the production of battery-grade lithium (see figure 19).

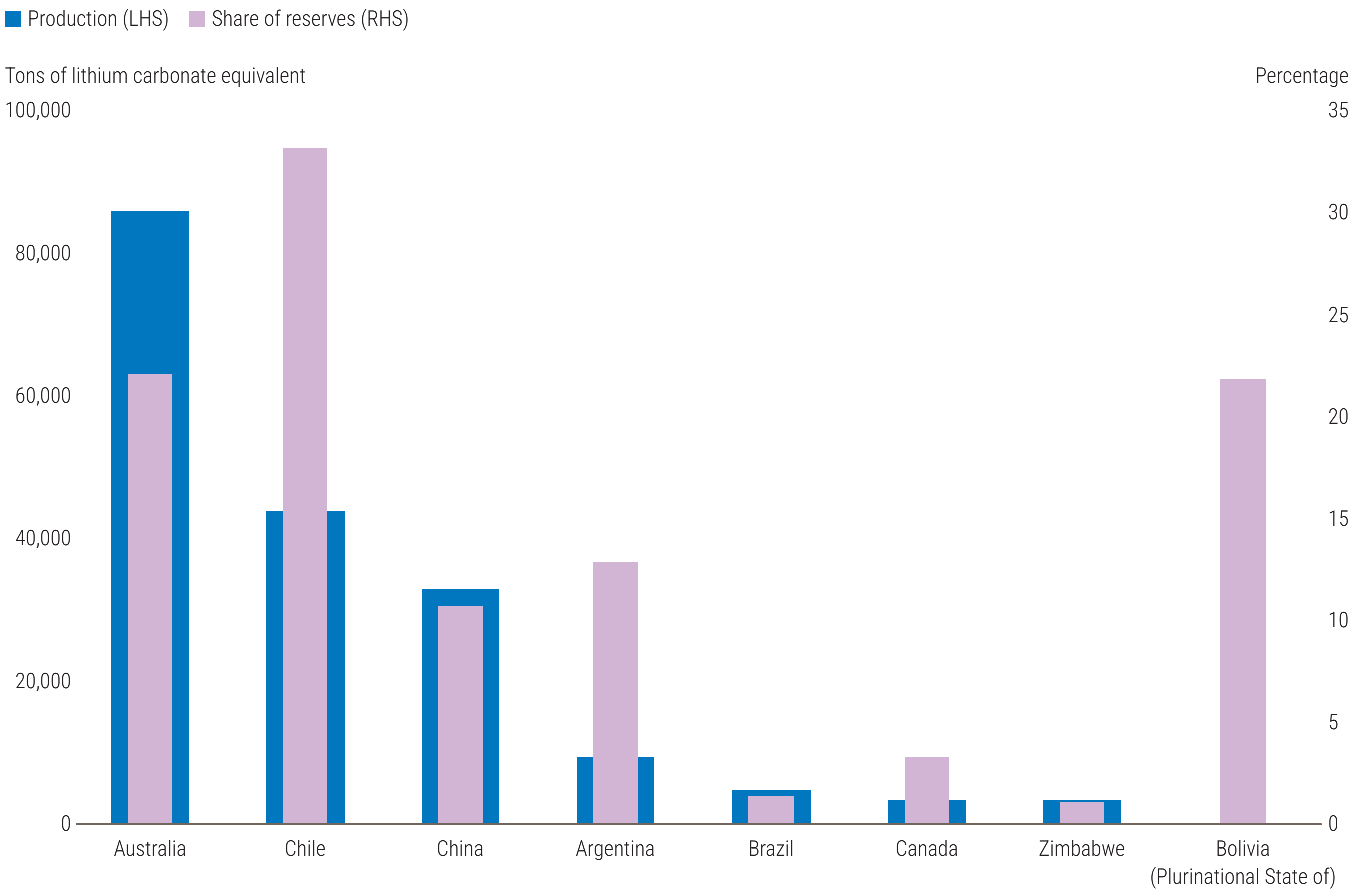
Under the federal system in Argentina, national and provincial governments share regulatory responsibilities, while private firms lead lithium operations. In recent decades, mining regulations have been inconsistent, however, oscillating between investment-friendly and more restrictive regimes. In 2024, Argentina introduced the Large Investment Incentive Regime, a new policy framework designed to further attract foreign and domestic investment. This regime offers generous long-term guarantees and incentives such as tax reductions, exemptions from export withholdings, and no import duties on capital goods, as well as other benefits. While these measures are expected to attract substantial investments, the absence of policies to foster productive linkages may hinder the development of local productive capacities (Obaya, Freytes and Delbuono, 2024). Additionally, there are significant concerns about the potential impacts on fiscal revenues (Freytes, 2024).

There is no one-size-fits-all

Developing economies with reserves of critical minerals face the challenge of designing and implementing a coherent set of industrial and innovation policies. Industrial and innovation policy experimentation in recent decades,

Figure 19

Lithium production and the share of global reserves among major producers, 2023



Source: UN DESA, based on data from United States Geological Survey (2024).
Notes: LHS = left-hand scale; RHS = right-hand scale. "Share of resources" is used instead of "share of reserves" for the Plurinational State of Bolivia only.

characterized by both successes and setbacks, has underscored several conditions that are necessary—but not sufficient—for accelerating diversification and structural transformation and promoting economic growth. These conditions also apply to industrial and innovation policy packages for critical minerals.

First, effective industrial and innovation policy packages require political and macroeconomic stability, sustained political commitment, and adequate long-term financing. Macroeconomic and political stability, in particular, are crucial for attracting investment in critical minerals from multinational firms. Experiences in Africa and Latin America demonstrate that a lack of consistent political support can significantly undermine the effectiveness of these policies (Peres and Primi, 2019). Therefore, it is crucial to align the typically short duration of political cycles with the longer time frames needed for the successful implementation of industrial and innovation policies for the development of critical minerals. Second, the impact of individual policy measures often depends on their interaction with other measures, so policy coherence is crucial (Andreoni, 2024; Anzolin and Pietrobelli, 2021). For example, Indonesia has advanced downstream activities in the EV value chain by implementing an export ban on nickel ore alongside measures such as infrastructure development, R&D subsidies, and the creation of special industrial zones. Third, the effectiveness of policy measures can be enhanced by applying targeted incentives and conditionalities set as eligibility criteria (ex ante) or performance standards (ex post). In the South African mining sector, for example, the Mining Charter imposes specific conditions related to local ownership, employment, and procurement (South Africa, Department of Mineral Resources, 2018).

Beyond these general conditions, various domestic and international factors influence not only the types of diversification strategies that economies can pursue but also the formulation of their policies. This underscores that there is no one-size-fits-all approach; each country must carefully design its policy package in alignment with its unique circumstances, institutional capacities, and economic and geopolitical priorities. Ultimately, the industrial and innovation policy approach should be integrated into a comprehensive national policy strategy that encompasses economic, environmental, and social dimensions.

Many developing economies play a significant role in the production of critical minerals, particularly in Africa (see figure 20). Proximity to major consumer markets or automotive industry hubs can further strengthen the competitive position of specific nodes within the value chain by lowering transportation costs. Additionally, the availability of essential infrastructure—such as transport, energy, water, and digital networks—is a major logistical advantage. For many countries, especially those with least developed status, basic infrastructure is an essential step towards capitalizing on their critical minerals.[24] For countries looking to expand into processing activities, the demands on energy infrastructure capacity and reliability are especially significant. Likewise, strong technological capabilities, including a skilled workforce, are essential for those prioritizing downstream activities.

In many developing countries, market concentration and market power—reflected in the production concentration index—are well above the threshold for "highly concentrated" industries (see figure 21) (United States Department of Justice and FTC, 2023), making it difficult for junior and local mining companies to access relevant technologies. As mentioned in the previous section, automakers and EV battery manufacturers are also increasingly adopting vertical integration strategies, and companies are expanding their operations into battery cell production and in some cases into mining (Ciulla and others, 2021).[25]

Meanwhile, green policies from major developed economies, along with existing and new international trade, investment, and cooperation agreements, create a challenging policy landscape.[26] For developing economies, the priority is to secure market access for their products while attracting capital and technologies and retaining policy flexibility. In practice, however, this is often complicated by asymmetric negotiating power. Thus, new trade, investment, and cooperation agreements may not fully align with the development needs of these economies.

In addition, free trade agreements (FTAs) between developed and developing economies often show a disparity in enforceability. For example, in FTAs between the European Union and developing countries, chapters on energy and raw materials typically include binding provisions to ensure access to raw materials, while commitments related to sustainability and industrial policy in resource-rich countries are often less enforceable (van der Ven, Sasmal and Torres, 2023). A notable exception is the Advanced Framework Agreement between the European Union and Chile, which

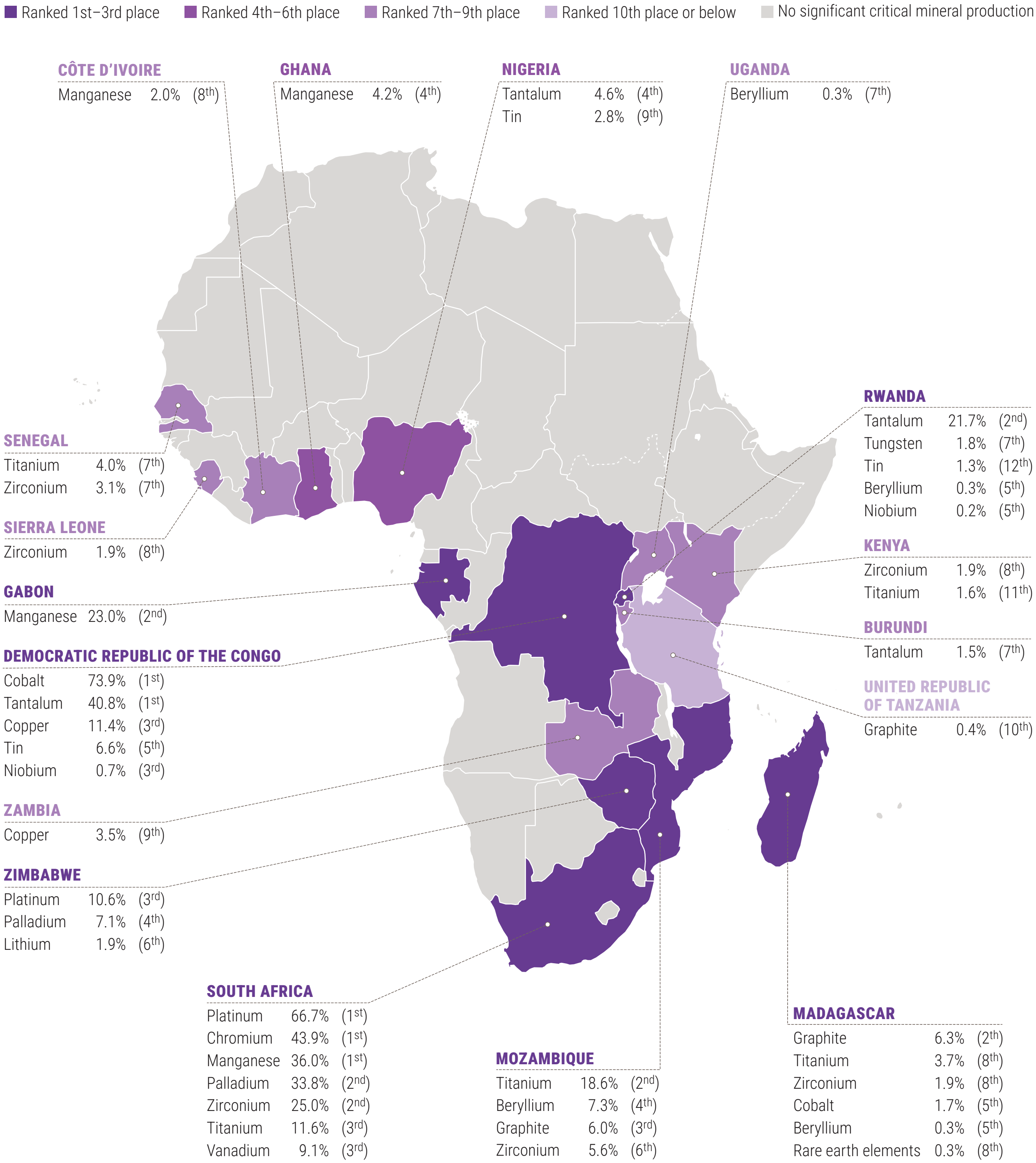
24 The Lobito Corridor is a major trade and transport route in southern Africa that connects the Democratic Republic of the Congo and Zambia to the Atlantic Ocean via the Angolan port of Lobito. This Corridor integrates road, rail, and port infrastructure and will facilitate exports from the Copperbelt region.

25 Additionally, studies in Latin America indicate that contractual practices and the hierarchical organization within the mining sector hinder the ability of domestic suppliers to upgrade within global value chains (Pietrobelli and others, 2024). Thus, there is an opportunity to promote greater transparency in supply opportunities and encourage the broader participation of local firms in procurement processes.

26 For example, the European Union Carbon Border Adjustment Mechanism imposes a carbon price on imports from countries with less stringent climate policies. The Mechanism is in a transitional phase (2023–2026), and only selected industries (iron and steel, aluminium, fertilizers, and hydrogen products, among others) are subject to the tariff. Lebdioui (2024) asserts that the Carbon Border Adjustment Mechanism could effectively act as an import restriction, violating provisions under the General Agreement on Tariffs and Trade, and impose significant costs for developing economies (Aggad and Luke, 2023).

Figure 20

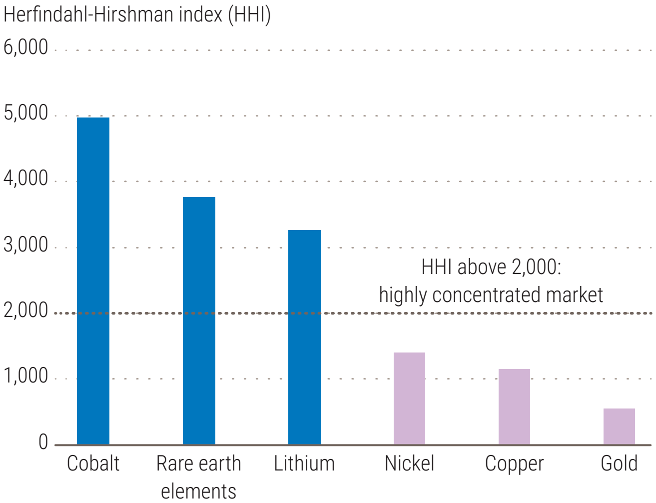
Global share and ranking of critical mineral production in African countries



Source: UN DESA, based on data from United States Geological Survey (2024).
Notes: The boundaries and names shown, and the designations used, on this map do not imply official endorsement or acceptance by the United Nations. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. Countries with the same share of production share the same ranking.

Figure 21

Production concentration index of selected minerals, 2020



Source: Castillo, del Real and Roa (2024).
Note: The HHI is calculated by squaring the market share of each firm in the market and then summing the resulting numbers.

protects the industrial policy space in the latter. It includes an exemption from dual pricing prohibitions, allowing Chile to sell lithium at preferential prices to domestic companies for refining, supporting local value addition. However, a preliminary assessment suggests these conditions may be overly restrictive and could even limit future policy flexibility (van der Ven, Sasmal and Torres, 2023).

Despite these challenges, a number of developing countries are benefiting as firms tend to invest in or relocate operations to take advantage of major policy shifts in developed economies. Mexico, for example, is well positioned to capture a significant share of new investment spurred by the United States Inflation Reduction Act due to its proximity to, and FTA with, the United States. Additionally, the United States and Chile have confirmed that Chilean-mined lithium will qualify for United States tax breaks under the Act. Overall, in the year following the passage of the Inflation Reduction Act, countries that had a free trade agreement with the United States saw greenfield FDI inflows into energy transition mineral value chains increase tenfold on average, compared with a fivefold increase in non-FTA countries (Castro and Brucal, 2024).

Ambitious yet pragmatic industrial policy measures

There are opportunities for developing countries to leverage their resource endowments, which are the strategic advantages they possess in terms of reserves of critical minerals, geographic location, or technological capabilities. The leverage a country has shapes its ability to negotiate with other Governments and leading mining firms, directly affecting the efficacy and effectiveness of its industrial policy initiatives. The success of the nickel export ban and the failure of the bauxite export ban in Indonesia illustrate how leverage—rooted in the scale of mineral reserves—can influence policy outcomes. However, having substantial reserves alone is not sufficient. The Democratic Republic of the Congo, which accounts for over 60 per cent of global cobalt ore extraction, has been less successful in leveraging its critical resource endowment due to continuing political instability, weak governance, and inadequate infrastructure. The country's mining practices, such as the widely reported use of child labour (ILO, 2019), are also among the factors hindering its ability to attract substantial investment in refining and other high-value activities.

Adequate institutional capacity is also crucial for designing and implementing effective industrial policy measures. Strong institutions are essential for integrating various policy measures, ensuring that they are cohesive and well coordinated. Preventing corruption and political capture is vital for ensuring the success of these policies and maintaining their credibility. The institutional framework in Botswana, for example, was critical to the development of refining and processing in the diamond industry (Besada and O'Bright, 2018). Key institutions such as the Diamond Trading Company Botswana and the Diamond Office were established to oversee diamond sorting, valuation, and marketing, while the Diamond Technology Park provided essential infrastructure. The Government also implemented a favourable governance framework, ensuring a stable supply of rough diamonds and offering tax incentives to attract foreign investment. Public-private partnerships played a crucial role in facilitating technology transfer and capacity-building within the industry.

Institutional capacity is particularly important when implementing local content policies.[27] These policies have been widely applied in the mining sector in countries such as Botswana, Ghana, South Africa, and Zambia. However, their effectiveness in promoting downstream activities can depend on additional factors. Recent research indicates that local content policies are more effective when complemented by measures supporting domestic supplier capabilities (Anzolin and Pietrobelli, 2021). Without these additional measures, such policies can end up being unsuccessful or even unproductive if they set broad or overly ambitious quotas (Lebdioui, 2019).

Strategic leverage and robust institutional capacity can create major opportunities for countries with substantial reserves and untapped potential, including Brazil (rare earth elements), India (rare earth elements), Mexico (copper), United Republic of Tanzania (graphite), and Viet Nam (bauxite). At the same time, well-designed industrial and innovation policies can encourage processing and refining activities in countries already engaged in critical minerals extraction. In certain cases, strong competitive leverage and effective institutional capacity can enable countries to adopt ambitious policies to increase downstream activities, particularly in medium- and high-technology industries. Morocco, for instance, is well positioned to enter the solar panel manufacturing value chain due to its abundant mineral resources (such as phosphate and cobalt), technological expertise, and robust regulatory frameworks (Andreoni and Avenyo, 2023). Capitalizing on these opportunities and implementing effective industrial policies is nevertheless a challenging task for many developing economies.

Leveraging financing instruments to promote investment in critical minerals

Bridging projected gaps in critical minerals investment requires a comprehensive industrial policy approach that includes creating a stable regulatory environment, improving infrastructure, and enhancing transparency and governance. Governments also need to provide targeted incentives to attract both domestic and foreign capital. Additionally, innovative private financing tools can mobilize private sector resources for mining projects.

Government incentives as an investment promotion tool

It is essential for resource-rich economies to create an attractive investment environment to mobilize private capital in support of the mining and processing of critical minerals, including the acquisition of technological innovations that can enhance efficiency, reduce environmental impact, and support the development of new methods for resource extraction and refinement.

Fiscal incentives can include income tax holidays and tax breaks, accelerated depreciation, investment allowances, tax credits, and reduced royalties (see table 5). Tax stabilization and income tax incentives are the most utilized in mining and concession contracts (IGF, 2019). The use of these tax measures increased during the commodity price crash of 2014–2016 and remains prevalent in many developing countries supporting their critical minerals industries,

27 Local content policies require that a certain share of goods, services, labour, or capital be sourced domestically. The requirements can relate to local procurement, employment and training, technology transfer, domestic ownership, or other priorities (Korinek and Ramdoo, 2017). Local content policies are increasingly restricted by WTO agreements.

Table 5

Tax incentives for mining

Instruments	Tax incentives	Selected country examples
Taxes	▪ Income tax holidays/tax breaks ▪ Accelerated depreciation ▪ Investment allowance/tax credits ▪ Longer loss carry forward periods ▪ Withholding tax relief on interest expense dividends and service charges such as management fees	▪ **Income tax holidays and breaks:** Argentina, Democratic Republic of the Congo, Senegal, Zambia ▪ **Longer loss carry forward:** Philippines, Zambia ▪ **Accelerated depreciation:** Chile, Peru, South Africa, Zambia
Royalties	▪ Reduced royalties ▪ Royalty holidays ▪ Sliding-scale royalties	▪ **Reduced royalties:** India, Indonesia, Namibia ▪ **Sliding-scale royalties:** Chile, Zambia
Tariffs	▪ Import duty relief	▪ **Import duty relief:** Argentina, Indonesia, India, Mozambique, Peru, Sierra Leone
Others	▪ Stabilization of fiscal terms ▪ Reduction of property taxes ▪ Reduction of value-added taxes	▪ **Tax stability clause:** Argentina, Chile, Ghana, Mongolia, Peru, Senegal

Source: UN DESA, based on IGF (2019) and official sources.
Note: The examples presented are not intended to be exhaustive but are provided to illustrate specific cases.

particularly where economic and political risks are high. Meanwhile, only a few economies offer investment allowances and tax credits, even though cost-based incentives are generally more targeted and easier to monitor than profit-based incentives (such as tax holidays) (IGF, 2019).[28]

The effectiveness of using tax incentives to promote the advancement of critical minerals development is open to debate, and countries need to be cautious in implementing them and ensure that they are well targeted. Tax incentives may prove ineffective in an unattractive investment environment marked by political instability, inadequate infrastructure, and higher business costs (Forstater, 2017). In addition, fiscal incentives and long-term stability provisions can decrease fiscal revenues, encourage profit-shifting, and hinder the ability of countries to mobilize domestic resources, particularly if fiscal incentives are overly generous (Albertin and others, 2021; Beer and Loeprick, 2018). It has been estimated that economies in sub-Saharan Africa lose between $470 million and $730 million per year in corporate income tax through tax avoidance by mining multinationals (Albertin and others, 2021). Eliminating aggressive tax avoidance practices, a key factor behind illicit financial flows, will require robust global cooperation. International tax cooperation efforts, such as those undertaken within the framework of the OECD/G20 base erosion and profit shifting project, offer valuable insights and guidance for advancing this goal. A recent World Bank survey has found that tax incentives are less important than other factors—such as macroeconomic and political stability, infrastructure, and labour skills—in attracting mining investments (Bogoev, 2018).[29]

Governments can also use financial incentives such as grants, subsidies, preferential loans, loan guarantees, and debt guarantees to lower financing costs and attract private capital to support their industries. Low-cost loans and loan guarantees can be effective for financing projects that struggle to secure funds from commercial lenders (IEA, 2023b). Guarantees, in

28 Profit-based incentives reduce the tax burden linked to the profitability of firms, usually through tax reductions such as lowered corporate income tax or income tax holidays. By contrast, cost-based incentives reduce the tax burden linked to incurred costs. These incentives are designed to lower the effective cost of capital and operational expenses, and they typically come as deductions, credits, or allowances.

29 More general studies on the use of fiscal incentives for stimulating FDI (such as Klemm and Van Parys, 2009) show rather limited impacts, particularly in developing countries.

particular, can significantly reduce investor risk by signalling the commitment of a Government to a project's success. However, guarantees are expensive and carry potential downsides. Guarantees can increase the financial burden on the State if a project fails, and they may create moral hazard problems, encouraging investors to take on higher risks with the expectation of a government bailout. With careful planning, however, financial incentives can be effective. The Government of Indonesia has offered preferential loans, investment allowances, and infrastructure subsidies, together with tax incentives, to promote downstream processing and EV battery manufacturing. This support extends to infrastructure development in designated economic zones such as the Morowali Industrial Park.

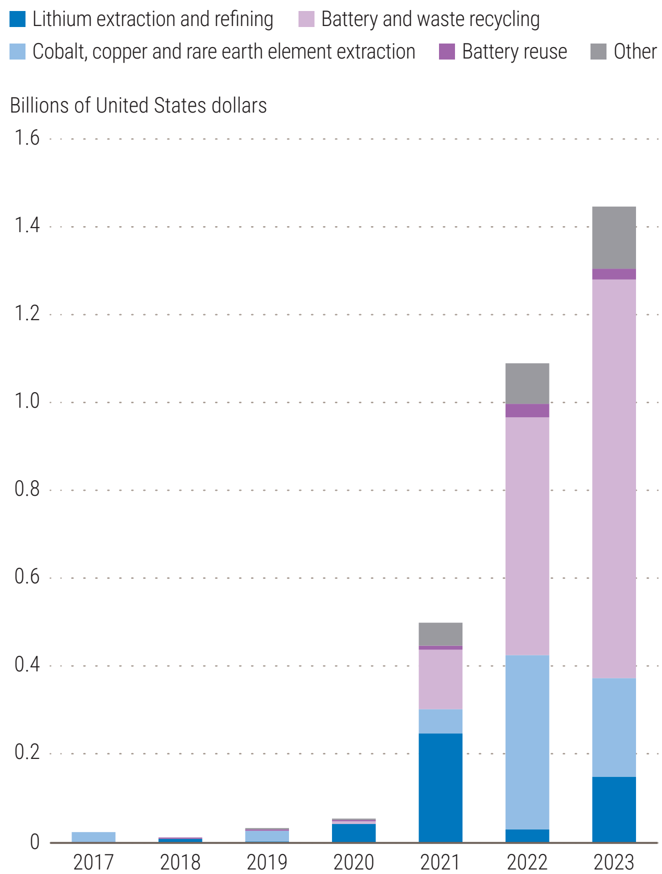
Private financing tools

While venture capital firms have historically steered clear of the mining sector, their engagement in critical minerals is gradually gaining momentum amid new innovations, growing demand, and increased policy support. For example, the Inflation Reduction Act and the CHIPS Act[30] in the United States are encouraging venture capital investment in critical minerals, particularly in battery manufacturing, EVs, and renewable energy technologies (Kessler, 2022). The Inflation Reduction Act allows mining companies to access tax credits aimed at boosting the production of lithium-ion batteries, solar panels, and other clean energy components (Groom and Scheyder, 2024), so raw materials and extraction costs are eligible for tax benefits under the Act. In addition, automakers and many other firms in the private sector are providing funding to start-ups to gain a stake in the development of new technologies. Hence, venture capital investment in critical minerals development has surged in recent years, reaching $1.4 billion in 2023 (see figure 22). Battery and waste recycling are attracting the largest share of venture capital investment.

The sustainable finance market is another emerging source of capital for sustainable development.[31] In particular, the use of sustainability-themed capital market products that align financing strategies with ESG commitments is a promising area for attracting private capital. A potential downside, however, is that these products are often subject to scepticism. Upstream mining and processing

Figure 22

Venture capital investment in critical mineral start-ups



Source: UN DESA, based on IEA (2024).
Note: Early- and growth-stage venture capital investment into critical mineral start-ups is covered.

30 CHIPS is an acronym for "creating helpful incentives to produce semiconductors".
31 Sustainability-themed capital market products include green loans, sustainability-linked loans, green bonds, social bonds, sustainability bonds, and sustainability-linked bonds. The term "green" is used for financial assets that are committed to environmental and climate-related projects. Sustainability-linked capital market products often target projects that fit into a broader definition of sustainable development (Baines and Speight, 2020).

activities are known for their negative social and environmental consequences. In addition, investors might worry about greenwashing, the lack of standardization and transparency in ESG compliance, and limited impact evidence, even when these products offer a risk/return profile comparable to that of other investment opportunities.

As competition in the critical minerals market and geopolitical uncertainties intensify, many industrial investors are showing more interest in investing in upstream projects. Original equipment manufacturers, battery manufacturers, and even automakers are establishing procurement agreements with extractors and processors. Policies aimed at securing a strategic advantage can also enable greater end-to-end control of the supply chain; for example, in recent years, some EV and battery manufacturers have started to secure their supply of raw materials through long-term offtake agreements.[32] Some companies have gone a step further, directly investing in upstream activities such as mining, refining, and precursor materials to secure full control over their supplies.[33]

Blended finance

As noted earlier in this section, private investors often hesitate to invest in critical minerals projects owing to several unique challenges. Blended finance, which combines public and private funding, can help improve the risk/return profiles for different types of investors. This approach adjusts the risk/return balance for private sector investments in areas or projects that may not be competitive on purely commercial terms, acting as a catalyst to attract private investment in the critical minerals sector. For instance, the Canada Growth Fund, a subsidiary of the Canada Development Investment Corporation, aims to raise $15 billion in private capital between 2022 and 2027, and to support this, the Government will provide $1 in public resources for every $3 of private investment, focusing on the extraction of 31 critical minerals (Canada Growth Fund, 2024). Additionally, the Kabanga mine in the United Republic of Tanzania, home to the world's largest high-grade nickel sulphide deposit, has secured funding from the International Finance Corporation, mining giant BHP, and several commercial lenders. While blended finance can help alleviate supply-side constraints, it can also exacerbate debt sustainability issues for some countries if they engage in mining projects with already high debt burdens. Therefore, Governments must carefully evaluate blended finance arrangements, ensure the economic viability of projects, maintain a diversified investment portfolio, and implement robust fiscal management and governance practices.[34]

To advance the development of their critical minerals sector, developing economies need to adopt well-defined strategies to attract FDI and multinational firms, implementing policies that mitigate risks and offer long-term incentives. In countries such as the Democratic Republic of the Congo and Zambia, for example, efforts can focus on building public-private partnerships, ensuring transparency in licensing, and carefully calibrating incentives such as tax breaks, streamlined regulations, and infrastructure support to attract foreign investment. Crucial elements are upgrading transport and energy infrastructure—exemplified by the strengthening of the Lobito Corridor, which connects Angola, the Democratic Republic of the Congo, and Zambia—and the establishment of special economic zones. Leveraging blended finance can reduce risks and encourage sustainable investments aligned with the SDGs, provided the arrangements are managed well.

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32 Offtake agreements are contracts between miners and buyers that outline the terms and conditions for the sale of minerals. These agreements allow buyers to secure a stable supply of minerals and protect them from potential future price increases.

33 In 2020 Tesla announced plans to invest in lithium mines, and in 2023 it started the construction of a lithium refinery in the United States. Other automakers (Volkswagen, General Motors, Stellantis and Chrysler) have also announced mining projects.

34 In 2020, Glencore withdrew from its copper operations in Zambia and sold its 90 per cent majority stake to ZCCM Investments Holdings, a State-owned entity. Zambia assumed $1.5 billion in debt at a time when the country was already facing an economic crisis and had defaulted on its international debt obligations (Cotterill and Hume, 2021).

Strengthening global cooperation to enhance the role of critical minerals in the energy transition and sustainable development

Spillovers from unilateral critical minerals policies

Global cooperation is essential for harnessing the potential of critical minerals and thereby accelerating the energy transition and promoting sustainable development. With demand surging for minerals critical to renewable energy technologies, economies must collaborate to increase the supply of these minerals, minimize supply chain disruptions, facilitate technology transfers, and boost investments in the sector. The demand for critical minerals goes beyond the energy transition. Country-specific lists of critical minerals also include minerals that are necessary for advanced microchips, cutting-edge electronics, and defence hardware. Technological progress is increasingly dependent on the availability and use of critical minerals. However, disparate national policies, growing trade restrictions, and protectionist measures risk disrupting the global supply chains for critical minerals and hinder progress on the energy transition. Effective multilateral cooperation and frameworks are crucial for improving the supply of critical minerals and can also contribute to mitigating adverse environmental and social impacts associated with extracting and processing these minerals and help ensure that the developing countries endowed with these mineral resources can actually benefit from the growing demand for critical minerals.

Several major developed economies aim to strengthen the resilience of critical minerals supply chains by diversifying sources, to boost the global competitiveness of local industries, and to reduce dependence through the targeted use of investment incentives, import tariffs, public-private partnerships, and strategic alliances (Brinza and others, 2024; The Aspen Institute, Energy & Environment Programme, 2023). Recent legislation in support of the energy transition is an instrument of industrial policy, seeking to encourage domestic private sector investment in critical minerals supply chains through large-scale government subsidies such as tax credits, grants, and loan guarantee programmes. Other measures raise tariff barriers against electric vehicle imports.[35] Efforts are also under way to establish strategic partnerships and alliances with resource-rich countries and geopolitically aligned countries—often through memorandums of understanding—to secure a reliable supply of critical minerals (Gao, Zhou and Crochet, 2024; Sasmal, 2024).[36]

Developing countries rich in critical minerals seek to capitalize on the rising demand for these materials primarily by bolstering extraction capabilities and developing opportunities for midstream and downstream value addition. An increasing number of resource-rich countries have implemented measures such as export controls, foreign investment screening, and nationalization to foster investment in domestic critical minerals processing (see the section on industrial and innovation policies).

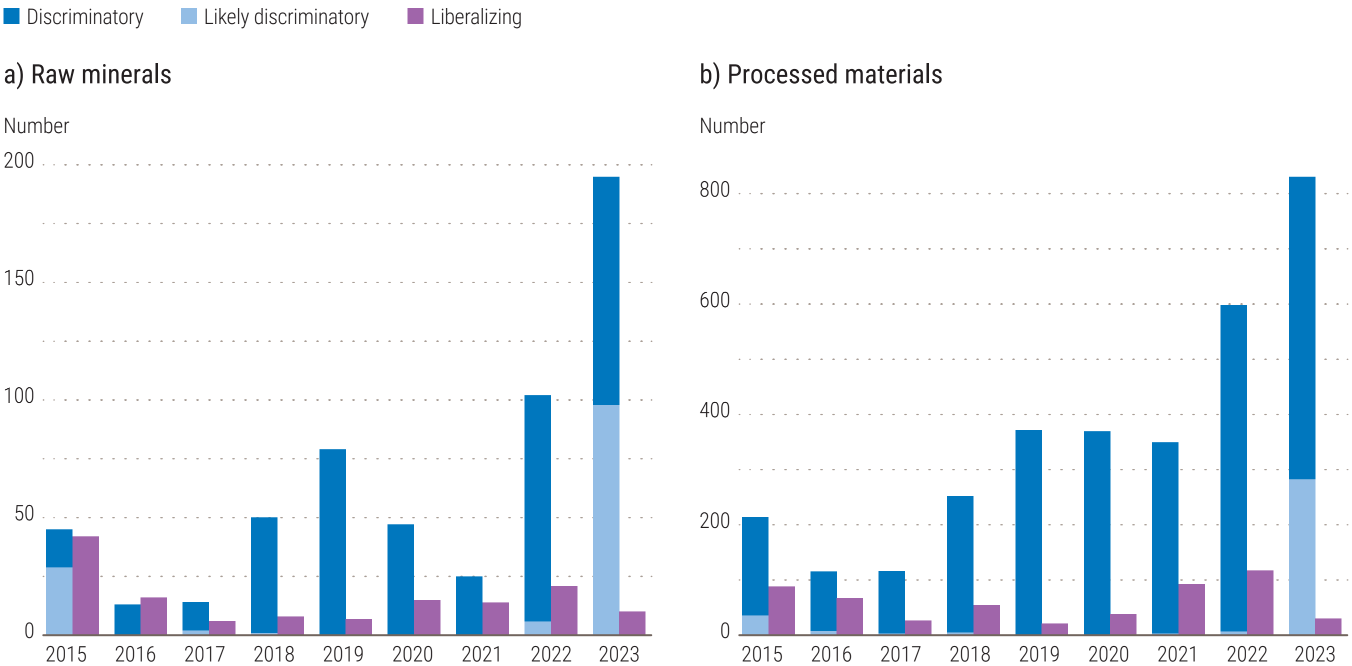
The number of unilateral trade-restrictive measures in the critical minerals sector—affecting both raw minerals and processed materials—has risen sharply in recent years (see figure 23). Developed economies, notably the European Union and the United States, account for the bulk of these measures, many of which negatively impact developing countries. Kowalski

35 In May 2024, the United States Government increased the tariff on electric vehicles imported from China from 25 to 100 per cent, while also raising tariff rates for lithium-ion batteries, battery parts, and selected critical minerals (The White House, 2024). In July 2024, the European Commission imposed provisional countervailing duties ranging from 17.4 to 37.6 per cent on imports of electric vehicles from China (European Commission, 2024). In August 2024, the Government of Canada announced its intention to implement a 100 per cent tariff on Chinese electric vehicles, effective 1 October 2024 (Canada, Department of Finance, 2024).

36 The European Union, for example, has formed partnerships for raw materials with 13 countries since mid-2021. The partners include four economies in transition, four African countries, three developed countries, and two Latin American countries (European Commission, n.d.).

Figure 23

Number of unilateral trade-related policy interventions in the critical minerals sector



Source: UN DESA, based on data from Global Trade Alert.
Notes: Global Trade Alert uses different terminology, categorizing interventions as harmful, likely harmful or liberalizing. An intervention is considered harmful if it is likely or almost certain to worsen the treatment of one or more foreign commercial interests relative to domestic rivals. The figure covers five critical minerals, namely cobalt, graphite, lithium, manganese, and nickel. Six-digit Harmonized System codes were used to identify each of the raw minerals and the related processed materials in midstream and downstream segments, including battery materials and battery cells.

and Legendre (2023) document a more than fivefold increase in the global incidence of export restrictions on critical raw materials between 2009 and 2021.[37]

Unilateral measures for critical minerals are driven by individual country priorities and are also part of a broader trend marked by the increasing prevalence of such initiatives in other sectors. The new wave of unilateral—as well as limited bilateral and plurilateral—measures indicates a preference for pursuing national priorities largely outside of multilateral frameworks (Aisbett and others, 2023; McMaster, 2024). This trend is also indicative of doubts over the ability of the World Trade Organization (WTO) to fulfil its core functions of promoting open markets, establishing new trade rules, and overseeing a transparent dispute settlement process.[38]

The rise of unilateral and protectionist measures may exacerbate market fragmentation along geopolitical lines and hinder progress towards a just and sustainable global energy transition. Unilateral actions that solely prioritize national interests can result in suboptimal global outcomes by increasing inefficiencies, raising costs, and ignoring global interdependencies and policy trade-offs. For instance, by subsidizing and prioritizing their own critical minerals industries as well as those in geopolitically

37 In value terms, it is estimated that 10 per cent of global exports of critical raw materials face one or more export restriction measures. China, India, Argentina, the Russian Federation, Viet Nam, and Kazakhstan are the top six countries in terms of the number of new export restrictions during this period.
38 It is also widely perceived among developing countries that existing WTO trade rules constrain policy space and hamper development. In a recent submission, the WTO African Group, echoing a widely shared sentiment, stated that “[WTO] Members have found themselves constrained from pursuing their development and industrialization objectives by rules which do not allow them to use the very policy tools that other advanced Members have used to industrialize” (WTO, 2023, para. 7).

aligned countries, developed countries risk depriving developing countries of growth and diversification opportunities, further exacerbating inequalities and fragile patterns of development.

Such measures can distort global trade and investment flows, diverting resources away from more cost-efficient production. This could hinder opportunities for developing countries to advance into higher-value segments of the critical minerals supply chain while also increasing costs for industries and consumers. When translated into high prices, such actions could delay the adoption of clean energy technologies beyond the initiation time frame necessary for effective climate action.

Several scenario-based studies highlight the scale of impacts associated with geoeconomic fragmentation (Aiyar and others, 2023; Bolhuis, Chen and Kett, 2023; Felbermayr, Mahlkow and Sandkamp, 2023). These studies indicate that the formation of rival economic blocs that have limited trade relations with one another would lead to considerable long-run global output losses, ranging from 0.2 to 6.9 per cent of world GDP, as trade and investment decline and knowledge and technology diffusion slows (IMF, 2023). Commodity markets are found to be particularly susceptible to fragmentation, resulting in significant price changes and increased price volatility (Aiyar and others, 2023). The long-run impact of fragmentation is uneven across countries, with developing countries—especially low-income countries—projected to face disproportionately large losses in real income (Hakobyan, Meleshchuk and Zymek, 2023; Bolhuis, Chen and Kett, 2023). This is largely due to the heavy reliance of many low-income countries on commodity trade and their lack of alignment with major geopolitical blocs, making them more vulnerable to disruptions in global trade.

A balanced approach that integrates national interests within collaborative frameworks is crucial for addressing these risks. Establishing new mechanisms for global cooperation can set standards for equitable access to critical minerals, promote technology-sharing, and ensure that benefits are fairly distributed across nations in the supply chain.

New mechanisms for global cooperation on critical minerals

International cooperation is essential to realize the promise of critical minerals in advancing sustainable development and addressing climate change, particularly in view of the urgent need to accelerate the energy transition. Such cooperation must be aimed at ensuring that the supply of these resources across the world is adequate, equitable, and secure and that prior adverse experiences are avoided. This approach must curb illicit financial flows and prioritize support for mineral-rich developing countries that will enable them to maximize the economic and social benefits while minimizing environmental damage. Developing countries that do not possess significant resource endowments should also be able to benefit through value chain participation and the acceleration of their own energy transition. Measures would include facilitating access to technology, bridging financing and investment gaps, and developing institutional capacities. Existing initiatives for global cooperation in these areas need to be brought into a cohesive and focused system of support.

Strengthening multilateral frameworks and partnerships

Recognizing these needs, regional and global multilateral institutions have intensified their efforts in recent years to strengthen international cooperation on critical minerals. In April 2024, the Secretary-General of the United Nations established the Panel on Critical Energy Transition Minerals, bringing together Governments, intergovernmental and international organizations, industry stakeholders, and civil society organizations to foster trust, guide a just transition, and accelerate the shift towards renewable energy (UN DESA, 2024). Building on the work of existing United Nations initiatives, the Panel developed a set of seven guiding principles and five actionable recommendations to ensure that opportunities to advance the global energy transition are pursued with equity, justice and sustainability (United Nations, 2024b).[39]

The 2024 Panel report on resourcing the energy transition highlights the commitment to mobilizing and strengthening multi-stakeholder cooperation focused on "non-discriminatory trade and investment, fair taxation to secure public revenues for industrial development and value addition, access to finance … [and] access to energy and support for the energy transition in developing countries" (United Nations, 2024a, p. 23). The Panel recommendations—which helped shape discussions at the recent Conference of the Parties to the United Nations Framework Convention on Climate Change in Baku, Azerbaijan—are expected to provide essential guardrails for the energy transition. The Panel report also outlines principles for fairness, transparency, investment, sustainability, and human rights—not just where minerals are mined, but along the entire critical minerals value chain. The recommendations include the establishment of a high-level expert advisory group to facilitate multi-stakeholder policy dialogue and coordination on economic issues in mineral value chains; a global traceability, transparency and accountability framework; a global mining legacy fund; an initiative that empowers artisanal and small-scale miners; and equitable targets and timelines to strengthen material efficiency and circularity.

Strengthening multilateral trade cooperation on critical minerals is now more important than ever. Unilateral trade restrictions and broader geoeconomic fragmentation threaten to drive up prices and limit availability, thereby delaying the energy transition and imposing immense additional costs across the world. The WTO recognizes that the ongoing trade tensions can potentially disrupt established supply chains for renewable energy technologies (RIGVC-UIBE and others, 2023). These disruptions can reduce investments in these technologies and slow the pace of decarbonization efforts. Within the WTO, carefully negotiated rules that liberalize trade while also incorporating environmental and social considerations and enabling developing countries to secure greater value from their resources can promote the more sustainable and inclusive development of mineral supply chains, ultimately benefiting all stakeholders.

International cooperation is also essential for preventing illicit financial flows. Collaborative frameworks can enable countries to share data, enhance regulatory practices, and strengthen enforcement mechanisms. A key multi-stakeholder endeavour is the Extractive Industries Transparency Initiative (EITI), which is being implemented by more than 50 countries worldwide and is engaged in efforts aimed at improving governance of, and increasing financial transparency within, the oil, gas and mineral sectors.[40] At the multilateral level, SDG target 16.4 calls on Governments to "significantly reduce illicit financial and arms flows, strengthen recovery and return of stolen assets, and combat all forms of organized crime" by 2030. United Nations agencies, most notably UNCTAD and the United Nations Office on Drugs and Crime—the custodians of the associated SDG indicators—support the efforts of member States to track and curb illicit financial flows. The two entities are currently developing a comprehensive statistical framework to compile estimates for total inward and outward illicit

39 It is noted in the Panel report that "the outcome of this process will overlay and complement the work of the UN Secretary-General's Working Group on Transforming the Extractive Industries for Sustainable Development", which was created in 2022 and leads the Critical Energy Transition Minerals Initiative (United Nations, 2024a).

40 Since the creation of EITI in 2003, several countries—including Liberia, Mongolia, and Nigeria—have made progress in terms of increased compliance. In February 2019, the EITI Board's second validation report on Nigeria highlighted data from the Nigeria Extractive Industries Transparency Initiative indicating that approximately $3 billion in predominantly illicit payments had been recovered (UNCTAD, 2020).

financial flows (UNCTAD SDG Pulse, 2024). Global efforts are being complemented by enhanced regional activity in this area. The Africa Initiative—a partnership between the Global Forum on Transparency and Exchange of Information for Tax Purposes, its 39 African members, and various regional and international organizations and development partners—has benefited from significant political buy-in and sustained momentum (OECD, 2024).[41] Moreover, much of the policy discussion on tax-related illicit financial flows takes place in the context of international tax norm-setting. Global norms developed with the universal participation of countries can play a crucial role in curbing illicit financial flows. It will also be important to help developing countries address aggressive tax avoidance, which is a significant element of such flows.[42]

International cooperation can help bolster market transparency and price stability in raw materials markets, facilitating a more predictable investment climate and unlocking increased private sector financing. In a recent industry survey of critical minerals markets, about one third of the respondents identified Governments as playing a decisive role in ensuring transparency in pricing (State of Play, 2023). Krol-Sinclair (2023) argues that limiting the extent of "over-the-counter" transactions—which are directly conducted between two parties—and strengthening the role of international commodity exchanges would improve transparency and enhance liquidity. Deeper derivative markets can also support liquidity, but efforts are needed to prevent excessive speculation that can lead to commodity prices becoming unhinged from their economic value (Epper, Handler and Bazilian, 2024). Majkut and others (2023) emphasize that international cooperation among key players is essential for establishing reliable price benchmarks. This can be achieved by innovating market technologies and requiring traders to disclose more information about their over-the-counter trades.

The idea of intergovernmental coordination to help stabilize prices of critical minerals has drawn support from both academics (such as Goldman and others, 2024) and industry (McClements, 2024). Proposed interventions include price insurance programmes for producers, the implementation of price floors and ceilings, strategic stockpiling, and other supply management strategies. However, any proposals for similar measures in the critical minerals sector must carefully consider the potential downsides of heavy-handed government intervention, including the distortion of incentives and the weakening of essential price mechanisms that balance supply and demand (Heil, 2021).

South-South cooperation can be important in enhancing technological capacity, adopting sustainable practices, strengthening governance and channeling finance. For example, the African Mining Vision, launched by the African Union, encourages African nations to collaborate on policies that promote value addition, sustainable mining practices, and equitable benefit-sharing. Meanwhile, the Renewable Energy Manufacturing Initiative—supported by Governments, multilateral agencies, private foundations and other stakeholders—aims to increase the renewable energy manufacturing capacity of Africa and South-East Asia through South-South cooperation.

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41 The recently released *Tax Transparency in Africa 2024* report shows that African countries are starting to reap the benefits of improved tax transparency and information exchange (OECD, 2024).

42 UN DESA has long supported the United Nations Committee of Experts on International Cooperation in Tax Matters. In August 2024, the Ad Hoc Committee to Develop Terms of Reference for a United Nations Framework Convention on International Tax Cooperation included tax-related illicit financial flows as a potential topic for one of two initial protocols. The General Assembly is reviewing a draft resolution to adopt the terms of reference and establish a negotiating committee, which will determine the focus of the second protocol in February 2025, aiming to complete work by September 2027. UN DESA has also launched a four-year project (2024–2027) to help developing countries address aggressive tax avoidance, which is a significant element of illicit financial flows. Insights from this project will guide the Committee of Experts and future intergovernmental work on tax cooperation, pending further direction from the General Assembly.

Supporting developing countries

Strategic international partnerships that promote technology transfer, skills development, and the involvement of domestic firms in downstream processing represent a key priority for countries rich in critical minerals. International cooperation can support technology transfer in several ways, in particular by strengthening contract negotiation capacities, enhancing innovation ecosystems, and expanding access to data-driven technologies.

Institutional capabilities

Among developing countries, building robust institutional capabilities is essential for unlocking the full potential of critical minerals. Iizuka, Pietrobelli and Vargas (2022) highlight insufficient knowledge within local and national innovation systems as a factor inhibiting the upgrading of technology for mining suppliers in Latin America. International cooperation can play a key role in building these capabilities, providing increased access to technical expertise, financial assistance, and opportunities for sharing knowledge and policy experience.

Developing countries face distinct challenges, and capacity-building efforts must target specific priorities. Middle-income countries need to focus on advancing technological capabilities, fostering innovation ecosystems, and strengthening downstream activities. Therefore, policy efforts should prioritize building domestic technological capabilities, promoting R&D investment, and ensuring transparent governance to manage environmental and social impacts effectively. To support these efforts, international cooperation should focus on providing technical expertise and promoting technology transfer to foster value addition and industrial upgrading. Multilateral development banks and international institutions can play a key role in supporting innovation and attracting private investments in these countries. Meanwhile, low-income countries confront more structural barriers, including weak governance structures, limited infrastructure, and a lack of human capital. Building institutional capacity in these countries requires a focus on establishing transparent governance frameworks and building basic public sector capabilities. Ensuring that environmental and social standards are in place is crucial for preventing corruption and environmental degradation. Given their relatively limited resources, these economies also need stronger international support to bridge infrastructure gaps and develop resource management practices, which can help them align the development of the critical minerals sector with the SDGs. Broadly speaking, recognizing the distinct needs of developing economies will allow international cooperation efforts to be more strategically and effectively directed towards supporting institutional capacity-building, enabling all countries to harness the potential of critical minerals for sustainable development.

Contract negotiations

International cooperation is critical for addressing knowledge and capacity asymmetries in business dealings and, more specifically, for helping developing countries negotiate fairer contracts with foreign mining firms. Soulé (2024) highlights the need to mobilize external negotiating capacity (including lawyers, trade and contract negotiators, and representatives of non-governmental organizations) and notes that countries with a clear and coherent set of development objectives are more likely to prioritize developmental clauses (including local supplier development, knowledge transfer, and training) in the contracts. In 2005, the International Institute for Sustainable Development published the IISD Model International Agreement on Investment for Sustainable Development (Mann, Howard and others, 2006), which proposed technology transfer as a provision under the article on assistance and facilitation for foreign investment. In 2019, Morrocco released a new model bilateral investment treaty based on guidance from IISD and UNCTAD which incorporates human capital development and technology transfer as key measures for host country advancement. As a positive example of cooperation for knowledge-sharing, Chilean mining company Codelco and BHP signed a five-year innovation agreement in 2023 to establish a joint framework for sustainable mining. In general, however, intellectual property protection measures within traditional mining contracts remain robust, requiring firms to purchase know-how, for instance, through technical assistance services (Blundi and others, 2022), which can create opportunities for non-transparent transfer pricing and illicit financial flows. In terms of targeted initiatives, the World Bank has supported Burkina Faso and the United Republic of Tanzania in developing legal and institutional capacities (World Bank, 2015), and the African Minerals Development Centre has created a capacity-building programme on contract negotiations in some African countries. These programmes and connections signal a move in the right direction; however, beyond the work of IISD and UNCTAD, current efforts to address the asymmetries in legal and institutional capacity remain limited in scale and scope.

Innovation capabilities and artificial-intelligence-supported open-source technologies

Developing countries face significant structural deficiencies in their national innovation systems, constraining their ability to move towards more local value-added and downstream activities. Global cooperation aimed at strengthening innovation ecosystems in these economies remains limited and is often characterized by fragmented efforts and a lack of coordinated strategies. Existing initiatives and partnerships tend to be sporadic, short-term, and narrowly focused on specific projects rather than fostering comprehensive, long-term innovation capacity. Many partnerships between entities from developed and developing economies do not sufficiently address critical issues such as technology transfer. To fill this gap, the United Nations and other multilateral entities are actively supporting innovation capacity-building in mineral-rich countries. The United Nations Technology Bank for the Least Developed Countries emphasizes building science, technology, and innovation capacities, while the World Bank Climate-Smart Mining Initiative offers technical support to help countries adopt climate-friendly mining practices and technologies.[43] However, to maximize the impact of these efforts, more robust and sustainable funding is required.

The increasing availability of open-source geospatial data interfaces and artificial intelligence (AI) protocols for analysis offers a significant opportunity for developing economies to strengthen their exploration capacities. Access to these technologies would allow countries rich in critical minerals to more accurately estimate the size and value of their deposits, providing them with strategic advantages in exploration efforts, particularly in attracting investment projects and negotiating favourable terms. As noted by Signé (2021), the digitalization of mining data can also help identify additional deposits and extend the life cycle of a mine. Lu (2024) highlights the potential of AI for supporting critical-mineral exploration efforts.[44] QGIS, a widely recognized open-source geographic information system tool, offers specific guidance and functionalities designed to facilitate its use in mineral exploration; this tool has been utilized by geologists in Angola and other developing countries (Boxer, 2024; Feria and others, 2022). The European Union has funded the Exploration Information System project, which aims to develop a joint tool to enhance exploration efforts, intended for release under the QGIS framework.

43 Other initiatives include the UNCTAD science, technology and innovation policy (STIP) reviews and UNESCO Global Observatory of Science, Technology, and Innovation Policy Instruments (GO-SPIN).

44 KoBold Metals, a technology company, has successfully utilized AI-based technology to identify new copper deposits in Zambia, paving the way for impactful new technology-driven discoveries (Bearak, 2024).

Price differentiation to incentivize environmental footprint reduction

International cooperation in establishing environmental footprint standards can support price differentiation for critical minerals, promoting sustainable practices in mining while ensuring fair market access for producers from both developed and developing economies. This can also enhance transparency, with multiple market segments for products encouraging the adoption of more environment-friendly practices. This approach is already being explored—most notably in the nickel industry. Recently, several key market players, including the Government of Australia and major mining corporations, have advocated for the establishment of "green nickel" as a distinct product to be traded on the London Metal Exchange. This differentiation aims to incentivize lower-carbon methods by commanding premium prices for sustainable practices.

Realizing this goal will require careful consideration of definitions and verification frameworks to prevent greenwashing and ensure that mining companies actually adhere to strict emission standards to achieve such designations. In this context, international support for developing countries will remain essential to align local production with global standards without creating unfair disadvantages. International partnerships should focus on technical assistance, knowledge-sharing, and financial support to help these economies adopt sustainable practices and build effective regulatory frameworks.

New financing initiatives from multilateral development banks

Hawser (2024) notes that because of the heavy environmental footprint of mining, there is limited appetite among commercial banks to invest in the critical minerals sector. While multilateral development banks (MDBs) have started to increase support for critical minerals supply chains, their efforts have thus far been modest in scale and ambition.[45] However, MDBs can play a crucial role in facilitating more robust social and environmental due-diligence processes. To make a meaningful contribution to securing the necessary resources, MDBs will need to significantly increase investments in upstream mining and processing. In mid-2024, the World Bank initiated a one-stop-shop guarantee scheme—a significant simplification of its regular process—to streamline all guarantee reviews, improve access to guarantee instruments, and focus resources on high-impact projects. This is expected to help de-risk investments in critical minerals projects. The critical minerals sectors will require more targeted capacity-building and technical assistance to effectively utilize the risk mitigation solutions available from the World Bank Multilateral Investment Guarantee Agency (World Bank, 2024).

Making sustainability standards fairer and more effective

As the global community accelerates its transition towards sustainable energy, the mining industry finds itself under intensifying scrutiny and increased pressure to establish and adhere to robust sustainability standards. In recent years, the landscape of sustainability standards in mining has been characterized by a proliferation of frameworks and guidelines. While this expansion partly reflects the industry's growing awareness of its responsibilities, it is mostly due to the increasing demand for transparency and ethical practices from stakeholders, including Governments, civil society organizations, communities, and investors.[46] The standards have consistently evolved, becoming more comprehensive and nuanced in addressing complex ESG challenges associated with

45 According to the *2021 Joint Report on Multilateral Development Banks' Climate Finance*, only 0.05 per cent of climate mitigation funding by reporting MDBs went into mining and metals production for climate action (African Development Bank and others, 2021).

46 The lack of community buy-in and the violation of environmental standards has undermined several large investment projects—one example being the Eco Oro gold mining project in Colombia (Center for International Environmental Law, 2017).

the industry.[47] The level of adherence to sustainability standards may substantially impact the ability of firms to benefit from government support programmes aimed at securing an adequate supply of critical minerals.[48] Regulatory initiatives such as the European Union Carbon Border Adjustment Mechanism illustrate how environmental standards are increasingly integrated into trade policies, impacting market access. Non-compliance with emerging carbon and sustainability standards could impose additional costs or limit access to markets, creating barriers for small mining firms from developing countries in particular.

Although progress has been achieved across various dimensions, the mining industry continues to face major challenges linked to international sustainability standards. The heterogeneity of standards and frameworks makes it difficult to compare sustainability performance across different mining operations and companies, leading to inconsistency in evaluations and reporting. The fragmentation and complexity of standards also impose a significant financial burden on companies, creating an uneven playing field that disproportionately affects junior mining companies, particularly in developing countries. Many small mining companies struggle with high costs and insufficient technical and administrative capacity to navigate complex certification and standards requirements. This often leads to non-compliance and missed market opportunities as these companies find themselves excluded from international supply chains (Rudžionienė and Brazdžius, 2023). Such dynamics perpetuate a cycle of disadvantage, enabling larger corporations with greater resources to dominate the market and set the pace for sustainable practices.[49]

Significant challenges in the implementation of sustainability standards and the lack of enforceability represent key obstacles to achieving genuine progress in responsible mining. Without robust enforcement mechanisms, firms may engage in greenwashing, publicly claiming adherence to sustainability practices while failing to implement meaningful changes on the ground. International cooperation in harmonizing and aligning sustainability standards can be essential for streamlining reporting requirements and enhancing the transparency and comparability of practices across the industry (ECCO, 2023). In January 2024, the Global Reporting Initiative launched a new sustainability standard for the mining sector that applies to all organizations involved in mining and quarrying. The standard, which will enter into effect on 1 January 2026, was developed by a working group that included representatives from businesses, civil society, labour unions, mediating institutions, and investors. Importantly, it incorporated inputs from other key industry standards.

Global sustainability standards must include implementation mechanisms that do not disproportionately disadvantage small mining operations in developing countries. To address these challenges, partnerships between Governments, non-governmental organizations, and the private sector should focus on developing adaptable frameworks and practical support mechanisms that enable such firms to meet sustainability requirements. This would promote inclusivity and enable equitable participation in the critical minerals sector and would make the critical minerals sector in developing countries more socially and environmentally sustainable and globally competitive.

47 Annex table provides an overview of selected key intergovernmental, multi-stakeholder, and industry standards and guidelines relevant for the mining sector.

48 The European Union critical raw materials act establishes a framework in which industry sustainability requirements must be recognized as a prerequisite for accessing government support.

49 In a global survey covering 16,423 small and medium-sized enterprises in 16 countries, 73 per cent of the respondents expressed concerns about the up-front costs of reporting, and 65 per cent stated that current reporting standards were too complex (Sage, 2023).

Annex

Selected key sustainability standards and guidelines relevant for the mining industry

Entity	Description	Standards/guidelines
Multi-stakeholder		
Extractive Industries Transparency Initiative (EITI)	Promotes transparency and accountability in the management of oil, gas, and mineral resources	EITI Standard
OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas	Provides recommendations to help companies respect human rights and avoid contributing to conflict through their mineral sourcing practices	OECD Guidelines for Multinational Enterprises on Responsible Business Conduct
Initiative for Responsible Mining Assurance (IRMA)	Establishes a multi-stakeholder and independently verified responsible mining assurance system	IRMA Standard for Responsible Mining
Industry and non-governmental organizations		
Towards Sustainable Mining (TSM)	A sustainability programme that supports mining companies in managing key environmental and social risks	TSM Guiding Principles and Protocols
Global Reporting Initiative (GRI)	Helps businesses and Governments worldwide understand and communicate their impact on critical sustainability issues	GRI Universal Standard GRI Sector Standard for Mining
International Council on Mining and Metals (ICMM)	Enhances environmental and social performance in the mining and metals industry	ICMM Principles and Position Statements
Responsible Minerals Initiative (RMI)	Promotes responsible sourcing of minerals globally from conflict-affected and high-risk areas	RMI Standards (per metal) ESG Standard for Mineral Supply Chains
Consolidated Mining Standard Initiative (CMSI)	Aims to consolidate multiple voluntary responsible mining standards into a single global standard	Under development
Intergovernmental		
United Nations Secretary-General's Panel on Critical Energy Transition Minerals	Launched in April 2024 by the Secretary-General of the United Nations; establishes a set of voluntary principles guiding sustainable extraction of critical energy transition minerals	Set of 7 Guiding Principles
United Nations Global Compact	The world's largest corporate sustainability initiative, guiding companies in the alignment of strategies and operations with universal principles on human rights, labour, environment, and anti-corruption	The Ten Principles of the UN Global Compact

Source: UN DESA.

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