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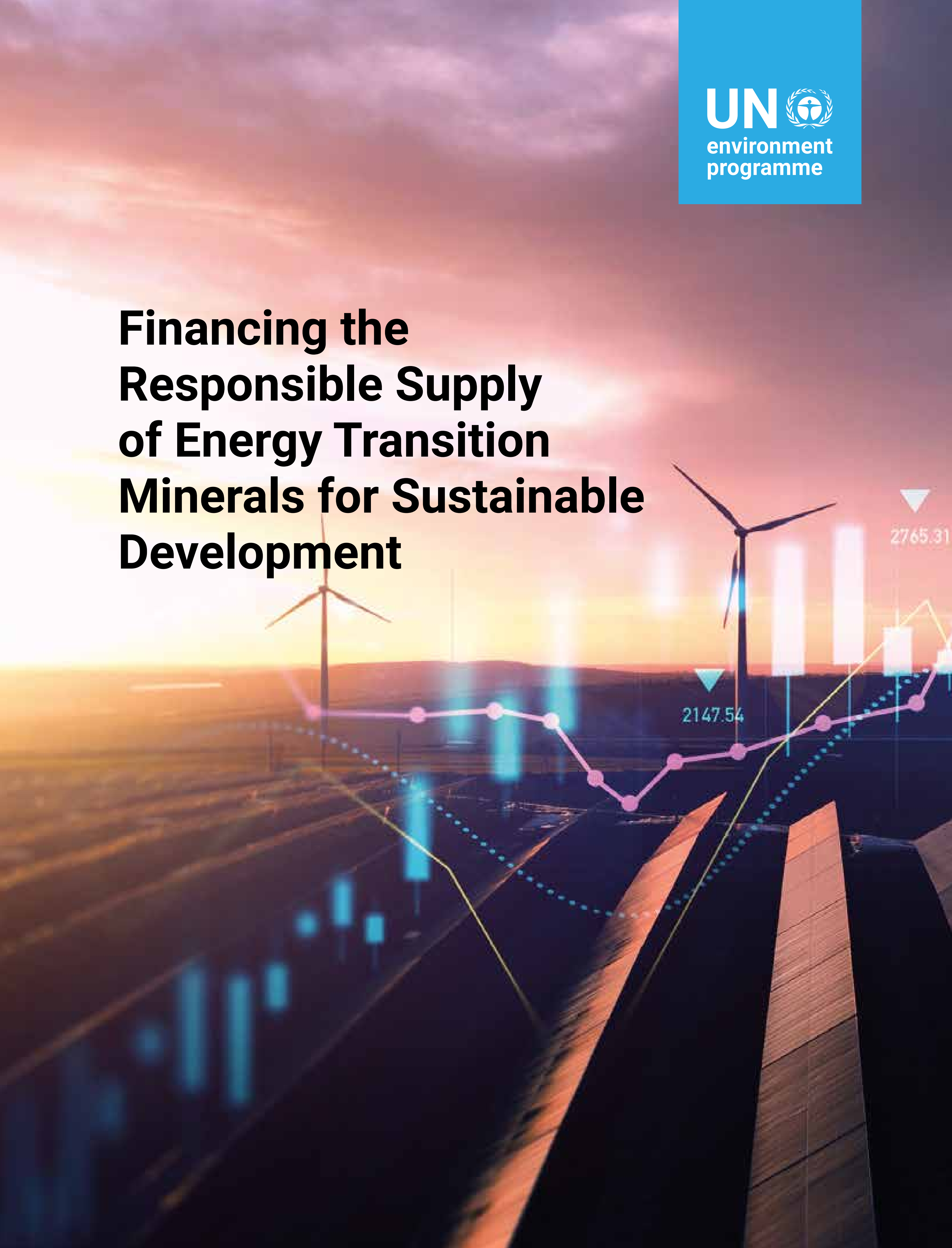
Financing the Responsible Supply of Energy Transition Minerals for Sustainable Development



International Resource Panel

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LIST OF ABBREVIATIONS

ASEAN	Association of Southeast Asian Nations
ASM	artisanal and small-scale mining
COP	United Nations Climate Change Conference of the Parties
EPFI	Equator Principles Financial Institutions
ECLAC	Economic Commission for Latin America and the Caribbean
ESG	environmental, social and governance
EV	electric vehicles
FDI	foreign direct investment
GHG	greenhouse gas
GRI	Global Reporting Initiative
ICMM	International Council on Mining and Metals
IEA	International Energy Agency
IFC	International Finance Corporation
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IRMA	Initiative for Responsible Mining Assurance
IRP	International Resource Panel
ILO	International Labour Organization
ISO	International Organization for Standardization
LCET	low-carbon energy technology/ies
LME	London Metal Exchange
MMSD	Mining, Minerals and Sustainable Development
MW	megawatt
NGFS	Network for Greening the Financial System
NZIA	Net-Zero Insurance Alliance
OECD	Organization for Economic Cooperation and Development
PGMs	platinum group metals
PRB	Principles for Responsible Banking
RMB	Chinese yuan renminbi
RMI	Responsible Mining Index
SCP	Sustainable Consumption and Production
SDGs	Sustainable Development Goals
SDLO	Sustainable Development Licence to Operate
SMEs	Small and medium-sized enterprises
TCFD	Task Force on Climate-related Financial Disclosures
TNFD	Task Force on Nature-related Financial Disclosures
UNEP	United Nations Environment Programme
UNEP FI	United Nations Environment Programme Finance Initiative
USGS	United States Geological Survey
WEEE	waste electrical and electronic equipment
WTO	World Trade organization

GLOSSARY

Advanced exploration: Advanced exploration relates to the later part of stage 2 (if early-stage exploration results justify the intensification of the exploration effort) and to stages 3 and 4 of figure 5.7. It includes the use of heavy machinery such as diamond-drilling rigs or tunneling activities. It uses the techniques mentioned under “early-stage exploration”, in addition to diamond drilling, trenching and tunnelling (if justified), down-the-hole geophysics, three-dimensional digital orebody modelling, the collection of one or several bulk samples and the performance of ore-processing pilot-scale tests, geotechnical and water resources assessment, mine planning, early engineering studies, environmental and social impact assessments, the preparation of strategic environmental management plans and economic modelling. A stepwise approach is used to assess the merits of the project in view of the extra investment needed to begin a new step. If warranted, advanced exploration leads to the preparation of a feasibility study.

Brownfield exploration: In mineral exploitation, “brownfield exploration” designates exploration in areas near already known mineral deposits or exploration for lateral or in-depth extensions of known deposits.

By-product: In some ores, it may be the case that two or more metals are present, but only one has sufficient value to economically justify the investment needed to mine and process that ore. By-products are any other metals incidentally present that may or may not be documented in feasibility studies. By-products may or may not be recovered during ore processing or, mostly, metallurgy and refining. On a case-by-case basis, mining companies may perceive additional income from the presence in ore concentrates of specific by-products (e.g. gold present in some copper ore concentrates) that they can sell to smelters. Payments received by mining companies for their by-product(s) are designated “by-product credits”. Some unwanted by-products (e.g. arsenic) that are above accepted thresholds may also translate into penalties applied to the concentrate price paid by smelters to miners.

Co-product: In some ores, two metals can be present, each with sufficient value to economically justify the investment needed in the mining and metallurgical recovery of that metal. In this specific case each of these metals is a co-product of the other. A well-documented example of a co-product case are the copper-cobalt deposits in the Democratic Republic of the Congo.

Construction minerals: Typical construction minerals are aggregates (sand, gravel and crushed natural stone), various brick clays, gypsum and natural ornamental or dimension stone

Dutch disease: The expression “Dutch disease” describes the various negative impacts on the Dutch economy (inflation, rising value of the local currency (hampering exports) and surging labour costs) that arose as a consequence of the discovery and rapid development of the Groningen gas fields in the Netherlands in the early 1960s. The expression was coined by the British journal The Economist.

Early-stage exploration: Early-stage exploration consists of activities relating to stage 1 and the early part of stage 2 of figure 5.7, excluding the use of heavy machinery such as diamond-drilling rigs or tunneling activities. It may include any combination of the following techniques: bibliographic analysis and compilation; airborne and satellite imagery compilation; field mapping and sampling; geochemical sampling; mineralogical, petrographic and age determinations; trenching; airborne geophysical data acquisition; light detection and ranging (LIDAR) surveys; hyperspectral surveys; and three-dimensional digital modelling

Exploration: This refers to all activities related to the search for new mineral deposits and the related development activities up to the completed feasibility study.

Feasibility study: A feasibility study is a comprehensive technical and economic study of the selected development option for a mineral project that includes appropriately detailed assessments of applicable modifying factors, together with any other relevant operational factors and detailed financial analysis needed to demonstrate, at the time of reporting, that extraction is judged (economically viable to mine). The results of the study may reasonably serve as the basis for a final decision by a proponent or financial institution to proceed with or finance the development of the project. The confidence level of the study will be higher than that of a pre-feasibility study.

Geological stocks: This refers to potential, as yet undiscovered, mineral concentrations contained in the upper part (between the surface and at a depth of +/- 3 km) that, pending successful exploration, will supply future needs (especially for metals). Tentative evaluations of geological stocks have been performed for some metals, such as copper.

Greenfield exploration: In mineral exploitation, "greenfield exploration" designates exploration in areas with no known mineral deposits

Home country: This is used to refer to the country where the mining company is registered. It is important to note that, with the emergence of the global value chain for minerals and metals, the distinction between home country and host country can be blurred.

Host country: This is used to designate the country where the minerals and metals are exploited. The caveat noted for "home country" also applies here.

Metallurgy: The science and art of separating metals and metallic minerals from their ores by mechanical and chemical processes; the preparation of metalliferous materials from raw ore (United States Bureau of Mines). Note: biological processes, such as bacterial leaching, may also be used to recover metals from certain ores. In this report, the use of the term includes the closely related refining activities needed to purify the raw metal obtained from the metallurgical process in order to meet required metal purity standards.

Metals: In most cases, a metal is an opaque, lustrous, elemental substance that is a good conductor of heat and electricity. It is also malleable and ductile, possesses high melting and boiling points, and tends to form positive ions in chemical compounds (United States Bureau of Mines). For the sake of simplicity, in this report the expression "metals" includes metalloids as these mostly occur as by-products of metals and are recovered during the metallurgy or refining processing of metallic ores.

Mineral deposits: A geological concentration of minerals of proven economic value.

Mineral reserve: "A Mineral Reserve is the economically mineable part of a measured and/or Indicated Mineral Resource. It includes diluting materials and allowances for losses, which may occur when the material is mined or extracted and is defined by studies at pre-feasibility or feasibility level as appropriate that include application of Modifying Factors. Such studies demonstrate that, at the time of reporting, extraction could reasonably be justified." Definition by the Canadian Institute of Mining, Metallurgy and Petroleum (2014, available at: https://mrmr.cim.org/media/1128/cim-definition-standards_2014.pdf). Reserves are reported as probable or proven in order of increasing certainty.

Mineral resource: "A Mineral Resource is a concentration or occurrence of solid material of economic interest in or on the earth's crust in such form, grade or quality and quantity that there are reasonable prospects for eventual economic extraction. The location, quantity, grade or quality, continuity and other geological characteristics of a Mineral Resource are known, estimated or interpreted from specific geological evidence and knowledge, including sampling." Definition by the Canadian Institute of Mining, Metallurgy and Petroleum (2014). Mineral resources are reported as inferred, indicated or measured in order of increasing certainty.

Mining: The science, technique and business of mineral discovery and exploitation. Strictly speaking, the word denotes underground work aimed at the severance and treatment of ore or associated rock. Practically, it includes opencast work, quarrying, alluvial dredging and combined operations, including surface and underground attack and ore treatment (United States Bureau of Mines).

Modifying factor: According to the Definition Standards for Mineral Resources and Reserves of the Canadian Institute of Mining, Metallurgy and Petroleum (2014) "modifying Factors are considerations used to convert Mineral Resources to Mineral Reserves. These include, but are not restricted to, mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governmental factors."

Ore: An assemblage of minerals from which at least one economically valuable substance, most frequently a metal (such as copper, gallium, gold, iron or zinc), can be extracted further to chemical or physical processing of the ore (see the terms 'ore processing' and 'metallurgy'). Typically, an ore comprises several minerals ('ore minerals') of which only one, or a few, have an economic value. All other minerals have no economic value.

Ore processing: (equivalent to 'ore beneficiation' or 'ore dressing', frequently found in the relevant literature): Especially for the production of metals, ore processing tends to be a specific combination of biological, chemical or physical processes needed to separate the economically valuable ore minerals from the other valueless minerals present in the ore. This separation results in the production of a concentrate of economic minerals and ore-processing waste that will have to be disposed of in the form of tailings (in specifically engineered reservoirs called tailing ponds).

In the case of construction materials, such as sand and gravel, processing is frequently limited to some crushing, sorting and washing operations.

Pre-feasibility study: A pre-feasibility study is a comprehensive study of a range of options for the technical and economic viability of a mineral project that has advanced to a stage where a preferred mining method (for underground mining) or the pit configuration (for an open pit) has been established and an effective method of mineral processing has been determined. It includes a financial analysis based on reasonable assumptions of the modifying factors and the evaluation of any other relevant factors that are sufficient for a qualified person, acting reasonably, to determine whether all or part of the mineral resource may be converted to a mineral reserve at the time of reporting. A pre-feasibility study is at a lower level of confidence than a feasibility study.

Refining: The purification of crude metallic products (United States Bureau of Mines). This activity is closely related to metallurgy, and is aimed at removing residual impurities contained in metallic melts and meeting market specifications on maximum allowed impurities.

Resource curse: Negative relationship described by several authors between resource abundance and poor economic, environmental or social performance, arising from an emphasis on exports and a failure to invest the resulting foreign exchange productively.

Responsible mining: Responsible mining or, rather, the responsible production of minerals and metals can be defined by the industrial and institutional rules, procedures and operational practice that align, at the level of individual production sites, to meet society's needs for minerals and metals, ensuring economic returns for investors and enterprises without causing unsustainable environmental and social harm as a result of production activities or their legacies after the end of such activities. Responsible mining strives to deliver the United Nations Sustainable Development Goals. Verifiable and auditable stakeholder integration and public reporting on production activities in a format conformable with international standards, such as the Standard for Responsible Mining (https://responsiblemining.net/resources/#full-documentation-and-guidance) developed by the Initiative for Responsible Mining Assurance, are important components to achieving recognition as a responsible mining (or metallurgical or metal refining) site.

Resource nationalism: Resource nationalism can take multiple forms. It can be defined as anti-competitive behaviour by individual nations, designed to restrict the international supply of a natural resource, for instance to maximize the added value generated on their territories. It can also be a politically driven means of exerting control over supply chains, depending on the specific minerals and metals involved, through financial control of key producing countries, generally in order to develop a competitive advantage or geopolitical leverage. Resource nationalism is frequently expressed by tariff and non-tariff barriers restricting the free trade of minerals and metals. Resource nationalism is likely to have a greater effect on the global terms of trade when a natural resource is only produced in a few countries. In these markets, countries can affect global prices for raw materials and have the most to gain from resource nationalism. In these cases, the main producers (companies or countries) may act together to manipulate global prices.

Sovereign wealth fund: This is resource revenue that is sequestered in a special fund by mineral-rich countries. These special-purpose financial vehicles are aimed at helping to ensure the proper management of resource revenues. Sovereign wealth funds can have a number of components that may include: a stabilization fund, which captures in excess a pre-determined commodity price (used to project flows for budget purposes) and releases these funds to support the budget when the price falls below the predetermined price; a development fund that captures a portion of the resource flows and puts them in a fund to focus on long-term projects such as infrastructure; and a heritage fund, which captures the resources and saves them for future generations. These funds are long-term investments to be drawn by future generations.

Sustainable development licence to operate: The sustainable development licence to operate is a project-specific, formalized governance framework to support the contribution of individual projects in the minerals and metals industry to the achievement of the Sustainable Development Goals and other international policy commitments. It argues for moving away from the amorphous and metaphorical nature of the social license to operate and the sectorial and one-dimensional nature of existing governance instruments. It consists of an integrated and inclusive approach that should be formally adopted by all stakeholders in individual operations, premised on the need for positive economic, social and environmental outcomes.

The sustainable development licence to operate is applicable to governments, companies, local populations and all other stakeholders involved in the mining sector. It forms an essential reference framework for evaluating the later environmental, social and governance performance of projects and companies.

The concept of the sustainable development licence to operate and its principles are detailed in the International Resource Panel (2020) report Mineral Resource Governance in the 21st Century.

Third sector: Civil society, research institutions, local communities, non-governmental organizations, concerned citizens, consumers, workforces and labour groups.

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FOREWORD

Achieving the 1.5°C climate target is no longer a matter of choice, but a critical necessity. 2024 has been confirmed as the warmest year on record, with global temperatures averaging approximately 1.5°C above pre-industrial levels. This marks the continuation of the trend where the past decade 2015-2024, has been the hottest ever recorded. Unsustainable consumption and production have strained our planet's finite resources, exacerbating global inequalities and undermining ecosystems that we all depend on. A global sustainable energy transition is crucial to stay within the 1.5-degree climate goal and achieve the SDGs, but it hinges on meeting the increasing demand for critical energy transition minerals such as lithium, cobalt, and copper. In 2023 alone, the demand for minerals such as nickel, cobalt, graphite, and rare earth elements saw increases of 8 per cent to 15 per cent.

This report shows that an increase in demand for energy transition minerals will require a financial investment in their production of up to US$450 billion from 2022-2030 and up to US$800 billion by 2040. Such investment will need to take social and environmental, as well as financial, outcomes into account to promote more responsible mining practices. This means ensuring that mineral supplies are secured, without compromising the environment or infringing upon human rights. This involves safeguarding Indigenous Peoples lands and rights, tackling energy poverty, and preventing water pollution, land degradation, and ecological destruction.

The significance of responsible mining and minerals' management across their entire value chain has led to the development of key principles set forth by the UN Secretary-General's Panel on Critical Energy Transition Minerals. In their report, "Resourcing the Energy Transition: principles to guide critical energy transition minerals towards equity and justice" the Panel highlights recommendations emphasising fairness, transparency, investment, sustainability and human rights.

To achieve these goals, comprehensive reforms in both the mining and finance sectors will be required to foster sustainable production practices. These reforms should accelerate the adoption of circular economy strategies and resource efficiency, crucial to managing the demand for primary minerals. Mutually beneficial partnerships between the communities and countries that host the mines and the importing and processing countries, based on the equitable sharing of benefits, are essential to address concerns about geopolitical security of transition minerals supply chains. In addition, efforts should focus on improving security, skills, working conditions, miners' incomes and gender equality related to all mining and especially to artisanal and small-scale mining. Finally, the report highlights the importance of international cooperation, without which the energy transition we aspire to is unlikely to succeed.

The International Resource Panel's findings reinforce and guide the uptake of the principles by the UN Secretary-General's Panel. UNEP and partners will prioritize efforts to advance the outcomes of the UN Secretary General's Panel, including responsible investment, transparency, accountability, circularity and material efficiency, and multilateral cooperation. I urge all stakeholders within the finance, mining, and industry sectors to commit to an environmentally and socially just transition. Together, we can ensure that the benefits of resource extraction are equitably shared, promoting the wellbeing of both people and the planet.

Sheila Aggarwal-Khan
Industry and Economy
Division Director

PREFACE

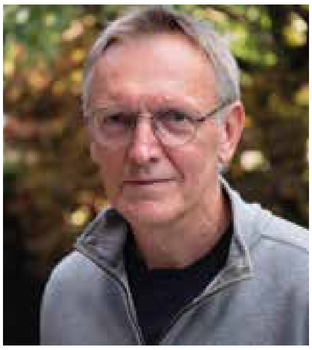
Minerals and metals are essential materials in our lives and play a critical role in driving economic, social, and technological development. As the world transitions to sustainable development and the achievement of net-zero emissions by 2050, which requires a significant shift in energy systems towards clean energy technologies, the demand for specific minerals and metals, such as lithium, nickel, and copper, is surging. These minerals are crucial for the development of batteries, solar panels, and electric vehicle, and therefore are central to clean energy technologies and to enabling the energy transition.

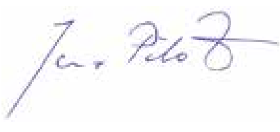
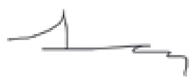
However, the intensifying demand for energy transition minerals poses significant challenges for the environment and the local communities where mining occurs. Without transformative changes to mining practices, this demand could amplify the negative consequences historically associated with extractive industries.

The International Resource Panel (IRP) has addressed some of these challenges in earlier reports including the Enabling the Energy Transition. This report outlines three key strategies for managing the demand for energy transition minerals and metals: reducing demand drivers, integrating circular economy principles, and ensuring that the supply of these materials adheres to rigorous environmental and social standards. Furthermore, the IRP's 2020 report, Mineral Resource Governance in the 21st Century: Gearing Extractive Industries Towards Sustainable Development, highlighted the need for strong governance to address the environmental and social challenges posed by mining. It advocated for a shift from the traditional "social license to operate" model toward a new governance framework—the "sustainable development license to operate". This new framework ensures that decisions in the extractive industry are in line with the 2030 Agenda for Sustainable Development, fostering shared benefits for all parties involved.

Building upon this foundation, the IRP has developed this new report: Financing the Responsible Supply of Energy Transition Minerals for Sustainable Development (2025). This report underscores the finance sector's pivotal role in fostering responsible mining. Given the massive investments required to meet the escalating demand for energy transition minerals—from exploration and extraction to processing and refining, this is a unique opportunity to drive transformative change. The report advocates for financial reforms that prioritize environmentally and socially responsible practices, ensuring equitable economic, social, and financial benefits for all involved.

We hope that the recommendations outlined in this report inspire a shift toward an industry that advances sustainable development: by combining sustainable finance with responsible mining, the mining sector can contribute positively to local communities, host countries, and the global transition to low-carbon technologies.



Janez Potočnik and Izabella Teixeira
IRP Co-Chairs

EXECUTIVE SUMMARY AND KEY MESSAGES

Introduction

Minerals and metals make a huge contribution to global economic activity and sustainable development. They underpin many of the products and services human life and well-being now depend on.

This Report ‘Financing the Responsible Supply of Energy Transition Minerals for Sustainable Development’ looks at that part of the minerals and metals sector that is important for the transition to clean energy, as envisaged by the Paris Climate Agreement and ongoing climate negotiations. The report examines the prospective future demand for a subset of minerals and metals, called in this report ‘energy transition minerals’, or just ‘transition minerals’, such as cobalt, copper, nickel, lithium, and manganese, that is particularly important to the transition away from fossil fuels.

Supplying these “transition minerals” at the scale envisaged will require a substantial increase in investment in the mining and processing industries. However, if this growth in mining is implemented according to current mainstream practices, it will result in considerable social and environmental damage, negatively affecting the local communities and environment where the mines are located. This assessment report covers the major issues that will need to be addressed if the low-carbon energy transition is to be supplied with the minerals it needs in a timely way and responsible manner.

Key message

To achieve the low-carbon energy transition by 2050, a significant increase in the supply of “energy transition minerals” is essential. Meeting the demand for these minerals by 2030 will necessitate investment of up to US$450 billion in their production.

The report focuses on how the financing of the extraction of these minerals should be reformed to help bring about their environmentally and socially responsible production, and the equitable distribution of the resulting financial and other economic and social benefits. The report explores the scale of the challenge, in terms of both increasing the supply of primary metals, and the need to manage the demand for them through circular economy approaches and resource efficiency policies. Finally, it describes how ‘sustainable finance’ combined with ‘responsible mining’ could lead to the emergence of a mining industry that contributes to the sustainable development of local communities and countries that host the mines, and the countries that import them for their low-carbon technologies, as envisaged by the Sustainable Development Licence to Operate (SDLO, IRP 2020).

The report is organized into two parts, with a total of eight chapters. The first four Chapters (Part 1) set the scene and context for the current situation in respect of minerals and metals. Part 2 focuses on the financing of minerals and metals production.

The eight chapters aim to answer the following questions:

Chapter 1: What are the basics of mineral production and trade and the patterns in mineral-producing areas in different regions?

According to the Global Resources Outlook (2024), between 1970 and 2024 the annual global extraction of raw materials increased by a factor of three and a half, from 31 billion metric tons to 107 billion metric tons, amounting to an annual average increase of 2.3 per cent. On current trends global extraction will increase by a further 60 per cent by 2060.

During this period, the relative tonnage of the raw materials such as biomass, fossil fuel carriers, metallic and non-metallic minerals has changed. Today non-metallic minerals extraction makes up half of annual global raw material extraction, up from 31 per cent in 1970. The **share of metals in total global material extraction** grew from 9 per cent in 1970 to around 10 per cent in 2024. In absolute numbers, this is a growth from 2.6 billion to 10.6 billion metric tons, or a 2.6 per cent growth of metals extraction per year.

The global geological availability of metals and minerals, with few possible exceptions, is unlikely to be an issue. However, many of them, and the processing capacity that is required to convert them into an industrially useful form, are very concentrated in certain countries and regions of the world, including China, Africa and South America.

China has a very large variety and quantity of mineral resources. The five materials of which it contains the highest proportion of the world's reserves are tungsten (56 per cent), molybdenum (46 per cent), vanadium (43 per cent), rare earths (37 per cent), and titanium (33 per cent). China is also dominant in the processing of these and other raw materials for downstream industrial applications, including most low-carbon energy transition technologies. The Chinese government has an ambitious policy for the ecological transformation of its mining sector.

Many **African countries** have the potential to play a substantial role in the provision of transition minerals. Fourteen important transition minerals are produced in the continent and in the case of chromium, cobalt, manganese, and platinum, Africa accounts for half of world production, and for over a quarter of the world's production of bauxite and palladium. As the exploitation of these minerals gathers pace, the key question is the distribution of the costs and benefits between the various stakeholders. Potential costs, including corruption, social disruption and environmental damage, will need to be strictly controlled, while there will need to be benefits to the local community and wider national economy. Companies will need to address such issues as a priority if they are to win a 'social licence to operate', while host governments will also need to pay close attention to these issues if a mining boom from extracting transition minerals is to contribute substantially to Africa's sustainable development.

Countries in South America have important mineral reserves, with a high percentage of the world's reserves of niobium (89 per cent), lithium (47 per cent), molybdenum (33 per cent), copper (30 per cent), silver (28 per cent), tin (21 per cent), iron (19 per cent), gold and zinc (10 per cent) and bauxite (9 per cent). The mining production of South America includes a large part of all the metals and minerals produced in the world. The economic contribution of mining is essential for several economies in the region, especially for Suriname, Peru, Bolivia, Colombia, Guyana and Chile. In these countries, mining accounts for a high percentage of exports and production. For example, in 2019 mining exports were most relevant in Chile, where they accounted for 51.3 per cent of total exports, followed by Peru, with 41.9 per cent foreign direct investment in mining grew strongly from the year 2000, driven by the increase in demand for base metals in China. In the future, it is expected to continue growing, driven by the increased demand for the metals necessary for the energy transition, such as copper and lithium.

Because of the geological concentration of different metals in different parts of world, **trade** plays a crucial role in supplying metals to industries in those countries which do not have those resources. The length and complexity of the ensuing supply chains can be a source of vulnerability to the industries and wider economies of those countries. Reducing trade dependencies is considered important for transition metals that will be demanded in much higher quantities for the necessary rapid decarbonization of the energy systems. The report suggests that a reliable quantification of the mutual dependencies between trade partners in individual metal markets could help countries to develop more balanced trade partner portfolios and to create more resilient supply chains.

Chapter 2: What are the relevant issues in relation to investment and investors?

Mining will need to attract very large quantities of financial capital to meet the projected demand for transition minerals. The great majority of this investment will need to come from the private sector and will only flow to mining if it offers the requisite balance between risk and return. So, the most important factor influencing investment in mining is current and expected future mineral prices, which are largely set globally but influenced by many factors. They include supply shocks, shifts in demand, macroeconomic conditions, currency fluctuations, geopolitical events, production and technology costs, government regulations, speculation, scams, and investment itself – in mineral exploration, mining, ore processing, metallurgy and in the required flanking sectoral public institutions, including those dealing with research and innovation. How these factors in aggregate influence global prices is still not well understood.

Supply and demand fundamentals are very important, but these signals can be obscured by geopolitical issues and speculation in financial markets. The long lead times from exploration to production, and possible shifts in technologies and therefore the demand for specific minerals, also increase the price uncertainties with which prospective investors and mining companies need to contend.

However, future demand for transition minerals generally seems certain to increase dramatically as a result of countries' increasing commitment to the low-carbon energy transition, running the risk of significant price increases if supply of these minerals fails to keep up with demand.

China has been investing strategically in the exploration, production and processing of transition minerals since the early years of this century, with investment being divided in different proportions over the years between private companies, and central and local government. From the late 1980s, Chinese companies have also invested heavily in mining in other countries, most notably in Australia, although since 2014, overseas mining investment by Chinese companies has declined.

In Africa, the key issues for investment are the stability of governance and policy, regulatory capacity and the skills of the labour force. Artisanal and small-scale mining (ASM) contributes a significant proportion of Africa's production of some important minerals. Illicit financial flows (IFF) are a key governance issue for many resource-rich African countries. These illicit flows rob many African countries of financial resources that should contribute to their sustainable development through investment in capacity-building, downstream industries and infrastructure.

In respect of South American countries that are important producers of minerals, this chapter focuses on their tax and royalty regimes, and the efficiency and effectiveness with which these regimes capture some proportion of the economic rents from mining for the State. It is shown that there is a balance to be struck as commodity prices change between guaranteeing a certain revenue for the State through ad valorem taxes, which in the extreme may make mining unprofitable at low prices, and taxes on profits, which will reduce State revenues when prices are low.

Chapter 3: What are the key social and environmental issues relevant to mining?

Mining companies have understood for many years that successful mining requires a 'social licence to operate'. The previous report by the International Resource Panel in 2020 recommended that this should be extended to a 'Sustainable Development Licence to Operate' (SDLO), so that mining could make a positive contribution across the economic, social and environmental dimensions included in the SDGs.

Regarding economic development, mining can play a positive role by increasing local value addition, using local goods and services and employing local people, where possible, by driving technology adoption both in mining and beyond it, and by providing infrastructure that continues to be useful beyond the life of the mine. Achieving such outcomes is not straightforward, and often requires commitment to capacity-building from local policy makers and international financial institutions.

> **Key message**
>
> **Greater focus on environmental, social, and governance issues in mining for transition materials is essential, more so than in the past.**
>
> **Responsible mining practices that secure a sustainable development licence to operate should become the standard.**

From a social perspective, mining needs to pay attention to land rights and displacement issues, as well as equity issues, such as the substantial discrimination against women in mining. The social cost of mining comes mainly from the disruption caused by forcing populations to relocate, from abuse of human rights and from conflicts caused by disruption of lifestyle and livelihoods, loss of rights to land and clean water, pollution and health concerns, and lack of representation. Local people should be properly consulted on and compensated for any detriment they may suffer from mining, and land should be restored and returned to them following the closure of a mine. These considerations are especially important in respect of indigenous people, who must have an opportunity to give prior informed consent to and have the power to refuse mining on their territories. Another equity issue is that women tend to be under-represented in mining, experience disproportionate negative impacts and face specific barriers to their involvement in it. Both corporate and public policy measures need to lead to greater gender equality.

From an environmental perspective, an understanding of the potential environmental impacts of mining activities is of paramount importance for their technical management and reduction to a socially and environmentally acceptable level. The International Resource Panel (IRP)'s *Mineral Resource Governance* report (IRP 2020) examined in detail the manifold environmental implications of mining, and measures to address them.

This report focuses particularly on mining's impacts on biodiversity, addressing which is most important when mining enters ecologically valuable and vulnerable ecosystems. The January 2024 commitment to 'nature-positive mining' by the International Council of Minerals and Metals (ICMM) illustrates how companies and industries can take responsibility to avoid degrading biodiversity and to restore ecosystems through their activities.

Chapter 4: What is the potential of recycling and wider circular economy approaches to contribute to the supply of minerals for low-carbon energy technologies?

> **Key message**
>
> **Adopting circular economy strategies and enhancing resource efficiency are crucial to managing the demand for primary minerals.**

When implemented with other circularity strategies, recycling of key minerals and metals can reduce the growth in demand for primary transition minerals. However, there are challenges which must be addressed for effective secondary production to be achieved. These challenges, presented below, can be addressed through a multifaceted approach, offering policy and business-driven approaches underpinned by financial instruments. For example: ***recycling targets*** (for whole products or for specific materials), focusing on key performance indicators, can track progress and incentivize investments in recycling infrastructure; recycling costs can be reduced through government-backed financing and extended tax provisions for recycling infrastructure, making recycling more economically viable; financial incentives for eco-design can encourage easily recyclable products; governments can finance research into new recycling technologies for transition minerals and metals; green bonds and impact investing can fund the development of recycling facilities to handle complex material streams and develop recycling systems in emerging economies, prioritizing worker safety and environmental sustainability; ***public-private partnerships***, supported by training and a mechanism of subsidies and penalties can promote less harmful recycling practices; ***public awareness*** campaigns financed by governments can promote household recycling.

In addition, the production of secondary materials could be enhanced through the creation and characterisation of a global database for former and operating mining tailings facilities to determine their potential for economically viable and sustainable metal production.

Chapter 5: How is the production of minerals and metals financed today?

Private investors play an important role in the delivery of minerals and metals to society, along with public policies and regulations in support of their investments, and the availability of public finance to create and maintain the institutional framework to develop global responsible mining. In general, and as indicated in Figure 1, different sources of finance (public, private or a mixture of both), are required for each of the stages of a mining project. For example, geological surveys mainly require public financing, exploration mainly involves equity-finance of small companies, mine construction is likely to be financed by a mixture of retained profits, loans and equity, while mine closure and remediation should be financed by ring-fenced funds accumulated during operation.

The complexities and long timescales associated with mineral production, and the large quantity of capital needed to construct a mine and start producing minerals, make mining a high-risk industry which requires high returns if it is to attract private investors.

Artisanal and small-scale mining (ASM) normally accesses finance through small-scale and often informal routes. Some formalization of ASM is likely to be required for it to be able to access more formal sources of finance to improve their economic returns and working conditions.

In addition to the development of new production facilities such as mines, substantial investment is also required for mineral-processing facilities, metallurgical plants and metal refineries, and for well-managed closure of the mines.

Public policies and regulations serve to inform finance decisions, e.g. through disclosure requirements that improve the availability, quality and comparability of data, and to attract finance, especially private finance. They also are an essential ingredient to foster trust among the multiple stakeholders who concur to make responsible mining projects possible.

Chapter 6: How would sustainable finance support the mining sector to contribute to sustainable development?

Key message

‘Sustainable finance’ that takes social and environmental, as well as financial, outcomes into account has an important role in promoting responsible mining.

The large investments required by mining companies put the financial sector in a strong position to exert pressure on companies and their stakeholders to include sustainability factors in their business practices. In recent years, many financial companies have committed to sustainability and used ‘sustainable finance’ as a means to encourage the uptake of responsible practices.

Sustainable finance includes social, green (and climate) finance, while also incorporating considerations about the economic sustainability of the whole financial system. *Sustainable investing* is an “approach that considers ESG factors in portfolio selection and management” and involves: the *exclusion* of certain activities or sectors; backing *best-in-class* activities; taking account of certain *norms* or *principles*; integrating *ESG assessments*; backing *sustainability-oriented projects*; delivering social or environmental *impacts*; and providing the opportunity for *corporate or shareholder* action.

Sustainable finance is characterized by different principles, frameworks and criteria at different levels. At the global level, as high-level objectives, there are UN-led Principles, sometimes oriented towards global objectives and agreements such as the SDGs or the Paris Agreement. From these, more operational frameworks or principles have been derived, such as the Equator Principles, the Meridian Principles (which have been proposed for ASM), the OECD Due Diligence Guidelines, the Task Force on Climate-Related Disclosure (TCFD), and, most recently, the Task Force on Nature-Related Disclosure (TNFD). At a more granular level, as tools and standards, there are investment taxonomies, sustainability-related financial products and the sustainability investments of development banks. In addition, there is the Global Financial Alliance for Net

Zero (GFANZ), which acts as an umbrella for a number of financial sector sub-groups, e.g. asset owners, insurers, banks etc. Finance taxonomies and non-financial reporting requirements seek to provide a robust and transparent framework for sustainable finance.

Given the importance of ESG factors in portfolio selection, access to information on ESG corporate performance in mining is very relevant and it is offered by the Responsible Mining Index (RMI) and the Initiative on Responsible Mining Assurance (IRMA). The RMI reports offer a detailed overview of ESG and mining, providing a mine-site assessment to monitor site-level actions including "local employment, local procurement, post-closure viability of communities, community grievances, worker grievances, air quality, water quality, water quantity, tailings management, and emergency preparedness". The 2022 RMI report assessed 250 mine sites belonging to 40 companies. The report shows that there is considerable room for improvement across the companies in all areas, but it also shows that this improvement is possible.

When deciding about financing mining activities, investors will take account of not only ESG risks from unsustainable practices, but also the extra costs that might be entailed in more sustainable, practices. A survey carried out for this report of a variety of mining-related companies showed that addressing ESG issues would be likely to involve extra costs for companies. Environmental issues (water resource management, soil restoration, energy use, environmental disaster prevention, biodiversity protection and restoration and greenhouse gas (GHG) emission reduction) were identified as the main likely source of extra costs. The costs of responding to social and governance issues were the most uncertain, because of the crucial importance of context- and client-specific features.

Clarification of these cost issues seems urgent. Calls for mining to support the SDGs, or to adopt a Sustainable Development Licence to Operate, or to implement a step change in respect of responsibility or sustainability are unlikely to be perceived as realistic, if financial markets do not reward such practices, and if downstream purchasers either cannot recognise metals and minerals produced to high-ESG standards, or are unwilling to pay more for them. Governments may need to mandate differentiation of those products produced to high standards, through certification and incentive schemes, such as favourable fiscal conditions or preferential market access, if they wish mining to be conducted responsibly.

Chapter 7: How can the artisanal and small-scale mining financing be reformed?

The artisanal and small-scale mining (ASM) sector is labour-intensive, sustaining millions of people and contributing significantly to national economies and global mineral supply chains. It is also the main source of the minerals used domestically in construction, manufacturing and agriculture. Operations are mostly informal and ASM miners are amongst the most marginalised workers globally.

Key message

Improving security, skills, working conditions, miners' incomes and gender equality related to all mining and especially to artisanal and small-scale mining, needs to be a priority.

Initiatives such as the Mosi-Oa-Tunya Declaration (September 2018) and the UN Environment Assembly Resolution on Mineral Resource Governance (2022) seek to reduce supply chain risks for buyers of commodities and improve the lives of communities.

Some degree of formalisation is essential to improve the wages and working conditions of artisanal miners. The barriers to such formalisation include compliance fees, land tenure, complex registrations, and lack of finance. These obstacles can be reduced with locally tailored and decentralised licensing procedures, as well as capacity building, tax incentives, access to funding and technical support, more local participation, and access to geological and geospatial data.

Because it is often perceived as high risk by financiers, and with unpredictable returns on investments and lack of collateral, the sector finds it hard to access traditional finance. It is therefore of subject to abusive and exploitative lending practices by informal lenders. Formalisation would give artisanal miners access to less exploitative sources of finance include microfinance, local savings and credit schemes, commercial banks, donor funded schemes, cooperative banks, government loans and national development banks, as well as, in time, equity financing. A survey of ASM miners in the World Bank's Delve Exchange knowledge network highlighted common finance needs for equipment and machinery, exploration, mapping, permits, licences, feasibility studies, and mine site preparation. Further costs include salaries for workers, food supplies, utilities, and fuel, as well as education.

The sector would benefit from the establishment of an international framework that directly addresses financial challenges. To this end the chapter proposes the Meridian Principles, inspired by the Equator Principles. These seek to benefit miners and their communities, for example through improved health and safety standards, but also through mitigation of ESG risks in ASM operations, and to make previously high-risk investments more attractive to financiers. Investment in ASM could also be made more attractive by establishing careful processes for selecting borrowers (e.g., prioritising groups that can demonstrate accountability for their loans), capacity building on both the supply and demand side, and provision of credit guarantee facilities.

Chapter 8: What is required to improve performance in both mining and finance across all the environmental, social and governance (ESG) issues and how can mining contribute to sustainable development and the well-being and prosperity of local communities?

This report has shown the need for internationally coordinated action by multiple stakeholders – the financial sector, including the banking sector, insurers and financial institutions more generally – bilateral agencies, public authorities, investors, academia and research and NGOs, to close the gap between minerals and metals production and sustainable development.

The drivers of pro-sustainability improvements in mining will need to be: effectively enforced legal frameworks; effectively enforced transparency, accountability and reporting, with short (next year), medium (2-5 years) and long-term (5 to 10 years) quantified improvement objectives; civil society engagement, with free and prior informed consent; informed and transparent investors' economic and ESG objectives; and an end to tax havens and tax evasion schemes, in line with the standards of the OECD's Global Forum on Transparency and Exchange of Information for Tax Purposes. The Responsible Mining Index has also played a very useful role in highlighting progress, or the lack of progress, in issues of social and environmental responsibility in the mining industry.

For private finance to flow at scale into the mining sector, the risk/return ratio will need to be sufficiently attractive. The risk side of the ratio is adversely affected by a number of circumstances that are not exclusive to, but are particularly relevant for, the mining sector: geopolitical risk, governance/policy risk, ESG risk, local social factors, and the risk of asset-stranding from technological innovation.

The return side of the risk/return ratio is obviously affected by the uncertainties surrounding both the cost at which the mineral can be produced, and the price at which it can be sold. These are particularly acute in respect of the minerals required for the low-carbon energy transition because of: the scale at which some of the minerals will be demanded and therefore of the investments required; the pace of innovation and technological change, which may mean that demand for minerals currently critical for the low-carbon energy transition may be lower than expected; many of the relevant minerals are currently produced as by-products of the production of other metals, so that their profitability of production is inextricably linked to that of the primary metal being produced; some of the minerals are needed in very small quantities and are expensive to process; and minerals produced to high ESG standards may incur higher costs and be uncompetitive in price-driven commodity markets.

Such issues need to be addressed so that private financial institutions feel sufficiently confident to provide the scale of finance that is required. One approach to these issues could be agreements founded on a mutually beneficial three-way partnership between the host community, the producing country and the importing country, that includes the major relevant stakeholders (companies, investors, trade unions) from each side.

> **Key message**
>
> **Mutually beneficial partnerships between the communities and countries that host the mines and the importing and processing countries, based on the equitable sharing of benefits, are essential to address concerns about geopolitical security of transition minerals supply chains.**

The report concludes with specific recommendations for the financial and other reforms that are required to ensure that the production of metals and minerals contributes to sustainable development. The recommendations are organized around the following 5 areas:

i. Improve transparency, reporting and local engagement

- Mining companies should report their financial and ESG outcomes on a site-by-site, gendered and 'shared value' basis, that also takes indigenous rights into account, according to an agreed industry-wide protocol.
- Site-by-site reporting should contain at a minimum the information covered by the IRP Protocol for the planning and monitoring of mining operations (IRP, 2020, p.311)
- Current corporate processes that engage with and involve local communities in data acquisition and reporting should be developed and become more widely adopted.
- A digital product passport for all mineral commodities and their value chains, including ESG information, should be developed on the basis of a standard reporting protocol, and be required by metal trading exchanges.

ii. Incentivise higher mineral recovery and recycling rates as part of the circular economy

- Incentives should encourage mining companies to extract high proportions of the metals in their ores.
- More information about tailings and other residues should be made available to open up possibilities for re-mining in the future.
- Exporting countries should benefit from the extraction of by-product metals recovered in the smelting and processing stages in other countries.
- The recycling of minerals and metals should be considered as the final stage in circular materials management, after the application of other circularity approaches before products reach their end of life.
- Policy makers should improve the economic viability of circular economy approaches to materials and product management by internalising the social and environmental costs of primary materials production, implementing circular policies through the transition minerals' value chains, validating novel financial instruments for increasing investment in circularity, and supporting innovative remanufacturing and recycling technologies.
- Material demand management is also likely to be necessary to ensure that material supply is sufficient for the essential uses in the low-carbon energy transition.

iii. Improve the management of mineral markets and build stronger national institutions

- Mineral-rich developing countries should be supported as necessary, through international development cooperation and other means, to legislate for and build the necessary institutions to regulate effectively and justly for responsible mining.
- Jurisdictions that wish actively to stimulate mining to high-ESG standards, and to import products from such mining, should join together in a 'Mining Club for Sustainable Development' and consider putting in place a raw material border adjustment aimed at leveling the playing field in terms of sustainability indicators in global trade.

iv. Reform the financial system: Financial taxonomies, architecture and instruments

- Mining that meets high ESG standards should be included in the list of sectors in finance taxonomies that qualify for 'sustainable finance' and 'climate finance'.
- Reforms should be made to the financial system, governance and regulation to ensure more capital flows to mineral exploration and to mining for the clean energy transition, while ensuring the implementation of risk management and ESG investment criteria.
- Mining investments and financing should be tied to mandatory climate and nature-positive requirements, subject to stringent audit requirements. Mining should not take place in protected areas.
- Investors' financial portfolios with climate and biodiversity goals should be assessed and monitored for their alignment with defined and disclosed pathways to companies' climate and nature alignment with climate and biodiversity goals.
- Companies with transition plans that have robust validation should be able to receive sustainable and climate finance.
- Financial institutions should enhance their capacity to recognise and finance mining to high ESG standards.
- Fiscal, financial and monetary policies should be used to support responsible mining and infrastructure and for the more circular use of metals in society.
- The mining industry should implement a global 0.1 per cent ad valorem levy on all companies as a contribution to a Mining Sustainable Development Fund.

v. Consider establishing international institutions

Key message

International collaboration and potentially new international, multilateral institutions have an important role in facilitating the responsible supply of energy transition minerals.

- Consider establishing an international minerals and metals agency to provide oversight and information about the state of and outlook for the world's non-energy mineral resources and markets, and provide support to capacity building and institutional strengthening, especially in developing countries.
- Encourage the central banks Network for Greening the Financial System (NGFS) to undertake systematic monitoring of macro-economic risks to the financial sector emanating from commodity markets, through a Global Commodity Price Observatory, eventually in collaboration with an international minerals and metals agency when it is created.
- Consider establishing an international framework for managing environmental and social risks and improving access to formal sources of finance in the artisanal and small-scale mining (ASM) sector.
- Governments, mining companies and NGOs should collaborate to establish a global database for mine tailings facilities, and the potential availability of minor (or companion) metals, eventually to be managed by the international minerals and metals agency.
- In due course, consider establishing a United Nations Convention on Sustainable Resources, to encourage the sustainable production and consumption of resources, including resource efficiency and moves towards a circular economy.

INTRODUCTION

SUPPLYING ENERGY TRANSITION MINERALS FOR SUSTAINABLE DEVELOPMENT

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CONTENTS

I.1 INTRODUCTION

The low-carbon energy transition – the transition of energy production away from fossil fuels – will require a huge increase in the production of the subset of the non-energy minerals (where energy minerals include fossil fuel minerals and uranium) that are required for the low-carbon energy technologies needed for the low-carbon energy transition. In this report, this subset of non-energy minerals is called energy transition minerals, or just transition minerals.

Many of the same minerals are also required for the digital revolution, but the quantities are considerably lower than for the energy transition. The minerals required for the digital revolution are not included in the scope of this assessment report, but the demand for them will obviously increase the overall demand for those transition minerals required for digital technologies.

This report is focused particularly on the financing required for the extraction of transition minerals and metals, and on how the financial sector can encourage mining to contribute more systematically to global sustainability and the sustainable development of resource-rich countries, as well as the low-carbon energy transition around the world.

Any failure of the minerals and metals industry to deliver the required quantities and qualities of transition minerals in a timely manner could derail the low-carbon energy transition. This could make it impossible to reach the climate objectives set out in the Paris Agreement of the 2015 United Nations Climate Change Conference (COP 21) to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels". The more ambitious climate change policy targets are, the more intensive the demand for a range of minerals and metals will be (International Energy Agency [IEA] 2023).

The minerals for the low-carbon energy transition are therefore an essential element of sustainable development, which also requires these minerals to be supplied in a way that is itself consistent with sustainable development. The *Mineral Resource Governance in the 21st Century* report of the International Resource Panel (IRP) (2020) made clear that this is very often not the case with the mining and production of minerals generally.

The annual global extraction of materials grew from 31 billion metric tons in 1970 to 107 billion metric tons in 2024, following an annual average growth rate of 2 per cent. The tonnage of metals and minerals extracted thus grew more than threefold between 1970 and 2024. Judging by current trends, it will increase by a further 60 per cent by 2060 (United Nations Environment Programme [UNEP] 2024), mainly as a result of the demand drivers outlined in IRP (2020): demographic growth, the development of the global middle-class and urbanization. For some transition minerals, the future growth in demand is much higher, as seen below (Figure I.9).

The *Mineral Resource Governance in the 21st Century* report sought to show "how the exploitation of [mineral] resources can contribute to achieving the SDGs [Sustainable Development Goals]". It noted: "This will require the capture of a fair share of mineral resource rents, equitable distribution and sensible investment of the rents, as well as a mitigation of the negative impacts of mining activities. … Translating mineral wealth into lasting economic gains will further require a broad range of policies that transform extraction from an enclave industry and link it to the broader economy through local content and value addition. … Mineral resource revenues should be leveraged to implement sustainable development projects – through stimulating economic diversification, careful investment in physical and social infrastructure and provision of public goods, while also addressing the externalities of mineral resource extraction (economic, social and environmental damage)" (p. 229). In the report, a sustainable development licence to operate for the mining and metals industry was envisaged to constitute such an approach.

The minerals and metals industry already delivers multiple major positive contributions to the United Nations Sustainable Development Goals (Columbia Center on Sustainable Investment *et al.* 2016; International Council on Mining and Metals 2016; International Resource Panel [IRP] 2020). Historically and today, the production of minerals and metals has been a major driver of the development of civilizations, enabling many of the products and services on which human life depends. It has made it possible to transform natural capital into other forms of capital, such as buildings, infrastructure, energy production and distribution, water supply and sanitation, and fertilizers.

Both the global low-carbon energy transition and human well-being in general are more dependent than ever on the multiple products and services made possible by the properties of minerals and the natural elements that are extracted from minerals, mainly metals, and their huge range of derivatives, such as alloys or chemical compounds.

Between 1950 and 2021, the world population grew by 218 per cent (an additional5.4 billion persons) (United Nations Department of Economic and Social Affairs [UNDESA] 2022), and lifestyles simultaneously involved a much more intensive use of metals and minerals. As a result, the world average per capita production of cement, aluminium and steel grew by 3,000 per cent, over 4,000 per cent and over 1,100 per cent respectively over that period (Kelly and Matos 2023).

This very rapidly rising global intensity in per capita minerals and metals is very unequally distributed across the world. According to the estimates for aluminium, copper, iron, lead, stainless steel and zinc published by IRP (2010), per capital metal intensities in more developed countries are 5 to 10 times higher than in less developed countries, with implications for huge increases in demand, if poorer countries were to reach higher development levels with similar patterns of resource use (IRP 2020).

This rapid intensification of the use of minerals and metals has had increasing negative environmental and social impacts that were all too frequently ignored in the past as the land available for mining was more abundant and the impacts were less severe than at present. These environmental and social issues present formidable challenges for humanity's future, including in relation to the internationally agreed efforts to transition the global economy to net-zero carbon emissions by or shortly after the middle of the century. IRP has consistently stressed that both resource use and environmental impacts must be decoupled from economic growth, especially but not only in more developed countries, through resource efficiency, management and reduction of demand, and moves towards a circular economy. These issues are emphasized in the 2023 think piece on energy transition minerals produced by the IRP Co-Chairs (IRP 2023). Addressing these issues urgently calls for well-coordinated international efforts by all stakeholders.

Concerns about the social and environmental issues related to mining are not new. They were raised 20 years ago by the Mining, Minerals and Sustainable Development Project,[1] possibly the largest analysis ever conducted of the complex linkages between any sector of the economy and sustainable development, involving about 5,000 stakeholders over 2 years, which produced a final report entitled *Breaking New Ground* (Mining, Minerals and Sustainable Development Project 2002).

Two recent publications (Danielson 2022; Responsible Mining Foundation 2022) looked at the developments that had taken place over the 20 years since the Mining, Minerals and Sustainable Development Project and concluded that there was still much to be done.

The *Closing the Gaps* report of the Responsible Mining Foundation concludes: "Some progress has been seen on a number of issues since the MMSD [Mining, Minerals and Sustainable Development] initiative 20 years ago, yet expectations of voluntary action from the wider mining industry have repeatedly proved disappointing. Where there is progress, it is evident that change is happening very slowly and companies leading their peers on ESG [environmental, social and governance] issues are still far from meeting society's expectations. With emerging environmental and socioeconomic issues (such as circular materials management and just transition) still off the radar of most companies, the industry worldwide could be said to be defensively losing ground rather than innovatively progressing on ESG management and harm prevention." (Responsible Mining Foundation, 2022, p.45) Danielson, the former Director of the Mining, Minerals and Sustainable Development project, elaborates on the report of the Responsible Mining Foundation, stating: "The ESG performance of big mining companies is extremely important. But for the sector to maximize its contribution to sustainable development, many other actors need to be effective in performing their roles in the minerals sector. RMF's [Responsible Mining Foundation] Closing the Gaps report usefully reflects on the inherent tensions and challenges faced by the key actors involved. Foremost among those with influence on the sector are governments. In a number of cases, these governments are highly dependent upon mineral revenues to support development efforts. But they may in poor countries have very limited capacity to deal with the complex issues of managing the industry. The interests of these governments may or may not coincide with the interests of communities in regions where mining is

1 Mining, Minerals and Sustainable Development Project: https://www.iied.org/mining-minerals-sustainable-development-mmsd.

important. There is a history of tension between national governments and mining communities over a variety of issues, perhaps most prominently the question of what part of the revenues is spent locally, and what part goes into national coffers. Other important players are the many and varied NGOs [non-governmental organizations] that play roles from supporting local development efforts to being watchdogs of environmental performance. Finally, there is a long list of international standards and certification systems that promulgate standards and assess or validate compliance with them." (Danielson, 2022, p.4 [pdf version]).

This report will cover all these issues.

I.2 SETTING THE SCENE

As already noted, the low-carbon energy transition is extremely dependent on a massive increase in the world production of minerals and metals needed for low-carbon technologies, particularly copper, cobalt, graphite, lithium, nickel and rare earth elements (Watari *et al.* 2018 and 2020; Hund *et al.* 2020; International Energy Agency 2021; International Energy Agency 2023; Marscheider-Weidemann *et al.* 2021, Christmann *et al.* 2022). These are the main minerals and metals required for the low-carbon energy transition. They are the energy transition minerals, henceforth for brevity called transition minerals in this report. Some of the key issues that will be explored in more detail in this report are introduced here.

I.2.1 Geological availability

As noted above, the production of transition minerals for low-carbon energy technologies will need to be scaled up dramatically if these technologies are to replace carbon-based fossil fuels over the next three decades. One issue that arises in this respect is the future geological availability of these minerals and the possibility of discovering and putting enough new mineral deposits into production in a timely manner.

Figure I.1 plots the expected availability of selected elements (essentially the global reserves/production ratio), using the current levels of demand and knowledge about their occurrence in the Earth's crust. Subsequent chapters will provide estimates of the possible growth in demand for selected minerals, in order to assess this aspect of the sustainability of their supply. It can be seen that none of the minerals has an expected availability of less than 10 years, and very few of them have an expected availability of less than 20 years. Given that there are still huge areas of the Earth's land that are still relatively unexplored, and that the recycling of some of these minerals is still at a very low level (UNEP 2011), it is very likely that these expected availabilities will extend further into the future as the minerals become required. This has occurred in the past and may not even require exploration of the oceans, which are known to be rich in mineral deposits in some parts.

This does not mean that there will be no bottlenecks in the supply of these minerals in the future. As will be made clear in later chapters, there are a number of reasons why demand for these minerals may not be met in a timely manner, but geological availability, based on this picture, is unlikely to be one of them.

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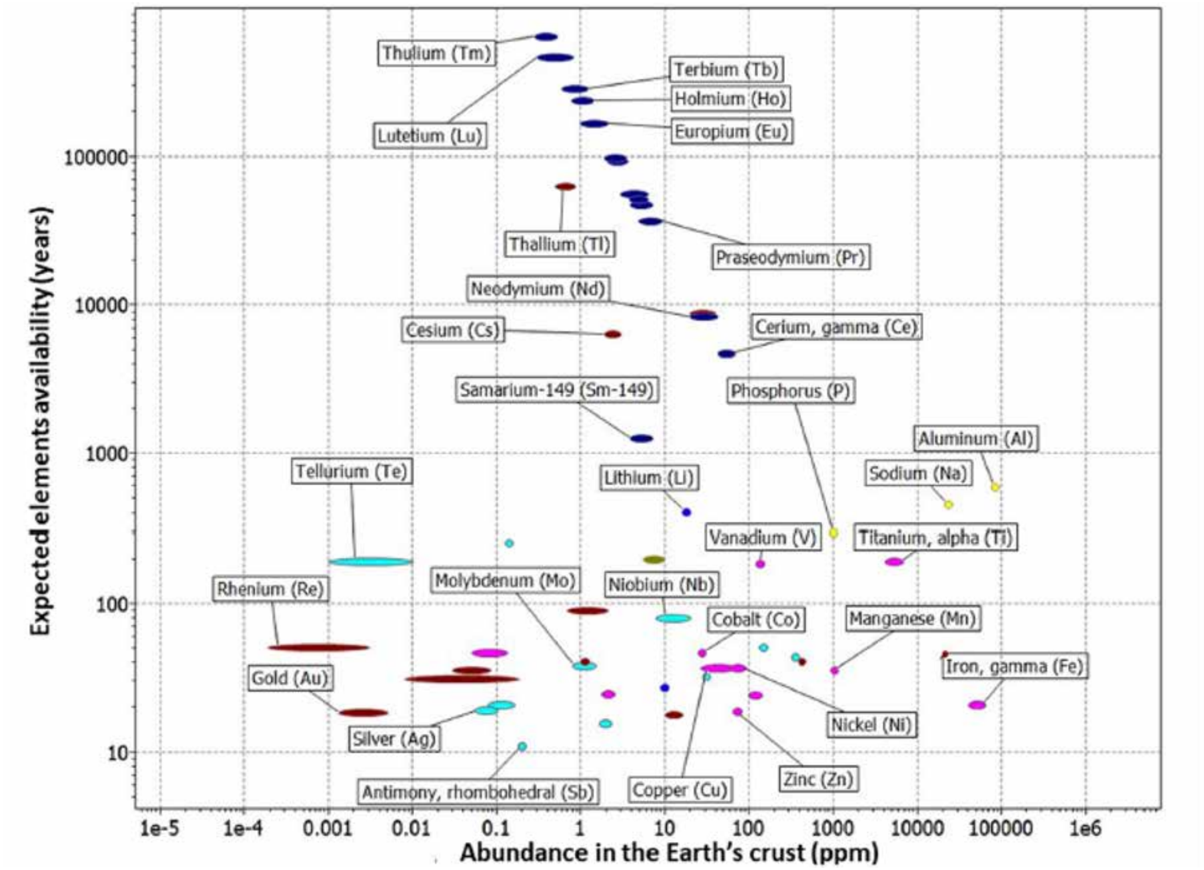
Figure I.1: Expected availability of elements (in years) versus their abundance in the Earth's crust (parts per million - ppm), not considering recycling

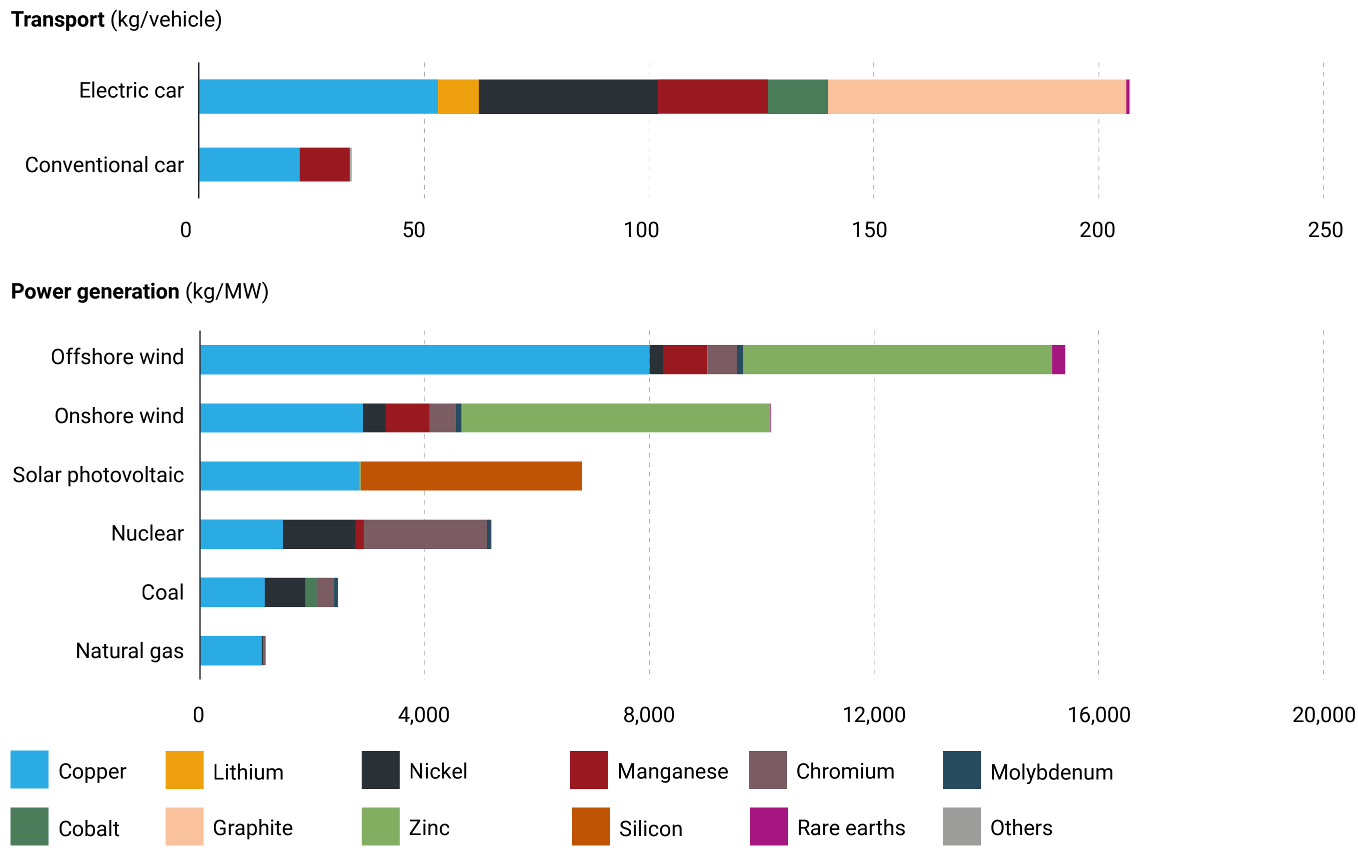


Source: Zanoletti *et al.* (2021, p. 2)

I.2.2 Low-carbon energy technologies

In 2021 and 2023, the International Energy Agency produced reports on the materials that would be needed for different low-carbon energy technologies. Figure I.2, from the 2021 report, shows that copper is required for all the technologies of power generation and transport listed. Lithium is important for the batteries of electric cars, as is nickel, which is also used in a number of power generation technologies. Manganese is needed for both kinds of vehicles and for wind turbines. Cobalt and graphite are currently important for batteries for electric cars, while zinc is needed for wind turbine masts (for steel protection through galvanization). Rare earth elements are found in the magnets of synchronous offshore wind turbines and chromium is essential to stainless steel used for metallic structures or tubing. Low-carbon energy options (electric vehicles, wind and solar power) have considerably higher demands for these minerals, per vehicle or per MW of power generation capacity, than the technologies they are seeking to replace, as shown in figure I.2.

Figure I.2: Important minerals (excluding steel and aluminium) for some low-carbon energy technologies



Source: International Energy Agency (2021, p. 6).

Figure I.3, from the same source, extends the list of both the technologies and minerals considered. It can be seen that nickel and the platinum group metals are important for hydrogen production; rare earth elements also have a role in hydrogen, as well as in wind turbines and batteries. Zinc is of high importance for wind turbines and is moderately important for hydropower, concentrated solar power and bioenergy. Aluminium is important across a wide range of the technologies shown, as well as having many other uses not shown here.

The French Central Bank (Banque de France) produced a study in January 2023 estimating the growth in the use of nine low-carbon technology materials (copper, lithium, nickel, graphite, cobalt, manganese, molybdenum, rare earth elements and vanadium) implied by the Net Zero by 2050 scenario of the Network for Greening the Financial System (a network of central banks seeking to promote decarbonization). They found that the output of these metals would need to grow by a factor of seven between 2021 and 2040, from 4.7 Mt to 32.8 Mt (Miller *et al.* 2023, figure 1, p. iii). The principal driver of this growth is copper, which increases from approximately 4 Mt in 2021 to over 15 Mt in 2040.

To the minerals mentioned above, table I.1 adds minerals related to fuel cells, namely scandium and platinum; gallium, indium, cadmium, tellurium and selenium are currently important elements for photovoltaic cells. Table I.1 also compares the ratios of demand for these minerals for the technologies shown in 2018 and those projected for 2040, alongside the total 2018 production level of these minerals. Three scenarios, with different levels of decarbonization and therefore low-carbon energy technology deployment, are compared.[2] Taking lithium as an example, batteries and airframes accounted for only 10 per cent of lithium production in 2018, but these demands alone are expected to rise in 2040 to 590 per cent of the 2018 production level in the most ambitious sustainability scenario. This means that lithium demand for these two technologies is expected to grow by a factor of nearly 60 between 2018 and 2040.

2 A brief description of the five scenarios may be found at https://unece.org/fileadmin/DAM/energy/se/pdfs/CSE/PATHWAYS/2019/ws_Consult_14_15.May.2019/supp_doc/SSP2_Overview.pdf. The three scenarios shown in table I.1 are the most relevant for the purposes of this report.

Figure I.3: Minerals for different low-carbon energy technologies

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

● High ◉ Moderate ○ Low

Note: Shading of the dots indicates the relative importance of a mineral for that technology. REEs = rare earth elements; PGM = platinum group metals; Solar PV = solar photovoltaic; CSP = concentrating solar power; EVs = electric vehicles

* Aluminium use for electricity networks only.

Source: International Energy Agency (2021, p. 45).

Table I.1: Global raw material demand estimates in 2040 for three scenarios, as a ratio of production in 2018, for a number of innovative technologies related to the energy transition

Raw material	Demand 2018 / Production 2018 (Per cent)	Demand 2040 / Production 2018			Emerging technologies with high demand
		SSP1 Sustainability (Per cent)	SSP2 Middle Path (Per cent)	SSP5 Fossil Path (Per cent)	
Ruthenium	40	240	590	1,900	Data centres, superalloys, synthetic fuels
Scandium	50	790	370	70	SOFC – solid oxide fuel cell, water electrolysis
Heavy rare earth elements	60	550	690	640	Electrical traction engines for motor vehicles, wind turbines
Lithium	10	590	400	90	Lithium-ion high-performance electricity storage, solid-state batteries, alloys for airframe lightweight construction
Iridium	0	500	290	30	Water electrolysis
Platinum	0	30	120	430	Data centres
Cobalt	40	390	290	120	Super alloys, lithium-ion high-performance electricity storage, solid-state batteries
Light rare earth elements	30	220	200	220	Electrical traction engines for motor vehicles, wind turbines, high-performance permanent magnets, data centres
Tantalum	70	140	140	210	Super alloys, microelectronic capacitors, radio frequency microchips, data centres
Germanium	40	170	170	190	Fiber optic cable
Lanthanum	0	110	30	3	Solid-state batteries, water electrolysis, SOFC – solid oxide fuel cell
Vanadium	0	70	80	70	CCS – Carbon capture and storage, redox flow batteries
Rhenium	10	60	50	70	Superalloys
Titanium	30	60	60	70	Alloys for airframe lightweight construction, superalloys, solid-state batteries, additive manufacturing of metal components (“3D printers”), water electrolysis, seawater desalination
Yttrium	0	60	30	20	Automatic piloting of road vehicles, water electrolysis, solid oxide fuel cells
Graphite	0	90	80	20	Lithium-ion high-performance electricity storage
Indium	30	50	40	40	Indium tin oxide in display technology, optoelectronics/ photonics, thin-film photovoltaics
Copper	20	20	30	40	Power grid expansion, electrical traction engines for motor vehicles, wind turbines, solid-state batteries, water electrolysis
Gallium	10	20	20	20	Radio frequency microchips, thin-film photovoltaics

Note on the scenarios: The three scenarios are among those developed by the International Institute for Applied Systems Analysis. For further details about these scenarios, please see the SSP online database, version 2.0 (https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=10, accessed 15 April 2023).

Source: Modified from Marscheider-Weidemann *et al.* (2021)

Geologically it may be possible to supply these minerals at this scale, as noted previously in this section. It seems much less likely that there will be sufficient investment to extract and refine them on a timescale consistent with the reductions to greenhouse gas emissions envisaged in the Paris Agreement. The speed of the transition required to meet the goals in the Paris Agreement emphasizes the importance of reducing the demands for these metals wherever possible (e.g. by moving towards smaller vehicles and promoting public transport and active travel in cities so that there is much reduced vehicle ownership in urban areas), and by adopting various circular economy-based approaches, together with providing appropriate infrastructure, in advance of the first generation of low-carbon energy technologies coming to the end of their lives. For these transition minerals, as well as more generally, there is an urgent need to decouple material use from economic growth through measures to promote a circular economy, as discussed further below.

I.2.3 Definitions of criticality

In several of the world's most economically important jurisdictions, many of the metals and minerals in table I.1 are classed as critical, a term used for those elements that are both of high economic importance to the country or region concerned, and where the supply chain is perceived as vulnerable or fragile for geological or geopolitical reasons. Different countries thus have very different perceptions of criticality. For example, in Africa and South America, from which many of these minerals are sourced, they are more likely to be classified as strategic than critical.

Criticality assessments have tended to be focused on geopolitical supply risks and economic importance, but there is a case for also including the environmental dangers associated with accessing materials required for the energy transition. This environmental dimension is often not considered in country- or bloc-level criticality indexes. Yan *et al.* (2021) provide an example as to how a criticality assessment using a three-dimensional framework (geopolitical supply, economic importance, environmental risk) may be carried out.

Table I.2 sets out the most recent official determinations of criticality for the European Union, the United States of America and China, together with the academic assessment for the United States of America carried out by Graedel *et al.* (2015). It can be seen that the criticality assessments vary markedly. For the European Union, which has the least availability of these minerals on its territory, many more metals and minerals are currently perceived as critical than in China and the United States of America.

However, it should be recognized that the technologies that use these critical materials are all the subject of intense global research, and their current material demands may therefore change dramatically over a relatively short period (e.g. five years). For example, if lithium were to replace graphite in the anodes of electric vehicle batteries,[3] graphite would suddenly cease to be a critical material in the European Union, where it is currently classed as such.

Perceptions of criticality can also change. While the Chinese lists from 2013 to 2021 remained relatively stable, the number of critical minerals in the United States of America between 2015 and 2022 jumped from 2 to 25. Criticality is therefore a highly dynamic concept, the perceptions of which need to be regularly updated.

To these national and regional criticality assessments could usefully be added a global assessment of geological and geopolitical supply risks, economic importance and environmental dangers associated with accessing materials required for the energy transition in order to inform financiers and policymakers. A global scale analysis of the environmental dimension could be conducted using three dimensional frameworks, such as the one developed by Yan *et al.* (2021), mentioned earlier.

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3 This possibility is described in the following sources: https://ses.ai/, https://www.saurenergy.com/solar-energy-blog/ses-bets-on-li-metal-batteries-for-ev-future, https://www.quantumscape.com/; https://www.cnbc.com/2022/12/20/quantumscape-starts-shipping-ev-battery-prototypes.html

Table I.2: Comparative view of the European Union, the United States of America and Chinese criticality indexes for materials used in low-carbon energy industries

Material	European Union 2023 index* (European Commission 2023)	European Union 2020 index* (European Commission 2020)	United States 2022 index** (Nassar and Fortier 2021)	United States 2015 index (Graedel, et al. 2015)	United States 2011 index (United States Department of Energy 2011)		China 2021 index*** (Yan et al. 2021)	China 2019 index* (Zhou et al. 2019)	China 2013 index* (Yang et al. 2013)
					Short term (2015)	Long term (2025)			
Aluminium (Bauxite)	Critical	Critical	Critical	Non-critical			Non-critical	Non-critical	
Boron	Critical	Critical	Critical				Near-critical (SR)		Near-critical (SR)
Cadmium	Near-critical (EI)	Near-critical (EI)	Non-critical	Non-critical			Non-critical	Near-critical	Critical
Cerium	Critical	Critical	Critical		Near-critical (LCET)	Non-critical	Non-critical	Non-critical	Non-critical
Chromium	Near-critical (EI)	Near-critical (EI)	Critical				Critical	Critical	Critical
Cobalt	Critical	Critical	Critical	Non-critical	Non-critical	Non-critical	Critical	Critical	Critical
Copper	Critical **** (EI)	Near-critical (EI)	Non-critical	Non-critical			Non-critical	Non-critical	Near-critical (SR)
Dysprosium	Critical	Critical	Critical		Critical	Critical	Non-critical	Non-critical	Non-critical
Europium	Critical	Critical	Critical		Critical	Critical	Non-critical	Non-critical	Non-critical
Gallium	Critical	Critical	Critical	Non-critical	Non-critical	Non-critical	Near-critical	Non-critical	
Germanium	Critical	Critical	Critical				Critical	Non-critical	
Graphite (natural)	Critical	Critical	Critical				Non-critical	Non-critical	
Indium	Non-critical	Critical	Critical	Critical	Near-critical (SR)	Non-critical	Non-critical	Non-critical	
Iron	Near-critical (EI)	Near-critical (EI)	Non-critical				Non-critical		Critical
Lanthanum	Critical	Critical	Critical		Near-critical (LCET)	Non-critical	Non-critical	Non-critical	Non-critical
Lead	Near-critical (EI)	Near-critical (EI)	Non-critical				Non-critical		Near-critical (EI)
Lithium	Critical	Critical	Critical	Non-critical	Non-critical	Near-critical	Near-critical (SR)	Non-critical	Near-critical (SR)
Magnesium	Critical	Critical	Critical	Non-critical			Near-critical	Non-critical	
Manganese	Critical	Critical	Critical	Non-critical	Non-critical	Non-critical	Non-critical	Near-critical	Critical
Molybdenum	Near-critical (EI)	Near-critical (EI)	Non-critical	Non-critical			Near-critical (EI)	Non-critical	Near-critical (EI)

Material	European Union 2023 index* (European Commission 2023)	European Union 2020 index* (European Commission 2020)	United States 2022 index** (Nassar and Fortier 2021)	United States 2015 index (Graedel, et al. 2015)	United States 2011 index (United States Department of Energy 2011)		China 2021 index*** (Yan et al. 2021)	China 2019 index* (Zhou et al. 2019)	China 2013 index* (Yang et al. 2013)
					Short term (2015)	Long term (2025)			
Neodymium	Critical	Critical	Critical		Critical	Critical	Non-critical	Non-critical	Non-critical
Nickel	Critical **** (EI)	Near-critical (EI)	Critical	Non-critical	Non-critical	Non-critical	Near-critical (EI)	Critical	Critical
Praseodymium	Critical	Critical	Critical		Non-critical	Non-critical	Non-critical	Non-critical	Non-critical
Samarium	Critical	Critical	Critical		Non-critical	Non-critical	Non-critical	Non-critical	Non-critical
Selenium	Near-critical (EI)	Near-critical (EI)	Non-critical	Non-critical			Critical	Near-critical	Near-critical (SR)
Silicon	Critical	Critical	Non-critical					Non-critical	
Silver	Near-critical (EI)	Near-critical (EI)	Non-critical	Critical			Non-critical	Near-critical	
Tellurium	Near-critical (EI)	Near-critical (EI)	Critical	Non or near-critical	Near-critical (LCET)	Near-critical (LCET)	Non-critical	Non-critical	Critical
Terbium	Critical	Critical	Critical		Critical	Critical			
Tin	Near-critical (EI)	Near-critical (EI)	Critical				Near-critical (EI)	Critical	Critical
Titanium	Critical*****	Critical	Critical				Non-critical	Non-critical	
Yttrium	Critical	Critical	Critical		Critical	Critical	Non-critical	Non-critical	Non-critical
Zirconium	Near-critical (EI)	Near-critical (EI)	Critical				Non-critical	Near-critical	Non-critical

Note: EI = Near critical owing to economic importance. SR = Near critical owing to supply risks associated with the raw material. LCET = Importance to low carbon energy technologies.

* These European Union and Chinese indexes do not distinguish near-critical and non-critical materials. Near-critical materials are described by the United States Department of Energy (2011) as those that either have economic importance or carry supply risks beyond the established thresholds. Zhou et al. (2019) refer to near criticality as "moderate" and "non-critical" materials were referred to as "low critical". Yang et al. (2013) use the term "potentially critical" for near-critical materials. For the sake of integrity of the table, these differences in terms have been eliminated.

** The United States 2022 index lists mineral commodities critical to the United States economy but considers qualitative aspects and disruption potential in addition to supply risks and economic importance. See the relevant United States Geological Survey publication (Nassar and Fortier 2021) for more information on the methodology.

*** Only the two-dimensional index, i.e. supply risk and economic importance, of Yan et al. (2021) was used. See also Yan *et al.* (2021) for the three-dimensional index involving environmental risks.

**** Copper and nickel are included in the 2023 Critical Raw Materials report of the European Union as 'strategic raw materials' despite being associated with low supply risks.

***** Titanium is distinguished as titanium (near-critical owing to economic importance) and titanium metal (critical) in the 2023 criticality list of the European Union.

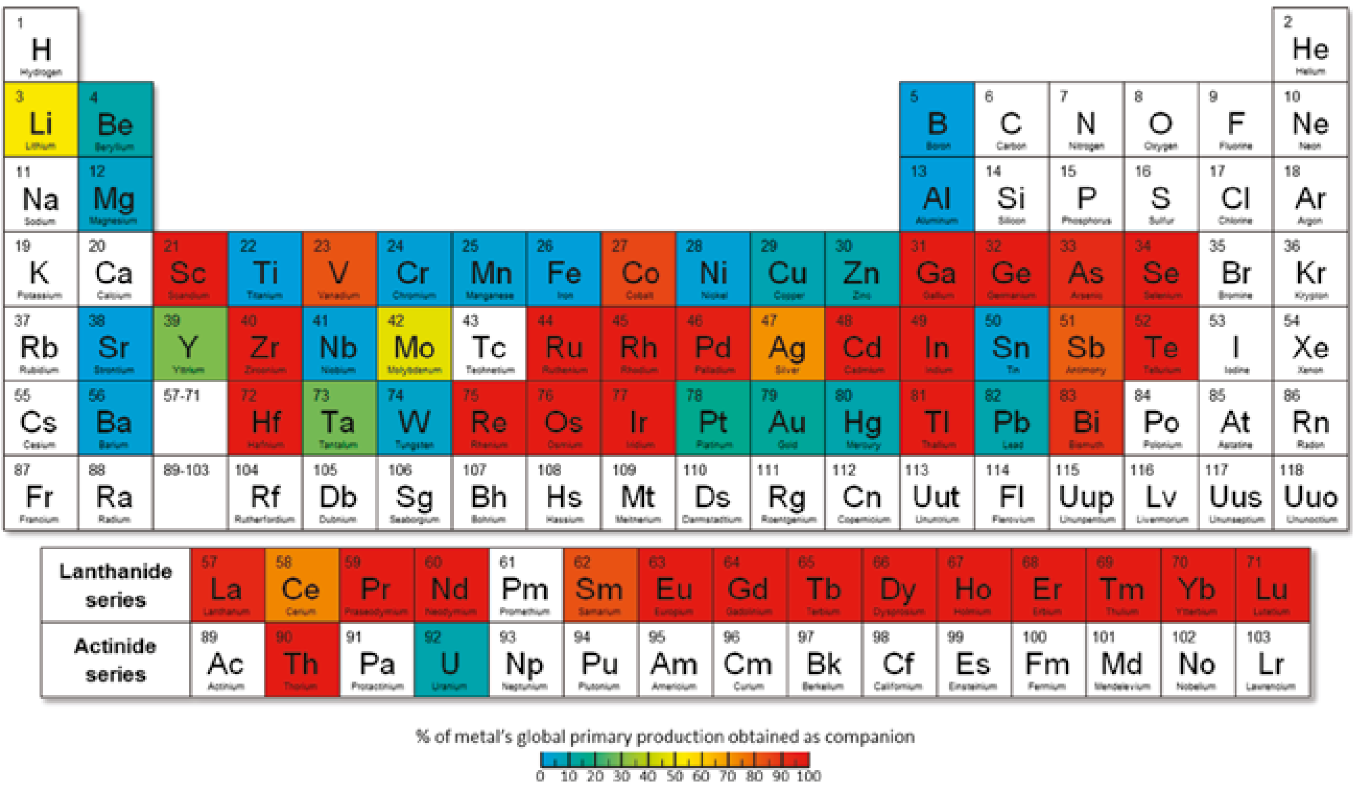
Source: European Commission (2020); European Commission (2023); United States Department of Energy (2011); Graedel *et al.* (2015); Nassar and Fortier (2021); Yang *et al.* (2013); Zhou *et al.* (2019); Yan *et al.* (2021).

I.2.4 Companion elements

Many of the minerals listed in the tables above are not produced as the primary product of extraction and processing, but as by-products or co-products, grouped together as companion elements. Figure I.4 shows the periodic table of elements, colour-coded to show the proportions of particular minerals that are produced as companion elements. Of the minerals most closely associated with the low-carbon energy technologies, as mentioned in the tables above, aluminium, chromium, molybdenum, nickel, copper, zinc and platinum are largely produced in their own right. However, scandium, cobalt, gallium, selenium, cadmium, indium, tellurium and the rare earth elements (lanthanides) have a high percentage of their production obtained as companion elements.

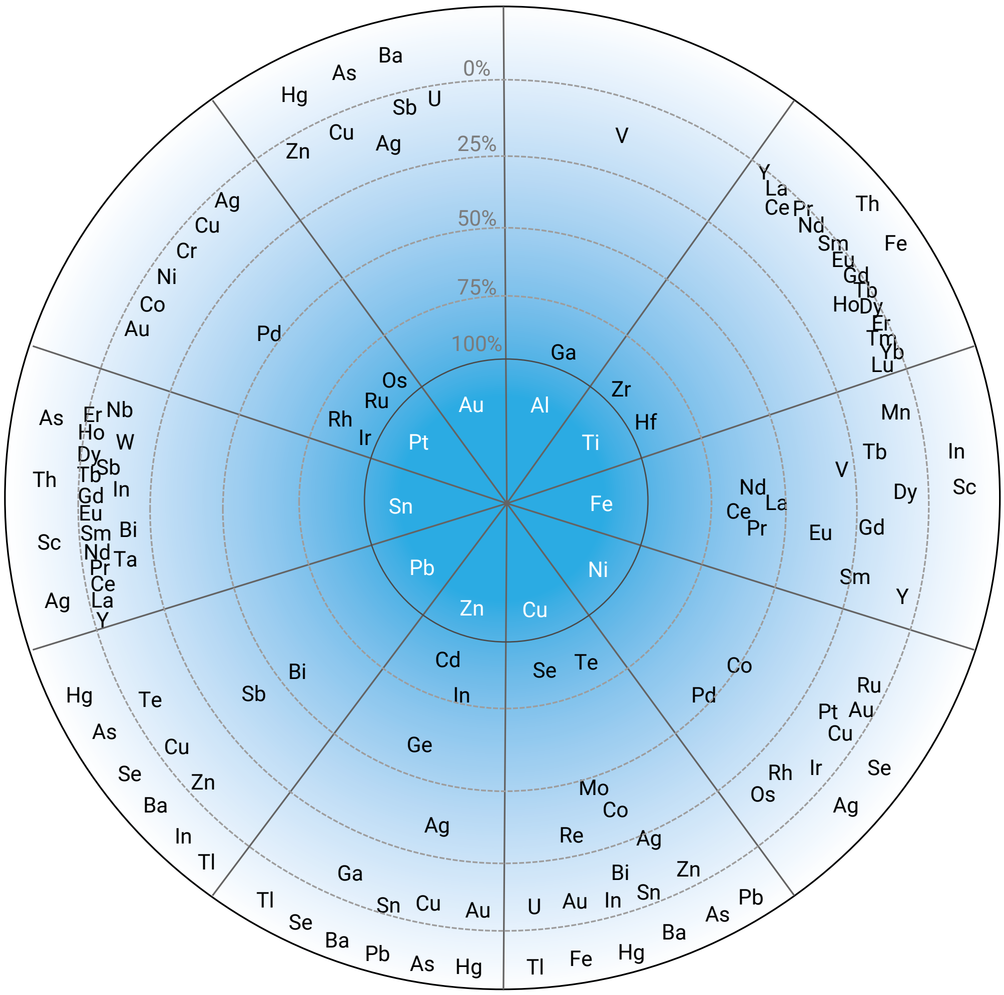
The wheel in figure I.5 shows which metals are companions to the principal element in the centre of the wheel. The elements in the centre derive 80–100 per cent of their production as the principal element being sought, but may also be companion elements to other principal elements. Copper is therefore a principal element, but is also a companion element to gold, platinum, lead, zinc and nickel. About 40 per cent of cobalt is a companion to nickel production, and slightly less as a companion to copper, with further small amounts as a companion to platinum. Gallium is mainly produced as a companion to aluminium, but it is also a companion to zinc. The main rare earth elements for renewable technologies (praseodymium, neodymium, dysprosium and terbium) are mainly companions to iron production. It should be noted that the proportions in this case refer to 2008 and may change over time as different ores are exploited or mining or metallurgical processes change (Nassar *et al.* 2015).

Figure I.4: Periodic table with the proportion of elements obtained as companion elements



Source: Nassar, Graedel and Harper (2015, figure 1, p. 2).

Figure I.5: Principal elements (in the centre) and their companions in 2008



Note: The closer to the centre, the higher the proportion (from 0–100 per cent) of the production of the companion element that comes from the production of the principal element in that segment of the wheel. The proportions of elements in the outer ring are undetermined.

Source: Nassar, Graedel and Harper (2015, figure 2, p. 3).

This dependency of the production of some minerals on the production of a principal mineral can be problematic because the companion metal will only be produced if the economics of its production are profitable. Where prices for the companion metal are low, it may remain in the waste of the principal metal's production, which may be a cause for concern if either the companion metal is toxic (e.g. cadmium) or if this results in considerable potential production of critical minerals being foregone. Nassar *et al.* (2015, p.7) find that "recovery efficiencies for some companion metals can be as low as 10%." Moreover, the financial dependence of companion metals on that of their principal metals means that the response of their production to increased demand, or an increase in their price, can be very slow or even zero. This is because increased production of the companion metal will inevitably result in increased production of the principal metal, which may then result in an over-supply of it, depressing its price and affecting the economic viability of the whole process.

I.2.5 Concentration of production and processing

Another important consideration for the availability of materials for the low-carbon energy transition is the concentration of their extraction and processing in different countries, and the ownership of producers of the patents and technologies necessary for production. Ownership structures are not well documented and can be very opaque or impossible to identify in the case of holdings and companies controlled by private equity. Ownership of patents is easier to identify but identifying which ones are of major importance is a difficult task. These issues are beyond the scope of this study.

Figure I.6, taken from the 2023 European Union *Critical Raw Materials* study, shows the countries that produce the highest proportions of selected materials either at the mining or the metallurgical stage (referred to as 'processing'[4] in figure I.6). The major role played by China in the supply of many of these materials, with many of them at above 50 per cent of global supply, and rare earth elements at 86 per cent, is striking.

Figure I.6: Countries which produce the highest proportion of selected materials

Main global supplier	Material	Stage [1]	Share
China	Aluminium	P	56%
	Antimony	E	56%
	Arsenic	P	44%
	Baryte	E	44%
	Bismuth	P	70%
	Cobalt	P	60%
	Coking coal	E	53%
	Copper	E	38%
	Fluorspar	E	56%
	Gallium	P	94%
	Germanium	P	83%
	Magnesium	P	91%
	Manganese	P	58%
	Natural graphite	E	67%
	Nickel	P	33%
	Phosphate rock	E	44%
	Phosphorus	P	79%
	Scandium	P	67%
	Silicon metal	P	76%
	Titanium	P	43%
	Tungsten	P	86%
	Vanadium	E	62%
	LREEs	P	85%
	HREEs	P	100%

Main global supplier	Material	Stage [1]	Share
South Africa	Iridium	P	93%
	Manganese	E	29%
	Palladium	P	36%
	Platinum	P	71%
	Rhodium	P	81%
	Ruthenium	P	94%
United States of America	Beryllium	E	67%
	Helium	P	56%
Democratic Republic of the Congo	Cobalt	E	63%
	Tantalum	E	35%
Türkiye	Borate	E	48%
	Feldspar	E	32%
Australia	Aluminium	E	28%
	Lithium	P	53%
Brazil	Niobium	P	92%
France	Hafnium	P	49%
Russian Federation	Palladium	P	40%
Iran	Strontium	E	37%
Spain	Strontium	E	31%
Chile	Copper	E	28%

Stage: E = Extraction stage P = Processing stage

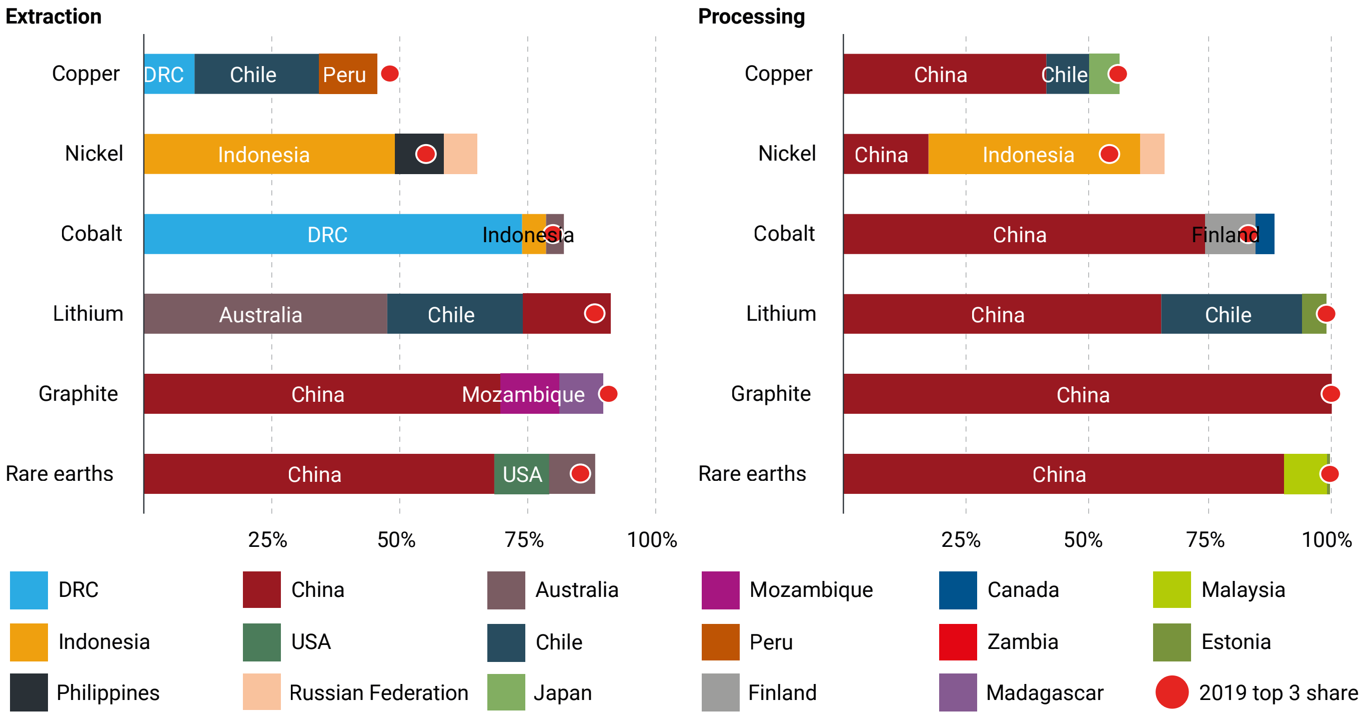
Source: European Commission (2023).

4 'Processing' as used here refers to the metallurgical process needed to extract metals from their ore.

The prominence of China is even more pronounced when it comes to the processing of extracted ores, as seen in figure I.7, which shows the shares of extraction and processing in the countries that are major producers of some of the minerals of greatest interest for the low-carbon energy transition (as well as for fossil fuels). China is among the top three extractors of copper, lithium and rare earth elements, but it is the top processor for all of them, with more than 50 per cent of global processing of cobalt, lithium and rare earth elements. Since 2019, the share of the top three countries in extraction and/or processing has grown for nickel, cobalt, lithium and rare earth elements. The metal production sector of China is explored in more detail in Chapter 1.

Figure I.8 shows that the 2020 value from non-energy minerals and metals production, including cement production, is similarly concentrated in relatively few countries, with the 20 countries shown representing 82 per cent of the global production value of these commodities. Nine of these countries are upper-middle income countries and four are high-income countries. The only low-income country in this list is the Democratic Republic of the Congo.

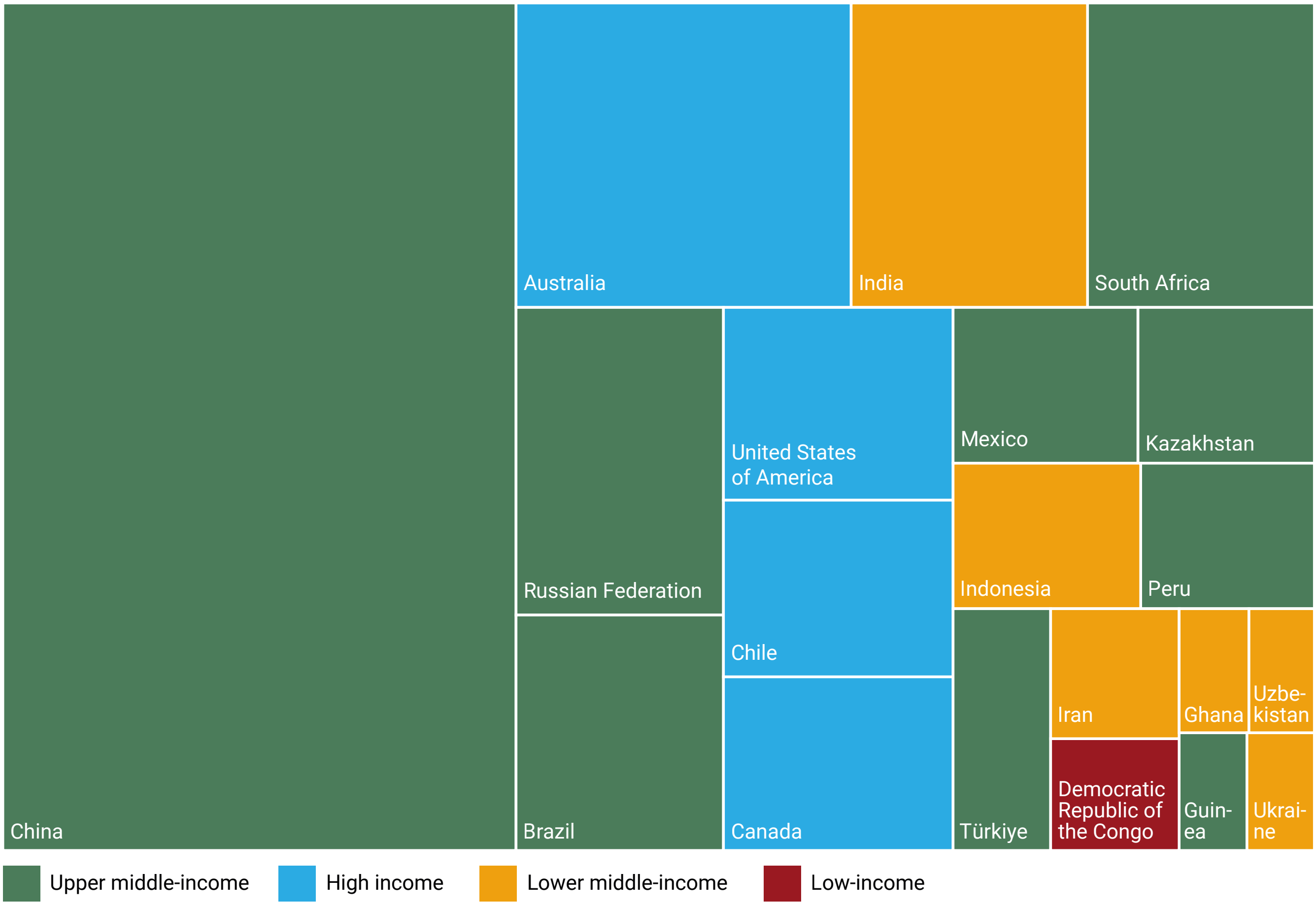
Figure I.7: Share of the top three producing countries in total production for selected resources and minerals, 2022



Note: DRC = Democratic Republic of the Congo; USA = United States of America. Graphite extraction is for natural flake graphite. Graphite processing is for spherical graphite for battery grade.

Source: International Energy Agency (2023, p. 68).

Figure I.8: Share of the 2020 production value of non-energy minerals and metals, including cement, of top 20 producing countries, by country and income group



Note: Cement production and value were added to their total values, on the basis of the United States Geological Survey 2022. The cement price is the average price in million United States dollars for hydraulic cement published in that report.

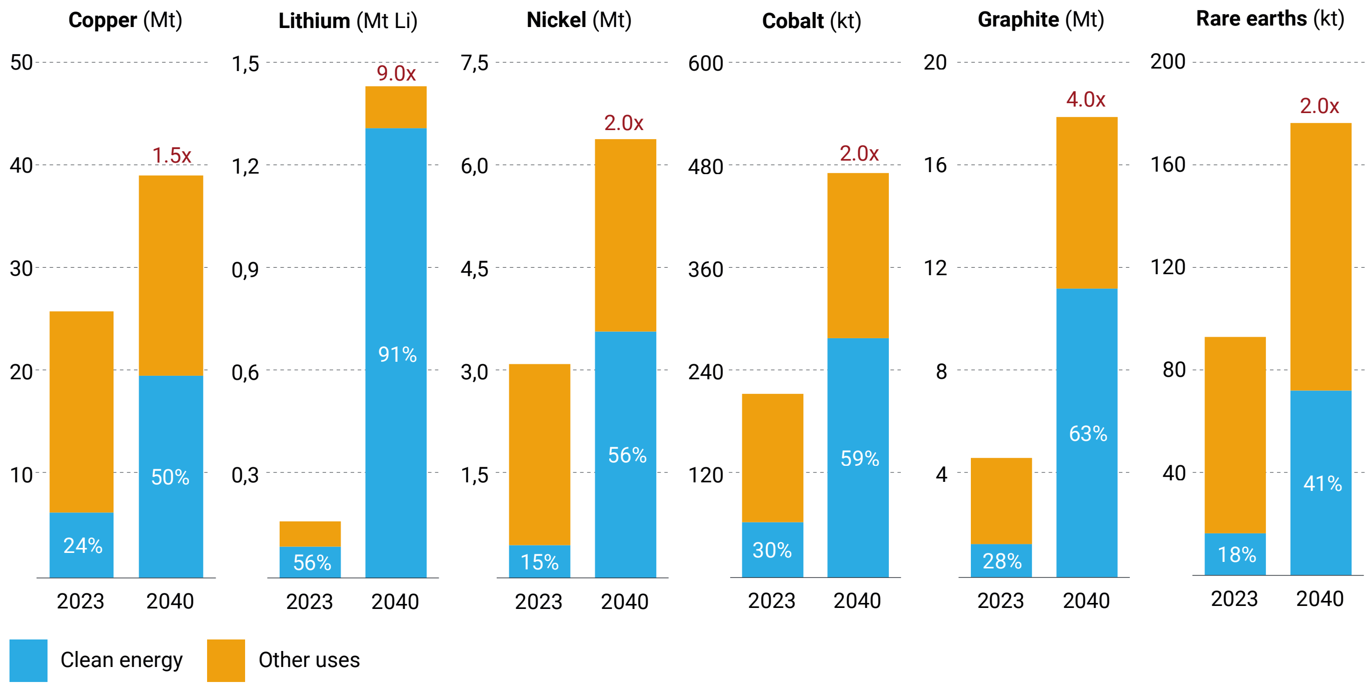
Source: Reichl and Schatz (2022, section 6.1.8.2). United States Geological Survey (2022).

I.2.6 Growth in demand

A number of scenarios on the future demands for minerals needed for the low-carbon energy transition have been published, including by the World Bank (Hund *et al.* 2020), IRP (2020), the European Commission (Moss *et al.* 2013, Bobba *et al.* 2020), the International Energy Agency (2021; 2022a; 2022b; 2022c; 2023), the International Renewable Energy Agency (Gielen 2021), the German Raw Materials Agency (Marscheider-Weidemann *et al.* 2021), the Finnish Geological Survey (Michaux 2021) and various academics, including Grandell (2016); Watari *et al.* (2018), Elshkaki and Shen (2019), Moreau *et al.* (2019), Habib *et al.*, 2020, Heijilen *et al.* (2021), Watari *et al.* (2021) and Christmann *et al.* (2022).

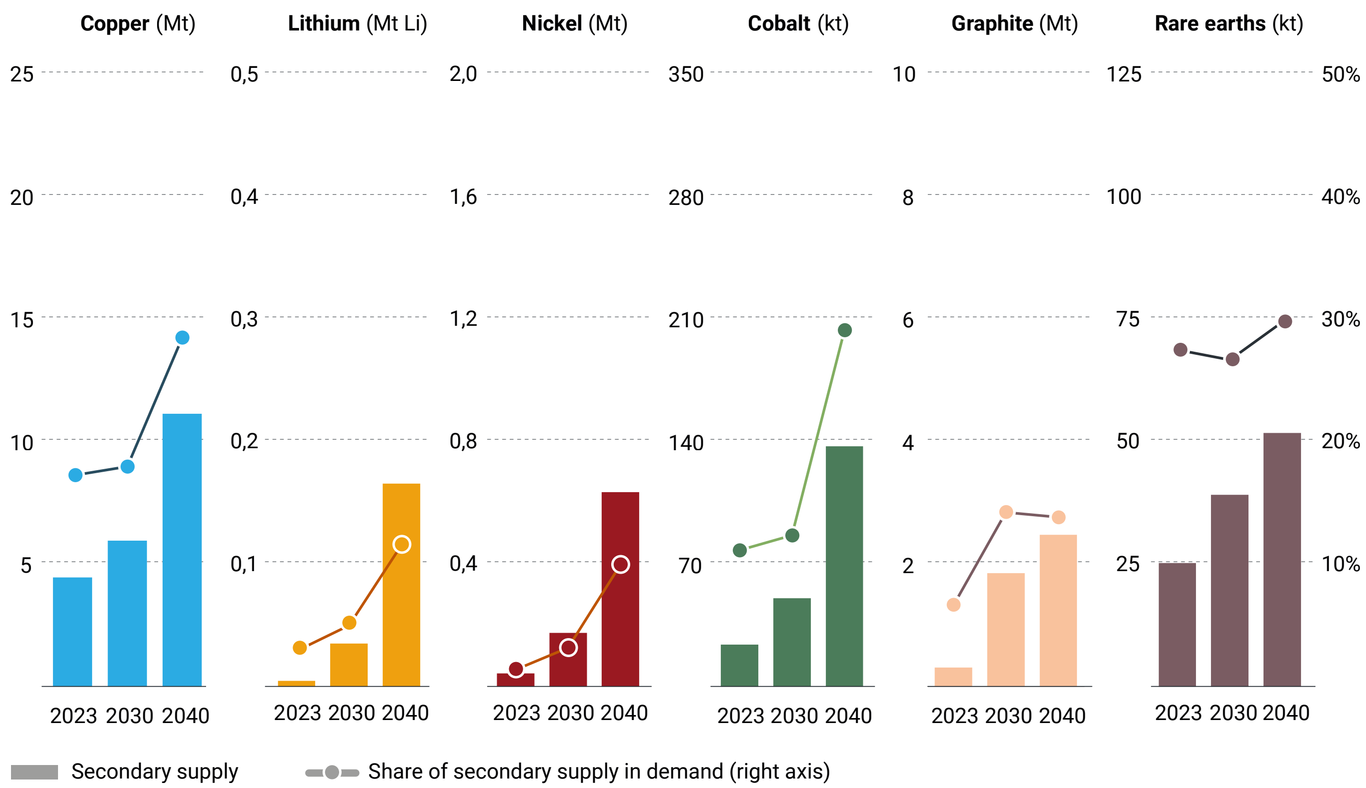
All these publications point towards a very high demand in the period up to, at least, the decade between 2040 and 2050 for the minerals and metals needed to make the global energy transition possible. They also point to the need for investment in mineral exploration and the development of new production sites, even taking developments in favour of the circular economy into account (as discussed in Chapter 4), such as the reuse, remanufacturing and recycling of products. Many of these reports underline the risk of forthcoming imbalances in supply and demand or increases in mineral and metal prices that could reverse the declining costs of photovoltaic cells, wind turbines and energy storage systems that have been observed over the last two decades. The rapidly growing demand for technologies that are among the key enablers of the energy transition is compounded by the high mineral and metal intensity of these technologies (tons of minerals or metals required per MWh of installed electrical production or tons of minerals and metals required for an average battery-operated electric car as compared for a comparable car using an internal combustion engine; see figure I.2).

Figure I.9: Growth from 2023 to 2040 of selected minerals in the IEA Net Zero Emissions (NZE) scenario



Source: International Energy Agency (2024, p. 96)

Figure I.10: Secondary supply volumes and share (%) of total demand for six minerals from 2023 to 2040 in the NZE scenario



Source: International Energy Agency (2024, p. 103)

Table I.1 showed the projected growth of demand by 2040 of many minerals important for low-carbon energy technologies, relative to their 2020 production, and figure I.9 shows the growth for six of these minerals by 2040, relative to their production in 2023, as projected in the Net Zero Emissions (NZE) Scenario of the International Energy Agency.[5] It is projected that the production of lithium will need to grow by a factor of 9, graphite by a factor of 4, and cobalt, nickel and rare earth elements by around a factor of 2. Their growth in the more ambitious Net-Zero Emissions Scenario of the Agency would be higher still.

In terms of secondary production, Figure I.10 shows that current percentage rates of recycling of six energy transition key minerals are generally low (around 10% or less, with the exception of copper and rare earths). Although this is likely to grow significantly to 2040, overall projected rates of recycling in 2040 in the International Energy Agency NZE scenario remain between 10 and 30 per cent. This emphasizes the importance of adopting circular economy approaches, as discussed above, over the full life-cycle of the products using the minerals, from first design through all the 9Rs (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover) of Potting *et al.* (2017).

The information about recycling, companion metals and the concentration of production is brought together in Figure I.11. The colour of the diamonds shows the recycling rate, the red diamonds show the many minerals which that have a recycling rate of less than 1 per cent. Moreover, more than 75 per cent of the production of many of these minerals is as companion metals. The concentration of production in a few countries is measured along the horizontal axis by the Hirschmann Herfindahl Index. The Index is calculated as the sum of the squares of the individual country production percentages. If 100 per cent of a mineral is produced in a single country, representing the maximum possible concentration, the Index is $(100)^{2,}$ or 10,000. If the production is split between two countries with 50 per cent each, the Index is $(50)^2 + (50)^2$, which equals 2,500 + 2,500, or 5,000.6 The higher the Index is, the more concentrated the production of this material is in relatively few countries. From this it becomes apparent that the rare earth elements that are more important for low-carbon energy technologies (praseodymium, neodymium, dysprosium and terbium) are exclusively companion metals (100 on the vertical axis), are very concentrated in production (a Hirschmann Herfindahl Index close to 10,000) and have very low recycling rates (<1 per cent).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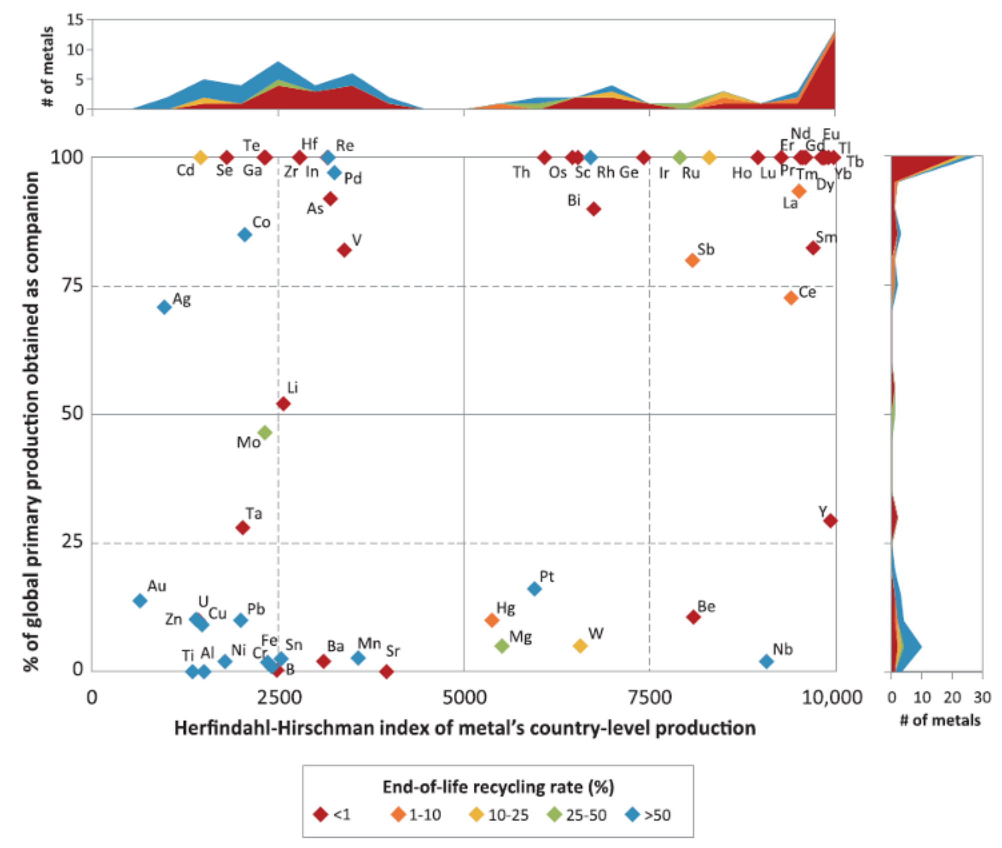
5 The *Net Zero Emissions by 2050 (NZE) Scenario* charts a pathway for the global energy sector to achieve net zero CO2 emissions by 2050 and limit the global temperature rise to 1.5 °C above pre-industrial levels in 2100 (with at least a 50 per cent probability) with limited overshoot. The NZE Scenario also meets the key energy-related Sustainable Development Goals (SDGs) such as universal access to reliable modern energy services and major improvements in air quality.

6 Chapter 1 expands on the Hirschmann Herfindahl Index in a novel way to include the concentration of consumption as well as production.

Figure I.11: The proportion of companion metal and their concentration of production, together with their recycling rate



Source: Nassar, Graedel and Harper (2015, figure 4, p. 5).

I.2.7 Mining and conflict

While there is widespread support for mining in many of the communities in which it operates because of the benefits it can bring to local communities, mining is also a major source of conflict in almost every country in which it takes place at scale. This especially true for Indigenous communities whose cultures may be especially negatively impacted by mining.

The Environmental Justice Atlas is a unique source of information about environmental conflicts resulting from mining and other extractive or land-use activities.

Figure I.12 shows places of conflict identified in the Atlas where the conflict is related to the extraction of mineral ores and building materials (the orange dots). The concentration of mining conflicts in the Andes in South America is particularly striking.

The scale of mining conflicts confirms that unless the mining industry can get widespread community consent for its operations in the future, including from Indigenous communities whose lands are often rich in minerals, there is very little prospect of it being able to expand to the extent necessary to satisfy the projected increase in the demand for minerals and metals, whether for the low-carbon energy transition or anything else.

Figure I.12: Map of conflicts related to the extraction of mineral ores and building materials in Latin America

Note: Orange dots indicate places of conflict owing to the extraction of mineral ores and building materials.

Source: Environmental Justice Atlas (https://ejatlas.org/category/mineral-ores-and-building-materials-extraction), © Attribution-NonCommercial-ShareAlike 3.0 Unported (CC BY-NC-SA 3.0).

I.3 FINANCING SUSTAINABLE MINERALS PRODUCTION

As noted above, the minerals and metals industry has played, and continues to play, a major role in support of human well-being, but it can also cause harm, sometimes centuries after the closure of production operations. Which outcome predominates depends not just on the policies of individual companies, but also on how governments regulate the industry and how it is financed. It is the financial sector, which provides capital to the industry, and the consumers of its products that enable the companies to earn a return. They have a crucial role to play, through the conditions they set, in ensuring that mining operations contribute to the sustainable development of minerals and metals and of the affected countries, throughout the whole of their dependent supply chains.

The *Mineral Resource Governance* report (IRP 2020) considered the implications of the sustainable development licence to operate for the minerals industry generally, especially in respect of minerals governance. This new report applies the insights and suggestions from the *Mineral Resource Governance* report on the financing of the exploration, extraction and mining, refining and processing, secondary production (recycling, etc.) of minerals, and mine closure and remediation. These areas are covered in more detail for what are here referred to as transition minerals, as defined above, but many of the issues raised in this report apply to the extraction and processing of metals in general. The report seeks to clarify how the revenues from the mineral operations are currently shared, what the environmental and social impacts of their extraction and processing are, and how current governance arrangements operate. It provides an evidence base for recommendations as to how the financial sector can contribute to winning these resources, which are so necessary for the low-carbon energy transition, in a way that contributes more broadly to sustainable development, where they do not do so already.

To make the minerals required for the low-carbon energy transition industrially available at the required quantities in a timely manner will require multi-billion dollar investments, as discussed in Chapter 5. For this to contribute to the Sustainable Development Goals more broadly, this investment will need to be carried out in an economically, socially and environmentally appropriate way taking account of the manifold risks involved. The review of business risks in the mining industry published by EY (2023) placed environmental, social and governance issues as the top of the ten major risks faced by the mining industry in 2024 (EY 2023).

This report makes suggestions as to how financing mechanisms can support responsible mining that supports sustainable development, along the lines of a sustainable development licence to operate. The report looks at the financing issues for two mineral production lines: listed companies (large and small-medium sized, private and publicly owned or listed) and artisanal and small-scale mining. The definition of the financing landscape will help to increase understanding of how investors, shareholders and stakeholders are operating, and how their practices can be improved in order drive financial resources towards more sustainable practices.

The report is organized into several chapters. Chapter 1 sets out the basics of mineral production and trade, using the Global Material Flow Database of the United Nations Environment Programme (UNEP), which currently covers the years between 1970 and 2019. Chapter 1 also goes into further detail about three crucial mineral-producing areas: China, Africa and South America. Chapter 2 introduces many of the issues that are important in relation to investment and investors. These include influences on the prices of mineral commodities, how the revenues from mining will be shared with different stakeholders, and how they will support local and national economic development in the host countries, again with further detail about China, Africa and South America. In both chapters, these regional treatments are discussed in relation to the most important mining-related issues in their areas.

Chapter 3 is focused on the key social and environmental issues relevant to mining. Many of these were dealt with in great detail in IRP (2020), and so the Chapter provides a more summary treatment, with only a more extended discussion of mining impacts on biodiversity. Chapter 4 explores the potential of recycling and wider circular economy-based approaches to contribute to the supply of minerals for low-carbon energy technologies. It is clear that these approaches are essential, but that there are many barriers to them, and there is no prospect of them completely replacing virgin supply in the foreseeable future.

These four chapters set the scene and context for what are the main investment- and finance-related chapters of the report. Chapter 5 discusses in detail investment issues across the life cycle of mineral extraction, from the initial geological surveys to mine closure. The sums of investment required across this life cycle are very large, and it will be a very substantial task to attract such investment for the low-carbon energy transition to take place in the timescale envisaged under the Paris Agreement.

Chapter 6 addresses the issues around the concept of sustainable finance; it is clear that there is no settled definition of this term, but that environmental, social and governance issues are at its core. For the increase in mining that is required, and for it to contribute to the sustainable development of the countries and local communities hosting the mines, the industry will need to bring about a step change in its handling of environmental, social and governance issues. Chapter 6 explores how the finance sector is currently addressing this need and how much further it needs to go.

Chapter 6 also indicates, on the basis of a survey carried out for this report, that addressing these environmental, social and governance issues could well involve extra costs; covering those costs will require trading arrangements that go beyond simple commodity markets. Notwithstanding these extra costs, the Chapter concludes that environmental, social and governance concerns will need to be given a higher priority not just by mining companies, but also by the investors who finance them, if greatly increased mining activities are to secure a sustainable development licence to operate.

The environmental, social and governance considerations as discussed in Chapter 6 are mainly of relevance to large-scale mining, but also important for some transition minerals is artisanal and small-scale mining, which is the subject of Chapter 7. The financing of artisanal and small-scale mining was the subject of a separate survey for this report, the results of which are reported in Chapter 7.

Chapter 8 distils the conclusions and recommendations of the previous chapters. It seeks to strike a balance between the various imperatives identified in this and the previous IRP report in this area: the present need for greatly increased investment in transition minerals; the need for improved performance in both mining and finance across all the environmental, social and governance issues discussed at length both in this report and in IRP 2020, with the recognition that such improvement takes time; and the overriding need for mining to contribute to the sustainable development of the countries in which it is carried out, as well as the well-being and prosperity of local communities affected.

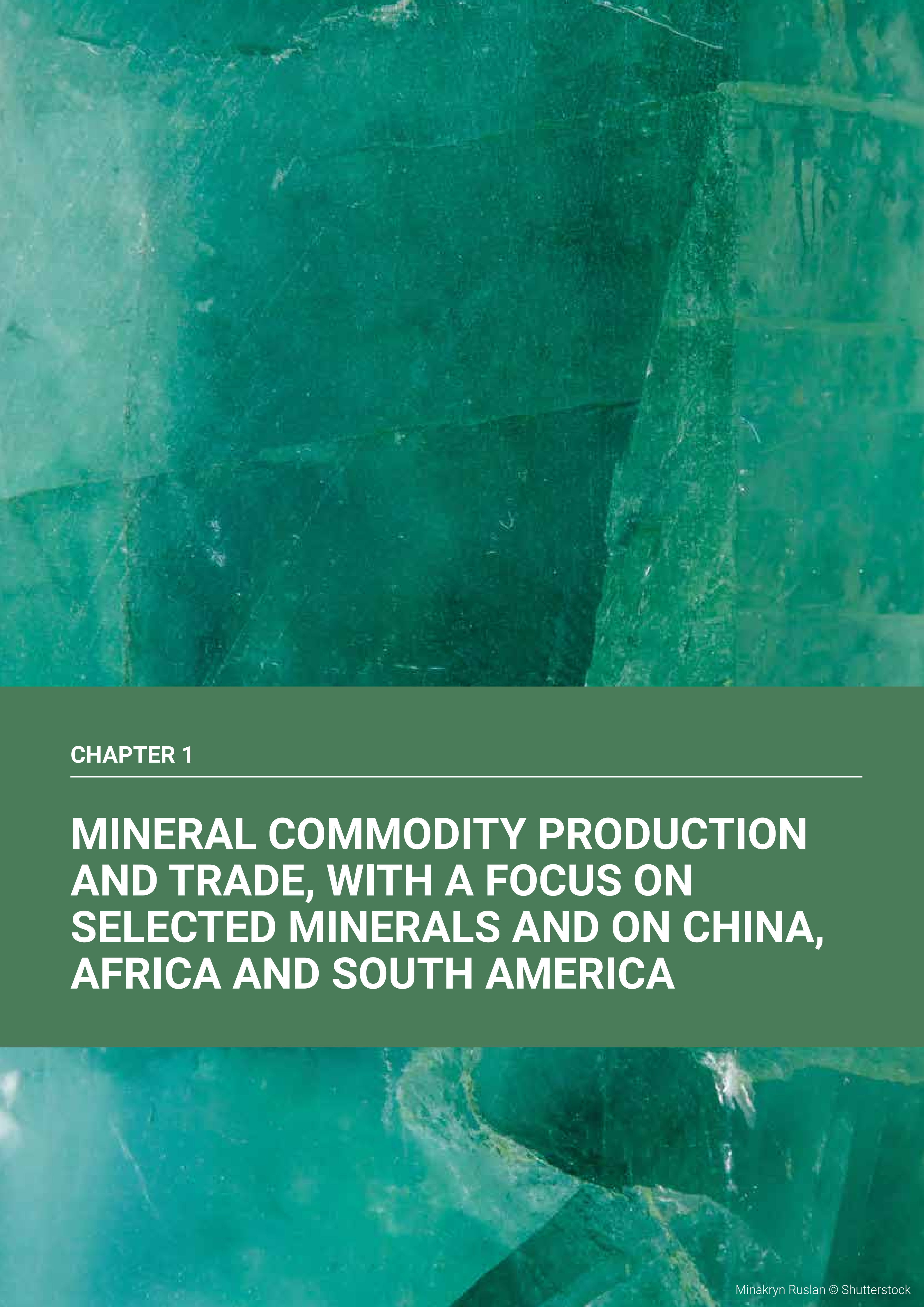
Failure in respect of any one of these imperatives could prevent mining from taking place at the required scale and act as a major roadblock to the delivery of the low-carbon energy that the world will need to meet the objectives and targets of the Paris Agreement.

I.4 CONCLUSIONS OF THE CHAPTER

The world needs a significant increase in the mining of the transition minerals required to underpin the low-carbon energy transition. The great majority of these minerals are geologically available. However, the appetite for these minerals, often in the world's richest and most developed countries, needs to be moderated by a clear recognition of the social and environmental limits to their extraction. This will require strong incentives in importing economies to limit their demand for these resources by economizing on their use and adopting radical circular economy approaches. Without such measures, and a commitment to obtain a sustainable development licence to operate in the countries and communities that host the mines, the mining industry will not succeed in building the trust that will be necessary for transition minerals to be produced at scale. This is especially true in respect of the need for the industry to acknowledge and respect the rights of Indigenous communities, on whose territories much of the mining is already taking place and is likely to take place in the future.

PART 1:

MINERALS AND METALS TODAY



CHAPTER 1

MINERAL COMMODITY PRODUCTION AND TRADE, WITH A FOCUS ON SELECTED MINERALS AND ON CHINA, AFRICA AND SOUTH AMERICA

CONTENTS

1.1 INTRODUCTION

The use of materials since 1970 has risen dramatically in line with the increases in human population and economic activity. The largest constituent part of that growth has been from non-metallic minerals, mainly for construction applications, but the quantity of metal ores used has also increased markedly.

An increasing variety of these metals is being extracted to fulfil different technological needs. The dominant country in the extraction and processing of metals is currently China, but Australia, Africa and South America are also important regions with significant mineral reserves.

A substantial proportion of these metal ores are traded, which can lead to supply chain dependency among either importers, who need the metals for their own economic activity, or exporters, who rely on the revenues from their exports.

This chapter explores these issues quantitatively.

1.2 THE ROLE OF METALS IN THE GLOBAL EXTRACTION OF RAW MATERIALS

Between 1970 and 2024, the annual global extraction of raw materials increased by a factor of three and a half from 31 billion metric tons to 107 billion metric tons (figure 1.1), amounting to an annual average increase of 2.3 per cent. However, in the period from 2000 to 2012, the growth rate was 3.5 per cent as major emerging economies, especially China, built infrastructure (United Nations Environment Programme [UNEP] 2024).

Since 1970, the relative tonnage of biomass, fossil fuel carriers and metallic and non-metallic minerals has also changed. Up to the late 1980s, biomass dominated global raw material extraction. Since then, the use of non-metallic minerals, mainly for construction applications, has surpassed biomass use. Today, non-metallic minerals extraction accounts for half of annual global raw material extraction, up from 31 per cent in 1970. The share of metals in total global material extraction grew from 9 per cent in 1970 to around 10 per cent in 2024. In absolute numbers, this is an increase from 2.6 billion metric tons to 10.6 billion metric tons, or an annual growth of 2.6 per cent in metals extraction (figure 1.2) (International Resource Panel [IRP] Global Material Flows database).

Metals therefore contribute a small proportion to global raw material extraction. However, as emphasized throughout this report, metals are essential for the performance of core technologies, such as renewable energy infrastructure, transport equipment and digital devices. In addition, the variety of metals used in major applications has continuously increased. Just a century ago, only four metals (iron, copper, gold and silver) were in wide use. Nowadays, all 62 metals and metalloids in the periodic system are in use (Graedel *et al*. 2015).


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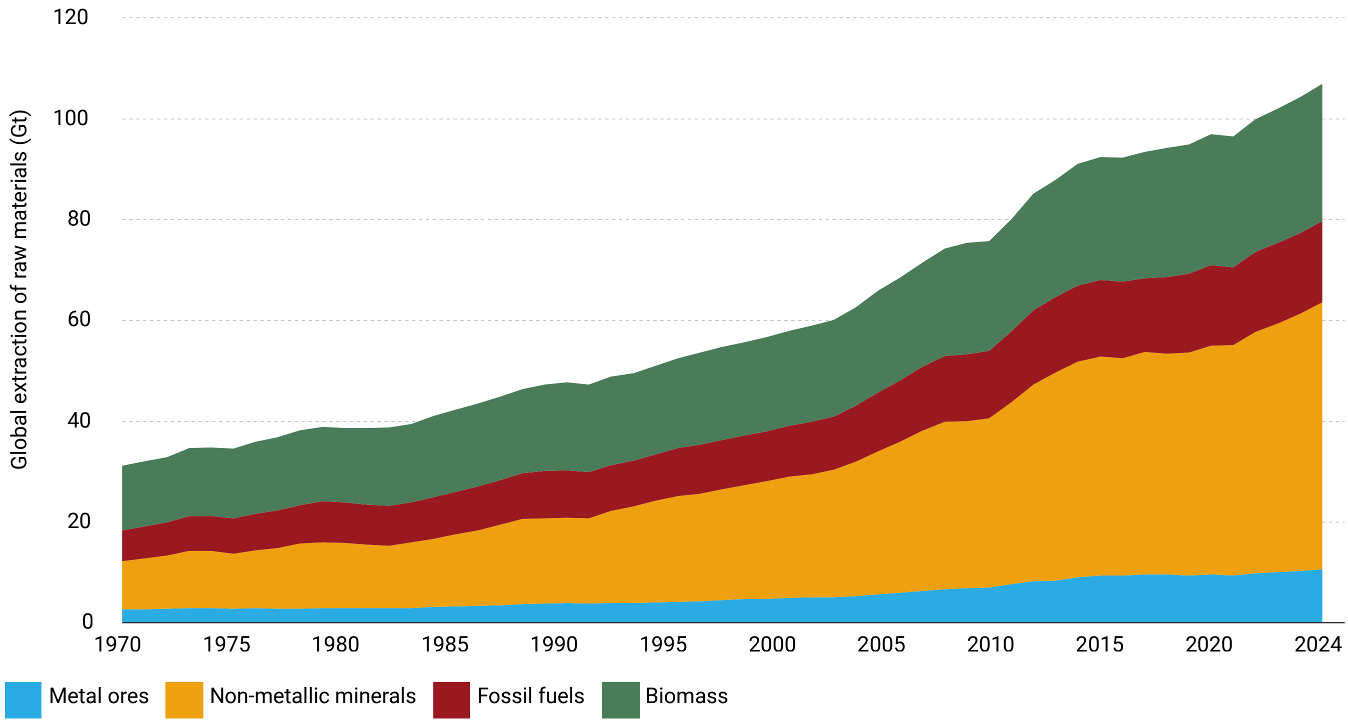
Figure 1.1: Global extraction of four categories of raw materials, 1970–2024



Source: IRP Global Material Flows database.

The massive growth in global minerals and metals production observed since the beginning of the twentieth century, and particularly after the Second World War (International Resource Panel [IRP] Global Material Flows database[7], Christmann *2021*), has been made possible by several interrelated factors:

- The development of know-how and general technological progress, especially since the early nineteenth century (Maddison 2001), and the related availability of skills and of cheap long-distance seaborne transport for minerals and metals;
- The development of geological knowledge and underpinning data, essential to the discovery of economically recoverable mineral concentrations (Winchester 2001);
- The availability of highly concentrated and cheap energy sources, so far still coming very dominantly from carbon-based fossil sources (82 per cent of the world energy production in 2021 according to BP (2022)), with consequent greenhouse gas emissions;
- The rapid development and urbanization of Asia in general, and of China in particular, since 2000.

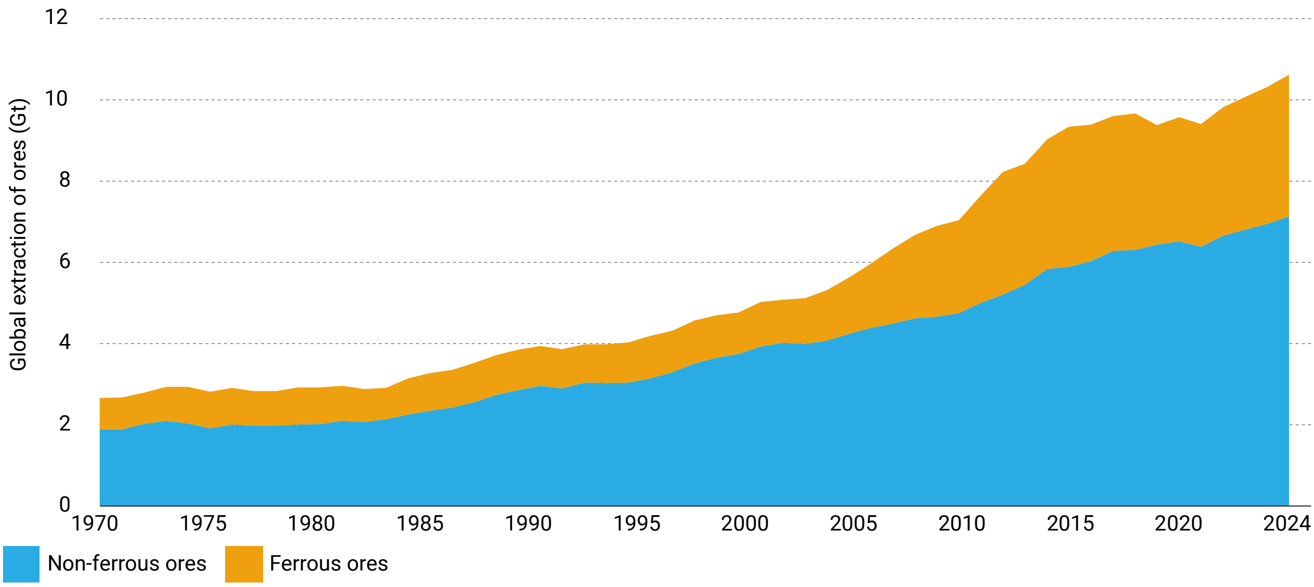
The United Nations Environment Programme (UNEP) IRP Global Material Flows database follows the Eurostat guidelines for material flow accounting;[8] the extraction of metal ores is therefore accounted for as gross ore (or run-of-mine, which means including sterile ore or tailings) and not as metal content. Because ore grades differ widely between different metals and mines, the extraction volumes displayed in figure 1.2 do not correspond to the extracted metals. Measured as extracted ore, ferrous ores far exceed the ores of all other metals.

Of the 10.6 billion metric tons of metal ore extracted globally in 2024, 20 per cent were extracted in China. This makes China the largest producer of metal ores, as discussed further below, followed by Australia with 14 per cent, Chile with 9 per cent, Brazil and the United States of America with 6 per cent. Ferrous ores constituted 33 per cent of globally extracted metal ores, while 67 per cent were non-ferrous. However, measured in pure metal content 2.8 billion metric tons of metals were mined in 2021 (United States Geological Survey 2022), of which 2.6 billion metric tons, or 93 per cent, were iron ores.

7 https://www.resourcepanel.org/global-material-flows-database

8 https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/ks-gq-18-006.

Figure 1.2: Global extraction of metal ores, 1970–2024



Source: IRP Global Material Flows database.

The extraction of metal ores is often "disproportionately concentrated in some world regions or else impractical to exploit where present in other locations" (IRP 2020). Metal mines are thus distributed very unequally across the globe, leading to a high geographical concentration of production sites and high trade volumes of metals in different stages of processing. Australia extracts 30 per cent of ferrous ores, followed by China with 29 per cent and Brazil with 12 per cent. The extraction of non-ferrous ores is distributed differently geographically. Here, China is the largest extractor with 16 per cent, in addition to being a major extractor of ferrous ores. Chile is close behind with 13 per cent, followed by the United States of America with 9 per cent (IRP Global Material Flows database). In 2021, the 27 member States of the European Union produced about 3 per cent of the world production of non-fuel minerals and metals (Reichl and Schatz 2023). According to the same source, during the period 2000–2021, the production of minerals and metals in the wider European region declined by 31 per cent, in stark contrast to all other world regions where production increased over the same period, with the record growth rate being in Australia (+137 per cent).

While, as noted in the Introduction, it is true that the low-carbon energy transition will require a substantial increase in the supply of transition minerals, the whole purpose of the transition is that these should substitute fossil fuels, the mass of which currently greatly exceeds the total global extraction of metal ores (see figure 1.1). It is very likely, therefore, that the transition will result in a substantial decrease of total material extraction. In terms of environmental impact, while the extraction of transition minerals certainly has significant environmental impacts (see Chapter 3) that need to be minimized, it should be borne in mind that the mining and burning of coal has enormous adverse impacts on both the environment and human health (Gopinathan *et al*. 2023), which would be eliminated entirely if coal could cease to be a significant part of energy supply.

In 2024 the physical trade volume of metals was 2.6 billion metric tons (IRP Global Material Flow database). The trade intensity of metals (measured as trade volume of metal ores and products of extracted metal content/ domestic extraction of ores) was 0.25 percent in 2024, i.e. much higher than that of any other raw material group displayed in figure 1.1, with the exception of fossil fuels that had a trade intensity of 0.27 percent. The geographical concentration of production sites in combination with high trade volumes, and increasing demand, e.g. to scale up renewable energy systems to meet the goals under the Paris Agreement on climate change, create complex interdependencies of individual countries and industries, and the risk of severe supply shocks, as has been seen in the coronavirus disease (COVID-19) pandemic in the period 2020/21 or as a consequence of the invasion of Ukraine by the Russian Federation in 2022. A more detailed look at these interdependencies follows at the end of this chapter.

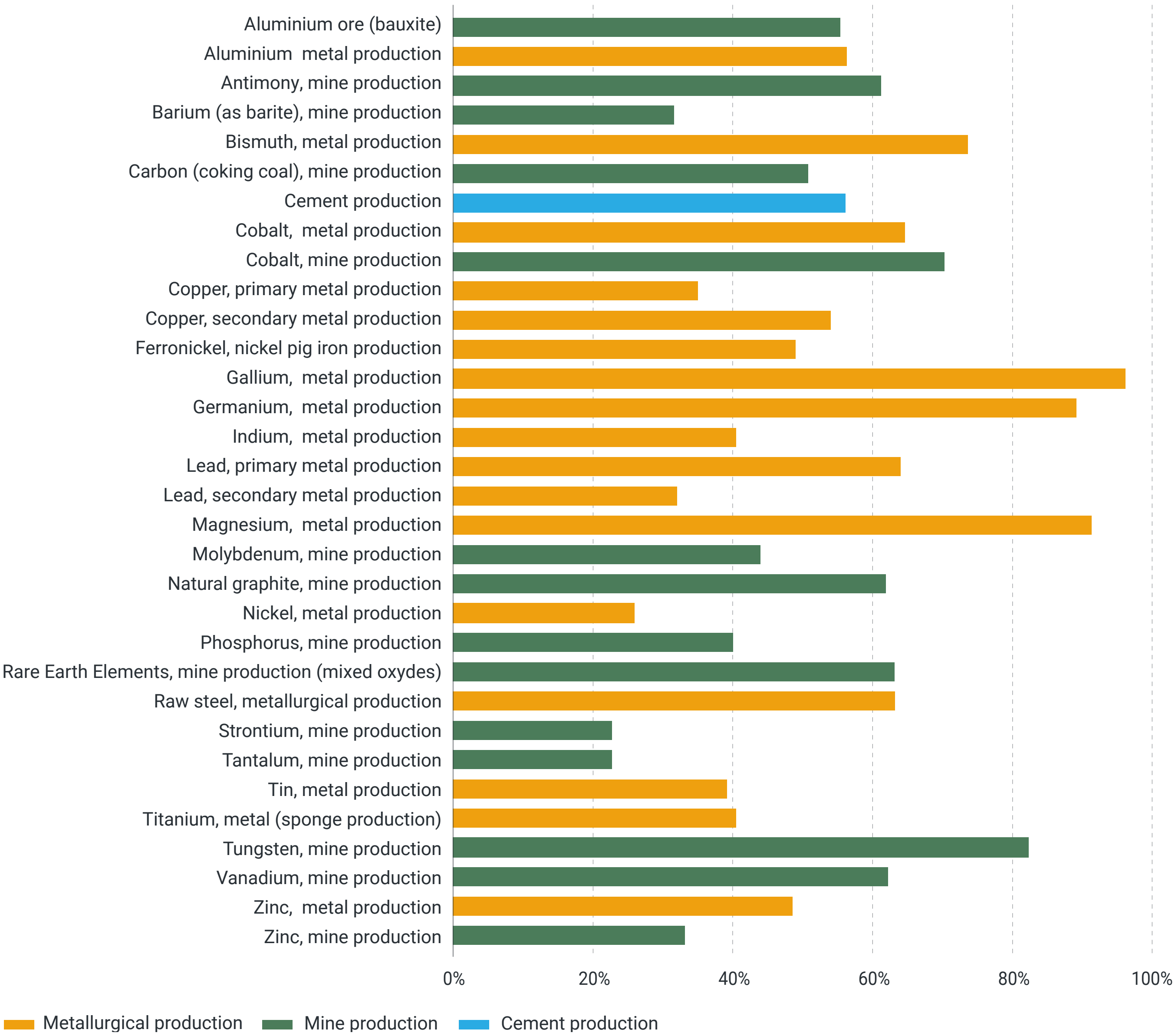
1.3 MINING AND METAL PRODUCTION IN CHINA

1.3.1 Introduction

The growth of the Chinese minerals and metals industry since 2000 has been of a magnitude and speed without precedent in human history, with huge impacts on the global economy and sustainable development issues.

Its share of global production of the minerals and metals of which it is the world's largest producer is shown in figure 1.3. Table 1.1 shows how this share and the tonnage of refined metal production in China have grown between 2000 and 2021.

Figure 1.3: Share of China's domestic production in the global production of minerals and metals of which China is the world largest producer



Note: Green bars relate to mine production and orange bars relate to metallurgical production. Cement production is shown with a blue bar, to reflect that it is neither a mine or a metallurgical product.

Source: 2018 data from Reichl and Schatz (2020), and the United States Geological Survey Minerals Yearbook, 2018 edition.

The Chinese mining industry has contributed significantly to the country's rapid development over the past three decades. As table 1.1 shows, China stands as the leading global producer of a wide range of minerals and metals. Its demand for mineral resources surpasses domestic needs, as it involves exporting intermediate and final products to the global market. Along the mineral supply chain, the prominence of China is reflected in its role in processing extracted ores to obtain the marketable products needed for global downstream industrial applications, especially for the critical raw materials needed for the low-carbon energy transition (here called transition minerals). These products can be refined metals, but also chemicals (for instance, nickel sulphate, lithium carbonate or hydroxide needed for the production of the lithium batteries used in electric cars). They can also be intermediate products, for instance nickel pig iron used for nickel-based stainless steel production.

Table 1.1: Chinese production of refined metals, of which it was the largest global producer in 2020, and of cement in 2000 and 2020 (except for titanium metal sponge: 2003 and 2019 estimates). Growth in the production of China over the period compared to the rest of the world.

Metal of mineral	Geography	Mass produced	Productions, year 2000	Productions, year 2021	Ratio 2021/ 2000	Proportion of world production, year 2000 (in %)	Proportion of world production, year 2021 (in %)
Aluminium[a]	China	Metric kilotonnes	3,250	37,080	11.4	13%	57%
	ROW		21,050	27,920	1.3	87%	43%
	World		24,300	65,000	2.7		
Cement[a]	China	Metric kilotonnes	597,000	2,377,000	4.0	36%	56%
	ROW		1,063,000	1,833,000	1.7	64%	44%
	World		1,660,000	4,210,000	2.5		
Cobalt[a]	China	Metric kilotonnes	1,20	90	75	3%	69%
	ROW		35	40	1.1	97%	31%
	World		36	130	3.6		
Copper (2000 and 2020 data)[a]	China	Metric kilotonnes	1,024	8,050	7.9	8%	38%
	Row		11,906	13,050	1.1	92%	62%
	World		12,930	21,100	1.6		
Gallium[b]	China	Metric tonnes	47	90	1.9	22%	69%
	ROW		163	40	0.2	78%	31%
	World		210	130	0.6		
Germanium[b]	China	Metric tonnes	12	86	7.2	29%	90%
	ROW		29	10	0.3	71%	10%
	World		41	96	2.3		
Gold[b]	China	Metric tonnes	180	365	2.0	7%	12%
	ROW		2,390	2,685	1.1	93%	88%
	World		2,570	3,050	1.2		
Lead[a]	China	Metric kilotonnes	998	2,800	2.8	31%	63%
	ROW		2,272	1,650	0.7	69%	37%
	World		3,270	4,450	1.4		
Magnesium[a1]	China	Metric kilotonnes	426	886	2.1	73%	89%
	ROW		158	114	0.7	27%	11%
	World		584	1,000	1.7		

Metal of mineral	Geography	Mass produced	Productions, year 2000	Productions, year 2021	Ratio 2021/ 2000	Proportion of world production, year 2000 (in %)	Proportion of world production, year 2021 (in %)
Mercury[a]	China	Metric tonnes	200	1 000	5.0	15%	86%
	ROW		1 160	160	0.1	85%	14%
	World		1 360	1 160	0.9		
Selenium[b,c]	China	Metric tonnes	65	1 400	21.5	4%	38%
	ROW		1 701	2 310	1.4	96%	62%
	World		1 766	3 710	2.1		
Silicon metal[a]	China	Metric kilotonnes	N/A	3 000	N/A	N/A	80%
	ROW		N/A	750	N/A	N/A	20%
	World		N/A	3 750	N/A		
Steel (raw)[a]	China	Metric kilotonnes	128 500	1 064 767	8.3	15%	57%
	ROW		721 500	815 233	1.1	85%	43%
	World		850 000	1 880 000	2.2		
Tellurium[b]	China	Metric tonnes	N/A	260	N/A	N/A	57%
	ROW		N/A	199	N/A	N/A	43%
	World		220	459	2.1		
Tin[a]	China	Metric tonnes	115 000	203 000	1.8	39%	59%
	ROW		183 000	141 000	0.8	61%	41%
	World		298 000	344 000	1.2		
Titanium sponge[d]	China	Metric tonnes	3 000	77 000	25.7	4%	35%
	ROW		72 000	143 000	2.0	96%	65%
	World		75 000	220 000	2.9		
Vanadium[a]	China	Metric tonnes	14 000	70 200	5.0	35%	67%
	ROW		26 400	34 800	1.3	65%	33%
	World		40 400	105 000	2.6		
Zinc[a2]	China	Metric kilotonnes	2 500	6 342	2.5	25%	47%
	ROW		7 500	7 058	0.9	75%	53%
	World		10 000	13 400	1.3		

Note: ROW is Rest of the World

Data sources: a "United States Geological Survey (USGS)Mineral Yearbook, annual editions 2004, 2020 and 2021, available from: https://www.usgs.gov/centers/national-minerals-information-center/commodity-statistics-and-information"

a[1] Same source as a, but does not include United States production (data withheld)

a[2] "USGS Minerals Yearbook, 2022 edition, available from: https://www.usgs.gov/centers/national-minerals-information-center/commodity-statistics-and-information. Data includes secundary production (from recycling)"

b World Mining Data, 2004 and 2023 editions

c British Geological Survey (2006) World Mineral Production 2000-2004

d (2003 and 2019 production estimates) Titanium sponge production data is from: Louvigné F. (2021). Etude de veille sur le marché du titane 2018 – 2020. Report on the global Ti market 2018-2020 (in French),158 p. https://www.mineralinfo.fr/sites/default/files/documents/2021-10/louvigne_titane_rapport_2018-2020_edition_publique.pdf

1.3.2 The mineral production and reserves of China

The share of the global production of metal-based marketable products of China is:

- 68 per cent for nickel-based products (including Class I nickel metal (see the IRP Nickel Factsheet in the Annex to this report);
- 38 per cent of refined copper metal production (table 1.1); and
- 59 per cent of lithium-based marketable products, such as lithium carbonate or hydroxide.

In addition, 75 per cent of cobalt-based marketable products are refined and produced in China (International Energy Agency 2021; Darton Commodities 2022; Yeomans and Harter 2022).

To support the growing domestic production capacity for metal refining and processing, China has become the world's largest importer of various raw mineral materials in the world. Chinese companies are therefore expanding investments and mining activities abroad, with the support of the Going Out strategy of China (Stone *et al*. 2022). With mining operations spreading across the globe, China plays an increasingly important role in the global supply of the products needed for the energy transition.

China is rich in a great variety of mineral resources. By the end of 2021, a total of 173 kinds of mineral resources had been found in China, including 13 types of energy raw materials,[9] 59 kinds of metallic minerals, 95 kinds of non-metallic minerals and 6 kinds of water and gases (China, Ministry of Natural Resources 2022). As shown in table 1.2, China has the world's largest reserves of seven minerals: vanadium, molybdenum, tungsten, tin, antimony, rare earth elements and strontium. Among transition minerals, in addition to rare earth elements, China has the world's second-largest natural graphite and zinc reserves, and the fourth-largest lithium reserves.

The proportion of Chinese reserves of each mineral in the world is shown in figure 1.4 (major transition minerals are marked in bold), where:

- 5 of them have reserves in China accounting for more than 30 per cent of the global total: tungsten, molybdenum, **vanadium, rare earth elements** and titanium.
- 4 of them had reserves in China accounting for 18.8 per cent to 30 per cent of the global total: tin, antimony, **graphite** and lead.
- 21 of them have reserves in China accounting for less than 18.8 per cent of the global total: **zinc**, magnesite, fluorite, coal, iron, barite, silver, **lithium**, natural gas, **phosphorus**, **manganese**, gold, **bauxite**, **copper**, **nickel**, boron, oil, magnesium, **cobalt**, **chromium** and zirconium.
- only 9 of them have per capita reserves above the world average: tungsten, molybdenum, **vanadium**, **rare earth elements**, titanium, tin, antimony, **graphite** and lead.

The dominance of China in global metal resources, encompassing reserves, production and consumption, is substantial. The population of China constitutes roughly one-fifth of the global total (18.8 per cent). For the per capita metrics of China to surpass the global average, they must therefore exceed this percentage.

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9 For a definition of this term, see https://inspire.ec.europa.eu/codelist/EndusePotentialValue/energyMinerals.

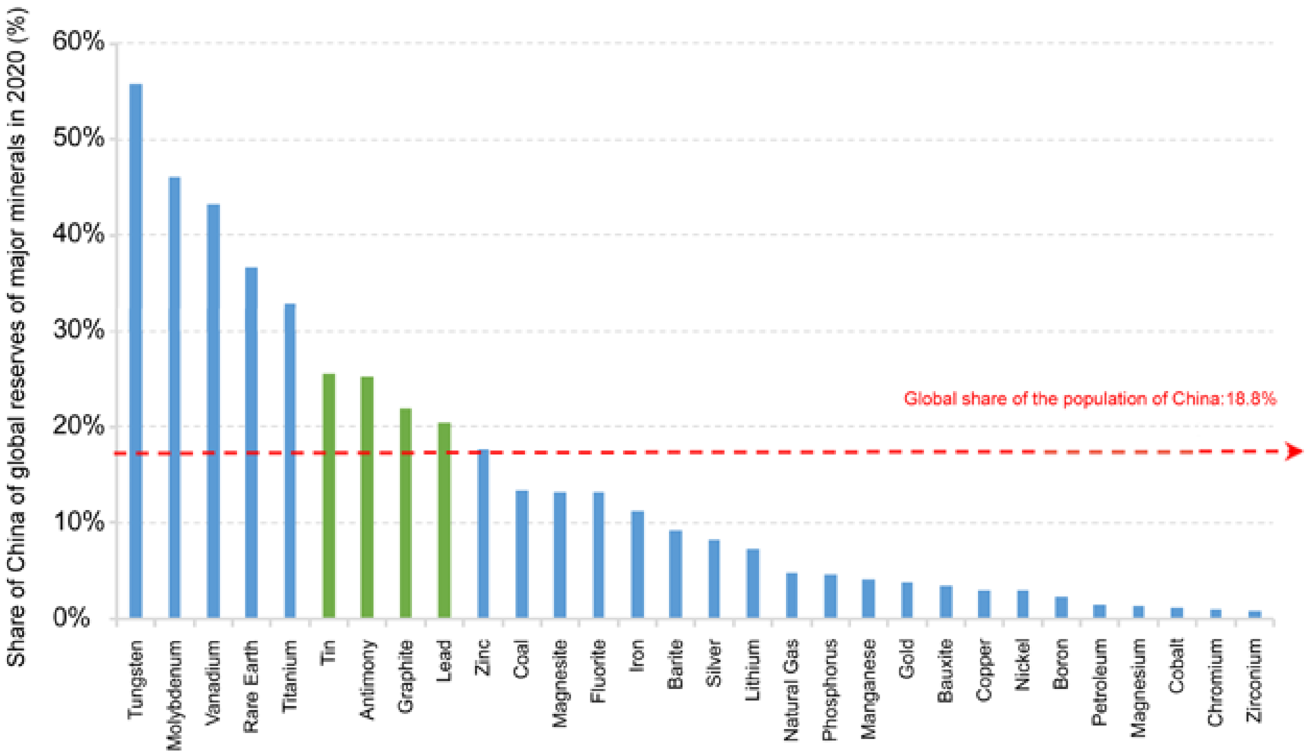
Table 1.2: Statistics on the major mineral reserves of China

Mineral	Unit	World		China		Global ranking of China	Mineral	Unit	World		China		Global ranking of China
		2019	2020	2019	2020				2019	2020	2019	2020	
Coal	100 million tons	10,696	10,741	1,416	1,432	4	Gold	tons, metal	50,000	53,000	2,000	2,000	8
Petroleum	100 million tons	2,445.8	2,444.2	35.5	35.4	13	Silver	10,000 tons, metal	56	50	4.1	4.1	5
Natural gas	trillion cubic meters	198.8	188.1	6	8.8	6	**Platinum group**	**tons, metal**	**69,000**	**69,000**	**-**	**-**	**-**
Iron	100 million tons, ore	1,700	1,800	196	200	4	**Rare earth**	**10,000 tons, REO**	**12,000**	**12,000**	**4,400**	**4,400**	**1**
Manganese	**10,000 tons, metal**	**81,000**	**130, 000**	**5,400**	**5,400**	**6**	Niobium	10,000 tons, metal	>1,300	>1,700	-	-	-
Chromium	**10,000 tons, ore**	**57,000**	**57,000**	**576**	**576**	**-**	Tantalum	tons, metal	>90,000	>140,000	-	-	-
Vanadium	**10,000 tons, metal**	**2,200**	**2,200**	**950**	**950**	**1**	**Lithium**	**10,000 tons, metal**	**1,700**	**2,100**	**100**	**150**	**4**
Titanium	10,000 tons, TiO_2	77,000	70,000	23,000	23,000	2	Strontium	10,000 tons, metal	>680	>680	-	-	-
Copper	**10,000 tons, metal**	**87,000**	**87,000**	**2,600**	**2,600**	**8**	Zirconium	10,000 tons, ZrO_2	6,200	6,400	50	50	5
Bauxite	**100 million tons, ore**	**300**	**300**	**26**	**10**	**7**	Rhenium	tons, metal	2,400	2,400	-	-	-
Lead	10,000 tons, metal	9,000	8,800	1,800	1,800	2	**Graphite**	**10,000 tons**	**300,000**	**320,000**	**72,000**	**70,000**	**2**
Zinc	**10,000 tons, metal**	**25,000**	**25,000**	**4,400**	**4,400**	**2**	Diamond	100 million carats	11	14	-	-	-
Magnesium	10,000 tons, MgO	850,000	760,000	100,000	100,000	2	**Phosphorus**	**100 million tons, ore**	**690**	**710**	**32**	**32**	**2**
Nickel	**10,000 tons, metal**	**8,900**	**9,400**	**280**	**280**	**7**	Potash	100 million tons, K_2O	>36	>37	3.5	3.5	4
Cobalt	**10,000 tons, metal**	**700**	**710**	**8**	**8**	**8**	Barite	10,000 tons	30,000	39,000	3,600	3,600	3
Tungsten	10,000 tons, metal	320	340	190	190	1	Magnesite	100 million tons, MgO	85	76	10	10	3
Tin	10,000 tons, metal	470	430	110	110	1	Fluorite	10,000 tons, CaF_2	31,000	32,000	4,200	4,200	2
Molybdenum	10,000 tons, metal	1,800	1,800	830	830	1	Boron	10,000 tons, B_2O_3	110,000	110,000	2,400	2,400	5
Antimony	10,000 tons, metal	150	190	48	48	1							

Note: Major transition minerals are marked in bold.

Data sources: United States Geological Survey (except energy raw materials), BP (energy raw materials).

Figure 1.4: The share of China of global reserves of major minerals in 2020, as a percentage of world reserves



Note: The 18.8 per cent horizontal line in the figure corresponds to the share of the global population of China.

Data sources: United States Geological Survey, BP.

As of 2021, China is still the world's largest producer of mineral resources from domestic mines. As shown in table 1.3, China ranks first in the production of 24 minerals, second in the production of 2 minerals, and third to fifth in the production of 11 minerals. Notably, in terms of transition minerals, China is the world's top producer of rare earths, zinc and graphite, the third-largest producer of lithium, copper and bauxite, and the fifth-largest producer of manganese. In addition, China is also the world's top producer of coal; the sixth-largest producer of petroleum; the third-largest producer of iron ore and the top producer of gold.

The proportion of Chinese production of each mineral in the world in 2020 is shown in figure 1.5, where:

- 14 of them have a production share exceeding 50 per cent of the global total in 2020: gallium, magnesium, tungsten, bismuth, magnesite, antimony, **graphite**, **rare earth elements**, germanium, fluorite, vanadium, chert for cement, indium and coal.
- 7 of them have a production share between 30 per cent and 50 per cent of the global total in 2020: lead, **phosphorus**, molybdenum, tin, **zinc**, titanium and barite.
- 3 of them have a production share between 18.8 per cent and 30 per cent of the global total in 2020: strontium, beryllium and sulfur.

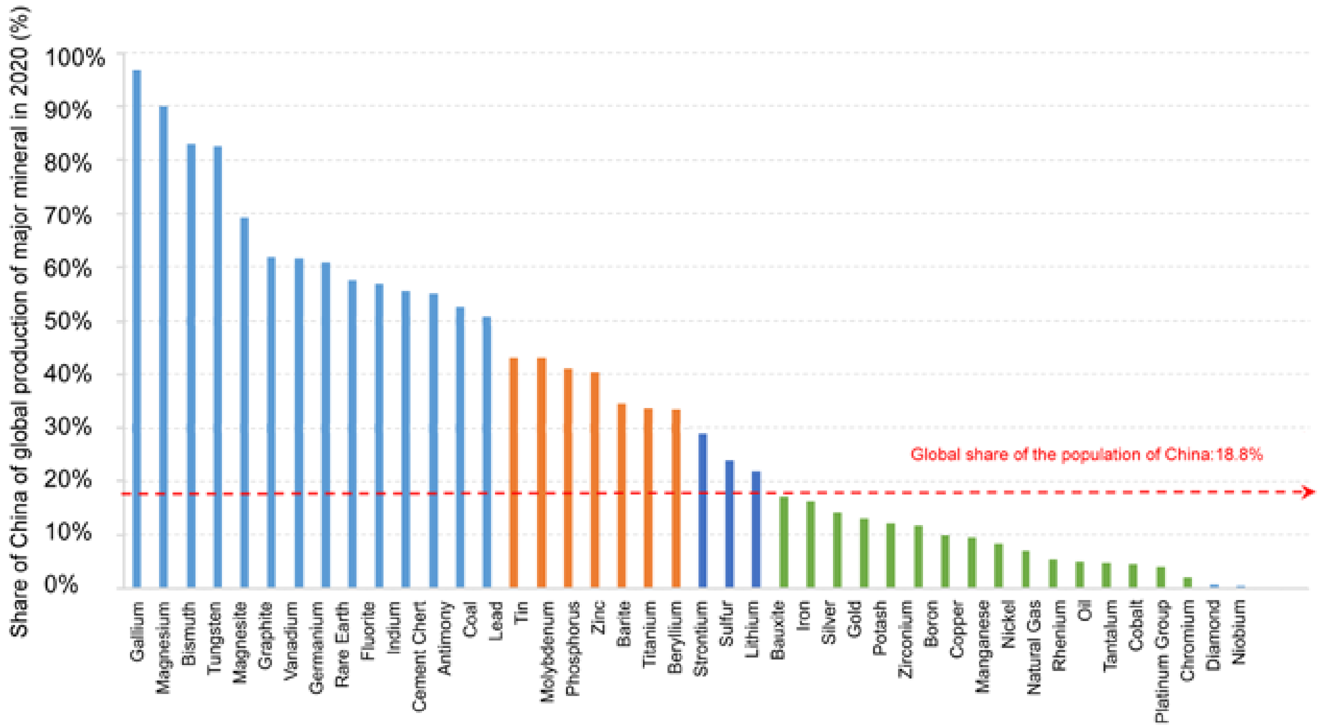
Table 1.3: Statistics on Chinese production of major minerals from its own mines (cf. table 1.1, which showed production including that from imports)

Mineral	Unit	World		China		Global ranking of China
		2019	2020	2019	2020	
Coal	100 million tons	81.3	77.4	38.5	39	1
Petroleum	100 million tons	44.8	41.7	1.9	1.9	6
Natural Gas	100 million cubic meters	39,893	38, 537	1,776	1,940	4
Iron	100 million tons, ore	25.4	24	3.5	3.4	3
Manganese	**10,000 tons, metal**	**1,900**	**1,849**	**133**	**130**	**5**
Chromium	**10,000 tons, ore**	**4,480**	**4,000**	**15**	**15**	**8**
Vanadium	**tons, metal**	**86,830**	**85,970**	**54,000**	**53,000**	**1**
Titanium	10,000 tons, TiO_2	687.9	688.9	230	230	1
Bauxite	**10,000 tons, ore**	**35,800**	**37,100**	**7,000**	**6,000**	**3**
Lead	10,000 tons, metal	450	440	210	190	1
Zinc	**10,000 tons, metal**	**1,275**	**1,218**	**430**	**420**	**1**
Magnesium	10,000 tons, metal	112	100	97	90	1
Nickel	**10,000 tons, metal**	**268**	**219**	**11**	**12**	**7**
Cobalt	**tons, metal**	**141,500**	**120,003**	**2,000**	**2,300**	**12**
Tungsten	tons, metal	84,640	83,670	70,000	69,000	1
Tin	tons, metal	226,300	188, 300	85,000	81,000	1
Molybde-num	tons, metal	291,900	292,400	130,000	120, 000	1
Antimony	tons, metal	159,705	152, 527	100,000	80,000	1
Bismuth	tons, metal	19,185	16,890	14,000	14,000	1
Gold	tons, metal	3,287	3,101	420	380	1
Silver	tons, metal	20,880	24,500	3,600	3,200	1
Platinum Group	**tons, metal**	**182**	**170**	**1**	**1**	**8**

Mineral	Unit	World		China		Global ranking of China
		2019	2020	2019	2020	
Rare Earth	**tons, REO**	**213,000**	**243,300**	**132,000**	**140,000**	**1**
Niobium	10,000 tons, metal	7.4	7.8	0	0	-
Tantalum	tons, metal	1,839	1,721	100	70	5
Beryllium	tons, metal	261	242	70	70	2
Lithium	**tons, metal**	**78,400**	**82,200**	**10,800**	**14,000**	**3**
Strontium	10,000 tons, metal	21,9	21	5	5	2
Zirconium	10,000 tons, concentrate	142	140	14	14	3
Germanium	tons, metal	137	141	85	86	1
Indium	tons, metal	760	900	300	500	1
Rhenium	tons, metal	48.9	53.1	2.5	2.5	4
Graphite	**10,000 tons**	**113**	**105**	**70**	**65**	**1**
Diamond	million carats	5,600	54	1	1	8
Phosphorus	**100 million tons, ore**	**24,075**	**22,306**	**11,000**	**9,000**	**1**
Sulfur	10,000 tons, sulfur	7,891	7,805	1,740	1,700	1
Potash	100 million tons, K_2O	4,130	4,300	500	500	4
Kaolin	10,000 tons	4,177	-	320	-	-
Barite	10,000 tons	952	745	290	250	1
Magnesite	10,000 tons, MgO	2,710	2,600	1,900	1,800	1
Fluorite	10,000 tons, CaF_2	699	755	400	430	1
Boron	10,000 tons, B_2O_3	264	263	25	25	3
Limestone for Cement	100 million tons, cement	41.53	39.91	23	22	1

Note: Major transition minerals are marked in bold. REO = Rare earth oxide
Sources: United States Geological Survey, BP, World Bureau of Metal Statistics.

Figure 1.5: The share of China of global production of major minerals in 2020, as a percentage of the global production



Note: The 18.8 per cent horizontal line in the figure corresponds to the global share of the population of China.

Data sources: United States Geological Survey, BP, World Bureau of Metal Statistics.

1.3.3 Mining and sustainability in China

In recent years, China has witnessed a shift towards environmentally sustainable practices in the mining sector. The introduction of the Green Exploration Guide in 2018, the inaugural standard of China for eco-friendly exploration, reflects efforts by the Government to standardize green exploration practices and safeguard the ecological environment during mineral development. Additionally, the Fourteenth Five-Year Plan of China outlines a pivotal period from 2021 to 2025 for the transformation of the Chinese mining industry. This period emphasizes initiatives such as enhancing ecological restoration in mines, fostering the responsible development and preservation of mineral resources, and promoting environmentally conscious mining practices, referred to as green mining. Furthermore, there is a focus on enhancing safety in metal production by encouraging the adoption of advanced technologies, equipment for deep mining, disaster prevention measures and automation in the mining industry, and comprehensive safety liability insurance (Ju 2021).

Despite recent strides in implementing the green mining concept, various studies have highlighted persistent environmental challenges linked to the extraction of mineral resources in China, including issues such as land occupancy, vegetation destruction, groundwater and air pollution, and engineering disasters. In response to these concerns, the Government of China introduced the Green Mine Construction Plan in 2010. However, the effectiveness of this Plan is brought into question by the fact that, as of 2019, only 1,220 mining companies were recognized as having pilot green mines, constituting less than 2 per cent of the total mines. Addressing these ongoing environmental issues remains a significant task for the Chinese mining industry (Li *et al*. 2022, Yu *et al*. 2022, Zhao *et al*. 2020).

In 2015, China published guidelines on the sustainability-related aspects of the investments of Chinese State-owned enterprises and private sector enterprises in mining ventures abroad,[10] which appear to yield encouraging results, as reported by Links *et al*. (2021) for cobalt mining ventures owned or co-owned by Chinese companies operating cobalt production activities in the Democratic Republic of the Congo: "Chinese companies in the sector demonstrate awareness of international priorities regarding responsible business by increasingly addressing issues such as human rights and responsible sourcing, instead of solely focusing on community development. They are also keen to emphasise their adherence to international standards and cooperation with foreign auditors. Recent publications by Chinese state institutions indicate that this movement towards increased alignment with international practices is also increasingly supported by China's government. Nonetheless, problems in the cobalt supply chain continue. These are not only China-specific, however, and are often rooted in the fragile political, social, and economic environment of the Democratic Republic of the Congo. Solutions are to be found in increasing collaboration with industry-wide platforms on responsible business, and in further supporting the Democratic Republic of the Congo to strengthen accountability and enforcement mechanisms."

In contrast, the Brookings Institution (Castillo and Purdy 2022) in the United States of America reports that "China shows few signs of moving toward mandatory due diligence requirements for critical minerals and their derivative products. It has taken some steps to strengthen due diligence in the past decade, but key standards, many of which are voluntary, remain unenforced. This means that broad transparency across critical minerals supply chains globally will be difficult to achieve, given the critical role of Chinese actors, particularly in the midstream." So far, publicly listed Chinese mining companies are not bound by rules on the public disclosure of their exploration activities that are comparable to the NI 43-101 standard applicable to companies listed on a Canadian stock market, or to the standard of the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (JORC code) applicable to companies listed on an Australian stock market. There is very limited public data available on the Chinese minerals and metals industry.

1.3.4 Chinese mineral and metal consumption

At the end of 2020, China remained the world's top consumer of mineral resources. The consumption of mineral resources contributes to a country's development and the improvement of people's living standards, but how China will address the sustainability issues related to minerals and metals production, at home and globally, will be of major importance to the global energy transition, and to the future of both China and the world.

Currently, as China has stepped into the later stages of industrialization, evidenced by the improvement of infrastructure construction, the increasing rate of urbanization and the rapid accumulation of social wealth, the growth rate of Chinese consumption of bulk mineral resources has started to slow down. The burgeoning development of strategic emerging industries will create a huge demand for strategic key minerals, especially for transition minerals. On the other hand, China has a complete metal industry system covering the entire production process including mining, beneficiation, smelting and alloy processing of non-ferrous metals. China thus takes over much of the global indirect demand for mineral resources, stemming from the demand for associated downstream products or services. As shown in table 1.4, China ranks first in the consumption of 36 minerals, second in the consumption of 2 minerals, and third to fifth in the consumption of 6 minerals. Unsurprisingly, China ranks first in consumption of the whole spectrum of transition minerals, such as lithium, cobalt, nickel and copper (table 1.4). In addition, China ranks second in the consumption of oil, third in the consumption of natural gas and first in the consumption of crude steel.

10 See https://mneguidelines.oecd.org/chinese-due-diligence-guidelines-for-responsible-mineral-supply-chains.htm.

Table 1.4: Statistics on the major mineral consumption of China (some of them refer to apparent consumption)

Mineral	Unit	World		China		Global ranking of China
		2019	2020	2019	2020	
Coal	100 million tons	81.3	77.4	40.4	40.6	1
Petroleum	100 million tons	44.2	40.1	6.5	6.7	2
Natural Gas	100 million cubic meters	39,039	38,228	3,084	3,306	3
Iron	10,000 tons, crude steel	177,510	177,180	91,190	99,500	1
Manganese	**10,000 tons, metal**	**1,900**	**1,849**	**1,007**	**1,075**	**1**
Chromium	**10,000 tons, metal**	**1,523**	**1,360**	**559**	**501**	**1**
Vanadium	**tons, metal**	**71,200**	**73,470**	**38,000**	**40,001**	**1**
Titanium	10,000 tons, TiO_2	687	702	155	195	1
Copper	**10,000 tons, metal**	**2,340**	**2,491**	**1,280**	**1,453**	**1**
Bauxite	**10,000 tons, metal**	**6,448**	**6,48**	**3,665**	**3,901**	**1**
Lead	10,000 tons, metal	1,293	1,354	592	648	1
Zinc	**10,000 tons, metal**	**1,379**	**1,316**	**682**	**676**	**1**
Magnesium	10,000 tons, metal	112	100	80	72	1
Nickel	**10,000 tons, metal**	**243**	**233**	**130**	**131**	**1**
Cobalt	**tons, metal**	**141,500**	**120,003**	**58,100**	**55,300**	**1**
Tungsten	tons, metal	84,640	83,670	68,000	72,000	1
Rare Earth	**10,000 tons, REO**	**21.3**	**24.3**	**12.7**	**15.2**	**1**
Niobium	tons, metal	74,100	78,200	25,410	20,078	1
Tantalum	tons, metal	1,839	1,721	210	123	3
Beryllium	tons, metal	261	242	75	75	3
Lithium	**tons, metal**	**78,400**	**82,200**	**21,800**	**22,016**	**1**
Strontium	10,000 tons, metal	21.9	21	6.1	6.2	1
Zirconium	10,000 tons, concentrate	142	140	14	14	2
Germanium	tons, metal	137	141	75.0	74.5	1
Gallium	tons, metal	600.6	550	306.7	288.5	1
Indium	tons, metal	760	900	190	347	1
Rhenium	tons, metal	48.9	53.1	2.0	2	4
Graphite	**10,000 tons**	**113**	**105**	**65**	**53**	**1**
Diamond	million carats	5,600	5,400	-	-	-
Phosphorus	**tons, phosphorus**	**2,650**	**2,455**	**914**	**727**	**1**
Sulfur	10,000 tons, sulfur	7,891	7,805	2,859	2,518	1
Potash	100 million tons, K_2O	4,130	4,300	1,033	1,011	1
Tin	10,000 tons, metal	36.7	38.4	17.8	21.6	1
Molybdenum	10,000 tons, metal	29.2	29.2	10.1	12.6	1
Antimony	10,000 tons, metal	16.0	15.3	8.0	8.3	1
Bismuth	tons, metal	19,185	16,890	12,500	12,500	1
Gold	tons, metal	3,287	3,101	1,003	821	1
Silver	10,000 tons, metal	20,880	24,500	5,707	5,849	1
Platinum Group	**tonnes, metal (platinum)**	**182**	**170**	**72**	**88**	**1**
Kaolin	10,000 tons	4,120	4,120	330	330	4
Barite	10,000 tons	952	745	189	205	1
Magnesite	100 million tons, MgO	2,710	2,600	1,647	1,623	1
Fluorite	**10,000 tons, CaF_2**	**699**	**755**	**462**	**490**	**1**
Boron	10,000 tons, B_2O_3	264	263	73	69	4
Limestone for Cement	100 million tons, cement	41.5	39.9	23.5	24.1	1

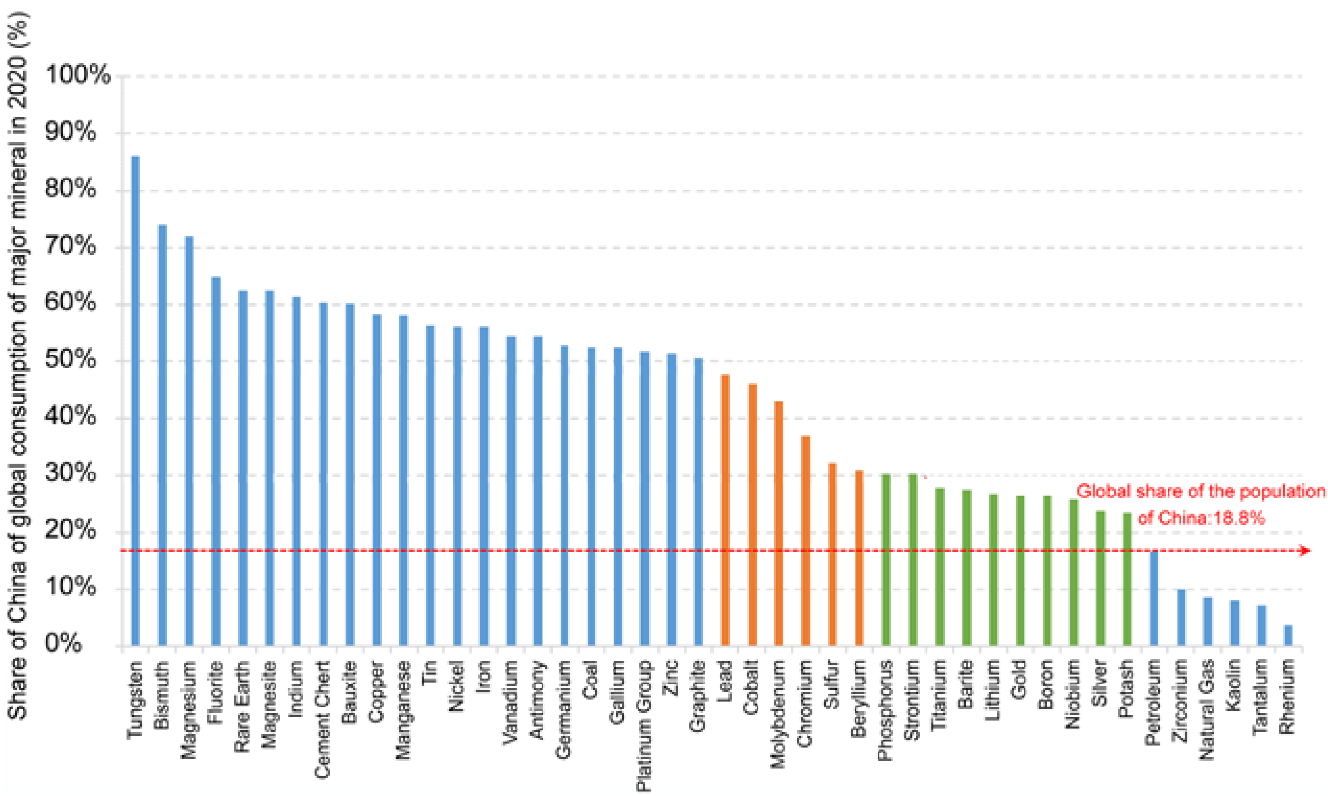
Note: Major transition minerals are marked in bold.

Data sources: United States Geological Survey, BP, World Bureau of Metal Statistics.

The proportion of Chinese consumption of each mineral in the world in 2020 is shown in figure 1.6, where:

- 22 of them have a share of global consumption of more than 50 per cent: tungsten, bismuth, magnesium, fluorite, **rare earth elements**, magnesite, indium, chert for cement (cement), **bauxite**, **copper**, **manganese**, tin, **nickel**, iron (crude steel), **vanadium**, antimony, germanium, coal, gallium, **platinum group metals**, **zinc** and **graphite**.
- 6 of them have a share of global consumption between 30 per cent and 50 per cent: lead, **cobalt**, molybdenum, **chromium**, sulfur and beryllium.
- 10 of them have a share of global consumption between 18.8 per cent and 30 per cent: phosphorus, strontium, titanium, barite, lithium, gold, boron, niobium, silver and potash.
- 6 of them have a share of global consumption below 18.8 per cent: petroleum, tantalum, zirconium, kaolin, natural gas and rhenium.
- 38 of them have a share of global consumption exceeding the global consumption average per capita (18.8 per cent).

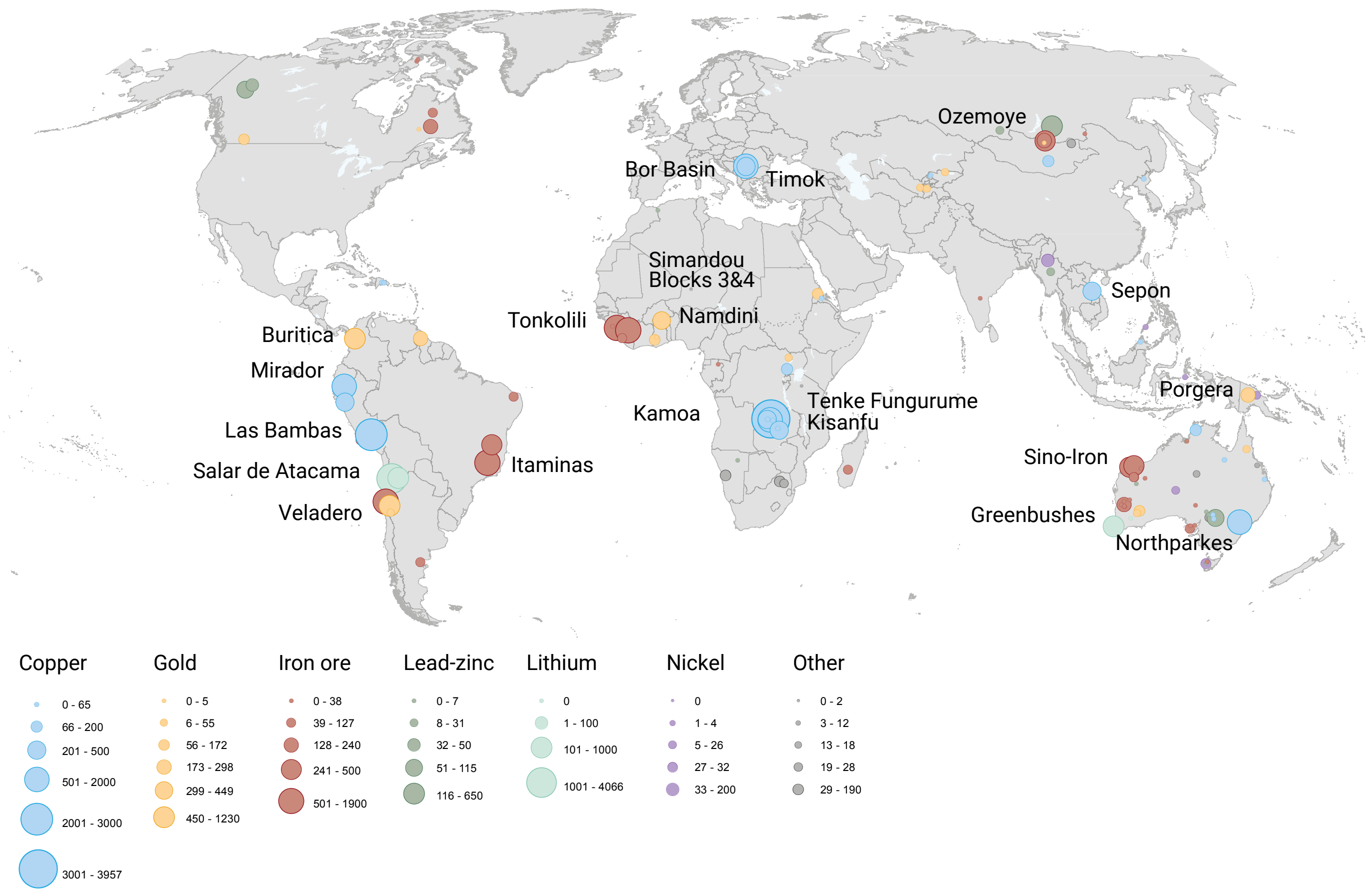
Figure 1.6: The share of China of global consumption of major minerals in 2020, as a percentage of world consumption



Data sources: United States Geological Survey, BP, World Bureau of Metal Statistics.

As an emerging economy, China has undergone rapid industrialization and urbanization over the past few decades, creating a substantial demand for input materials to build up in-use stock. Despite the significant production capacity of China, it remains dependent on international trade to import raw materials. Meanwhile, as the global "manufacturing hub", China has taken over a large amount of overseas indirect demand for mineral resources, in addition to demand in its home country. However, limited by the resource endowment of China, the huge imbalance between the supply and demand of Chinese mineral resources has directly led to the long-term dependence of Chinese mineral resources consumption on trade and investments in the mining industry in other countries (figure 1.7). Through trade, China ships its production around the globe. According to the Global Mining Development Report (2020-2021). report (China, Ministry of Natural Resources 2021), in 2020, the total mineral imports of China amounted to US$463.3 billion, down 10.8 per cent year-on-year, with the largest decline of 22.4 per cent for energy raw materials. Among them, energy raw materials accounted for 58.2 per cent of the value traded, and metal ores accounted for another 40.3 per cent of the value traded.

Figure 1.7: The overseas mining mergers and acquisitions deals of China by primary commodity as of 10 February 2021



Notes: The size of the circles refers to Deals (US$ M)

Source: S&P Global Market Intelligence.

China faces pressing imperatives in advancing its domestic ecological civilization. Given its status as the world's foremost producer and consumer of coal, the transition of China from coal to clean energy is pivotal for achieving both national and global decarbonization goals (He *et al*. 2020). Concurrently, China contends with fierce global competition for transition minerals. A major risk China faces in its mining industry is its high level of external dependence. China is externally dependent on 31 of the 45 major minerals, while having net exports in the remaining 14 minerals. The external dependence of China for major minerals in 2020 is shown by the fact that:

- 8 of them have an external dependence exceeding 70 per cent: niobium, **chromium**, **cobalt**, **nickel**, **manganese**, **platinum group**, **copper** and petroleum.
- 3 of them have an external dependence between 50 per cent and 70 per cent: boron, iron and potash.
- 8 of them have an external dependence between 30 per cent and 50 per cent: tin, tantalum, natural gas, **bauxite**, silver, **zinc**, **lithium** and sulphur.
- nearly the whole spectrum of transition minerals in China is highly reliant on imports.

1.3.5 Conclusion

China has a large variety and quantity of mineral resources, with 56 per cent of the world's tungsten reserves, 46 per cent of the world's molybdenum reserves, 43 per cent of the world's vanadium reserves, 37 per cent of the world's rare earth reserves, and 33 per cent of the world's titanium reserves, which are the five resources of which China has the highest percentage globally (see figure 1.4). However, given the large population of China, the country's resource endowment is not outstanding.

China is crucial in processing raw materials for downstream industrial applications, including most low-carbon energy transition technologies. In 2021, China claimed the top spot in producing 24 minerals, including critical minerals for the clean energy transition. Noteworthy is the status of China as the world's top producer of rare earth elements (58 per cent), zinc (34 per cent) and graphite (62 per cent), the third-largest producer of lithium (17 per cent), copper (8 per cent) and bauxite (16 per cent), and the fifth-largest producer of manganese (7 per cent). Meanwhile, as the globe's major producer and consumer of minerals, the impact of China on the global supply chain extends beyond domestic consumption.

Nevertheless, China faces many challenges, including ecological concerns and global competition for critical resources. In this context, the Going Out strategy of China has driven investments in overseas mining projects by Chinese companies to secure their supply chain. Over the past decade, the Government of China has emphasized ecological transformation in the mining sector, introducing green exploration standards and promoting sustainable practices.

1.4 MINING AND METAL PRODUCTION IN AFRICA

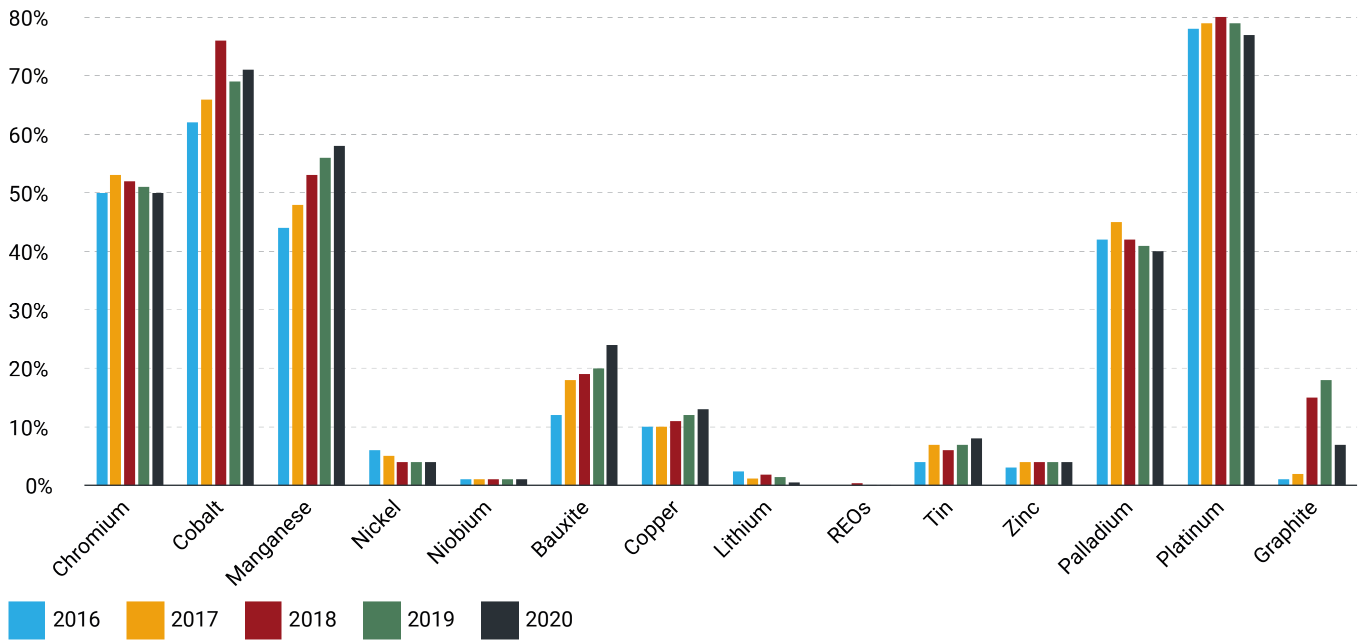
The role of Africa in the provision of transition minerals[11] is key to the global energy transition (Griffin and Pickens 2023). Fourteen important transition minerals are produced in the continent (figure 1.8); Africa accounts for half of global production of chromium, cobalt, manganese and platinum and over a quarter of the global production of bauxite and palladium. Production has generally been on an upward trajectory.

In Africa, production is concentrated in relatively few countries. For example, for most commodities the two top producers tend to account for over 80 per cent of the production. Production is also largely dominated by Southern and Central African countries (see the production for the various countries in table 1.5).


Lucian Coman © Shutterstock

11 Minerals that are needed to support the energy transition away from fossil fuels. These include lithium, nickel, manganese, aluminium, cobalt, copper, graphite and platinum group metals.

Figure 1.8: **The share (percentage) of Africa of the global production of transition minerals**



Source: Reichl and Schatz (2020).

Table 1.5: **Share of producing countries in the production of key minerals in Africa**

Manganese		Copper		Zinc		Cobalt		Niobium		Tin	
South Africa	53.7%	Democratic Republic of the Congo	62.3%	South Africa	31.9%	Democratic Republic of the Congo	93.9%	Democratic Republic of the Congo	63.5%	Democratic Republic of the Congo	63.6%
Gabon	33.3%	Zambia	32.1%	Eritrea	24.2%	Morocco	2.6%	Rwanda	18%	Nigeria	25.9%
Ghana	7.4%	Morocco	1.2%	Burkina Faso	15.7%	Madagascar	1%	Nigeria	9%	Rwanda	8.8%
Côte d'Ivoire	4.8%	South Africa	1.1%	Namibia	12.4%	Zimbabwe	1%	Uganda	5.8%	Namibia	1%
Morocco	0.4%	Mauritania	1.0%	Morocco	7.1%	South Africa	1%	Mozambique	1.9%	Burundi	0.5%
Kenya	0.1%	Eritrea	0.8%	Nigeria	5.3%	Zambia	0.4%	Ethiopia	1.2%	United Republic of Tanzania	0.2%
Zambia	0.1%	Namibia	0.6%	Democratic Republic of the Congo	3.0%	Botswana	0%	Burundi	0.6%	Uganda	0%
Namibia	0.1%	United Republic of Tanzania	0.4%	Congo	0.2%						
Senegal	0.1%	Congo	0.4%	Algeria	0.2%						
Nigeria	0.1%	Zimbabwe	0.3%								
Egypt	0%	Botswana	0%								
Democratic Republic of the Congo	0%										
Sudan	0%										

Nickel		Chromium		Bauxite		Graphite		Lithium		Palladium		Platinum	
South Africa	39.5%	South Africa	90.3%	Guinea	96.9%	Madagascar	72.6%	Zimbabwe	100%	South Africa	83.7%	South Africa	88%
Côte d'Ivoire	22.9%	Zimbabwe	9.5%	Sierra Leone	1.5%	Mozambique	27.4%	Namibia	0%	Zimbabwe	16.3%	Zimbabwe	12%
Zimbabwe	18.5%	Madagascar	0.1%	Ghana	1.3%	Namibia	0%	Nigeria	0%				
Madagascar	12.6%	Sudan	0.1%	Côte d'Ivoire	0.3%	Zimbabwe	0%						
Zambia	6.5%	Ethiopia	0%	Mozambique	0%								
Morocco	0.2%												

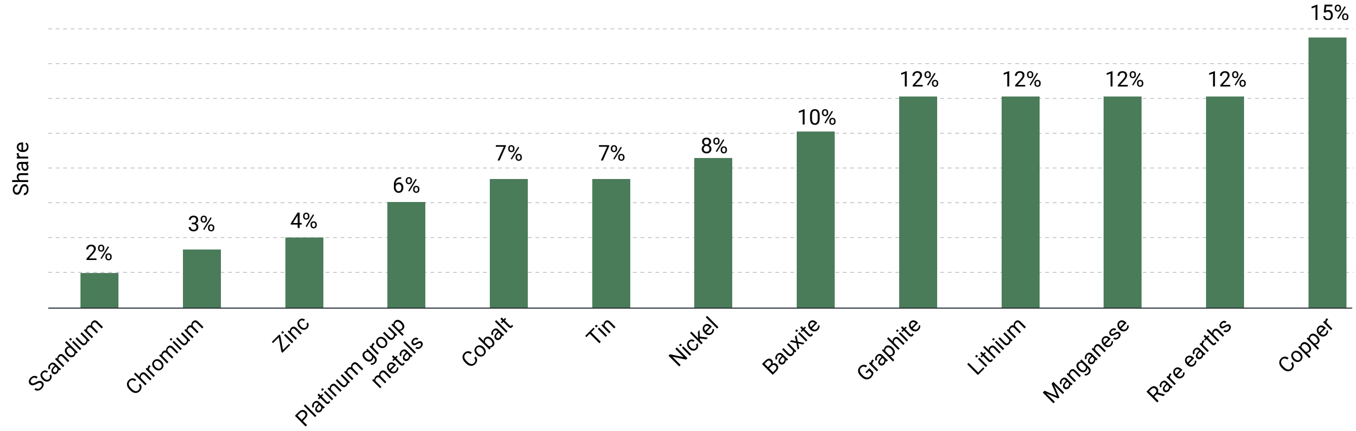
Source: World Mining Data (2022).

Based on the exploration activities underway, the position of Africa in the production of transition minerals is likely to become more significant. At the 2022 United Nations Climate Change Conference (COP 27), the International Energy Agency stated that is important to ensure that "Africa's rich critical minerals endowment crucial to global energy transition is leveraged to promote SDG7 [Sustainable Development Goal 7] on the continent".[12]

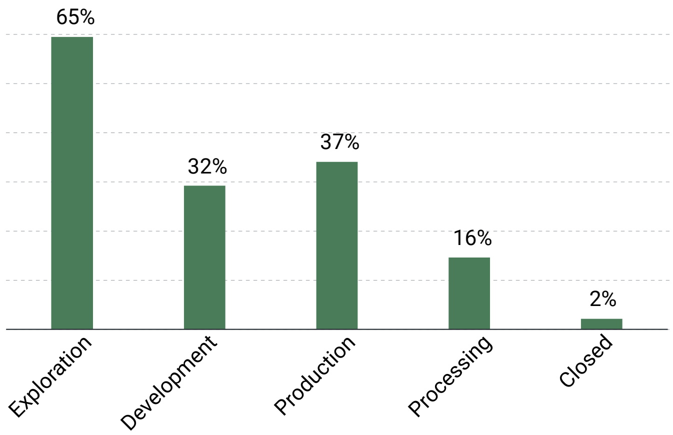
A survey for this report identified 170 projects being undertaken by 129 companies in 25 countries. As can be seen in figure 1.9, most of the projects are in the exploration or development stage. Africa is thus likely to become a key player beyond bauxite, cobalt, platinum group metals, chromium and manganese, where Africa is already dominant.

Figure 1.9: African involvement in the production of transition minerals

Minerals share, out of 170 projects identified (%).



Share of activities by stage of extractive stage



Mineral	Number of Countries	Main region
Bauxite	5	West
Chromium	2	Southern
Cobalt	7	Central and Southern
Copper	7	Central and Southern
Graphite	4	East
Lithium	9	All across
Manganese	8	East, South, West
Nickel	10	All across
Platinum group metals	4	Southern
Rare earth elements	13	All across

Source: Authors. Survey for this report.

12 https://www.iea.org/events/iea-at-cop27-ensuring-africa-s-rich-critical-minerals-endowment-crucial-to-global-energy-transition-is-leveraged-to-promote-sdg7-on-the-continent.

1.4.1 Importance of the mining sector in the regional economy

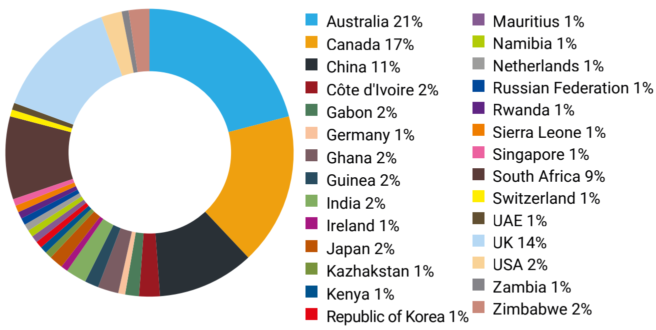
Mining in general plays a central role in many economies of the countries producing transition minerals. In the most recent survey of the mining contribution to economies, the Democratic Republic of the Congo is ranked as the country with the largest contribution of mining to its economy, with minerals contributing 12 per cent of its gross domestic product (GDP) and 86 per cent of its total exports (Ericsson and Löf 2018).[13] Mining activities can have potentially huge benefits for countries. Indeed, Botswana has been able to transform its economy and achieve high standards of living based on the exploitation of its vast diamond deposits (International Monetary Fund 2018). The current demand for transition minerals therefore has the potential to benefit countries, and can transform economies (and societies) if their institutions succeed in providing public goods and services that increase productivity across the non-extractive sectors (Dietsche 2017). At the macro level, mining can deliver benefits in terms of taxes, royalties, exports and investments. At the community level, mining can bring jobs to local communities, infrastructure (such as roads and water) and other benefits (Otto 2018).

However, it should always be remembered that mining activities can come with costs, including macroeconomic costs, leading to exchange rate increases and making other exports uneconomical (Dutch disease), alongside corruption, social disruption and, in particular, environmental costs. Furthermore, large-scale mining has tended to promote 'enclave' economies of high capital intensity with few linkages to other sectors of the economy, thus generating few benefits for those sectors. As a result, it often generates little employment, often only accounting for between 1 and 3 per cent of the jobs in the economy (Ericsson and Löf 2018).

1.4.2 Foreign direct investments in mining

The survey of 170 projects also shows that mining companies from many parts of the world are active in Africa. A total of 25 countries have activities producing 13 minerals (bauxite, chromium, cobalt, copper, graphite, lithium, manganese, nickel, platinum group metals, rare earth elements, scandium, tin and zinc). Companies from Canada, Australia, the United Kingdom of Great Britain and Northern Ireland and China constitute about two thirds of the companies (figure 1.10a). In terms of the size of mining companies, junior mining companies from Australia and Canada are the most active. In terms of financing, the majority of companies are listed mainly on the Australian (ASX), Toronto (TSX) and London (LSE) stock exchanges (figure 1.10b). Other financing arrangements include international banks, international development banks, private equity firms, large mining houses, local banks and governments.

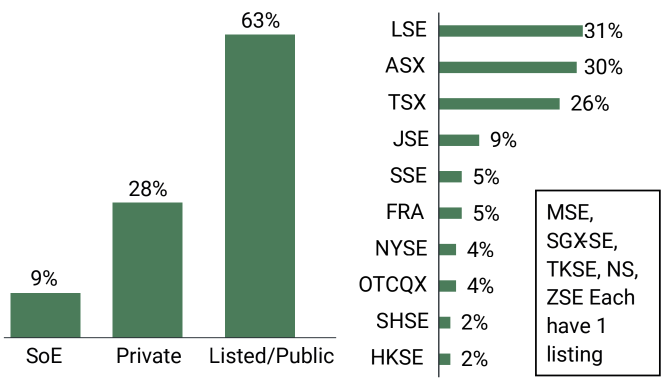
Figure 1.10a: Home countries of mining companies active in Africa



Source: Authors. Survey for this report

Note: UAE = United Arab Emirates; UK = United Kingdom of Great Britain and Northern Ireland; USA = United States of America

Figure 1.10b: Company ownership structures (left) and share listing (right) of mining companies active in Africa



13 Other countries ranked in the top 20 included Burkina Faso (2), Mali (3), Eritrea (5), Namibia (6), Botswana (11), Zambia (13), Sierra Leone (15), Guinea (18) and the United Republic of Tanzania (19). Also see the Appendix.

Note: SoE refers to State-owned enterprises

Source: Authors. Survey for this report.

China, through its State-owned enterprises, is the key government financier in mining. However, the governments of developed countries are also starting to invest directly (Japan, Republic of Korea) and indirectly (United States of America). Companies are facing a growing risk from tendencies for some countries (e.g. in Burundi, Congo, Democratic Republic of the Congo, Zimbabwe and Guinea) to claim sovereign rights over natural resources (also referred to by some as resource nationalism), and governments are demanding a greater share of revenues and investment. In Kenya, Malawi and the United Republic of Tanzania, companies face litigation actions against contracts. Issues relating to the environment (especially forest destruction) are being raised. These companies are starting to deploy Industry 4.0 (digital) technologies, especially for traceability and optimization.

1.4.3 Conclusion

Many African countries have the potential to play a substantial role in the provision of transition minerals. As the exploitation of these minerals gathers pace, the key questions are whether benefits to the host countries of mining will outweigh the costs, and, more crucially, who will capture the benefits and who will bear the costs. Potential costs that will need to be strictly controlled include corruption, social disruption and environmental damage, while the local and national economic benefits from mining will depend on the extent to which it contributes the wider economy. Companies will need to address such issues as a priority if they are to win a social licence to operate, as discussed further in Chapter 3, while host governments will also need to pay close attention to these issues if a mining boom from extracting transition minerals is to contribute substantially to the sustainable development of Africa.

1.5 MINING AND METAL PRODUCTION IN SOUTH AMERICA

1.5.1 Major South American mineral reserves

South America has abundant natural resources and accounts for a significant share of global mineral reserves (table 1.6). This has historically defined the region's primary export specialization, further strengthened by the latest mineral price boom (Bárcena 2018).

According to information from the United States Geological Survey, by 2022 it was estimated that the region contained 89 per cent of the world's reserves of niobium, 47 per cent of those of lithium, 33 per cent of those of molybdenum, 30 per cent of those of copper, 28 per cent of those of silver, 21 per cent of those of tin, 19 per cent of those of iron, 10 per cent of those of gold and zinc, and 9 per cent of those of bauxite.

Brazil has the world's largest reserves[14] of niobium, the second largest reserves of iron ore and graphite, the fourth largest reserves of bauxite and manganese, and the sixth largest reserves of tin. Chile is the country with the world's largest reserves of copper and lithium, is second in iodine reserves and fourth in molybdenum. Peru is first in silver reserves, third in copper and molybdenum, and fourth in zinc. Argentina is the country with the third largest lithium reserves. The Plurinational State of Bolivia ranks seventh among the countries with the largest tin reserves. It also has the largest lithium resources in the world, although there is no lithium production in the country, except for some relatively small pilot trials, and the reserves are currently unknown owing to insufficient investigations of the huge potential of Salar de Uyuni.

14 Reserves are mining resources that it is economically feasible to extract, at the time of determination. In turn, resources are a concentration of naturally occurring material in or on the Earth's crust in such a form and quantity that its economic extraction is currently or potentially feasible.

Table 1.6: Reserves of some minerals with significant contributions from certain South American countries

Copper (thousand metric tons of contained copper)		Lithium (thousand metric tons of contained lithium)		Molybdenum (thousand metric tons of contained molybdenum)		Niobium (thousand metric tons of contained niobium)		Silver (metric tons of contained silver)	
Chile	**190,000**	**Chile**	**9,300**	China	3,700	**Brazil**	**16,000**	**Peru**	**98,000**
Australia	97,000	Australia	6,200	United States of America	2,700	Canada	1,600	Australia	92,000
Peru	**81,000**	**Argentina**	**2,700**	**Peru**	**2,400**	United States of America	210	China	71,000
Russian Federation	62,000	China	2,000	**Chile**	**1,400**			Poland	65,000
Mexico	53,000	United States of America	1,000	Russian Federation	430			Russian Federation	45,000
United States of America	44,000	Canada	930	Türkiye	360			Mexico	37,000
Democratic Republic of the Congo (Kinshasa)	31,000	Zimbabwe	310	Armenia	150			**Chile**	**26,000**
Poland	30,000	**Brazil**	**250**	Mexico	130			United States of America	23,000
China	27,000	Portugal	60	**Argentina**	**100**			**Bolivia (Plurinational State of)**	**22,000**
Indonesia	24,000	Other countries	3,300	Canada	72			India	7,200
Kazakhstan	20,000			Iran	43			**Argentina**	**6,500**
Zambia	19,000			Uzbekistan	21			Other countries	57,000
Canada	7,600			Republic of Korea	8				
Other countries	200,000								
World total (rounded)	**890,000**	**World total (rounded)**	**26,000**	**World total (rounded)**	**12,000**	**World total (rounded)**	**17,000**	**World total (rounded)**	**550,000**

Source: United States Geological Survey, Mineral Commodity Summaries (January 2023).

1.5.2 South American production

In 2020, mining production in South American countries included a large share of many of the world's metals and minerals. Notable for their share of world production were bauxite (8.8 per cent), copper (39.9 per cent), iron (17.5 per cent), silver (23.1 per cent), gold (11.7 per cent), lead (7.1 per cent), molybdenum (32.3 per cent), tin (18.8 per cent), zinc (15.1 per cent), niobium (91.5 per cent), lithium (35.6 per cent), rhenium (39.6 per cent), tantalum (18.3 per cent) and vanadium (7.2 per cent) (Reichl and Schatz 2022).

Five South American countries were among the world's largest producers of various minerals in 2021. According to World Mining Data (Reichl and Schatz 2022, tables 3, 4 and 5), Brazil was the world's largest producer of niobium, the second largest producer of tantalum and iron, the fourth largest producer of bauxite and vanadium, and the fifth largest producer of lithium and tin. Chile was the world's leading producer of copper and rhenium, the second largest producer of lithium and molybdenum, and the fourth largest producer of silver. Peru was the world's second largest producer of copper and zinc, the third largest producer of silver, the fourth largest producer of molybdenum and tin, and the fifth largest producer of lead. Argentina was the fourth largest producer of lithium. Bolivia (Plurinational State of) was the sixth largest producer of tin, the seventh largest producer of zinc and the tenth largest producer of silver.

1.5.3 Importance of the mining sector in the economy of the region

The development of the mining sector in South America, and its importance to the continent's economies, varies between countries in the region. One indicator to measure the importance of mining in countries' economies is through mining GDP as a percentage of total GDP. This indicator is shown in table 1.7. GDP figures at constant prices have been used to calculate it in order to observe variations in production, in isolation from the effect of metal price fluctuations. On the other hand, it should be taken into account that the available data also include the production of the hydrocarbon sector, which is particularly relevant to Argentina, the Bolivia (Plurinational State of), Colombia, Ecuador and the Bolivarian Republic of Venezuela.

Table 1.7 shows that the mining sector is particularly relevant for the economies of Bolivia (Plurinational State of), Chile, Peru and Guyana, where the share is close to 10 per cent of GDP. In the Bolivarian Republic of Venezuela, the sector's contribution exceeds 10 per cent of GDP, which is explained almost exclusively by the hydrocarbon sector. Paraguay and Uruguay are the two countries in the region where mining has the least economic importance, both in relative and absolute terms. In aggregate, mining in South America accounts for around 4 per cent of GDP.

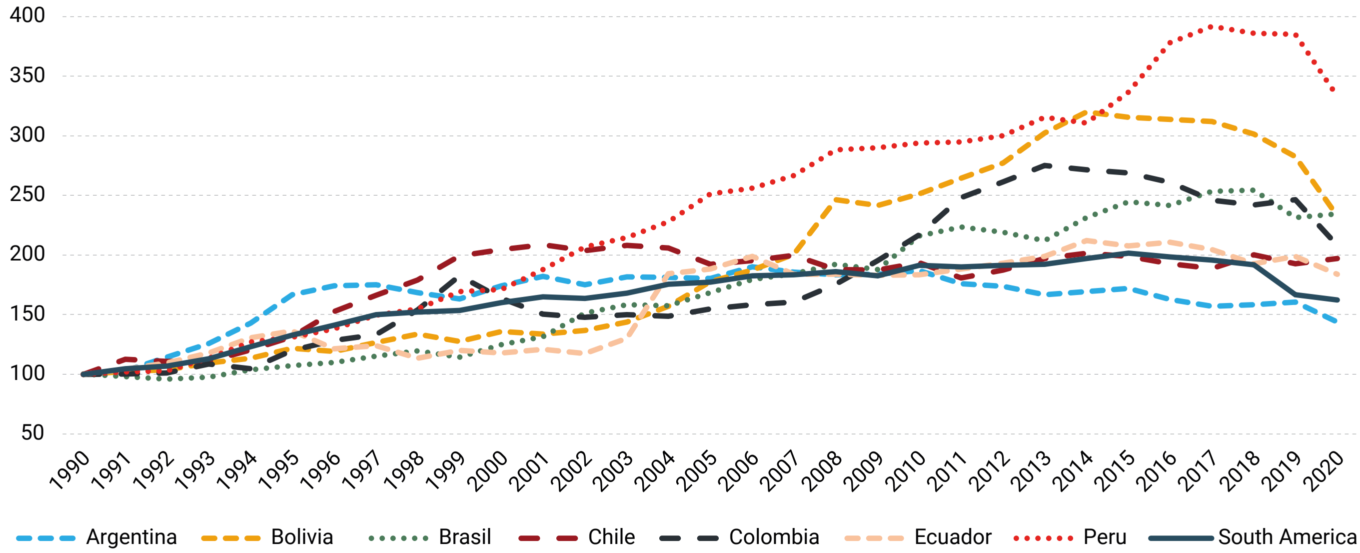
Between 1990 and 2020, all countries have experienced a significant increase in the contribution of mining to GDP, measured at constant prices (figure 1.11). The high growth rate of Peru, of around 3.5 times, stands out, followed by those of the Bolivia (Plurinational State of), Brazil and Colombia. The contribution of mining to GDP for the region as a whole grew by around a factor of two.

Table 1.7: Mining GDP, constant prices

Mining GDP, constant prices (percentage of GDP)										
Country	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Argentina	4.2	4.2	4.0	4.1	4.1	3.9	3.7	3.8	4.0	3.9
Bolivia (Plurinational State of)	13.5	13.4	13.7	13.8	12.9	12.4	11.8	10.9	10.0	9.0
Brazil	2.1	2.0	1.9	2.0	2.2	2.3	2.3	2.3	2.1	2.2
Chile	9.8	9.6	9.8	9.8	9.5	9.0	8.7	8.9	8.5	9.2
Colombia	2.7	2.7	2.7	2.6	2.5	2.3	2.2	2.1	2.1	1.9
Ecuador	6.6	6.4	6.3	6.5	6.3	6.5	6.2	5.7	5.9	5.9
Guyana	9.2	10.2	10.7	9.0	10.0	14.5	13.0	12.8	13.5	37.9
Paraguay	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Peru	9.3	9.0	8.9	8.6	9.0	9.7	9.8	9.3	9.1	8.8
Suriname	7.9	7.9	7.5	7.0	6.2	5.1	5.7	5.8	4.5	3.8
Uruguay	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Venezuela (Bolivarian Republic of)	11.9	11.4	11.3	11.2	11.8	12.8	12.8	12.2	NA	NA
South America	**4.1**	**4.1**	**4.0**	**4.1**	**4.2**	**4.3**	**4.2**	**4.1**	**3.6**	**3.7**

Source: https://statistics.cepal.org/.

Figure 1.11: **Evolution of mining contribution to GDP in some South American countries, 1990–2020**



Source: https://statistics.cepal.org/.

Table 1.8: **Share of mining in exports**

Share of mining in exports (percentage of total exports)										
Country/Customs code	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Bolivia (Plurinational State of)	**28.8**	**29.7**	**19.9**	**17.9**	**18.9**	**22.0**	**31.7**	**35.1**	**32.6**	**ND**
Lead minerals and their concentrates	2.2	2.7	1.4	1.4	1.4	1.6	2.4	3.4	3.0	ND
Zinc minerals and their concentrates	12.7	10.5	6.7	6.4	8.4	10.4	14.9	19.3	19.0	ND
Minerals and concentrates of silver, platinum and metals from the platinum group	9.8	12.1	9.1	7.3	6.2	7.0	9.9	7.9	6.6	ND
Tin	4.1	4.4	2.7	2.8	2.9	3.0	4.5	4.5	4.0	ND
Brazil	**14.4**	**16.5**	**12.9**	**13.6**	**11.6**	**7.5**	**7.3**	**8.9**	**8.5**	**10.2**
Iron minerals and their concentrates	14.4	16.5	12.9	13.6	11.6	7.5	7.3	8.9	8.5	10.2
Chile	**57.2**	**54.7**	**53.0**	**50.0**	**48.4**	**45.5**	**43.7**	**52.7**	**51.9**	**51.3**
Iron minerals and their concentrates	1.7	2.0	1.8	1.8	1.5	ND	1.4	1.5	1.3	1.0
Copper ore and concentrates	19.6	18.2	20.8	22.1	21.3	21.2	20.9	24.4	25.0	26.8
Titanium, molybdenum, vanadium, tantalum	1.8	1.8	1.6	1.1	1.6	1.2	ND	1.5	2.0	1.9
Copper (refined)	34.1	32.7	28.8	25.0	24.0	23.1	21.4	25.3	23.6	21.6
Colombia	**14.5**	**14.3**	**12.8**	**11.1**	**12.1**	**12.3**	**14.9**	**18.9**	**16.3**	**13.0**
Coal	14.5	14.3	12.8	11.1	12.1	12.3	14.9	18.9	16.3	13.0
Guyana	**20.2**	**19.4**	**19.9**	**17.9**	**17.3**	**15.1**	**11.6**	**11.2**	**18.8**	**ND**
Bauxite and its concentrates of aluminium	20.2	19.4	19.9	17.9	17.3	15.1	11.6	11.2	18.8	ND
Peru	**40.7**	**37.3**	**36.8**	**34.5**	**33.3**	**37.4**	**41.9**	**45.5**	**44.2**	**41.9**
Copper ore and concentrates	21.9	21.5	23.0	22.1	21.0	23.8	29.4	32.3	31.8	31.0
Lead	4.5	4.9	5.5	3.3	3.1	3.9	3.9	2.9	2.5	2.5
Zinc	5.3	3.3	2.9	3.0	3.5	4.3	4.0	5.4	5.3	4.1
Copper (refined)	9.0	7.6	5.4	6.1	5.7	5.4	4.6	4.9	4.6	4.3

Note: This takes into account mining products that constitute part of the 10 main export products in each country.
Source: https://statistics.cepal.org/.

Table 1.8 shows the exports of mining products for six South American countries as a percentage of total exports. The table shows those countries that have mining products among their top 10 export products and gives the tariff headings under which those 10 products fall for each country. In 2019, mining exports were most relevant in Chile, where they accounted for 51.3 per cent of total exports, followed by Peru with 41.9 per cent.

Between 2002 and 2008, during the super cycle of high commodity prices, the amount of regional mining exports almost quadrupled in value. Since 2007, the sector's share of the region's total goods shipments has fluctuated between 17 and 20 per cent. After a fall in 2009 in the context of the global financial crisis, and a significant recovery in 2010 and 2011, mining shipments have not regained the dynamism of the previous decade in terms of value. However, they have increased steadily in terms of volume. In 2017, Latin American and Caribbean exports of minerals and metals reached US$170 billion, equivalent to 17 per cent of the value of the region's total shipments of goods and 8 per cent of world exports of minerals and metals (Latin America and the Caribbean International Trade Outlook 2018 – United Nations, Economic Commission for Latin America and the Caribbean [ECLAC] 2018).

1.5.4 Foreign direct investment in mining

The mineral wealth of South America has historically attracted the attention of foreign capital in the search for natural resources, and the recent commodity price boom has intensified inflows of foreign direct investment (FDI) to this sector in the region. Over the last 15 years, the natural resources sector has attracted an increasing share of foreign investment inflows to Latin America and the Caribbean.

International demand has been profoundly transformed since the early 2000s and the main factor is related to the increasing role of China. The remarkable growth process of China and its industrialization strategy caused consumption of iron ore and base metals in the country to outstrip the increase in its domestic production. This gap started in the 1990s and widened from 2000 onwards. In 2005, the consumption of iron ore and base metals in China tripled and domestic extraction doubled. This boosted the country's mineral imports, a situation that favoured exports from Latin American countries, reversing the historical trade balance, with extraction levels of base and ferrous metals now close to seven times higher than the level of consumption (ECLAC 2016).

The average relative weight of natural resources in total FDI inflows rose from 16.6 per cent and 17.1 per cent in the 1990s and 2000s, respectively, to 22.3 per cent in the period 2010–2014. In those years, US$170.6 billion of FDI inflows to the region went to all natural resource sectors, and in several of the host countries mining accounts for the vast majority of FDI in natural resources (ECLAC 2016).

Between 2003 and 2015, US$445.7 billion in metallic mining investments were announced globally, with most of these announcements corresponding to projects in developing countries. Latin America and the Caribbean, the Asia Pacific region and Africa accounted for 84.6 per cent of the total amount of announced investments, whereby each region attracted 33.8 per cent, 29.7 per cent and 21.1 per cent of the total FDI flow respectively (ECLAC 2016).

Investment in non-ferrous metals exploration accompanied the expansionary phase and increased tenfold between 2003 and 2012, when it peaked at US$21.5 billion, before falling to US$11.4 billion in 2014. Latin America and the Caribbean received the largest share of the exploration budget between 2004 and 2014, with a share reaching 27 per cent of the total in 2014. The largest share was invested in base metals (42 per cent) and gold (41 per cent) (SNL Metals & Mining 2015). Australia and Canada, which prior to the expansion phase received the largest share of the budget, reached shares of 12 per cent and 14 per cent, respectively, while 16 per cent was invested in Africa. The privatization process in Latin America and the Caribbean in the 1990s and the higher costs of mining in traditional countries, such as Australia, Canada or the United States of America, helped the region to consolidate its position as the main destination for exploration investments between 2003 and 2012 (ECLAC 2016).

In Latin America and the Caribbean, 510 metallic mining investment projects were announced between 2003 and 2015 for an estimated US$150.54 billion, representing 12.2 per cent of the total announcements for the region. On average, each project announced was worth US$300 million, although several mega-projects far exceeded this figure. For example, a gold-mining project for Chile in 2003 reached US$8 billion and another copper project in Panama reached US$ 6.4 billion in 2014. In total, 25 projects were announced with an investment amount of more than US$ 1 billion, accounting for 40 per cent of the total amount between 2003 and 2015 (ECLAC 2016).

Most of the projects announced in the region were in mining for gold and silver (44.0 per cent of the announced amount), followed by copper, nickel, lead and zinc with 37 per cent. Brazil, Chile and Peru were the countries with the most projects announced, together accounting for 75.6 per cent of the total amount). In Chile and Peru, metal mining accounted for about 40 per cent of total announcements for the country, while in Brazil and Mexico the share was lower. Gold and silver mining was the most widespread type of mining in the region, with projects announced for 19 countries. Copper, nickel, lead and zinc mining projects showed a higher concentration, with Chile, Panama and Peru accounting for 88.4 per cent of the amounts announced. In iron ore mining, Brazil attracted most of the amounts announced (69.0 per cent), followed by Peru (27.2 per cent). Similar is the case of aluminium, where Brazil accounted for 72.1 per cent of the total, with further significant investments in Guyana and Jamaica, where there are important bauxite deposits (ECLAC 2016).

Historically, the transnational mining companies that have invested in the region were mainly from developed countries, with companies from Australia, Canada, the United States of America and the United Kingdom of Great Britain and Northern Ireland standing out. Half of the announced investment in metallic mining between 2003 and 2015 came from companies in Canada (50.6 per cent), accounting for 83.0 per cent of the total amount in gold and silver mining. The second ranked country was the United Kingdom of Great Britain and Northern Ireland, whose companies accounted for 52.2 per cent of the amount going into iron ore mining and 21.3 per cent into copper, nickel, lead and zinc. Australian companies invested in copper, nickel, lead and zinc mining, while the United States of America led investments in aluminium and ranked second in iron ore mining.

In recent years, the investment of Chinese capital in South American mining has increased significantly, especially in lithium and copper. In the case of lithium, it is important to mention the purchase by Tianqi in 2018 of 24 per cent of the company SQM for a value of US$4.1 billion, as well as the purchase from Lithium Americas in 2019 of 51 per cent of Minera Exar in Argentina, for US$290 million. In copper, it is worth mentioning the investment of US$1.3 billion in Peru (Chinalco) and US$920 million in Ecuador (China Railway Construction), both in 2018.

Significant investment flows are also expected for the future, especially in copper and lithium mining. In Chile, the latest update of the mining investment portfolio (Chile, Chilean Copper Commission 2022), covering those projects to be materialized in the decade from 2022 to 2031, includes 53 initiatives that in total reach an investment of more than US$73 billion. Copper projects represent 88.6 per cent of total mining investment. The investments come from 12 countries, led by Chile, Canada, the United States of America and Japan. Regarding lithium, the two current operations in Chile are making investments of approximately US$750 million to expand their production capacity. In the future, there could be new investment projects, thanks to the recently announced national lithium policy.

In Peru, there is an investment portfolio made up of 47 mining projects (MEM 2023), which encompass an investment of US$53.7 billion, of which nearly US$7 billion is expected to materialize during 2023 and 2024. A total of 71.7 per cent of the investments correspond to copper projects, 13 per cent to investments in gold mining and the rest to iron, silver and zinc projects. Regarding the countries of origin of the investments, 19.7 per cent come from China, followed by Mexico with 16.5 per cent, Canada with 15.2 per cent, the United States of America with 15.2 per cent and Australia with 5.4 per cent.

Argentina, for its part, has a portfolio of 87 mining investment projects, for a total of US$9,314.36 million, of which 94.5 per cent will be earmarked for construction and expansion (Secretaría de Minería 2022). Copper projects will receive investments of US$4.60 billion, equivalent to 49.5 per cent of the total, followed by lithium projects with US$3.4 billion, representing 36.3 per cent of the total. The rest corresponds to gold and silver projects. Regarding the origins of the investments, Canada has positioned itself as the main investing country, with US$5.5 billion, followed by China with US$1.2 billion, the United States of America with US$974 million and the Republic of Korea with US$831 million.

1.5.5 Conclusion

South America has important mineral reserves, with a high percentage of the world's reserves of niobium, lithium, molybdenum, copper, silver, tin, iron, gold, zinc and bauxite.

The mining production of South America includes a large part of all the metals and minerals produced in the world. In 2020, it stood out for its high proportion – more than a third – of the global production of niobium, copper, rhenium, lithium and molybdenum.

The economic contribution of mining is essential for several economies in the region, especially for Suriname, Peru, Bolivia (Plurinational State of), Colombia, Guyana and Chile. In these countries, mining accounts for a high percentage of exports and production.

FDI in mining grew strongly from 2000, driven by the increase in demand for base metals in China. In the future, it is expected to continue growing, driven by the increased demand for the metals necessary for the energy transition, such as copper and lithium. In this sense, it would be desirable for future investments to be focused on transition minerals, and less on gold and silver as has been the case until now.

1.6 TRADE NETWORKS AND CONCENTRATION IN THE GLOBAL TRADE OF METALS

1.6.1 Introduction

As noted in previous sections, metal ores trail fossil fuels, biomass and non-metallic minerals in global extraction. In physical trade volume, however, metals rank second to fossil fuels. In line with the global transition away from fossil fuels, metals are likely to become the most traded global material. It is well known that today's global supply chains are extremely fragmented and countries' trade volumes are highly skewed in most markets, with a few countries dominating trade volumes while the majority of countries trade in tiny volumes. The vast majority of trade flows between countries are of a very low volume and a tiny majority of trade flows have large volumes.

This structure of international trade networks represents imbalances, market concentrations and dependencies that are difficult to distil. Traditionally, such dependencies are evaluated by using measures of market concentration, above all the Herfindahl-Hirschman Index, which ascribes the highest power to the supplier with the highest market share, with a monopoly (Herfindahl-Hirschman Index 1) being the most extreme form of power concentration.

Industrial ecology research has addressed this risk as supply chain risk in criticality analysis. In the criticality literature, the supply risk of metals is operationalized as an index for the geopolitical concentration of primary production and is combined with other indicators or indices for, for example, estimated depletion time, political stability or substitutability in major applications (Graedel *et al*. 2015, Schrijvers *et al*. 2020, Sprecher *et al*. 2017).

Recent supply chain disruptions owing to the COVID-19 crisis and the invasion of Ukraine by the Russian Federation has brought this issue to the attention of policymakers and analysts once again. Examining the structure of these trade networks and their embodied dependencies is especially important in metals markets, where an ongoing surge in demand for transition minerals is expected to accelerate in the future.

1.6.2 Structure of the international trade network

Here our analysis is focused more comprehensively on the structure (called topology in complex network analysis) of the international trade network of metals to distil which dependencies are created between importing and exporting countries. The basic idea is that not only the importer but also the exporter can become dependent, considering that importers depend on the traded goods for their industries and exporters depend on the revenues from these traded goods. In box 1.1, a methodology for the analysis of important export power is developed.

Box 1.1: An index for market power in global trade

Recent network extensions to the well-established Herfindahl-Hirschman Index allow trade dependencies to be measured. In a first step, this is done for the bilateral case, i.e. a trade flow between country (i) (the exporter) to country (j) (the importer). We calculate for the importer the ratio of this bilateral trade flow to all imports to (j) in metric tons ($\frac{q_{ij}}{Q_j^{imp}}$) and for the exporter, we calculate the ratio of this bilateral trade flow to all exports in United States dollars ($\frac{v_{ij}}{V_i^{exp}}$). We then compute the difference between the two now dimensionless numbers (see formula (1), arbitrarily set as the importer share minus the exporter share). This gives us a measure of the bilateral trade balance (tsbij: bilateral trade share balance between importer (j) and exporter (i). This bilateral trade share balance is particularly meaningful for specific commodities, such as individual metals.

Trade share balance: $tsb_{ij} = \left[\frac{q_{ij}}{Q_i^{imp}} - \frac{v_{ij}}{V_i^{exp}}\right]$ (1)

The higher the share of imports from country (i) to country (j) is in all imports of country (j), the more country (j) relies on the exports of country (i). At the same time, the higher the share of exports from country (i) to country (j) in all of the exports country (i) is, the more the exporter relies on country (j) as a buyer. The difference between the shares simply reveals who relies more on this bilateral trade flow. The measure can have values between -1 and 1. If the import share of the bilateral trade flow is larger for the importer than the respective export share is for the exporter, the difference is positive and this means the trade share balance is in favour of the exporter. If the difference is negative, the balance is in favour of the importer.

Because countries trade the same commodities with many other countries, this bilateral trade balance is then used to define a country measure that shows a country's power position as importer and as exporter in relation to all its trade partners in any defined commodity market.

For export power, we calculate for each individual export flow of country (j) the bilateral trade share balance with the importing country (tsbji) and multiply the individual trade share balances with the respective trade volumes. This provides a weighted average of the individual trade shares balances of the exports of one country. Summing up all these weighted trade share balances and dividing them by the total exports results in a dimensionless number between -1 and 1, with -1 indicating the most powerless position and 1 the most powerful position for the exporter.

Export power: $P_j{}^{exp} = \frac{1}{V_j^{exp}} \Sigma[tsb_{ji}]xv_{ji}$ (2)

The same can be done using physical trade data. This is displayed in formula (3).

Import power: $P_j{}^{imp} = \frac{1}{Q_j^{imp}} \Sigma[-tsb_{ji}]xq$ (3)

Formula (3) shows a direct correspondence to formula (2), except for the inclusion of negative values for bilateral trade share balances. The objective is to ensure that the numerical values for import and export power are the same. A value of 1 thus represents the maximum power of the importer in the import power metric, and the maximum power of the exporter in the export power metric.

A country importing from few exporters that themselves have many other buyers of their material will lead to a negative score (down to -1), illustrating the disadvantaged position of the importer. As a country diversifies its imports and individual exporters become dependent on specific trade flows with the country, the import power increases until it eventually becomes positive (up to 1), signalling a favourable position for the importing country in the international trade network. The same is true for exporters. If a country delivers a large part of its total exports to one country, while this country imports the same raw material in significant amounts from other countries too, the exporter is more dependent than the importer and export power will become negative for the exporter.

The determination of market power for a dominant exporter or importer in a specific country and product is therefore on the comprehensive assessment of the country's import and export connections in relation to those of its trading partners.

Box 1.2

The analytical method for market power described above is here applied to lithium, in respect of the trade of lithium (lithium oxide and hydroxide and lithium carbonate, normalized to lithium context (see also the Lithium Factsheet in the Annex to this report).

Lithium is a key material for current battery technologies and demand for it is estimated to increase substantially in the coming years. Lithium is abundant in the Earth's crust, but is only mined in a few places on the planet. Its extraction methods and impacts are discussed in more detail in the IRP Lithium Factsheet. In general, with the exception of China, lithium is mined in the Southern Hemisphere, but further processing takes place in the Northern Hemisphere.

The production of lithium-ion batteries, for which the mineral is primarily used, takes place mainly in the Northern Hemisphere in countries including the European Union, China, Japan or the Republic of Korea. Without domestic mining activities (apart from China), these countries are dependent on lithium imports.

Figure 1.12

Source: Authors

Figure 1.12 illustrates this complex global trade network and shows the origin of each trade flow by continent. The main sources are South America (blue) and Asia (red), culminating in Europe with its high level of internal trade within the European Union (orange). The data is compiled from reconciled United Nations Comtrade records for global trade in 2021 (Gaulier and Zignago 2010). Trade in lithium is reported in the form of lithium carbonate, oxide and hydroxide, which were normalized according to their lithium content (European Commission 2020).

In 2021, global primary production of lithium (normalized to metal content) was around 107,000 metric tons (United States Geological Survey, Mineral Commodity Summaries 2022).

The major lithium producers in 2021 were: Australia: 61 kt; Chile: 39 kt; China: 19 kt; Argentina: 6 kt; Brazil: 2 kt; Zimbabwe: 0.8 kt (United States Geological Survey, Mineral Commodity Summaries 2022).

Since 2014, domestic production data on lithium have been withheld by the United States of America to avoid disclosing company proprietary data from only two construction sites (Jaskula 2024). According to news reports almost all of the lithium produced in Australia is exported to China.[15] Assuming 55kt mine production of lithium in Australia is exported to China, and using United Nations Comtrade data for all other trade flows, the import and export power of the largest lithium importers and exporters (defined as > 1,000 metric tons of trade volume in 2021) are displayed in table 1.9. Lithium trade data are only available as lithium oxide and hydroxide and as lithium carbonate. Their weight was normalized for their lithium content of 16.5 per cent and 18.8 per cent respectively (Christmann, Gloaguen, Labbé, Melleton, and Piantone 2015).

Australia, despite being the largest producer and largest exporter of lithium, has a negative export power in the lithium trade network (-0.22), whereas China has a positive import power (0.24), a situation that has already raised geopolitical concerns for the Government of Australia.[16]

Table 1.9: Export and import power of selected countries involved in lithium trade

Lithium export power				Lithium import power			
Country	Quantity (metric tons)	Value (US$1,000)	Export power	Country	Quantity (metric tons)	Value (US$1,000)	Import Power
Australia	55,016	358,248	-0.22	China	70,551	955,844	0.24
Chile	27,378	1,000,771	0.06	Republic of Korea	16,950	950,919	0.02
China	13,608	920,634	-0.02	Japan	9,613	510,290	-0.12
Argentina	5,724	247,366	-0.27	European Union	4,807	173,654	-0.19
European Union	2,181	94,816	0.35	United States of America	2,581	98,972	-0.36
United States of America	1,932	113,177	-0.19	Russian Federation	1,819	64,443	-0.10
Russian Federation	1,461	82,102	-0.20				

Source: Authors

15 New York Times; https://www.nytimes.com/2023/05/23/business/australia-lithium-refining.html.
16 New York Times; https://www.nytimes.com/2023/05/23/business/australia-lithium-refining.html.

Table 1.10: Import power for various countries in relation to nickel, cobalt and copper

Import power	European Union	Republic of Korea	China	Japan	United States of America
Nickel	-0.26	-0.55	0.03	-0.36	-0.24
Cobalt	0.18	-1.00	0.01	-1.00	0.06
Copper	0.24	0.00	0.62	0.12	-0.49

Source: Authors

The import power of large importers of other mining products needed for new energy technologies can vary to a large degree, as shown in table 1.10 for nickel, cobalt and copper.

Table 1.10 shows the import power of key materials for the energy transition (nickel, cobalt and copper) for five major importers: the European Union, the Republic of Korea, Japan, China and the United States of America. Data for trade with metal ores and concentrates was used, which is the earliest stage of metal production represented in trade statistics.

Both the Republic of Korea and Japan are highly dependent on imports of cobalt from the Democratic Republic of the Congo. While China also sources almost all of its cobalt from the Democratic Republic of the Congo, it is also the destination for almost all of the cobalt exports of the Democratic Republic of the Congo, creating a much more balanced trade relationship. Overall, the countries studied are the least dependent on copper imports, with the exception of the United States of America, which is dependent on Canadian copper exports. China has a powerful importer position in the trade networks of all three metals.

1.6.3 Conclusion

After decades of expanding trade networks through globalization, recent supply shocks have revealed that many countries are vulnerable to global supply chains. This has motivated reindustrialization policies in countries such as France, the United States of America and Germany that are aimed at reducing the dependence on imported critical raw materials and products. Reducing trade dependencies is especially important for transition metals that will be demanded in much higher quantities for the necessary rapid decarbonization of energy systems. However, for densely populated Western countries, including much of Europe, a massive reindustrialization of the mining sector is unlikely or not feasible. Here, a reliable quantification of the mutual dependencies between trade partners in individual metal markets could help countries to develop more balanced trade partner portfolios and create more resilient supply chains.

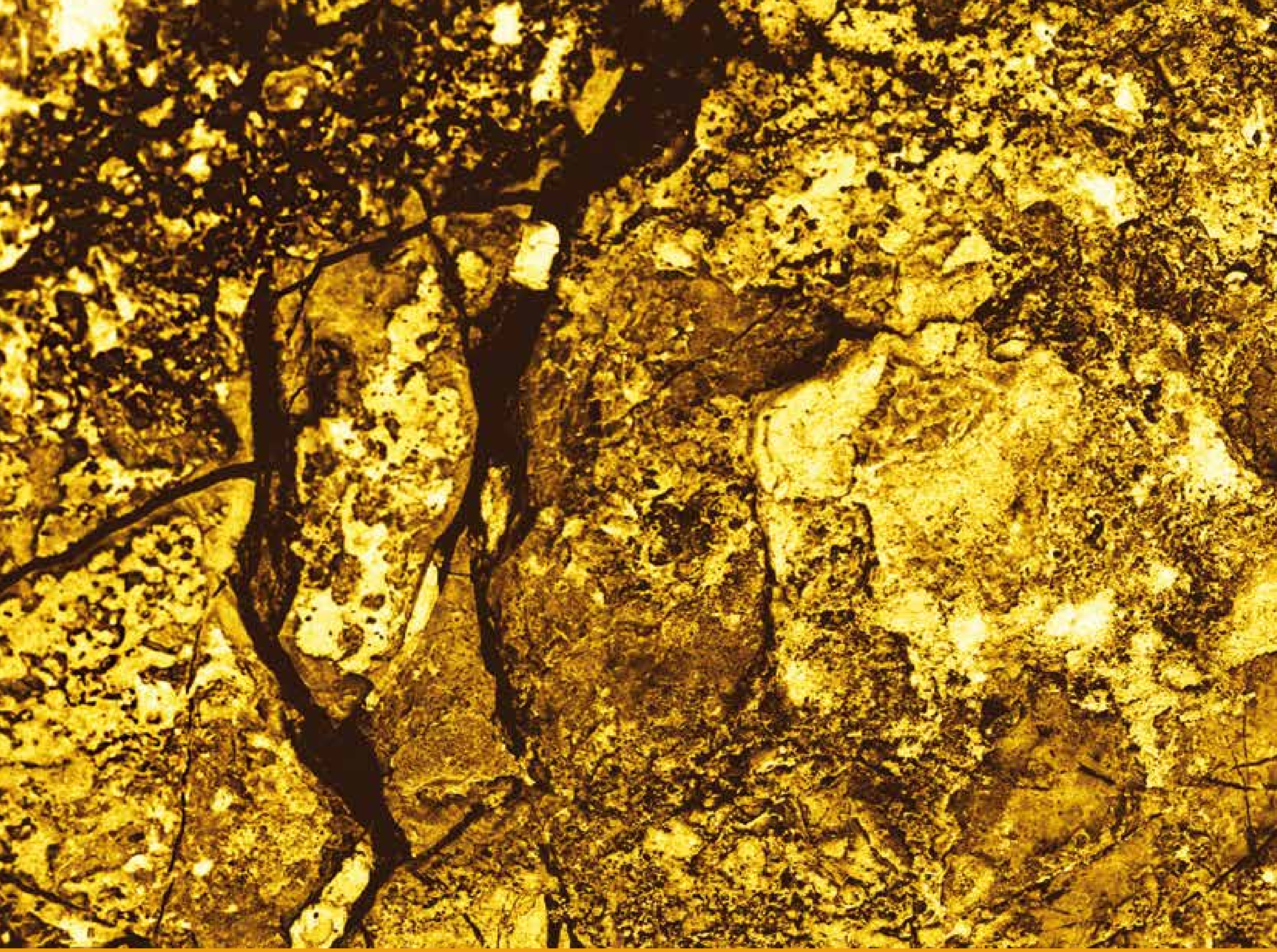
1.7 CONCLUSIONS OF THE CHAPTER

The use of metals underpins a wide range of economic activities. Such use has grown enormously in the past 40 years and is projected to grow again in the next 40 years, not least to supply the metals that are required for low-carbon energy technologies.

This Chapter has provided a review of the contribution to the metal industry made by three of the most important regions that have reserves of metals relevant to the energy transition: China, Africa and South America. Each of these regions has a crucial role to play in supplying these metals.

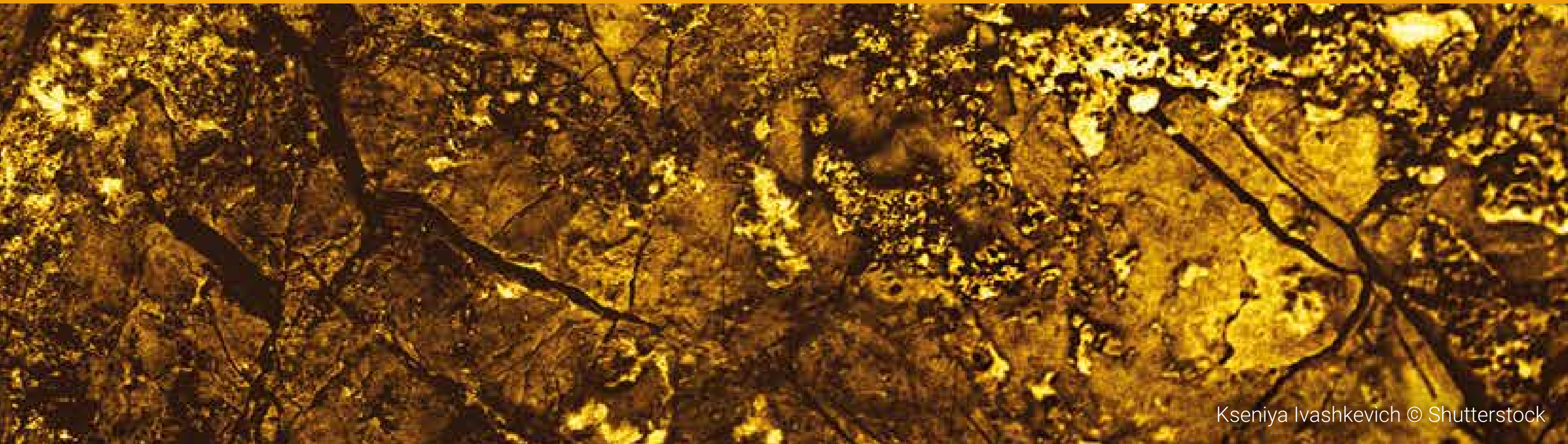
Because of the geological concentration of different metals in different parts of world, trade plays a crucial role in supplying metals to industries in those countries that do not have those resources. The length and complexity of the ensuing supply chains can be a source of vulnerability to the industries and wider economies of those countries, as expressed in the statistics of import and export power developed in this Chapter.

In a multipolar world, the geography of minerals extraction and trade, as described and analysed in this chapter, is of increasing geopolitical importance. It reveals that the supply security of essential raw materials is an important aspect of the low-carbon energy transition.



CHAPTER 2

INVESTMENT ISSUES IN MINING



Kseniya Ivashkevich © Shutterstock

CONTENTS

2.1 INTRODUCTION

As will be seen in Chapter 5, mining is resource-intensive and will need to attract very large quantities of financial capital to meet the projected demand for transition minerals. The great majority of this investment will need to come from the private sector, and this investment will only flow to mining if it offers the requisite balance between risk and return. Given that mining requires large amounts of sunk capital investment at the beginning and is a riskier activity than many other economic sectors, the returns from mining will need to be relatively high for new mines to be financed.

Financial assessments of investments in the mining sector lend themselves to the application of a sophisticated risk-adjusted investment calculus. In particular, drawing on real-options theory, it becomes evident that mining investments often contend with considerable uncertainty, encompassing variables such as resource quality, market demand and geopolitical factors. Acknowledging this uncertainty, investors' assessments regularly employ a real-options framework to evaluate the flexibility of individual mining projects. This perspective allows them to make adaptive decisions in response to changing market conditions, thereby managing risks more effectively and potentially seizing valuable opportunities as they arise. Furthermore, at the corporate level, portfolio optimization comes into play by diversifying the individual asset level risk-return profiles of investments across various mining projects, commodities and geographic locations, creating a strategy that is more robust financially, mitigates sector-specific risks and maximizes dynamic profit streams. By combining these methodologies, investors can assess the risks inherent to mining investments, weigh them against their overall profit potential and strategically allocate real mining assets and financial assets to achieve the optimal risk-reward balance among companies in the mining sector. The evolution of commodity prices reflects the fundamentals of complex commodity markets, including political risks. These prices, at which the metal produce will be sold, are the most important single factor in mining profitability. The many influences on these prices are the subject of the first part of this Chapter.

The Chapter then moves on to discuss other factors that are important to mining investment in China, Africa and South America. Local and central governments play an important role in Chinese minerals investment. China also makes significant investments in other countries. In Africa, most of the investment is foreign direct investment, but both here and in South America the governments of several countries are very dependent on the revenues from exporting the products. The various tax and royalty systems that enable governments in the major South American mineral-exporting countries to benefit from these exports are the subject of the South American section of this Chapter.

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2.2 METALS MARKETS AND PRICES

2.2.1 Introduction

Metal prices are important for producer and consumer countries alike. Prices are a key input factor in many industries, as well as for the availability of many services. The dynamics of metal prices are thus highly relevant to global economic activity and drive the speed of sustainability transitions. There are many factors that impact the price of metals, such as supply shocks, demand shifts, economic conditions, currency fluctuations, geopolitical events, production costs, government regulations, speculation and scams, as well as investment in mineral exploration, mining, ore processing, metallurgy and the required flanking sectoral public institutions, including research and innovation.

It is important to highlight that for a large number of critical minerals, many of which stem from by- or co-products of mining activities, traded price information is not publicly available. It is precisely these minerals and metals that exhibit most systemic risks. These therefore play a major role in risk assessments by investors.

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2.2.2 Supply and demand

A supply shock in the metal market refers to a sudden unexpected change in the supply of a metal, which can either increase or decrease its availability. This can be caused by natural disasters, strikes, political instability, changes in production processes, oil shocks or market manipulation.[17] It can also be the result of a sudden drowning of the market owing to dumping with oversupply, or export restrictions (e.g. the restrictions of China on the export of various forms of rare earths, tungsten and molybdenum in 2012).[18] One of the examples of a supply shock is that observed during the recent coronavirus disease (COVID-19) pandemic, when many mining operations were temporarily disrupted, which, together with raising freight rates, added to an increase in metal prices. In line with the proposed Wellmer and Becker-Platen (2002) theory of feedback control mechanism for metal prices, based on the interaction between the physical supply, technology and demand for metals, Stuermer (2022) provides empirical evidence, using a structural Bayesian vector autoregressive model, that supply is driven by the feedback control cycle of mineral supply, i.e. in the event of a shortage in the market, prices rise and encourage investment and innovation in mineral exploration, mining, metallurgy and the substitution of expensive or scarce minerals and metals, as well as in recycling. This control mechanism might not be at play for co-mined (companion) products where supply is mostly driven by the quantities of the principal product.

Short-term shocks in metal prices are typically hedged in the financial markets through futures trading and options contracts, which, in turn, could even affect metal prices in the longer term. The feedback control mechanism is driven by the interaction between physical, technological and financial market forces. According to Wellmer and Becker-Platen (2002), metal prices tend to revert to a long-term equilibrium level

17 In February 2023, Trafigura, one of the two largest global metal traders lost US$577 million after discovering that nickel shipments to its premises contained no nickel (see for instance: https://www.reuters.com/article/markets/currencies/trafigura-to-record-577-million-charge-after-nickel-fraud-idUSKBN2UJ18P/). Another example of market manipulation is the Big Nickel Short on the London Metal Exchange in 2022, see, e.g. https://www.warriortrading.com/nickel-short-squeeze/.

18 WTO dispute settlement DS431: China — Measures Related to the Exportation of Rare Earths, Tungsten and Molybdenum: https://www.wto.org/english/tratop_e/dispu_e/cases_e/ds431_e.htm.

that is determined by the underlying physical supply and demand fundamentals, as well as by financial market expectations and hedging activities. If prices deviate significantly from this equilibrium level, it can trigger new hedging activities and market interventions that help to bring prices back into alignment with the fundamentals. This is a strong conjecture that also needs to be scrutinized for strategic behaviour that exploits or leads to market power, where periods of low prices can be used by monopolists to crowd out competing market participants or new entrants.

A demand shift, on the other hand, refers to a change in the demand for metal, which can result from changes in consumer preferences, technological advancements or changes in economic conditions. An example of such a demand shift for metals is the adoption of clean energy technologies to avoid the negative effects of climate change. For example, lithium, nickel, cobalt, manganese and graphite are crucial to battery performance, longevity and energy density. Charging stations, and the specific grid needed to supply them with electricity, require substantial amounts of copper. Solar panels use large quantities of copper, silicon, silver and zinc, while wind turbines require iron ore, copper and aluminium. For more detail, see, for instance, International Energy Agency (2021).

2.2.3 Stylized facts of price behaviour in mineral and metal prices

Some of the most widely recognized stylized facts about metal prices include:

- *Volatility clustering:* Metal prices exhibit significant and persistent fluctuations over time, with periods of high volatility often followed by periods of low volatility and vice versa. The demand for certain metals used in clean energy production may cause price volatility, as well as market manipulations or distortions, particularly if the supply is limited or subject to supply chain disruptions. The wild fluctuations of prices show also how inelastic demand is in key mineral or metal markets in the short term (University of Houston Energy Fellows 2022). The modelling of volatility in metal markets is a crucial issue, as volatility can affect the decisions of investors with respect to portfolio allocation and value-at-risk management, as well as in generating reliable forecasts for policymakers (see Shahbaz *et al*. 2023; Hammoudeh and Yuan 2008). Akram (2009) shows that shocks to real interest rates and the real (dollar) exchange rate account for substantial shares of fluctuations in commodity prices (including metals). Hong *et al*. (2022) study the characteristics of the volatility aggregation effect and asymmetries in the nickel futures and spot prices at the London Metal Exchange and Shanghai Metals Market, using a copula-GARCH approach. The modelling of the volatility of metal prices helps to predict the uncertainty and risks associated with metal prices in the future. In addition, the results in Ng and Pirrong (1994) strongly suggest that fundamental factors (namely supply-demand conditions measured by the spread between spot and forward prices) determine the dynamics of industrial metal prices and explain a large proportion of their volatility changes.
- *Asymmetric price responses:* Metal prices tend to respond differently to positive and negative news, with negative news having a larger impact on prices than positive news. In addition, the response of metal prices to economic news is strong during global downturns and weak during expansion periods (see Chevallier and Ielpo 2013). The evidence of the asymmetric behaviour of short-run price cycles of minerals is found in Rossen (2015) and Roberts (2009), who show that slump phases last significantly longer than boom phases.
- *Non-linear price movements:* Metal prices often exhibit non-linear dynamics, with large price changes often occurring quickly and with little warning. Chen *et al*. (2019) construct a theoretical framework for analysing the effects of financial factors on fluctuations in the prices of non-ferrous metals and employ the Markov-switching vector autoregression model to conduct an empirical analysis employing nonlinear models and data on international copper futures prices. The results show that price fluctuations in copper futures present a regime-switching dynamic. In addition, Crespo Cuaresma *et al*. (2021) develop an econometric modelling framework to model and forecast commodity prices, using non-linear models to consider potentially different dynamics and linkages that exist in different countries.

- *Seasonality:* Metal prices often exhibit regular patterns of seasonality, with prices often higher at certain times of the year and lower at other times. Weather-related factors can affect the seasonality of supply and demand for certain metals or drive input prices for their production. Construction cycles, which tend to be seasonal, can drive demand for metals such as steel, aluminium and copper. Production cycles for some metals, such as gold and silver, can be affected by seasonal factors such as weather conditions, which may slow down during the rainy season, for example. The availability of transportation and logistics infrastructure can also affect the supply and demand for metals, leading to seasonal fluctuations in prices. For example, shipping routes may be affected by ice during the winter months, making it more difficult and expensive to transport metals by sea.

2.2.4 Price dynamics of metals

The clean energy transition represents an important source of continued demand for transition minerals for decades to come and has led to the reemergence of the super-cycle discussion (Jerrett 2021). As claimed by Heap (2005), there have been three demand-driven commodity price super cycles since the late 1800s, occurring during industrialization in the United States of America, post-war reconstruction in Europe and then in Japan, and the industrialization and urbanization of China beginning in the early 2000s. Cuddington and Jerrett (2008) and Jerrett and Cuddington (2008) found evidence supporting the existence of three super cycles over the past 150 years. The examination of super cycles is provided also in Rossen (2015). In all these studies, authors rely on the bandpass filter methodology for identifying super cycles; this was originally introduced in the business cycle literature by Baxter and King (1999). Gilbert (2022) points out the shortcomings of this method and contrasts the results obtained from the bandpass filter with those obtained by using an unobserved components model, which should provide a more satisfactory framework for analysing the existence of price cycles. Gilbert (2022) analysed price data for copper, lead and zinc and finds some evidence for short and poorly defined cycles, but only weak evidence for a long copper super cycle at best. These results do not deny the possibility that non-ferrous metal prices may tend to follow repeating cyclical processes, but underline that two centuries of price data appear insufficient to allow such an inference.

Jacks and Stuermer (2020) provide evidence on the dynamic effects of aggregate commodity demand shocks, commodity supply shocks, and storage demand or other commodity-specific demand shocks related to real commodity prices (including those of metals). They establish that commodity demand shocks strongly dominate commodity supply shocks in driving prices over a broad set of commodities and over a long period of time. While commodity demand shocks have gained importance over time, commodity supply shocks have become less relevant. Similar findings were presented by Baumeister, Verduzco-Bustos and Ohnsorge in the World Bank Commodity Market Outlook (2022) where the impact of four different (supply and demand) shocks on aluminium and copper prices were studied using a Bayesian vector autoregression framework using monthly data up to July 2022 (thus including the COVID-19 pandemic period), and the authors corrected for the unusual nature of the pandemic. The authors adopted the methodology of Baumeister and Hamilton (2019), who identified these shocks as the main drivers of oil prices. The results point to metal price swings as an important transmission channel from the global business cycle to countries that rely heavily on their copper or aluminium sectors for exports, fiscal revenue and economic activity. More swings in aluminium and copper prices can be expected as the energy transition away from fossil fuels towards renewable fuels and battery-powered transport gathers momentum because renewable electricity generation is considerably more metal-intensive than traditional energy generation.

In their recent study, Christmann and Lefebvre (2022) point out the importance of supply and demand scenarios to better assess risks to supply and resource depletion and to focus attention on the importance of integrating future technology shifts into future demand scenarios; such shifts are likely to have large impacts on the demand for some minerals and metals. They present some examples of probable major forthcoming technology shifts that have the potential to deeply alter the future demand for cobalt, dysprosium, graphite, neodymium, praseodymium, rhenium and tantalum.

Rossen (2015) investigates the co-movements, and short- and long-run price dynamics of a variety of mineral commodities during the past 100 years. She finds cyclical behaviour of commodity prices in both the short run and the long run (super cycles). In addition, the majority of metal prices are found to be characterized by four super cycles during the previous 100 years, where the boom and slump phases take the same time on average. Finally, co-movements seem to be a phenomenon that is valid within a specific group of metals, but not necessarily between them. Another contribution to the empirical evidence on the co-movement and determinants of commodity prices is Byrne *et al*. (2013), who, using non-stationary panel methods, found a statistically significant degree of co-movement owing to a common factor that is negatively related to the real interest rate and uncertainty and risk. A dampening impact of rising interest rates for metal (copper, gold, silver) prices was also observed in Hammoudeh and Yuan (2008), as well as in Akram (2009), who used structural vector autoregressive models to show that commodity prices (including metal prices) increase significantly in response to a reduction in real interest rates and the real value of the dollar.

2.2.5 Influences on metal prices

Chiaie *et al*. (2022) find that the bulk of the fluctuations in commodity prices is well summarized by a single global factor, which is persistent and follows the major expansion and contraction phases in the international business cycle. It is strongly related to measures of economic activity, thus suggesting a close link with demand factors. On the other hand, Kagraoka (2016) identifies four common factors through the application of a generalized dynamic factor model that is applied to panel data. These correspond to the inflation rate in the United States of America, global industrial production, the world stock index and the price of crude oil. Kwas *et al*. (2021) extract four factors that explain commodity prices, exchange rates, and financial and macroeconomic indicators and then evaluate them as potential predictors of the movements of four non-ferrous metals (aluminium, copper, nickel and zinc).

Linkages across non-energy commodity price developments were examined in Lombardi *et al*. (2012), where, by means of a factor-augmented vector autoregressive model, the authors extract two factors of non-energy commodity price series, identified as common trends in metals and food prices. Impulse response functions confirm that exchange rates and economic activity affect individual non-energy commodity prices.

A range of other influences on metal prices are listed below.

Geopolitical events

These can have a significant impact on metal prices. Some of the most common factors that can affect metal prices include changes in government policies, economic sanctions, political instability and military conflicts. Most of these factors have been most recently observed in the context of the war between the Russian Federation and Ukraine. Geopolitical tensions between China and Japan were also the cause of the 2010–2011 crisis in rare earth elements (Kalantzakos 2017; Pitron 2021).

Government regulations

Environmental or other regulations (e.g. to limit the environmental impact of metal mining and production), tariffs and trade agreements, quotas and production limits, and taxes and subsidies related to clean energy technologies can have both positive and negative impacts on metal prices and sometimes severely affect trade. Tariff and non-tariff measures, the dumping of cheap raw minerals and metals, disinformation and secrecy about production capacities, resources and reserves can be used by governments to manipulate markets and exert dominance to the benefit of their industries. International organizations serve as custodians of international trade data, including the World Bank[19], World Trade Organization (WTO)[20], and Organization for Economic Co-operation and Development (OECD)[21]. This data encompasses information on exports, imports, and both tariff and non-tariff trade barriers. In-depth studies at the commodity level and relevant data are made available through specialized reports, such as those on critical raw materials[22], which are now published regularly by the OECD. Research organizations, such as CEPII, offer high-resolution trade data tailored for the economic modeling community, including resources like the BACI database[23]. Additionally, for environmental impact assessments concerning Sustainable Production and Consumption (SCP) including trade issues, the SCP-HAT[24] database stands out as a leading data source. This information has been compiled by the UN Life Cycle Initiative, UN One Planet Network, and the UN International Resource Panel.

19 https://wits.worldbank.org/countrystats.aspx
20 https://www.wto.org/english/res_e/statis_e/statis_e.htm
21 https://www.oecd.org/en/data/indicators/trade-in-goods-and-services.html
22 https://www.oecd.org/en/topics/sub-issues/export-restrictions-on-critical-raw-materials.html
23 https://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele_item.asp?id=37
24 https://scp-hat.org/methods/

Commodity price regulations

Commodity price regulation has long been underestimated as a lever to understand and eventually control inflation, thus underscoring the importance for policy of both forecasting commodity price changes and of understanding the factors that drive those changes. Commodity price forecasts are crucial for inflation projections and thus for the monetary policy of central banks (see Gargano and Timmermann (2014), Guidolin and Pedio (2021) and Crespo Cuaresma *et al*. (2004; 2021) on commodity price forecasting, and Ceccheti and Moessner (2008), De Gregorio (2012) and Gelos and Ustyugova (2017) on inflationary responses to commodity price changes, among others). More recently, academic research has started to include commodity price uncertainty in the discussion. Explicitly considering commodity price uncertainty may, for example, prove useful in commodity price forecasting. While financial and economic uncertainty have been widely used and analysed in academic and political discussions since the financial crisis of 2007–2008, the research related to commodity price uncertainty is still comparatively small. It seems that the scientific community is still far away from an adequate understanding of how commodity markets really work, and how to measure their performance and provide insights into effective rule-making domestically and internationally.

Speculation and investment

Gorton and Rouwenhorst (2004) demonstrate that investors are able to reduce portfolio risk by diversifying into raw materials as the returns to these types of assets are negatively correlated with equity returns. This has increased the importance of speculative trading in metals, which is also a side effect of the financialization of commodity markets. Such a development gave rise to presumptions that speculation might increase the level and volatility of metal prices. Pichler *et al*. (2012) focus on quantifying the impact of speculation on both metal prices and metal price volatility and found no evidence of a systematic impact of futures trading on spot or futures prices, which is the same finding as in Korniotis (2009). However, Pichler *et al*. (2012) find that speculation increases the price volatility of aluminium and copper specifically. The theme of financialization of commodity markets and its link to noise trading and momentum strategies is explored also in Arezki *et al*. (2014). Speculation, using techniques such as Ponzi schemes, short selling and fraud, can severely distort a given market for months or even years.

Speculation exploits very lax global regulation and oversight of financial markets, sometimes with the consent of the authorities of countries that see an advantage in this state of affairs. Some examples of major speculations and scams that had a severe impact on the market at the time they happened are:

- The Hunt brothers' attempt to corner the silver market in 1980 (United States of America);[25]
- the Sumitomo copper affair (Japan) in 1996;[26]
- the Kingold Jewelry (China) fake gold scam in 2020;[27]
- the Qingdao aluminium stockpile scam (China) in 2014,[28] with a smaller scale repeat in 2022;[29]
- the Fanya Rare Metals stock market (China) scam (2011–2015);[30]
- the big nickel short selling (China and the London Metal Exchange) in March 2022, which caused a price-spiralling event, which lead to an ex-post cancellation of trading at the London Metal Exchange and nearly triggered a Lehman Brothers-style crash of the banking system;[31] and
- the 2023 nickel fraud at the expense of Trafigura.[32]

25 https://en.wikipedia.org/wiki/Silver_Thursday.

26 https://en.wikipedia.org/wiki/Sumitomo_copper_affair.

27 https://www.businesstoday.in/latest/world/story/biggest-gold-fraud-busted-in-china-83-tons-of-fake-gold-bars-used-as-loan-collateral-262661-2020-06-30.

28 https://www.reuters.com/article/us-qingdao-metals-ahome-idUSKBN0JW18620141218.

29 https://www.gtreview.com/news/asia/china-aluminium-fraud-allegations-suggest-lessons-not-learned-from-qingdao/ and https://www.japantimes.co.jp/news/2022/06/06/business/financial-markets/aluminum-stocks-china-commodities/.

30 https://en.wikipedia.org/wiki/Fanya_Metal_Exchange.

31 https://www.bloomberg.com/news/articles/2022-07-06/thanks-to-lme-tsingshan-s-xiang-guanda-escapes-nickel-chaos-a-billionaire.

32 https://www.bloomberg.com/news/articles/2022-07-06/thanks-to-lme-tsingshan-s-xiang-guanda-escapes-nickel-chaos-a-billionaire.

Systemic trade risk

The role of systemic trade risk on metal prices was addressed in Klimek *et al*. (2015), where it is shown that the international trading network of critical resources contains information that can explain a large fraction of the price volatility of these resources. This information is quantified by a systemic risk measure, and the authors show that supply risk, scarcity and the price volatility of non-fuel mineral resources are intricately connected with the structure of the global trade network of these resources or spanned by them. Price disruptions in mineral resources can reflect cascades of supply shocks in the underlying trade network, which can be mitigated by lowering trade barriers.

Policy interventions

Apart from domestic taxation and resource-pricing policies, and trade instruments such as tariffs and quotas, commodity prices are not typically subject to rigid international market price control mechanisms by governments. Most of the time, prices are determined through private market actors. Businesses that rely heavily on commodity prices use hedging instruments to protect themselves against price fluctuations by using financial instruments such as futures contracts, options or swaps to reduce exposure to price risk. Commodity price risks can pose significant challenges for businesses and economies, particularly for those that are heavily reliant on commodity exports or imports. There are several risk mitigation measures that can be used to protect against large price swings. For example, stabilization funds and non-parametric insurance solutions have been proposed to buffer the risks of commodity price extremes. Such funds would be triggered for exporting countries when prices are exceptionally low to guarantee macroeconomic budgetary stability or, alternatively, would protect importing countries from extreme price hikes of essential imported goods. Such price-related or insurance products could, however, end up reinforcing price volatility at the global level, if widely used. The European Union SYSMIN special financing facility was such a stabilization fund created by the European Union as part of its broader development assistance efforts. It operated for 20 years from 1980 to 2000 and was established to support the stabilization of metal prices in African, Caribbean and Pacific States.

Policy interventions and recommendations in the context of financialization suggest that, regarding the strengthening of financialization in non-ferrous metal markets, regulators should strengthen the monitoring of international financial flows, seek international cooperation and establish a warning mechanism for international non-ferrous metal prices based on the effective identification of the impacts of exchange rate shocks, speculative manipulation, interest rate shocks and oil linkages on fluctuations in the prices of non-ferrous metals (Chen *et al*. 2019). Since financial factors in different regimes have different action mechanisms, dynamic management control is required to assess the financial factors that influence fluctuations in non-ferrous metal prices. Policymakers should distinguish the regime state of the international market for non-ferrous metals, clarify the main drivers of fluctuation in non-ferrous metal prices in different regimes and take targeted measures. For example, when international non-ferrous metal prices rise steadily in the short term, regulators must focus on the reverse effect on the federal funds rate. In the downward cycle, the risk linkage between crude oil prices and non-ferrous metal prices is particularly significant. Regulators must therefore focus on monitoring the impact of international oil prices.

The analysis in Akram (2009) implies that shocks to real interest rates in the United States of America and to the real value of the dollar might be a useful indicator of movements in commodity prices and metal prices. However, the prices may temporarily overshoot their long-run values in response to real interest rate shocks, a feature that needs to be considered by monetary and fiscal authorities when responding to these shocks.

Hong *et al*. (2022) suggest that policymakers should improve the efficiency of information acquisition, ensure the truth and accuracy of the information and improve the market risk control system. The University of Houston Energy Fellows (2022), following the invasion of Ukraine by the Russian Federation, stress the importance of developing multiple supply chains for the energy transition and note the price tags involved in doing so.

Transparency in metal price formation

There are considerable concerns about the lack of transparency and the challenges in determining accurate prices in the minerals and metals market. These issues have real-world consequences for market participants and can have an impact on investment decisions, resource allocation and overall market stability. Addressing these challenges will require collaboration between industry stakeholders, regulators and technology providers to develop solutions that benefit all parties involved while maintaining market integrity.

The following issues need to be highlighted about the transparency of price determination:

- There is a general absence of real prices for most minerals and metals, which can create uncertainty and inefficiencies in the market. Investors, producers and consumers rely on price information to make decisions, and the lack of accurate pricing data can hinder their ability to do so effectively.
- Indicative spot prices are useful as a reference point, but they often fail to capture the nuances of the market. They are typically based on specific conditions and may not represent the broader supply and demand dynamics.
- The lack of data on cash trades can make it challenging to understand market trends and fluctuations. Without comprehensive data, it is difficult to assess whether indicative spot prices are accurate or whether they are influenced by a small subset of trades.
- Offtake agreements and long-term contracts play a crucial role in the minerals and metals market. These agreements can involve negotiated prices, which may not be publicly disclosed. They are essential for both producers and consumers to secure a stable supply and demand relationship.
- The presence of trading houses in opaque tax havens can raise concerns about transparency and accountability. Such locations may facilitate confidentiality in trading activities, making it harder for regulators and stakeholders to monitor the market effectively.

Limited transparency in pricing and trading can lead to market inefficiencies, price manipulation and reduced competition. Participants in the market may be at a disadvantage if they do not have access to comprehensive pricing information. Potential solutions to address these issues include increased transparency in pricing and trading activities to ensure that a more accurate picture of the market is communicated to market participants. Regulatory authorities may consider measures to ensure that pricing information is more readily available and that market manipulation is discouraged. Industry organizations and associations could promote best practices for pricing and reporting to enhance transparency. More recently, technological solutions have been discussed, such as blockchain and other emerging technologies, which could be used to create more transparent and immutable records of transactions.

2.2.6 Conclusions

There are two main conclusions emerging from this commodity price analysis.

The first conclusion relates to the impact of commodity prices on the macroeconomy and sustainability transition. We highlight that commodity price surges, particularly related to energy commodities, can lead to inflation, supply chain disruptions and a cost-of-living crisis. Moreover, the uncertainties and instabilities in commodity prices can have an impact on the viability of sustainability transitions, especially those linked to renewable energy and transition minerals. It is therefore recommended that short-term macroeconomic policies and long-term sustainability policies should explicitly consider and manage commodity price risks, and macroeconomic stress testing should include risks from key commodities.

The second conclusion derives from the fact that despite modern tools in economics and data science, the price formation and evolution of commodities are still not fully understood owing to a paucity of information. Most commodity markets are highly interconnected and vulnerable to price volatility, which may be triggered by strategic market actors. There is therefore a need for a global commodity price observatory that monitors and analyses price behaviour, promotes price transparency and establishes an early warning commodity price capacity that captures moves in market fundamentals. Subsequent steps could point towards establishing new trading rules that cover the emergence of systemic risks, as well as market manipulation.

2.3 INVESTMENT ISSUES IN CHINA

2.3.1 Financing of minerals exploration in China

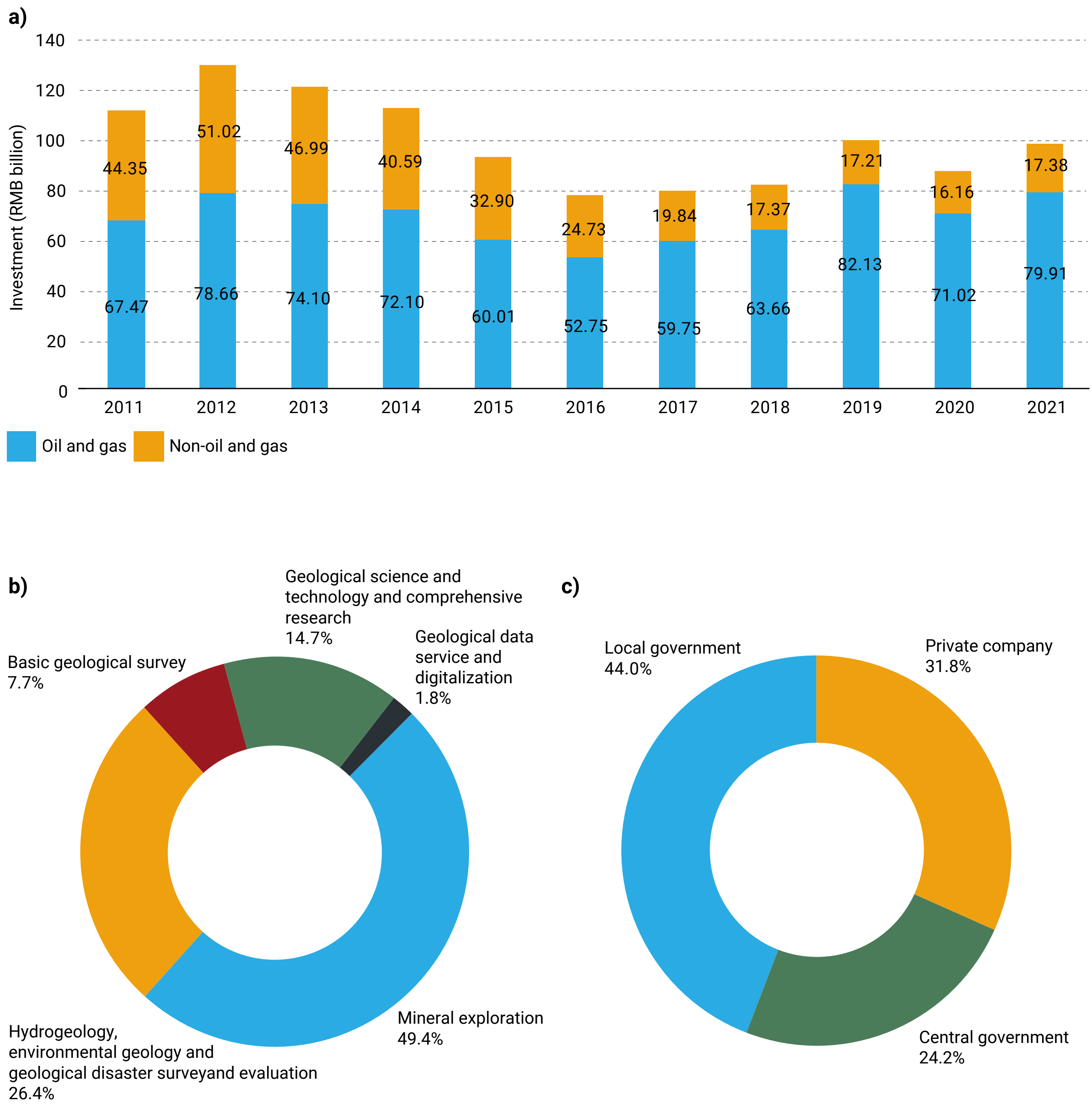
According to the China Mineral Resources Report 2022, Chinese investment in geological surveys in 2021 was RMB 97.3 billion (US$15.1 billion). Investment in the geological surveying of oil and gas reached RMB 79.9 billion (US$12.4 billion). In addition, geological survey investment in non-oil and gas minerals was RMB 17.4 billion (US$2.7 billion) in 2021, an increase of 1.0 per cent compared to 2019 before the pandemic, the first positive growth since 2013 (figure 2.1a). In 2021, 49.4 per cent of the geological survey investment of China in non-oil and gas minerals was for mineral exploration, reaching RMB 8.6 billion (US$1.3 billion) (figure 2.1b). Among investments in the geological survey of non-oil and gas minerals in China in 2021, financial investment from the Government of China was RMB 11.9 billion (US$1.8 billion), accounting for 68.2 per cent of the total. Of this figure, RMB 4.2 billion (US$652 million), or 24.2 per cent of the total, was invested by the central Government, and RMB 7.6 billion (US$1.2 billion), or 44.0 per cent of the total, was invested by local governments. Moreover, private companies invested RMB 5.5 billion (US$857 million), accounting for 31.8 per cent of the total in 2021 (figure 2.1c).

Governments at all levels in China have set up geological exploration funds, such as the Central Geological Exploration Fund, which is focused on supporting the preliminary exploration of scarce mineral species by investing in mineral exploration projects with high potential and potentially high risk. The central Government of China predominates, primarily owing to its leadership in exploring most large-scale and high-quality mineral resources. However, a survey conducted by the Ministry of Natural Resources of China reveals that the majority of mining rights in the country are held by small-scale private companies with diverse business types.[33] These facts highlight a deficiency in alternative financing channels, such as securities markets or investment funds in China, resulting in an imperfect market system for mineral exploration investments, especially for suboptimal mineral resources. Most private companies in China are involved solely as speculators and lack professional exploration technical capabilities. While State-owned geological exploration agencies play a crucial role in providing technical services, they are not the primary market entities.


Jose Luis Stephens © Shutterstock

33 https://www.mnr.gov.cn/dt/kc/202305/t20230531_2789807.html.

Figure 2.1: (a) Trend of the investment of China in geological surveys from 2011–2021; (b) Structure of investment types in the geological survey of non-oil and gas minerals in China in 2021; (c) Structure of funding sources in the investment of China in the geological survey of non-oil and gas minerals in 2021.



Source: China, Ministry of Natural Resources (2022).

Table 2.1: The non-oil and gas mineral exploration investment of China in 2021

Mineral	Investment (100 million RMB)	Year-over-year growth (%)	Drilling completed (10,000 metres)	Year-over-year growth / %
Nationwide	85,85	4,1	637	20,6
Coal	13,49	10,3	52	-46,9
Iron ore	4,34	75	35	75
Manganese	0,8	-48,1	4	-50
Copper	6,55	6,9	33	-2,9
Lead-zinc	5,95	-7,2	60	30,4
Bauxite	3,04	5,6	29	-9,4
Nickel	0,45	4,7	1	-50
Tungsten	1,58	-0,6	15	25
Tin	0,38	-50,6	4	0
Molybdenum	0,55	-6,8	5	25
Gold	10,9	4,3	76	8,6
Silver	1,12	-18,2	8	-11,1
Phosphate	1,46	18,7	10	11,1
Graphite	1,8	13,9	15	36,4
Potash	1,02	21,4	3	50

Source: Ministry of Natural Resources of China. (2022). China Mineral Resources

Regarding the investment of China in non-oil and gas mineral exploration, as indicated in table 2.1, the country's domestic mineral exploration of non-oil and gas minerals is dominated by coal, gold, lead, zinc, uranium and copper, accounting for 51.2 per cent of the total investment in mineral exploration in 2021.

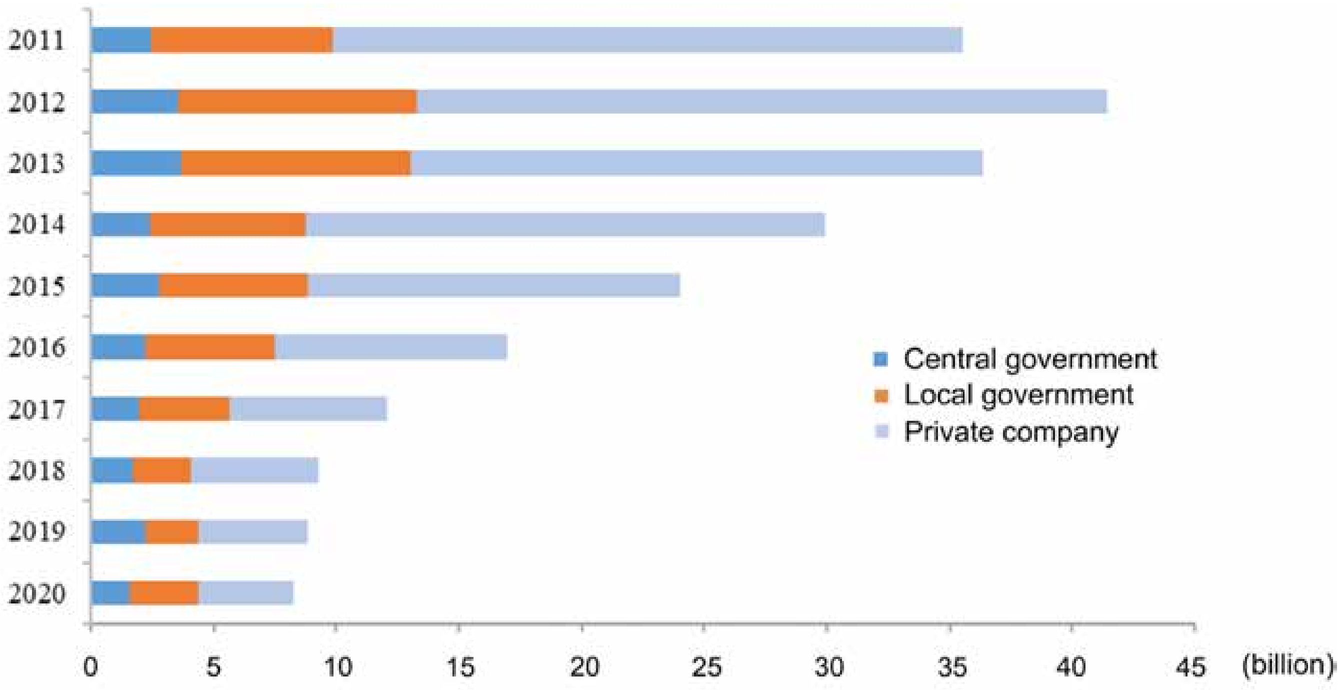
In 2021, the investment of China in mineral exploration for non-oil and gas minerals (RMB 8.6 billion (US$1.3 billion)) rebounded from RMB 8.2 billion (US$1.3 billion) in 2020. As for funding structure, RMB 1.6 billion (US$245 million), or 19.1 per cent of the total, came from the central Government in 2020, a decrease of 28.1 per cent year-on-year; RMB 2.8 billion (US$432 million), or 33.8 per cent of the total, came from local government in China, an increase of 26.5 per cent year-on-year; and RMB 3.9 billion (US$602 million), or 47.1 per cent of the total, came from private companies, a decrease of 11.9 per cent year-on-year. In 2021, the provincial geological exploration funds invested RMB 1.8 billion (US$273 million) in mineral exploration for non-oil and gas minerals, accounting for 20.5 per cent of the investment of China in mineral exploration for non-oil and gas minerals (RMB 8.6 billion (US$1.3 billion)) and 39.9 per cent of government investments in mineral exploration for non-oil and gas minerals (RMB 4.4 billion (US$685 million)). In 2021, 414 mineral exploration projects were implemented, with the most funds invested in gold, geothermal, copper, bauxite and coal. Among them, the provincial geological exploration funds invested in 85 mining areas, including 35 large, 29 medium and 21 small mining areas.

Overall, the investment of China in mineral exploration of non-oil and gas minerals declined significantly from 2012 to 2020 (figure 2.2), with the 2020 figure only 19.9 per cent of that in 2012. Constrained by domestic resource endowment, China faces high extraction costs for non-oil and gas minerals, dampening the enthusiasm of Chinese companies to make domestic investments in mineral exploration of non-oil and gas minerals. The largest decrease comes from reduced funding from private companies, which is only 13.8 per cent of the amount received in 2012, directly leading to the decrease in Chinese investment in mineral exploration for non-oil and gas minerals; the funds from local government are only 28.7 per cent of the amount received in 2012; the funds from central Government finance is 44.1 per cent of the amount received in 2012. The top five provinces (regions) in China in terms of investment in mineral exploration for non-oil and gas minerals are Inner Mongolia (13.9 per cent), Xinjiang (12.1 per cent), Guizhou (7.9 per cent), Jiangxi (6.6 per cent) and Qinghai (5.7 per cent).

As shown in figure 2.3, the total domestic fixed asset investment of China (initial capital expenditure) in the mining industry turned from a decline to an increase in 2021. In 2020, fixed asset investment in the mining industry of China declined by 14.1 per cent from the previous year, but it increased by 10.9 per cent in 2021. Specifically, the fixed asset investment of China in mining of coal, ferrous metals and non-ferrous metals has recovered to pre-pandemic levels, increasing by 11.1 per cent, 26.9 per cent and 1.9 per cent, respectively, during 2020. Moreover, the fixed assets investment of China in oil and gas increased by 4.2 per cent compared to 2020, but was still about one-third lower than in 2019. Finally, fixed asset investment in non-metallic minerals has increased by 26.9 per cent compared to 2020, maintaining the momentum of sustained growth.

Before 2013, fixed asset investment in the Chinese mining industry had maintained a long period of growth. It laid a solid foundation for the country's production capacity of major minerals. From 2013 to 2020, the fixed asset investment of China in the mining industry continued to decline owing to falling mineral prices and the pandemic. Even in 2017 when the prices of major mineral products rebounded, the fixed asset investment of China in the mining industry was only RMB 9.2 trillion (US$1.43 billion), down 10.0 per cent compared to 2016.

Figure 2.2: Investment structure of the non-oil and gas mineral exploration of China by funding source, from 2011 to 2020



Source: China, Ministry of Natural Resources (2021).

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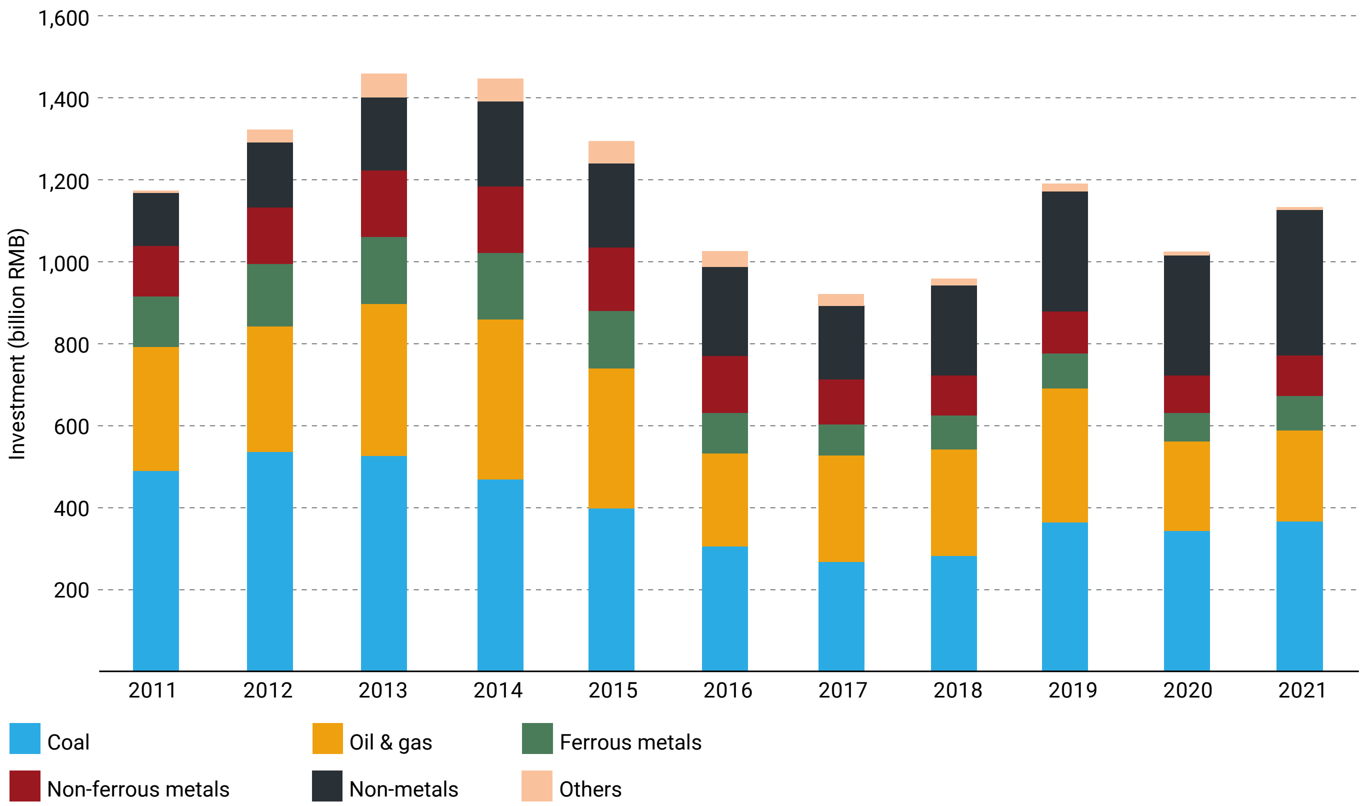
Figure 2.3: Changes to the fixed asset investment of China in the mining industry from 2011 to 2021



Source: China, Ministry of Natural Resources (2022).

2.3.2 Investment in minerals extraction and processing worldwide

Since China started its reform and opening-up policy in the 1980s, mining has gradually become a major area of overseas investment for Chinese companies. According to Wang *et al*. (2022), mining accounted for as much as 20-40 per cent of the overseas investments of China before 2013 and reached a peak of US$24.8 billion in 2013. The figure has declined year by year since then, with a sum of only US$4.6 billion of Chinese overseas mining investment in 2018. Based on the cyclical changes in investment fever, as well as different investment subjects and investment characteristics, the overseas mining investments of China can be roughly divided into three phases.

Phase I - Initial stage - Discovering opportunities (before 2004):

The overseas mining investments of China started in the late 1980s, with 70 per cent of the main investment bodies being large State-owned mining companies and 30 per cent being private companies. Most mining projects in this phase were developed in the context of intergovernmental cooperation. Of these, 39 per cent of the mining projects were developed through cooperative operations with foreign companies. In this phase, as many as 78 per cent of these projects were put into production. Most of these mining projects have survived 30 years of bumpy development and are still economically viable.

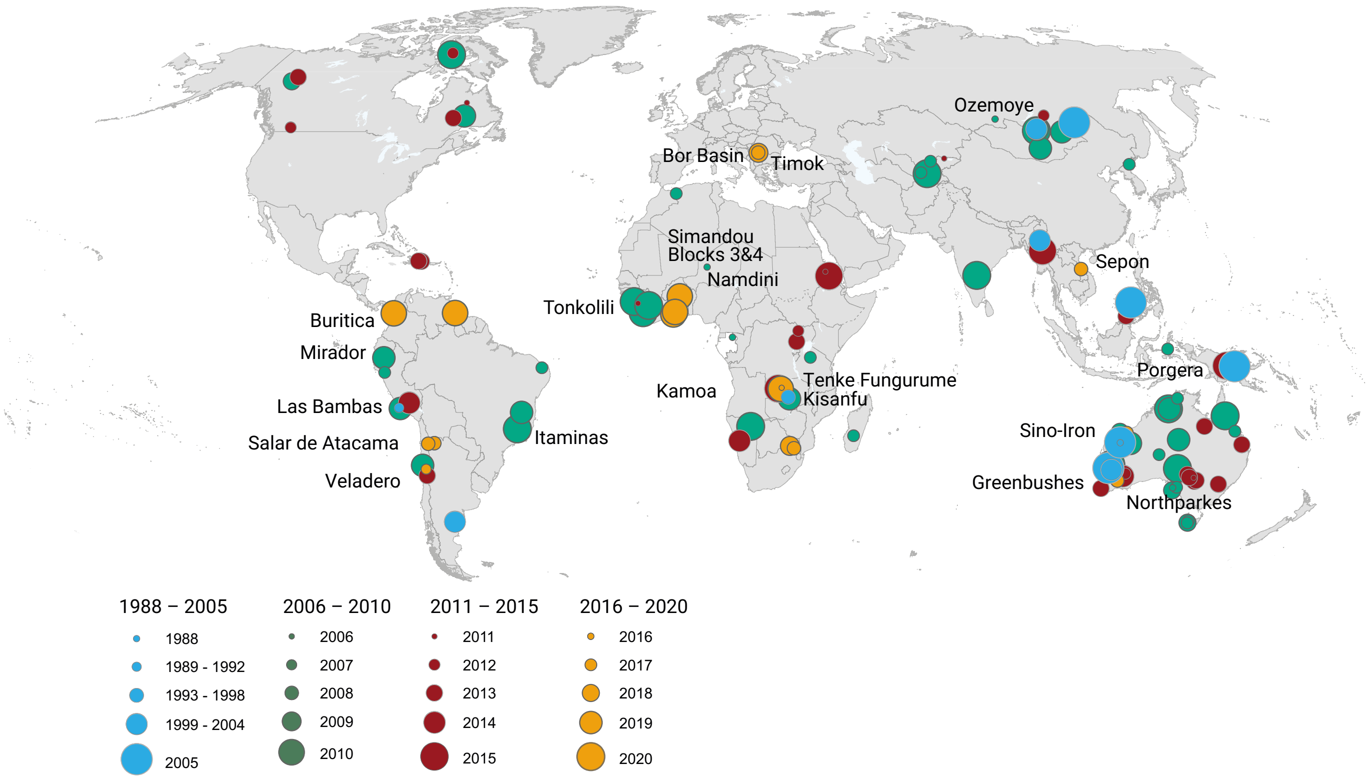
Phase II - Rapid Growth (2004–2013):

Beginning in 2004, Chinese mining companies began to invest abroad on a large scale, with the number of projects reaching a peak in 2011 (figure 2.4). Until 2013, the proportion of mining investment in the overseas investment of China has remained high, with an average share of 20 per cent. In this phase, in addition to large State-owned companies, private companies began to get more involved in overseas mining investments, and the proportion of their investment projects increased to 47 per cent, with many cross-industry companies involved. The proportion of companies from trading, manufacturing, construction and real estate industries in overseas mining investment increased to 24 per cent. In this phase, the pattern of Chinese participation in global mineral resource allocation was established. However, many irrational investments also occurred during this phase. For instance, the majority of mining rights acquired by Chinese geological exploration units were lost during this phase. Meanwhile, a lack of understanding of the rules of the international mining industry and due diligence on mining projects resulted in investment in many mines that were later suspended (Liu 2012).

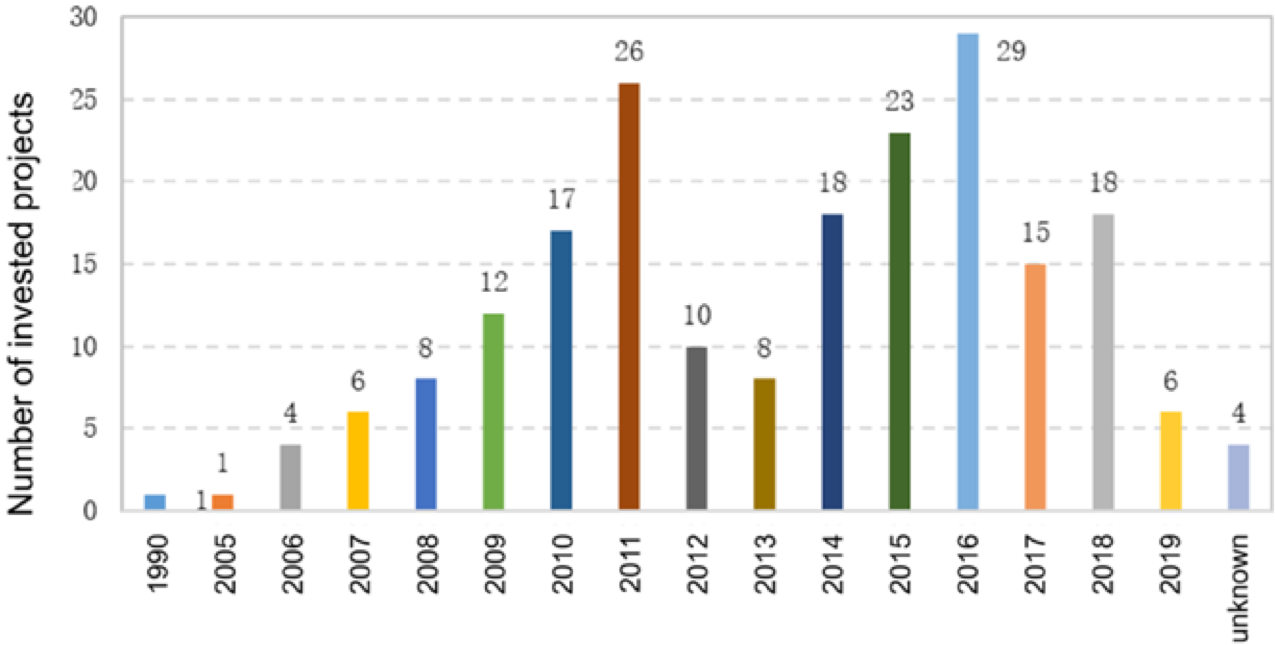
Phase III - Transformation and Development (2014–present):

Since 2014, the enthusiasm of Chinese companies for overseas mining investment has continued to decline. As shown in figure 2.4, the number of Chinese overseas acquisitions and mergers and acquisitions projects showed a decreasing trend from 2016 to 2019. The proportion of mining in Chinese overseas investment dropped to 5 per cent. However, the proportion of large-scale mining projects is increasing, reaching 62 per cent in 2021. Meanwhile, along with the accelerated competition in the mining industry, large Chinese State-owned companies and companies in the mining sector have regained their dominant position in the overseas investments of China. In this phase, Chinese companies increased their investment in minerals for manufacturing battery cathodes (lithium, cobalt and nickel) and copper, with the number of projects rising by 44 per cent and 26 per cent respectively compared to Phase II. Meanwhile, Chinese companies' investment in iron ore and coal decreased significantly, with a decrease of 49 per cent and 40 per cent respectively. Notably, 40 per cent of Chinese companies' overseas mining projects progressed to the production stage during this time period.

Figure 2.4: (a) A world map showing Chinese companies' overseas mergers and acquisitions deals by time intervals; (b) Number of Chinese companies' overseas acquisitions and mergers and acquisitions projects, 1990–2019



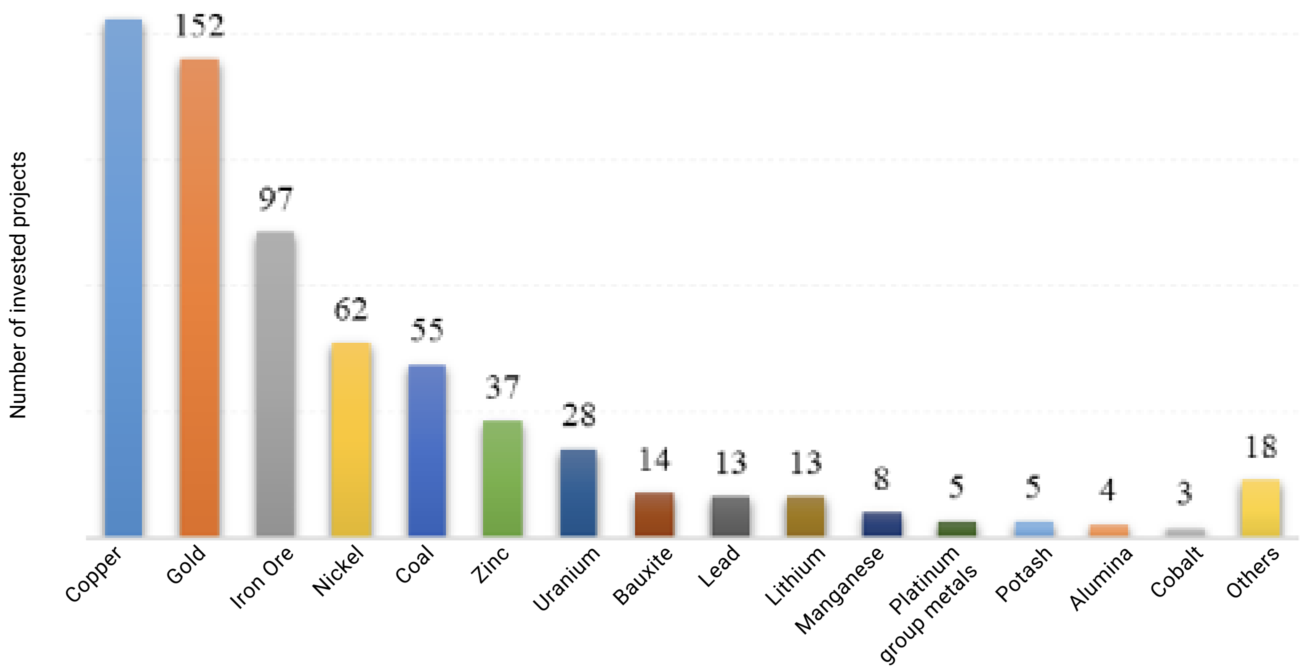
Source: S&P 2022



Source: China, Ministry of Natural Resources (2021).

According to the S&P database, as of the end of June 2021, there were at least 679 overseas mining acquisitions and mergers and acquisitions projects by Chinese companies. The projects with clear information are dominated by copper (25 per cent) and gold (22 per cent), with fewer other minerals as primary commodities (figure 2.5). In terms of the total amount of funds for these mergers and acquisitions projects (including completed and proposed mergers and acquisitions), the mineral with the highest cumulative amount is lithium, accounting for more than 40 per cent, followed by copper and gold. On the one hand, it shows Chinese companies' preferences for investing in overseas copper resources in previous years owing to the poor copper resource endowment of China and huge demand for copper ores. On the other hand, it shows Chinese companies' also have a preference for investing in overseas lithium resources in recent years as a result of the rise of the electric vehicle industry in China.

Figure 2.5: Number of Chinese companies' overseas acquisitions and mergers and acquisitions projects by major mineral commodity as of the end of June 2021

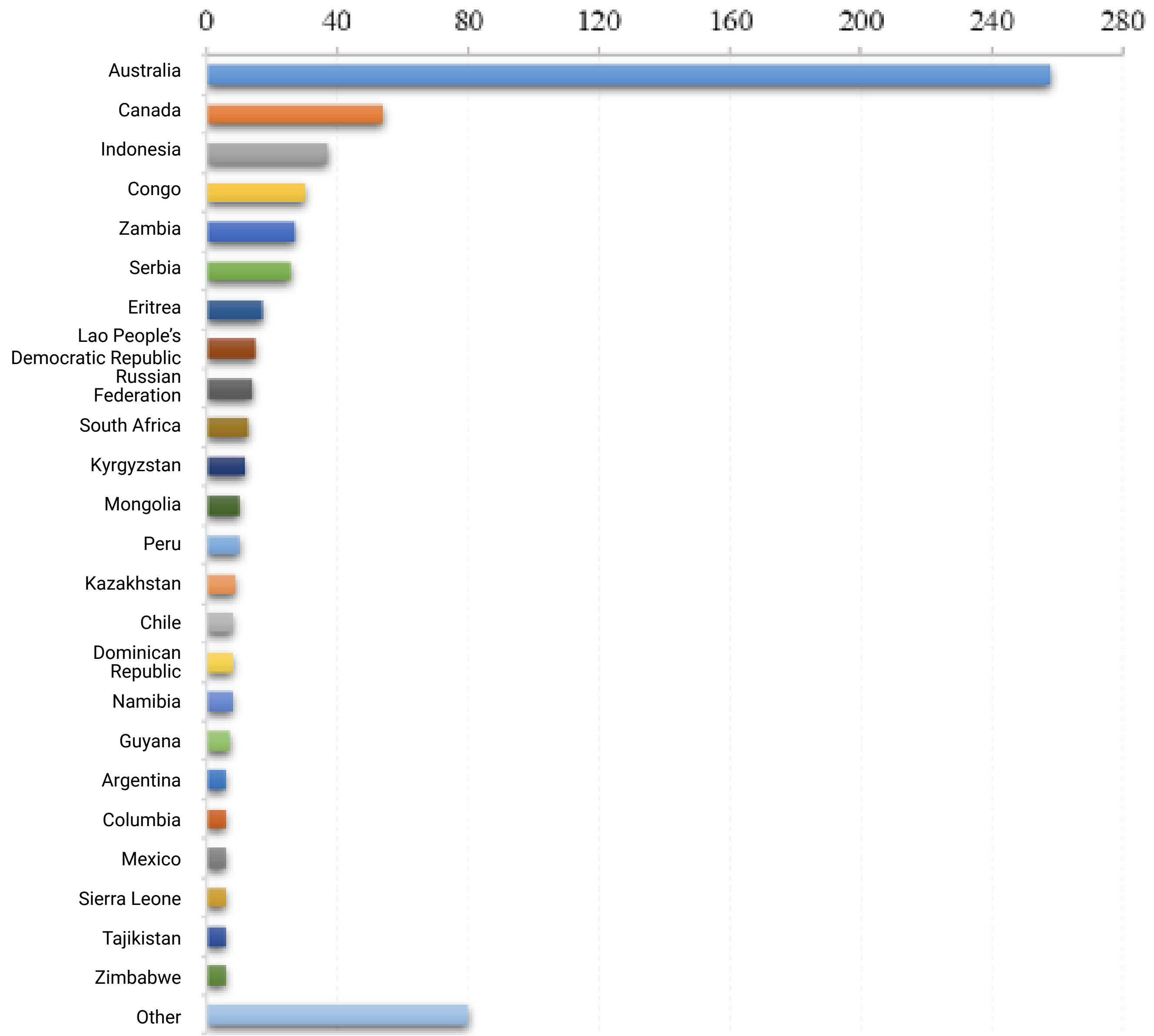


Data source: S&P Global Market Intelligence as cited in the Global Mineral Resources Situation Report, China Geological Survey Bureau

The distribution of mining projects by country shows that the overseas investment of China in the mining industry is uneven (figure 2.6). As of June 2021, the overseas investment of China in mining projects was mainly concentrated in Australia, with 38.0 per cent of the total number of overseas projects invested, followed by Canada with 8.0 per cent. Chinese mining companies also have significant investment projects in Indonesia (5.5 per cent), the Democratic Republic of the Congo (4.4 per cent), Zambia (4.0 per cent) and Serbia (3.9 per cent).

In terms of regional distribution, as of June 2021, the overseas investment of China in mining projects was mainly concentrated in the Asia and the Pacific region, with the number of projects accounting for 51 per cent of investment, followed by the African region with 19 per cent (figure 2.7). In addition, Chinese mining companies have invested 19 per cent, 11 per cent and 9 per cent of their mining projects in Europe, Latin America and the Caribbean, and the United States of America and Canada, respectively.

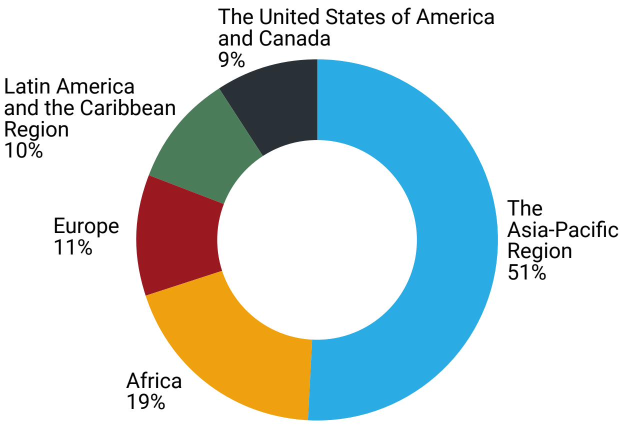
Figure 2.6: Number of Chinese companies' overseas acquisitions and mergers and acquisitions projects by country as of the end of June 2021



Note: Congo refers to Democratic Republic of the Congo

Data source: S&P Global Market Intelligence as cited in the Global Mineral Resources Situation Report, China Geological Survey Bureau

Figure 2.7: Number of Chinese companies' overseas acquisitions and mergers and acquisitions projects by region as of the end of June 2021



Data source: S&P Global Market Intelligence as cited in the Global Mineral Resources Situation Report, China Geological Survey Bureau

Overall, the overseas mining investments of China have become increasingly rational, stable and precise in recent years, and its strategy of global resource allocation has become more mature.

2.3.3 Conclusions

The investment patterns of China in the domain of mineral exploration, particularly concerning non-oil and gas minerals, have undergone significant shifts over the past decade. The nation's spending on geological surveys and mineral exploration saw a period of decline from 2012 to 2020, but began showing signs of revival in 2021. Notably, the increased investments from local governments have played a pivotal role in this resurgence, while private sector funding has dwindled in comparison to previous years. The preference for investing in specific minerals has also transitioned, emphasizing those directly contributing to the burgeoning new energy sector, such as lithium and cobalt. Moreover, since the initiation of its reform and opening-up policy in the 1980s, the approach of China towards overseas mining investments has evolved through three discernible phases: the initial stage of discovering opportunities; a period of rapid growth; and a current phase focused on transformation and development. These overseas ventures are now more distributed, mature and strategic, targeting regions and minerals essential for the long-term growth and technological advancement of China. Emphasizing regions such as the Asia and the Pacific region and minerals such as copper and gold, China continues to solidify its position in global mineral resource allocation.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2.4 INVESTMENT ISSUES IN AFRICA

The previous section has shown the way in which China has strategically employed the power of the State over 20 years to mobilize investment in the extraction and processing of minerals and metals.

A similar strategic approach for African countries is articulated in the Africa Mining Vision.[34] This has the following objectives for the African mineral sector: "(i) increasing local upstream support (supplier/input industries) sectors; (ii) enhancing downstream industries based on increased local beneficiation and value addition of goods; (iii) facilitating lateral migration of mining technologies to other industries; (iv) increasing social and human knowledge and institutional capital (which can be used in other sectors); (v) promoting the development of sustainable livelihoods in mining communities; and (vi) creating small- and medium-sized enterprises and a more balanced and diversified economy with greater multiplier effects and potential to create employment" (African Union 2009, p. 5).

2.4.1 Financial benefits and costs of mining in Africa

Mining is an important contributor to African economies, as shown in table 2.2. Indeed, mining can bring huge financial and social benefits. However, as an individual mine only has a limited lifetime, defined by its reserves and the extraction rate of these reserves, these benefits may only be temporary, if minerals and metals production activities are not managed with clearly defined intergenerational sustainability objectives to reduce negative environmental and social activities, as laid out by the International Resource Panel (IRP) (2020) and in this report. Otherwise, there is a risk that the sudden influx of wealth from mining activities may lead to unsustainable squandering of the temporary rent. Past phosphate mining in Nauru, and the large but temporary wealth it bestowed on its habitants, is one sad example of unsustainable resource revenue use (Clifford *et al*. 2019).

Depending on governance and governance capacities, both at the level of companies and of public authorities, mining can deliver long-lasting benefits or long-lived cost legacies (Stilwell *et al*. 2000; Ge and Lei 2013; Fleming and Measham 2014; Tserkezis and Tsakanikas 2016; Ge and Kinnucan 2017; Moritz *et al*. 2017; Sulista and Rosyid 2017; Gildermeister *et al*. 2018). Mining legacies can have an impact on human health and the environment for decades, centuries and beyond, long after the end of mining and metallurgical activities. The remediation costs of a single large-scale industrial site can be close to US$1 billion (Jerrold 2000; Canada, Government of the Northwestern Territories, Indian and Northern Affairs Canada 2010), with the risk of additional recurring costs to occur for an undefined, but very long, number of years.

Benefits from mining come from public direct and indirect mining-related revenue (royalties and taxes) and from industries created downstream or to support mining activities. Though mining has a long history in Africa, only one country, Botswana, has been able to achieve high living standards for its citizens (Sebudubudu and Mooketsane 2016). South Africa has also done well in establishing a strong local mining and mining services sector (Leeuw and Mtegham 2016).[35] This remains very fragile given the worsening South African political, social and economic situation, evidence of these being provided, for instance, by the deep problems in Eskom (the State-run energy monopoly of South Africa), with severe blackouts that threaten, inter alia, the viability of its minerals and metals industry. Whether the successes in Botswana and South Africa can be replicated elsewhere in Africa is a major question. Indeed, this concern has seen governments and development partners look for new means of leveraging mining to drive economic transformation through local content and local value addition mandates (see Chapter 3).

34 The Africa Mining Vision is a comprehensive governance framework that is aimed at integrating mining into industrial and trade policy and extricating Africa from its historical role as an exporter of raw materials to become a manufacturer and supplier of knowledge-based goods and services. It espouses a developmental approach meant to break mining enclaves by fostering economic and social linkages between the extractive sector and other sectors of the local economy, promoting resource-based industrialization and economic diversification, developing socioeconomic infrastructure for broader use and accelerating regional integration (https://www.africaminingvision.org/about.html).

35 South Africa was a net exporter of mining equipment, with a 37 per cent market share in sub-Saharan Africa in 2009 (Kaplan 2011).

Table 2.2: African countries with a 2018 share of minerals in exports of more than 20 per cent

Country	Mineral export contribution 2018 (percentage of exports)	Production value 2018 (percentage of GDP)	Mineral rent (percentage of GDP)
Botswana	91.5	13.39	0.54
Democratic Republic of the Congo	91.1	32.97	16.17
Guinea	82.6	14.30	9.68
Burkina Faso	76.6	16.06	9.64
Zambia	76.1	20.64	14.62
Mali	75.6	16.04	6.00
Mozambique	67.2	11.13	0.62
Sierra Leone	59.1	12.61	0.96
Rwanda	55.6	0.01	0.28
Burundi	53.1	0.27	0.91
Namibia	50.6	6.61	4.19
Zimbabwe	44.5	17.00	3.74
Sudan	40.6	12.15	12.70
Mauritania	40.5	20.34	14.88
South Africa	40.2	10.26	2.20
Liberia	39.7	14.29	8.29
Ghana	38.3	8.48	5.65
Lesotho	32.2	0.74	0.00
Niger	29.4	0.32	0.23
Madagascar	27.2	4.03	1.60
Togo	25.8	0.00	7.21
United Republic of Tanzania	25.3	2.96	2.16
Senegal	24.2	2.55	1.11
Uganda	23.4	0.02	0.14

Source: International Council on Mining and Metals (2020).

2.4.2 Contribution of mining to fiscal revenues

The most straightforward benefit of mining comes from the capture of revenue generated from sales and exports, mainly through taxes and royalties.[36] From a distribution perspective, the key claimants are the mining company, the government and the community where mining is done. The distribution is usually determined by law and stipulated in mining contracts, but the latter are rarely made publicly available to the detriment of concerned communities.

However, this does not necessarily mean the distribution is equitable. It may be undermined by taxation base erosion, transfer pricing and other "creative" tax evasion processes, as well as by plain corruption. There have been concerns that mining companies, on account of better resources and better information, can get contracts that are more favourable owing to better negotiation capacity and government desperation to attract investment (Kimani 2009). Also, as a result of their complex organizational structures, companies can often avoid paying taxes, such as through transfer pricing.

36 An ideal mining legislative framework would include modest royalties and taxes that should be paid for the benefit of the country and local community and on the basis of the recovered value extracted.

Tackling illicit financial flows from the sector is also a key global governance issue for many resource-rich African countries confronted with utmost poverty. Owing to the opaqueness of illicit financial flows, robust estimates of the magnitude of their impacts on African economies are impossible to establish. Consequently, estimates vary widely. The International Monetary Fund (Albertin *et al*. 2021) estimates that key sub-Saharan African countries that produce minerals and metals "are losing between US$470 million and US$730 million per year in corporate income tax on average from MNE [multinational enterprise] tax avoidance". The African Union and the United Nations Economic Commission for Africa (2021) estimate that Africa loses a further US$50 billion annually to illicit financial flows related to the extractive sector (oil, gas and minerals), noting that "these estimates may well fall short of reality because accurate data do not exist for all African countries, and these estimates often exclude some forms of illicit financial flows that by nature are secret and cannot be properly estimated, such as proceeds of bribery and trafficking of drugs, people and firearms". Central governments collect revenues from mining activities through taxes and royalties.

The assumption is that these revenues will benefit the economy by being invested in other productive sectors. However, there has been scepticism about this as revenues from mining resources are not automatically directed to the production of goods and services in other sectors (Diestche and Esteves 2020). Indeed, there has been a tendency for these revenues to fuel patronage networks, with the political elites capturing a big share of benefits (IRP 2020). Through such mechanisms, resource abundance has tended to cause economic deterioration, with the so-called 'resource curse' (Natural Resource Governance Institute 2015) leaving communities with little additional income and with the environmental consequences of mining and metallurgical activities. Many countries have sought to renegotiate contracts, mainly through changes to mining tax regimes, including windfall taxes. For instance, in 2008 the Government of Zambia revamped its mining tax code to increase its take from mining: corporate income tax was increased from 25 per cent to 30 per cent and royalties rose from 0.6 per cent to 3 per cent, and a 25 per cent tax on windfall profits was instituted, along with a 15 per cent profit variable tax (Investing News Network 2013).[37] However, the aggressive approach of Zambia saw many companies start to reconsider their capital investments in the country, including investments in the kind of specialized smelting equipment needed to process cobalt. That may have been why Zambian cobalt output plunged by more than 50 per cent by 2012 compared to 2008. Indeed, the Government of Zambia scrapped the controversial windfall profits tax in 2010 to appease investors (Investing News Network 2013).[38]

Communities where mining takes place tend to benefit the least from mining revenues. Macdonald (2018) points out that although the total benefits from mining may be large, these benefits accrue predominantly at the national level and are typically concentrated in the hands of those in power and in capital cities. In many countries, the mineral resources are owned by national governments. Although local governments and communities may get a share of the revenues by law, this tends to be small. For instance, the sharing of benefits in Kenya gives communities 10 per cent of mining royalties (Ngeno 2022), 10 per cent in the Democratic Republic of the Congo, 20 per cent in Ghana and 3 per cent in Uganda (Wankhede 2020).


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37 The Government first annulled the existing mineral development agreements. These were individual mine-by-mine agreements that had earlier prevented the Government from legally enforcing legislative fiscal adjustments. There were stability clauses in the mineral development agreements that were supposed to override and protect against legislative changes made locally (also prescribing international arbitration if this occurred) (Lundstøl and Isaksen 2018).

38 https://investingnews.com/daily/resource-investing/battery-metals-investing/cobalt-investing/is-zambia-the-next-cobalt-hotspot/.

2.4.3 Infrastructure for minerals and resource-financed infrastructure

An emerging model being driven by China is infrastructure provision in exchange for minerals. This has potential good benefits as Africa suffers an annual infrastructure financing gap of between US$68 billion and US$108 billion (African Development Bank 2018). Sub-Saharan African countries are already involved in five dozen Chinese resource-backed loan arrangements totaling US$66 billion (Aluminium Insider 2020). For example, in 2017, China agreed to loan Guinea US$20 billion in the form of an infrastructure-for-minerals[39] concession. The deal guarantees three Chinese bauxite mining projects whose revenues will repay the loan over 20 years. This model has also been applied in the Democratic Republic of the Congo (for a copper concession) and in Ghana (for a bauxite concession). While this model provides badly needed infrastructure, the model has been criticized as not providing equal benefits. Benefo and Addaney (2021) argue that if commodity prices fluctuate, it might affect the revenue generated from the production and sale of these natural resources. Furthermore, these deals are mainly to the benefit of Chinese construction companies, who often receive the building contracts for these Chinese loans,[40] as well as creating jobs for many Chinese people living in Africa.[41] Broadly, it has also been pointed out that these kinds of loans will introduce fiscal distortions (see Chapter 5).

Perhaps a more damaging aspect of these types of deals is the fact that resource-financed projects tend to be conflated with bigger government development plans. The fact that the government is under political pressure to deliver this kind of big infrastructure plan means that the various instruments of government charged with ensuring the sustainability of mining projects tend to be compromised. In an analysis of a Ghanaian resource-financed infrastructure project, Neal (2021) notes that although internationally accepted best practices dictate that the Government of Ghana should have performed a strategic environmental assessment at the conceptual stage of the country's integrated aluminum industry plan before the Government pledged to rely on revenues from its domestic aluminium industry to satisfy its infrastructure loan obligations, Ghana has not performed one. This can be partly attributed to ambiguous provisions of Ghanaian environmental assessment laws that do not clearly state whether a strategic environmental impact assessment is required for government sectoral plans and that fail to establish procedures for performing strategic environmental assessment. Further, the Ghanaian Environmental Protection Agency is likely to issue environmental permits for all planned projects because Ghanaian law provides the Agency with a high level of discretion in issuing environmental permits and the decision-making processes of the Agency are influenced by presidential priorities and politics (Neal 2021).

2.4.4 Conclusions

The African continent possesses an abundance of mineral resources that play an integral role in its economic landscape. While mining activities present substantial financial benefits, both directly through fiscal revenues and indirectly through related industries, they also come with significant challenges. The temporary nature of mining revenues, coupled with a lack of sustainable management practices, has historically led to short-lived financial booms, followed by long-standing socioenvironmental costs. Botswana has successfully leveraged its mineral wealth to transform the national economy, but whether such successes will be replicated across the continent remains an open question.

The Africa Mining Vision presents a comprehensive strategy to optimize the benefits from mining, focusing on several pillars from local supplier development to promoting sustainable livelihoods in mining communities. However, the effectiveness of this vision largely depends on governance structures at both the corporate and governmental levels. History shows that without adequate governance, mineral wealth can lead to economic deterioration and the so-called resource curse, where economic gains are offset by sociopolitical issues and environmental degradation.

39 https://www.reuters.com/article/us-guinea-mining-china/china-to-loan-guinea-20-billion-to-secure-aluminum-ore-idUSKCN1BH1YT.
40 https://www.ccpwatch.org/single-post/2020/02/27/resource-backed-loans-revisited-infrastructure-for-aluminum-in-ghana-and-guinea.
41 https://www.economist.com/middle-east-and-africa/how-chinese-firms-have-dominated-african-infrastructure/21807721.

The rise of resource-financed infrastructure, particularly influenced by Chinese investments, offers a potential solution to the infrastructure deficit of Africa. However, these deals often tilt benefits towards external actors and might compromise domestic sustainability standards owing to intertwined political agendas. The need for critical analysis and clear governance mechanisms has become evident to ensure equitable distribution of mining benefits and to safeguard long-term environmental and socioeconomic well-being.

The transition to a green economy and the rising concerns in some developed countries regarding their dependence on critical minerals from China (or a few suppliers), the so-called near-shoring, offers a new opportunity to develop new strategies to leverage the abundance of critical materials in Africa.

The Governments of the United States of America, the Republic of Korea and Japan have started to re-engage more directly with the mining sector in Africa as they seek to guarantee security of supply. African governments need to be more proactive in shaping their engagement with both China and the West. The African Development Bank is currently developing an Africa Green Minerals Strategy with its partners: the African Union/Africa Mineral Development Centre, the United Nations Economic Commission for Africa and the Africa Legal Support Facility.

In conclusion, while mining in Africa offers substantial financial opportunities, the continent's challenges lie in optimizing these benefits in a sustainable manner, ensuring that gains are not ephemeral but lead to lasting positive change for most of its people.

2.5 INVESTMENT ISSUES IN SOUTH AMERICA

2.5.1 Royalties and taxation related to mining in South America

Tax instruments for mining

In South America, mineral resources are public domain assets: they belong to the State and, through it, to its citizens, which means that the State has the sovereign right to decide how and under what conditions these resources are exploited. For many countries, mineral resources represent a significant proportion of their wealth, and their proper management can have very positive effects for inclusive economic development.

One of the essential elements for extractive activity to generate sustainable benefits and promote intra- and intergenerational equity is to have a tax regime that allows adequate appropriation, use and distribution of economic rent. However, the design of such a tax regime presents technical and administrative challenges, which are linked to the exclusive characteristics of the extractive activity, and others that, without being exclusive, are exacerbated in this sector. Among these characteristics, it is worth mentioning the prospects of high economic rents, high sunk costs and long production periods, the uncertainty of the industry, State ownership of resources. the existence of limited and non-renewable resources, and the impacts of the activity on communities and the environment.

For the exploitation of non-renewable natural resources, States essentially have three strategies (Nakhle 2010). The first is to exploit resources independently, through a State company that explores, produces and markets the products. The second is by delegating these activities entirely to private companies. The third is a hybrid of the two. In South American mining, the second strategy prevails, except for in Chile, where the main copper miner is the State company Codelco, and in the Plurinational State of Bolivia, which created a State company to exploit lithium (YLB).

It is important to point out that these two experiences of State companies have had different results. Codelco was created in 1971 with the copper nationalization process. It is currently the largest copper company in the world and is responsible for almost 30 per cent of copper production in Chile. On the other hand, YLB was created in 2017, with the responsibility of carrying out the national lithium strategy developed in 2013. This strategy gives the State, through YLB, the exclusive power to exploit lithium, and includes three stages:

(1) construction of lithium carbonate and potassium chloride pilot plants; (2) industrial scale production of lithium carbonate and potassium chloride; and (3) production of lithium-ion batteries. So far, only the first stage has been completed, while the inauguration of an industrial-scale plant has suffered successive postponements.

Regarding the ways in which the private sector participates in the exploration and exploitation of non-renewable resources, two types of regulatory frameworks or fiscal regimes are normally considered: concession systems and contract systems.

In the concession system, the State grants a company the exclusive right to explore, develop, produce, transport and commercialize non-renewable natural resources at its own risk and expense within a determined area during a specific period. If they remain underground, the resources remain the property of the State, but once they are extracted and the corresponding royalties and taxes are paid, the property passes to the private sector.

In the contractual system, the State appoints a contractor to carry out operations of exploration, development, production, transportation, and commercialization of resources in a determined area. The ownership of the production remains with the State, while the private company operates at its own risk, under the specifications of the contract and under the control of the State. If the exploration is successful and allows marketable production, the contractor will be entitled to receive compensation that covers investment and operating costs, plus a profit margin. The most common types of contracts are production sharing contracts and service contracts.

In South America, the contractual system is reserved for hydrocarbons, while in the mining sector only the concession system is used (Gómez-Sabaini *et al* 2015).

Normally, mining companies that hold concessions are subject to all the same tax obligations as most companies in other economic sectors. This includes company profit tax, capital gains tax, payroll tax, property tax, value added tax (VAT) and import duties. Similarly, they are usually obliged, like other taxpayers, to withhold another set of taxes, such as those on dividends paid to their shareholders, interest remitted abroad, payments remitted abroad for services, remuneration paid to their workers and social security.

However, in addition to the above, governments apply particular taxes to mining activity in order to extract part of the economic rents that it generates. At the same time, it is frequently the case that certain tax benefits are granted in respect of income tax, as a way of mitigating the risks inherent to the activity and stimulating investment.

Special taxes on mining are often called royalties. There are three such types: specific, ad valorem and on profits.

Specific royalties consist of a fee charged per unit of volume or weight. They are most often applied to industrial minerals or those that are sold in bulk. Its application is simpler than that of other methods, since it does not depend on price, production costs or other values that may be the subject of disputes (Otto *et al*. 2006). Its main advantage is that it guarantees a stable income flow, and from the first year of exploitation, since it is independent of the mineral price cycle or the cost structure of the mining company. However, on the other hand, they do not allow for higher revenues in the event of windfall profits owing to the high end of the price cycle and, in general, they will contribute a relatively low proportion of the economic rents of the most profitable projects. In turn, it is an inefficient tax, since they are equivalent to an additional production cost, which must be paid even if the mining companies have losses. This means that the profitability of a mining project will be lower than for the alternative without royalty, so that some projects with lower profitability will not be carried out.

Ad valorem royalties consider as the tax base the value of the mineral extracted or sold, on which a rate that can be flat or variable is applied. Regarding the variable rate, it can grow depending on the total production of the mine or depending on the market price of the mineral. Its main advantage is that it ensures tax collection in all the years that the exploitation of the deposit lasts. However, there will be fluctuations, mainly owing to variations in the price of the mineral. Its main disadvantage is that, like the specific royalty, it equates to an additional cost of production, decreasing the amount of ore that is profitable to extract.

Royalties on profits consider the profits of the mining company or another concept similar to profits as the tax base. There are variations of this general definition. Some jurisdictions allow only some of the expenses to be deducted or introduce certain adjustments in the calculation of the tax base. Its main advantage is that it is a more efficient alternative since the payment of taxes varies proportionally with the profitability of the project. Its main disadvantage is that it does not provide tax revenue when prices are low and companies make losses.

In addition to royalties, there are taxes on economic rents, for which there are several theoretical definitions, but few examples of application. Its purpose is to define as the tax base the economic rent generated in the exploitation of the mining deposit, on which a flat or progressive rate would be applied. A tax of this type is the most efficient, since it only taxes profits above normal, not affecting the returns required by investors.

Taxes of the general regime in South America

In all reviewed cases, the general tax regimes for mining in South America include taxes on profits with flat rates between 25 per cent and 35 per cent (see table 2.3). In most of the countries analysed, the taxable base is global profits, except in Bolivia (Plurinational State of), which taxes the net profits earned in the country. On the other hand, the tax regimes accept deductions such as the necessary and usual expenses for mining exploration and exploitation. In Bolivia (Plurinational State of) and Peru, the payment of other tax obligations specific to the mining activity can be deducted from the tax base of the profits tax. In Colombia and Chile, mining companies are allowed to amortize their exploration expenses over a maximum period of five and six years, respectively.

Regarding the carry forward of tax losses, in general this can be done within a period of five years, with a limit of 25 per cent of the annual profits in Ecuador. In Chile, tax losses can be amortized without any limit of time or percentage of the profits of future periods, while in Peru they can be offset from future profits with one of the following two systems, at the taxpayer's choice: (i) against the net income generated within the following four fiscal years after the year in which the loss is incurred; or (ii) against 50 per cent of the net profit generated in the following fiscal years after the year in which the loss was generated, with no time limit to transfer the losses.

In the general regime, mining companies are also subject to other types of taxes such as a withholding tax on profits distributed to partners or shareholders. In the specific case of Chile, the partners or shareholders are taxed with an integrated system, which allows the income tax paid by the company to be discounted. In the case of non-resident shareholders, the final rate (company plus shareholder) is 35 per cent.

Other types of taxes that make up the general regime are property taxes. In Bolivia (Plurinational State of) and Peru, there is a tax on financial transactions of 0.3 per cent and 0.005 per cent, respectively, on all debits and credits from taxpayers' bank accounts. Peru also applies a temporary tax on net assets of 0.4 per cent, on the historical value of the net assets of the company that exceeds approximately US$270,000. Another case is the new tax, called the Contribution for Regional Development, adopted in Chile in February 2020. This tax is levied at 1 per cent of the acquisition value of all the physical assets that comprise the same investment project, but only in the part that exceeds the sum of US$10 million.

Finally, a noteworthy aspect is that in almost all the countries analysed, mining companies enjoy a tax invariability regime that assures them, for a determined time, stability in their tax obligations. In Chile, Decree Law No. 600, promulgated in 1974, granted, inter alia, the right to foreign investors to sign a foreign investment contract with the State of Chile, in which they were guaranteed that a rate of 42 per cent as the total effective tax burden on earnings would remain unchanged for a period of 10 years. Although this Decree was repealed in January 2016, its effects remain until today, especially with respect to the royalty created in 2005.

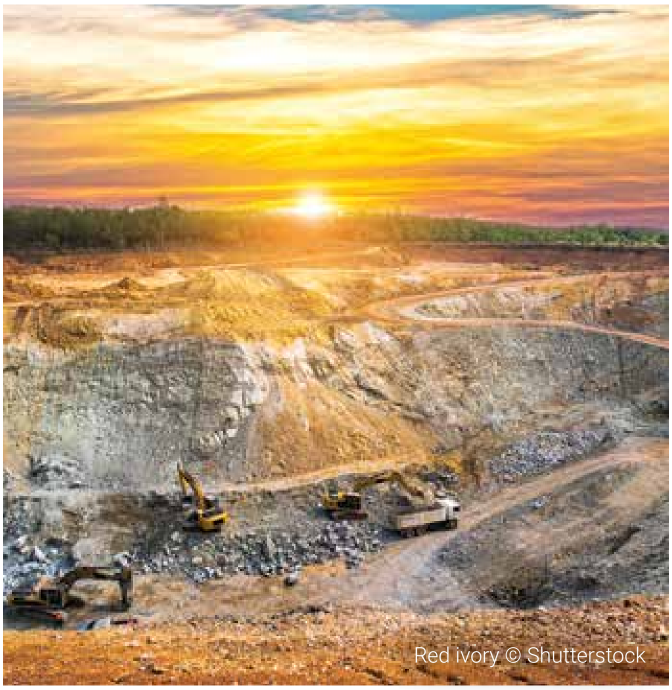
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Table 2.3: General taxes on economic activities in South America

Country	Corporate income tax			Dividends (per cent)	Other taxes (subsidies)	Tax invariability
	Rate (per cent)	Deductions	Depreciation			
Argentina	35	Double deduction of exploration expenses Carry forward tax losses up to 5 years Royalties	Constructions: 3 years Machinery and equipment: 3 years	7	Export duties (4.5 per cent) Financial transactions (0.6 per cent) Refund to exports (1.5 per cent)	Yes
Bolivia (Plurinational State of)	25	Patents, royalties and mining interests Exploration expenses Environmental restoration expenses Carry forward tax losses up to 5 years	Buildings: 40 years Roads and facilities: 10 years Machinery: 8 years Vehicles: 5 years	12.50	Financial transactions (0.3 per cent)	No
Chile	27	Exploration expenses amortized in up to 6 years Carry forward tax losses without limits	Constructions: 16 years Machinery and equipment: 3 years Installations in mines: 1 year	8 (over gross dividend)	Regional Development Contribution (1 per cent of fixed assets for one time)	Yes
Colombia	30 (20 in free zone regime)	Exploration expenses amortized in up to 5 years 50 per cent of the amount paid for tax on financial transactions Carry forward tax losses to the up to 12 years	Buildings: 45 years Machinery, equipment and facilities: 10 years Vehicles: 5 years Hardware and software: 5 years	10	Financial transactions (0.4 per cent)	Yes
Ecuador	25	Carry forward tax losses for up to 5 years, with an amortization limit of 25 per cent per year on the tax base. Payment for employee participation contribution Royalties up to 1 per cent of the tax base	Buildings: 20 years Machinery, equipment, and facilities: 10 years Vehicles: 5 years Hardware and software: 3 years	10	Employee participation (15 per cent of gross profits) Equity (0.15 per cent) Foreign currency outflow (5 per cent of the value of foreign currency transactions)	Yes
Peru	29.5 (31 under a tax invariability regime)	Profit sharing payment to workers, tax on financial transactions and mining royalties. Carry forward tax losses up to 4 years or against 50 per cent net income of subsequent years without time limit.	Vehicles: 20 per cent Machines and equipment: 20 per cent Equipment for data processing: 25 per cent Other fixed assets: 10 per cent Buildings: 5 per cent	5	Employee participation (8 per cent of profits) Financial transactions (0.005 per cent) Net assets (0.4 per cent)	Yes

Source: United Nations, Economic Commission for Latin America and the Caribbean (2022)

Special taxes on mining activity in South America

All the special tax regimes for mining activities in South America include the payment of a royalty for the extraction and sale of minerals (see table 2.4). However, its design and application differ greatly depending on the country, being applied in a differentiated way according to the minerals, types of contracts or size of the companies. In Chile, the Specific Tax on Mining Activity is a progressive tax on the operating result of mining activity and corresponds conceptually to what was called royalty on profits. Created in 2005, the Specific Tax contemplates progressive rates according to the size of the company and the profit margin. Those companies whose annual sales are less than 12 thousand metric tons of fine copper are exempt from the Tax.

In Peru, there are three types of royalties that are applied to companies in the sector depending on whether they exploit metallic or non-metallic minerals, or if they have a tax invariability contract with the State. Until 2011, the mining royalty in Peru was paid on the value of the concentrate or its equivalent, according to international market prices, with progressive rates of 1 per cent to 3 per cent depending on the range of sales of each company. In 2011, the law was amended, starting to consider the quarterly operating profit as the taxable base of the royalty and applying an effective rate that is a function of the operating margin for the quarter. This margin is the result of dividing the quarterly operating profit by the income generated by the sales of the quarter. Effective rates are in the range of 1 per cent to 12 per cent. On the other hand, the Special Tax on Mining (IEM) taxes the operating profit obtained by the subjects of the mining activity from the sales of metallic mineral resources. In this case, the effective rates are in the range of 2 per cent to 8.4 per cent. Finally, Peru adopted the Special Tax on Mining (GEM) that applies to the subjects of mining activity that have signed guarantee contracts and investment promotion measures with the State in accordance with the General Mining Law (contracts of legal stability). This tax has the same characteristics as IEM, but its effective rates vary, depending on the operating margin, in the range of 4 per cent to 13.12 per cent. The amounts paid for the mining royalty are deducted from the amount thus determined.

Another relevant case is that of the mining royalties applied in Ecuador. For metallic minerals, the royalty is equivalent to a percentage of the sale of the main mineral and secondary minerals. The rates are 3 per cent to 8 per cent of net revenue for medium and large-scale mining and 3 per cent for small scale mining. For large mining, royalties are negotiated by contract; artisanal mining is exempt from paying royalties. In the case of non-metallic mining, the royalty corresponds to a percentage of production costs, with rates that vary between 10 per cent and 100 per cent, depending on the volume of annual production. Small non-metallic mining companies pay a royalty of 3 per cent of the mineral production cost.

On the other hand, in Bolivia (Plurinational State of) companies that carry out extractive activities of non-renewable natural resources must pay an additional rate of 25 per cent on annual profits. The tax base for this surcharge results from the deduction of the following items from the tax base of the income tax: (i) a variable percentage, of the taxpayer's choice, of up to 33 per cent of the accumulated investments in exploration, development, exploitation, benefit and environmental protection, directly related to said activities. This deduction is used in a maximum amount equivalent to 100 per cent of said investments; and (ii) 45 per cent of the net income obtained from each extractive operation of non-renewable natural resources during the declared fiscal year. There is also an additional rate of 12.5 per cent, the purpose of which is to tax additional profits originated by favourable mineral and metal price conditions, which is applied on the same tax base as income tax. To encourage the transformation of raw materials in the country, the regulation provides that companies that produce metals or non-metallic minerals with added value will apply 60 per cent of the surcharge.


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Table 2.4: Special taxes on mining activity in South America

Country	Royalties			Other taxes	Land use charge
	Specific	Ad valorem	On profits		
Argentina		3 per cent on mine head value			Yes
Bolivia (Plurinational State of)	…	Rates from 1 per cent to 7 per cent depending on the product	Additional tax on extraordinary profits from extractive activities: 25 per cent Surcharge of the corporate tax of 12.5 per cent on extraordinary profits	…	Yes
Chile	…	…	Progressive rates between 5 per cent and 14 per cent depending on company size and sales volumes (Specific Tax on Mining Activity)		Yes
Colombia	…	Rates from 1 per cent to 12 per cent depending on the product	…	…	Yes
Ecuador	Non-metallic products: rates from 10 per cent to 100 per cent on production costs depending on the size of the producer and tons of production.	Metal products: rates of 3 per cent and 8 per cent depending on the size of the producer.	Sovereign Adjustment to Mining Exploitation Contracts (applies when the participation of the State in the economic rent is less than 50 per cent).		Yes
Peru	…	…	Progressive between 1 per cent and 12 per cent according to the operating margin of the quarter (Mining Royalty, Law No. 28.258 of 2004) Progressive between 2 per cent and 8.4 per cent depending on the operating margin of the quarter (Special Tax on Mining) Progressive between 4 per cent and 13.12 per cent according to the operating margin of the quarter (Special Tax on Mining, tax invariability contracts)	Contribution to the regulatory body (OSINERGMIN) Mandatory contribution to the Complementary Mining, Metallurgical and Steel Retirement Fund (0.5 per cent annual income before taxes)	Yes

Source: United Nations, Economic Commission for Latin America and the Caribbean (2022).

2.5.2 Government take and effective tax rates

An interesting question to answer is how effective tax regimes are in achieving a reasonable appropriation of economic rents by States. It is also interesting to evaluate the tax burden that mining companies must bear and the relative weight of the different types of taxes as this affects how attractive countries are for foreign investment.

In relation to this issue, the United Nations Economic Commission for Latin America and the Caribbean (ECLAC) (2022) analyses the fiscal frameworks for the exploitation of non-renewable natural resources in Latin America and the Caribbean. Based on the data of a typical copper exploitation project, the government take and effective tax rate are evaluated in several countries of the region, including Bolivia (Plurinational State of), Chile, Colombia, Ecuador and Peru. The project considers a fixed investment of US$2,093 million and an annual production equivalent to 125,000 metric tons of fine copper, exploitation of which lasts 25 years. The results, considering a long-term copper price of US$3.3/lb, are shown in table 2.5.

Table 2.5: Government take and effective taxation rate in mining

	Bolivia	Chile	Colombia	Ecuador	Peru
Net present value before taxes (a) (mUS$)	546	1,639	1,106	-137	1,310
Present value of taxes (b) (mUS$)	911	819	972	550	943
Government take (b/a) (%)	166.9	50.0	87.8	-	72.0
Present value of profits (c) (mUS$)	1,995	2,928	2,476	1,392	2,649
Effective tax rate (b/c) (%)	45.7	28.0	39.2	39.5	35.6

Source: United Nations, Economic Commission for Latin America and the Caribbean (2022).

The government take reaches its minimum value in Chile, with 50.0 per cent, followed by Peru, with 72.0 per cent, and Colombia, with 87.8 per cent. In the case of Bolivia, a government take of more than one hundred per cent is obtained, which means that the State appropriates, through taxes, an amount of resources greater than the economic rent generated by the project. In the case of Ecuador, given the high opportunity cost of investors, the project did not generate economic rents.

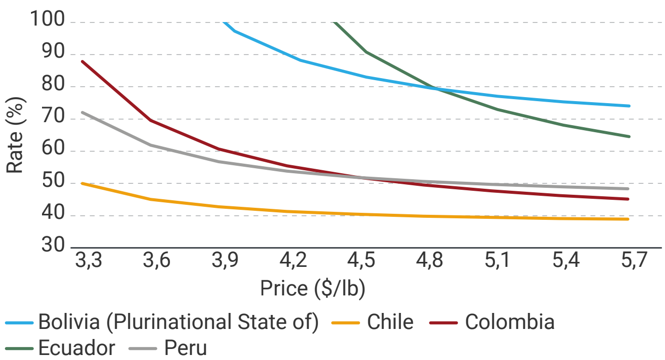
The effective tax rate behaves similarly, but at lower levels, which is consistent with its definition. In Chile, taxes are equivalent to 28.0 per cent of the financial profits generated by the project. They are followed, in ascending order, by Peru (35.6 per cent), Colombia (39.2 per cent), Ecuador (39.5 per cent) and Bolivia (Plurinational State of) (45.7 per cent).

The results depend on the assumptions of the model, in particular the price of copper. Figure 2.8 and figure 2.9 show both indicators based on the price of copper. In the first graph it can be seen that in the five countries the government take is reduced as the price rises, which means that the tax instruments used are not progressive enough to achieve at least a proportional participation of the State in the economic rents generated by the project.

In turn, the analysis of effective tax rates shows that the tax regime is regressive in Colombia (the rate falls as the price, and therefore utility, increases), it is almost proportional in Ecuador and it is progressive in Bolivia (Plurinational State of), Chile and Peru. This has to do with the relative use of ad valorem and profit royalties. In Colombia, ad valorem royalties have a greater weight, which determines a very high effective rate when prices are low. Bolivia (Plurinational State of), Chile and Peru, on the other hand, mainly collect through royalties on profits, which determines a progressive effective rate structure, with fewer disincentives to invest.

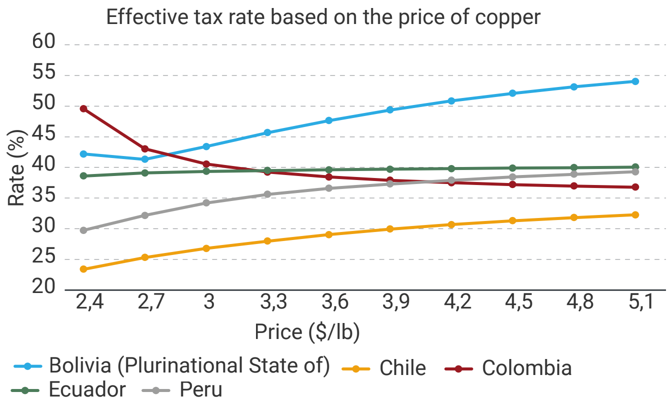
The study concludes that Colombia and Ecuador rely heavily on ad valorem royalties, and that replacing these taxes with others on profits could mean gains in efficiency and progressivity. In turn, Bolivia (Plurinational State of) has a very burdensome tax regime for a mining project such as the one analysed, resulting in collections that are higher than the economic rent generated, at least with the long-term prices that have been assumed. Regarding Chile and Peru, it is concluded that they have defined reasonable tax instruments to tax mining activity, combining the corporate income tax with royalties based on profits.

Figure 2.8: Government take based on the price of copper



Source: United Nations, Economic Commission for Latin America and the Caribbean (2022)

Figure 2.9: Effective tax rate based on the price of copper



Source: United Nations, Economic Commission for Latin America and the Caribbean (2022)

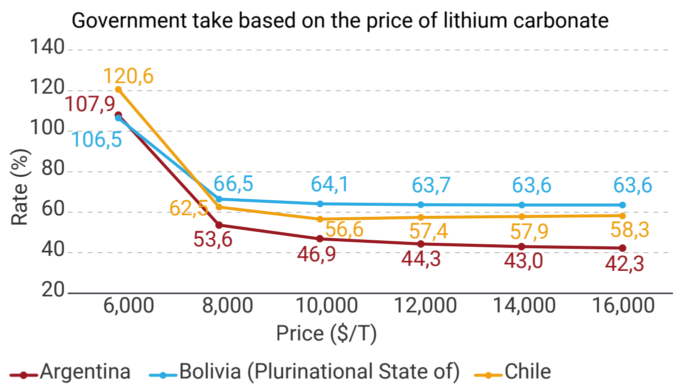
In Jorratt (2022), the case of lithium in Argentina, Bolivia (Plurinational State of) and Chile is studied. The application of the tax systems of the three countries on an investment project for the exploitation of lithium in a salt flat is simulated, measuring the government take and the effective tax rate. The technical parameters of the lithium carbonate production project in the Cauchari-Olaroz salt flat, in the province of Jujuy, Argentina, which is being executed by Minera Exar S.A., are used as a reference.

Figure 2.10 shows the estimates of the government take based on the price of lithium carbonate. In all three countries, when the price is low enough, at US$6,000 per ton, for instance, the rate is higher than 100 per cent, which means that the State collects taxes, even though there is no economic rent. From a price of around US$10,000 per ton, the trajectory of the rates is different between countries. While in Argentina it continues to drop as the price rises, in Chile it tends to increase slightly and in Bolivia (Plurinational State of) it remains practically constant. This has to do with the design of the current taxes in each country. In Argentina, the corporate income tax is combined with flat-rate ad valorem taxes. The latter give it a regressive character, collecting a lower percentage of economic rent with increases with price. In Chile, on the other hand, lithium exploitations are subject to a progressive ad valorem royalty, where the rate rises rapidly as prices increase.

Figure 2.11 shows the effective tax rate based on the price of lithium carbonate. In the case of Argentina, a relatively flat effective rate of around 38.5 per cent is observed. In Bolivia (Plurinational State of) and Chile, on the other hand, it is growing. In Bolivia (Plurinational State of), the rate is increasing throughout the price range, reaching levels above 58 per cent at the maximum price considered. In Chile, the rate exceeds 50 per cent for prices around US$14,000 per ton. In both Argentina and Chile, taxation becomes regressive for low prices, because of ad valorem taxes, which are charged even when companies have losses.

The study concludes that an effective tax rate of around 60 per cent, such as the one that Chile and Bolivia (Plurinational State of) theoretically have, seems reasonable, and that Argentina is the country that has more scope to increase its tax collection in lithium mining. In turn, it is mentioned that the discussion of the tax burden of lithium in Bolivia (Plurinational State of) is not very relevant, as long as this country continues with the one hundred per cent state strategy. For Chile, it is emphasized that, although the effective tax rates are close to 60 per cent, this is largely the result of the contracts with the two current operators, and nothing ensures that a new lithium exploitation project would have the same conditions.[42]

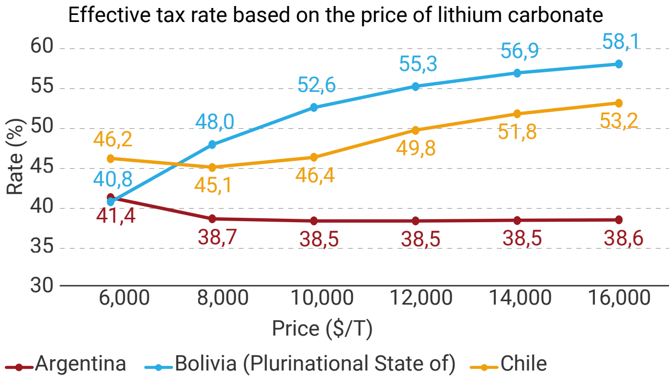
Figure 2.10: Government take based on the price of lithium carbonate



Source: Jorratt (2022).

42 The two operations currently in place in Chile are located in the Salar de Atacama, in sectors concessioned to the State agency CORFO. As the owner of these properties, CORFO has signed lease contracts for the mining properties with the companies that exploit lithium. These contracts establish rental income similar to an ad- valorem royalty, with progressive marginal rates of up to 40 per cent, depending on the price of the exported lithium compounds.

Figure 2.11: Effective tax rate based on the price of lithium carbonate



Source: Jorratt (2022).

2.5.3 Conclusions

From the point of view of economic efficiency, the best special tax with which to tax mining activity is the economic rent tax. A tax with these characteristics does not produce the typical distortions of specific or ad valorem royalties, such as affecting the cut-off grade for minerals. However, a fiscal regime that relies on that single instrument will have the disadvantage of postponing the moment at which a project begins to generate income for the State or will lead to no income being received in years in which the price is not high enough to cover the opportunity cost of capital. That is why specialists consider it a good practice for developing countries to combine various instruments, for example, an ad valorem royalty with a moderate rate, which guarantees income from the beginning of the operation; a corporate income tax, which guarantees income even when the yield obtained by the mining operator does not exceed the normal yield; and a royalty on profits or a tax on the economic rent of natural resources, which makes it possible to extract a greater portion of the economic rent of the extractive industry.

Ad valorem royalties also have the disadvantage of resulting in regressive tax regimes, in the sense that the effective tax rate is reduced as prices increase, wasting the opportunity to capture rents from those projects that are most profitable.

The tax regimes of South American countries are diverse, both in terms of the instruments used and the effective tax burdens. Chile and Peru rely mainly on royalties on profits, achieving lower efficiency costs and progressive structures, which allow more to be collected when prices are high. Bolivia (Plurinational State of) also uses royalties on utilities. However, these can lead to excessive tax burdens for certain projects, which can discourage investment. Colombia and Ecuador have preferred ad valorem taxes and would probably benefit from a gradual shift towards royalties on profits. For its part, Argentina, in the case of lithium mining taxation, is characterized by moderate taxation, with scope to increase collection.

2.6 CONCLUSIONS OF THE CHAPTER

Easily the most important factor influencing investment in minerals is their current and expected future prices, which for highly traded minerals and metals are largely set globally. The factors that influence global prices are many and are still not well understood. Currently a large share of price behaviour remains unexplained owing to the lack of transparency of commodity markets. In particular, issues relating to market power, strategies of exercising stock holdings or production planning cannot be properly assessed at the moment.

The fundamentals of supply and demand are undoubtedly important but these signals can be obscured by geopolitical issues and speculation in financial markets. The long lead times from exploration to production, and possible shifts in technologies, and therefore in the demand for specific minerals (see Chapter 5), also increase the price uncertainties with which prospective investors and mining companies need to contend.

However, future demand for transition minerals generally seems certain to increase dramatically as a result of countries' increasing commitment to the low-carbon energy transition, running the risk of significant price increases if the supply of these minerals fails to keep up with demand.

China has been investing strategically in the exploration, production and processing of transition minerals since the early years of this century, with investment being divided into different proportions over the years between private companies, and central and local governments. Chinese companies have also invested heavily in mining in other countries, most notably in Australia. This early investment has resulted in Chinese dominance of the production of many transition minerals discussed in Chapter 1.

Africa and South America are resource-rich continents with long histories of mining, and mining contributes substantial shares of exports, GDP and fiscal revenues for many countries in both regions. Mining countries in these regions are looking to benefit economically from the predicted increase in demand for transition minerals.

In Africa, the key issues for investment are the stability of governance and policy, regulatory capacity and the skills of the labour force. Artisanal and small-scale mining contributes a significant proportion of African production of some important minerals, the financing of which is explored in detail in Chapter 7. Illicit financial flows are a key issue that rob many African countries of the fruits of the production of their resources that should contribute to their sustainable development by providing the finance to invest in capacity-building, downstream industries and infrastructure. Financial transparency in mining, backed by international regulation, is an important requirement to stop this haemorrhaging of vital funds from the African continent.

In respect of South American countries that are important producers of minerals, this Chapter has been focused on their tax and royalty regimes, and the efficiency and effectiveness with which these regimes capture some proportion of the economic rents from mining for the State. It is shown that there is a balance to be struck as commodity prices change between guaranteeing a certain revenue for the State through ad valorem taxes, which in the extreme may make mining unprofitable at low prices, and taxes on profits, which will reduce State revenues when prices are low.

In conclusion, this Chapter has shown that the most important influence on investment in the production of minerals and metals is current and expected future prices, but that that these are volatile and the underlying causes of price movements are complex and not well understood. At the country level, investment risk can be reduced, and therefore investment encouraged, by good governance and regulatory stability, combined with a tax and royalty regime largely based on profits rather than turnover. This, in turn, emphasizes the importance of tackling illicit financial flows so that declared profits in a country truly reflect the economic activity that has been carried out there.

Many national governments whose annual budgets depend on international commodity prices are unprepared for sudden price movements in terms of macroeconomic planning. International commodity price shocks, of an intransparent and stochastic nature, thus drive inflation and consumption crunches, leading all the way to hunger and unrest in many countries. There is a need to build a more transparent and robust international system of natural resource management and macroeconomic planning (including sovereign debt management). Chapter 8 will introduce a recommendation for an international minerals and metals agency with this as part of its role.

CHAPTER 3

ISSUES IN MINING TODAY RELATING TO THE SOCIAL LICENCE TO OPERATE AND THE ENVIRONMENT

CONTENTS

3.1 INTRODUCTION

The International Resource Panel (IRP) Mineral Resource Governance report (International Resource Panel [IRP] 2020a) examined in detail the social and environmental implications of mining and concluded that there was a need to go beyond the conventional approach to the issues of seeking a social licence to operate by engaging with the full spectrum of sustainable development issues expressed in the United Nations Sustainable Development Goals. This broader approach would ensure that mining promotes sustainable development across the board for the local communities where mines are located, host national governments, countries that import the metals and minerals and, of course, the companies that extract them. The need for all involved in mining to obtain a sustainable development licence to operate is intended to encapsulate this broader sustainable development objective.

There is little to be gained by this report repeating the analysis and recommendations of IRP (2020a), which remain valid and relevant. The aim of this Chapter is therefore to recapitulate some of the points made in the earlier IRP publication, with a particular focus on the issues that are likely to affect investors' perceptions and valuation of a project. On the economic side, these issues include local value addition and content, technology adoption and employment, and other environmental, social and governance (ESG)-related issues. This Chapter addresses local value addition and content, technology adoption and employment from an African perspective, with a brief look at artisanal and small-scale mining, the financing of which is discussed in more detail in Chapter 7. ESG-related issues are also discussed later (Chapters 5 and 6) in the context of the ESG concerns that are increasingly being considered by both mining companies and the finance sector.

One of the environmental, social and governance issues that is explored in more detail in the second section of this Chapter is equity. The analysis shows that there is substantial discrimination against women in mining, and there are many barriers to their equal participation in the sector. The section shows how these issues can be addressed.

The final section of this Chapter turns to the environment. It briefly reviews the issues of energy use and climate impacts, water quantity and quality, and waste, before dealing with the impacts of mining on biodiversity in more detail, in view of the Fifteenth Meeting of the Conference of the Parties (COP15) of the United Nations Convention on Biodiversity held in 2023. Its outcome, the Global Biodiversity Framework, addresses pollution risks, brings land-use planning to the fore and seeks co-benefits and synergies of finance, targeting both the biodiversity and climate crises. The section shows that in addition to triggering and contributing to land conversion generating biodiversity impacts, an important and underappreciated set of impacts on biodiversity are generated in and transferred through freshwater habitats.

These are some of the most important issues which mining, and the investors that finance mining, will need to address if mining is to fulfil its potentially very important contribution to sustainable development.

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3.2 MINING AND THE SOCIAL LICENCE

The social licence to operate "refers to the perceptions of local stakeholders that a project, a company, or an industry that operates in a given area or region is socially acceptable or legitimate" (Raufflet *et al*. 2013). Without a social licence, approvals for a mining licence will not be issued, and may even be cancelled, as when the Government of Serbia revoked the licence of Rio Tinto to develop the Jadar lithium-borates project in January 2022.[43]

The social licence to operate covers social, economic and environmental issues. The most important issues concerning the licence are discussed in this section, while environmental issues are discussed in the sections that follow. All these issues are relevant to the broader sustainable development licence to operate, developed in IRP (2020a) and referred to above.

3.2.1 Local value addition

Through local value addition, extra economic welfare can be generated in mining areas that traditionally export unprocessed minerals and metals, and therefore receive fewer economic benefits while bearing the environmental and social costs. One example of a policy aimed at greater local value addition is that of Indonesia through banning the export of unprocessed lateritic nickel ore. However, plans for local value addition for mineral resources related to the energy transition are limited. For instance, Goodenough *et al*. (2021) note that that while lithium mining is anticipated to grow in Africa in the coming years with projects proposed in Zimbabwe, Namibia, the Democratic Republic of the Congo, Mali and Ghana, the proposed plan in most cases is to produce a lithium mineral concentrate in-country and then ship the concentrate to a refinery elsewhere in the world. An exception is the Manono Project (Democratic Republic of the Congo) where primary lithium sulphate will be produced and exported. Even then, the local value addition will remain limited when compared to what can be achieved when the production of lithium-ion batteries is mastered.

The issue of local value addition has gained attention and countries are increasingly seeking to process locally. Producers in Africa with a dominant position are starting to leverage their power to support local processing. For example, two of the world's leading chromite producers, South Africa and Zimbabwe, are using their market power to force local processing. Zimbabwe has banned the export of raw chromite (chrome ore), while South Africa has put an export tax on ferrochrome. Both of these measures are meant to boost local ferrochrome producers, as well as the production of stainless steel (Dzirutwe 2021). Guinea, which has some of the world's largest bauxite deposits, has threatened to withdraw mining licences if companies do not invest in processing (Reuters 2022).

The desire for local value addition will have to contend with new geopolitical developments as countries seek to reduce the supply risk for critical metals. For instance, Australian lithium has traditionally been exported as mineral concentrates and processed largely in China. However, lithium processing plants are now being commissioned in Australia, with the aim of keeping processing in the country (Tabelin *et al*. 2021). This reconfiguring of supply chains is also likely to impact Africa as it develops the new resources. For instance, Syrah Resources has been granted a loan by the Government of the United States of America to build a processing plant in Louisiana to process the graphite it will mine in Mozambique (Scheyder 2022).

Looking ahead, countries are seeking to leverage their abundance of critical minerals to drive local value addition and support the green transition. The Democratic Republic of the Congo has launched a Battery Council with the aim of piloting the government policy to develop a regional value chain around the electric battery industry (Reuters 2021). The South Africa Industrial Action plan seeks to make South Africa a manufacturer of fuel cells and an exporter of green hydrogen based on its platinum group metals. This initiative, dubbed the Hydrogen Valley, is seen as a key to helping South Africa to achieve more economic benefits from its platinum group metal resources.

43 See https://www.riotinto.com/en/operations/projects/jadar.

There is also much debate on the local value addition to lithium mining in South America. There have been calls to participate in the lithium value chain more locally through the domestic production of electric vehicle battery chemicals, components and assembling facilities, as well as research and development efforts for domestic battery production (Heredia *et al*. 2020).

3.2.2 Local content

About 60 per cent of the operating cost in mining companies is related to the purchase of goods and services (Bravo-Ortega and Muñoz 2015). The ability of local companies to provide these goods and services from local sources can thus have a huge impact and even create whole new areas of competitive advantage. The production of minerals and metals is becoming less labour-intensive and more technologically intensive, requiring complex equipment as well as advanced engineering services (Ali *et al*. 2018). The rapid development of digital technologies (sensor webs, robotics, remote mining, digital twins) and of electrification further adds technological complexity and important competitiveness gains to the ore processing and metallurgical plants of most modern mines. This is creating new demands for skills and services in the sector and new avenues for competitive advantage. For example, the Australian mining equipment, technology and services[44] sector is globally competitive and now account for 7 per cent of Australian employment, compared to a contribution of 2 per cent to employment by the mining sector itself (Korinek and Ramdoo 2017; Bravo-Ortega and Muñoz 2015). However, this is a result of the long history of mining in Australia, with decades of public and private investment in education, research and innovation.

The desire to capture greater benefits through local content has seen many countries in Africa develop local content policies (Östensson 2017). Such policies usually target (local) industrial and technological development, value creation or addition, wealth increase, employment creation and the development of backwards, forwards and sideways linkages along the value chain (Ramdoo 2016). Local content is seen as an instrument to promote equality, social justice and the empowerment of historically disadvantaged communities (African Center for Economic Transformation 2017). A review of local content requirements of countries with transition minerals projects is shown in table 3.1.

Table 3.1: Policies to enhance local value capture in different African countries

Countries	Local ownership	Local procurement	Local content requirements	Local employment requirements
Angola	●	●		●
Botswana	●	●		●
Burkina Faso	●	●		●
Cameroon	●	●	●	●
Côte d'Ivoire	●	●	●	●
Democratic Republic of the Congo	●	●	●	●
Ghana	●	●		●
Guinea	●	●	●	●
Mali		●	●	●
Mozambique	●	●	●	●
Namibia	●	●	●	●
Sierra Leone	●	●	●	●
South Africa	●	●		●
United Republic of Tanzania	●	●	●	
Zambia	●	●	●	●
Zimbabwe	●			

Source: Gatune (2024).

44 Includes services, such as technologies for exploration, mineral processing and mine communication, and consulting services, such as geological and geotechnical assessment and environmental management.

Implementing local content policies has been a problem, however. The expectations that governments place on mining companies and the flexibility or exemptions required expose the mining company to regulatory uncertainty, and the balance between goals and feasibility has not yet been achieved (Gatune 2024). Local content policies tend to create demand for suppliers, but many countries have a weak supply base, particularly for larger-scale operations. Moreover, mineral processing requires competitive and reliable energy supply and adequate transport infrastructure.

The economies of many African countries are largely informal and characterized by small informal enterprises. For example, 99 per cent of all Mozambican enterprises are either run by individual entrepreneurs or are micro-enterprises with fewer than five employees (African Development Bank *et al*. 2016). The weak supplier base makes it difficult for most businesses to access high-value procurement contracts given the high requirements in terms of technological specifications, quality, and health and safety systems that are typical of extractive contracts (Barnard *et al*. 2021).

At the same time, governments do not do enough to develop suppliers. If local value addition is to be successfully achieved, there will need to be considerable capacity-building of local technical staff, engineers and managers to ensure the safe and environmentally compatible operation of these new processing and manufacturing plans. University-industry collaboration could be further strengthened to support skills development. Another avenue to be explored is co-investment by governments and industry in the creation and functioning of national and regional training centres in order to develop a local skills base employable in a developing minerals and metals industry. This can foster competitiveness and social acceptance. The case histories of the Nigerian oil industry, the Malian gold industry or the Senegalese phosphate industry provide interesting examples of the progressive and successful replacement of expatriates by qualified local staff in a great diversity of functions, from management level to worker levels. However, this took many years, if not decades, of consistent joint efforts by public authorities and mining companies to be achieved. Many governments also lack the institutional capacity to implement and monitor local content polices (Oyewole 2018; Dietsche and Esteves 2018; Barnard *et al*. 2021). Essentially, local content policy should dovetail with education, research and innovation, as well as with industrial policies and the wider transformation agenda. However, this is not happening. As Radley (2019) has noted in the case of the Democratic Republic of the Congo, "there is no broader industrial policy to increase the 'capacity', 'availability,' or 'accessibility' of Congolese actors and facilitate their inclusion and advancement in global mining value chains".

While local content benefits are hard to capture, local content policies can also produce perverse unintended effects, which can include:

- Accelerating brain drain: Developing local experts in extractives does not mean an increase of capacity in that locality. Locally trained experts can become globally competitive and can easily be attracted to other countries (Gatune 2020). Moreover, duly trained and well-qualified local experts employed by local public institutions (environmental agencies, geological surveys, mining directorates) may quit their public jobs and seek income from private sector activities owing to the incapacity of the public sector to offer them acceptable professional perspectives or, worse, to regularly pay them their contractual salaries.
- Entrenching corruption: Local content enables chiefs, politicians, businessmen, and businessmen-cum-politicians or politicians-cum-chiefs to accumulate more financial capital and control rent (Geenen 2019). In return, the extractive companies may use it as an opportunity for policy or State capture (Gatune 2020). One very sad example of this was the Mobutu era in the Democratic Republic of the Congo and the fate of the State-owned mining company, GECAMINES (World Bank 2007).
- Income reduction: Highly prescriptive local content requirements can have a negative impact on companies' profitability (Geneen 2019).
- Entrenched exclusion: Dziwornu (2015) finds that medium- and large-scale Ghanaian firms benefit from localization policies at the expense of new and small businesses, which continue to face multiple barriers.

In the United Republic of Tanzania, local content regulations that require parties who are supplying goods and services to the relevant parties to incorporate a company in the country, and to give 20 per cent of their equity to domestic companies has created significant problems owing to the fact that the United Republic of Tanzania does not manufacture many of the goods required in mining operations and there was a shortfall of Indigenous-run companies with the required capital to effectively enter a joint venture with established suppliers. The result was that mining companies found themselves in a difficult position as they were unable to source goods from many of their current suppliers without potentially being in breach of the law and their mining licences (Ngocho and Magai 2020).

A review of local content efforts shows mixed results (Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development 2018). One country's success cannot be easily translated to another country because of differing resource endowments, skill sets, infrastructure assets and challenges, and investment environments. Great care is thus needed to craft successful local content policies. To support countries in local content policy design and implementation, the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development has produced guidance for countries on the choice and conditions for local content policies and case study examples (Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development 2018).

Looking ahead, new local content opportunities may arise, especially in such sectors as construction (given a suitably qualified workforce), as mining companies increasingly seek to transition to locally produced renewable energy. For example, the "FutureSmart Mining strategy of Anglo American is to overhaul and modernize operations to achieve carbon neutrality by 2040. The company has recently introduced a green hydrogen-powered mining truck (Cuthrell 2022). In Mozambique, Syrah Resources plans to install a 11.25-MWp solar farm with an 8.5-MW/MWh battery energy storage system at its Balama graphite operation in Mozambique (Djunisic 2022). In line with these examples, Toledano et. al. (2021) note that there is some evidence supporting a high localization potential in Africa for solar photovoltaic and wind energy value chains, given the right conditions and to fill the existing knowledge gaps. The examples illustrate how the green energy transition provides an opportunity for local content, but it requires significant development in local capacity to offer the solutions as in both cases the green energy solutions are provided by companies based in Asia, Europe and the United States of America.

There is also much debate on the local value addition to lithium mining in South America. There were calls from the scientific communities and the population to escalate their countries in the global lithium value chain, e.g. through the domestic production of electric vehicle battery chemicals, components and assembling facilities (see below for references), to which governments responded by promoting research and development efforts for domestic battery production (Dorn and Gundermann 2022). However, no considerable facility for lithium processing has been opened so far and no concrete steps have been taken towards commercial production.

3.2.3 Driving technology adoption

Lin and Chang (2009) argue that the first step towards improving a country's technological capability is to increase the adoption of more sophisticated technologies that have been developed elsewhere. If the mining industry can bring new technologies that have broad-based application in other sectors, such as information and communications technologies, it can thus help to drive transitions. This is happening, for example in Rwanda, where LUNA is seeking to build a blockchain solution to improve the traceability of tin (Mining.com 2020), while in South Africa, Sibanye-Stillwater[45] has built a digital twin of a mock mine in collaboration with the University of Witwatersrand to help to improve the efficiency and safety of its mines (Gatune and Cloete 2022).

Mining services companies are also at the forefront of developing new industries. For example, one mining company is deploying a service-based business model where companies pay for use of the machines rather than owning them (Gatune and Cloete, 2022). Indeed, mining companies have the potential to drive the adoption of new technologies, management and business models, for example repositioning themselves as material providers, combining mining and recycling (urban mining). This offers the potential for a transition to more circular economies (Gatune and Cloete 2022; Dietsche 2018).

45 DigiMine - Wits University

3.2.4 Employment, infrastructure and urbanization

Mining companies need to work harmoniously with and in the communities where they operate to secure their sustainable development licence to operate. Otto (2018) points out that there is a history of mines contributing to community development in ways ranging from building schools and health clinics, and providing financing and training for local enterprises, to supporting local sourcing of goods, services and employees. However, when conventional corporate social responsibility efforts have not included the communities around mining in their design, those communities may remain largely unsatisfied with the benefits coming from mines (Otto 2018).

While mining companies may construct social and economic infrastructure directly related to their mines and employees (e.g. housing, utilities), mining activities also tend to drive urbanization more broadly (Bryceson and MacKinnon 2012), which may take place without the construction of the concomitant local capacity (financial and human) to cope with rapid growth. The result is that mining may create uncontrolled settlements lacking services and plagued by crime and other social challenges (Mondoloka 2018). All the same, communities do benefit from infrastructure that comes with the mines. An evaluation of Chinese mining activities in Africa finds that populations living close to Chinese mining areas have access to better infrastructure, such as paved roads or piped water, than areas further away (Vella 2018[46]).

Employment is perhaps one of the main social benefits of mining activities. However, large-scale mining tends to be capital-intensive, providing relatively few jobs. These jobs are high-skilled and consequently inaccessible to many locals. On the other hand, as pointed out in Chapter 7, artisanal and small-scale mining generates a lot of employment that can translate into local economic benefits (see box 3.1). For example, artisanal mining of tin, tungsten and tantalum in Rwanda was estimated to contribute approximately US$39.5 million in the form of expenditures to the local economies through the miners' income spent on local goods and services, education, health care, acquisition of assets (e.g. land, livestock) and investment in small enterprises, which can have a significant impact on the affected communities (Pact Global UK and Alliance for Responsible Mining 2018). However, the scope for artisanal mining in transition minerals is limited. Artisanal methods are used to mine tin (Indonesia and Rwanda), chromium (Rwanda), cobalt and coltan (Democratic Republic of the Congo), lithium (Zimbabwe) and copper (Peru and the Democratic Republic of the Congo).

3.2.5 Land rights and displacement

The social cost of mining comes mainly from the disruption caused by forcing populations to relocate, abuses of human rights and conflicts. Conflicts (see also Chapter 5) can have several causes: disruption of lifestyle and livelihoods; loss of rights to land and clean water; pollution and health concerns; and a lack of representation (Andrews *et al*. 2017; Conde 2017). Conflicts may also arise between artisanal miners themselves in competition for minerals, or between them and medium-sized companies.

The debates on local and Indigenous people's rights to land are focused on consent, appropriation processes and the distribution of benefits (Tarras-Wahlberg and Southalan 2022; Owen *et al*. 2023). Together with mining regulations, these rights are complex. There are numerous reported cases of land rights being overridden by the mining industry and the local authorities, resulting in severe conflicts (Hilson 2002; Conde 2017). Land rights are regulated in a range of ways, ranging from human rights and customary rights systems to property rights laws. At the United Nations level, the Food and Agriculture Organization (FAO) and the Committee on World Food Security have produced Voluntary Guidelines on Land Tenure,47 a legal document that has found wide dissemination and is now referenced by human rights bodies and courts in many countries while interpreting binding law.

46 https://www.mining-technology.com/author/heidi-vellanridigital-com/.

47 https://www.fao.org/3/i2801e/i2801e.pdf.

As mining generates significant land use changes, protecting local and Indigenous people's rights is particularly important in these processes, as well as in cases where States go for expropriation. In such cases, a clear public interest must be given, transparent procedures must be followed and compensation must be meaningful. It is important to respect these procedures to ensure legitimacy, reach an appropriate and socially sound design for the project (often there may be a need to redesign the project or have an impact on a smaller area, for example) and avoid future conflict. Legitimizing procedures must not be disrespected, even given the urgency of extraction of transition minerals. They are a key part of the framework to increase trust and legitimacy, potentially also uncovering+, which may incentivize sustainable consumption and a more circular economy.

Owen *et al.* (2023) show that over 50 per cent of occurrences of transition minerals overlap with the lands of Indigenous and peasant peoples. Under international and national constitutional law, the territories of Indigenous communities are strictly protected, and communities insist on their rights to enact prior and informed consent if access to land is required. This necessitates time, transparency and real engagement to consult in a meaningful way in order to ensure legitimacy. Respecting these rights is especially important, given that Indigenous communities also tend to be custodians of high value ecosystems. It also implies that proposals to mine in such lands can be rejected, a decision that needs to be respected. There are many reports of human rights violations of workers and the prevalence of other issues that cause conflict in the Democratic Republic of the Congo and mines around Africa (Human Rights Watch 2011). For instance, cobalt mining in the Democratic Republic of the Congo highlights important and very complex sustainability issues, including working conditions often characterized by widespread exploitation and labour rights abuses, including child labour in artisanal mines and negative environmental impacts, with local populations having very limited economic alternatives to engaging in such activities (Amnesty International 2016; Baumann-Pauly 2023). Many workers do not earn a living wage, have little or no health provision and far too often are subjected to excessive working hours, unsafe working conditions, degrading treatment, discrimination and racism. As an example of rights violations, the Ghana Manganese Mining Company has been accused of the unlawful demolition of houses and farmlands, including cash crops without paying due compensation (Gyebi 2020).

Mining also causes social disruption through an influx of immigrants. For example, the rise in Chinese investment in copper mining in Zambia has seen a huge rise in the number of Chinese migrants, many of whom arrive as employees of the mining companies, but later venture into small-scale trading, displacing local people from jobs (Vella 2018).

Conflict can also arise from competition to capture mineral resources. High-value minerals that can be easily mined pose the greatest threat. Tin, tungsten, tantalum and gold are particularly prone to driving conflict (IRP 2020a). These minerals have largely been responsible for the ongoing conflicts in the Great Lakes region. As these minerals have high value and are artisanally mined, controlling a particular location and forcing the people there to mine is sometimes done with force. It is estimated that today close to 120 armed groups operate in the east of the Democratic Republic of the Congo and survive by not only generating income mainly from extraction of natural resources, but also from roadblocks, kidnapping for ransom and illegal taxation (Matthysen and Gobbers 2022).

Another important issue, from a social perspective, is that mining activities tend to be temporary, rarely lasting more than a few decades. This means that the benefits arising from mining activities must be used, as far as possible, to fund activities that can generate long-term returns lasting well beyond the closure of mining activities, such as education, health, sustainable infrastructure and diversification activities.

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Box 3.1: Artisanal and small-scale mining (ASM)

Artisanal mining has been credited with creating many rural jobs and helping to diversify income, thus reducing vulnerability. For this reason, many have called for increased support of this sector owing to these social benefits (see IRP 2020a). Though artisanal mining seems to have more direct social benefits, it also poses a range of significant environmental and social challenges (IRP 2020a). Some of the challenges in relation to sustainability metals in Africa include:

- Artisanal mining has a poor safety record.
- The ambivalent nature of artisanal mining regulation also creates room for illegality in the sector. Illegal gangs emerge to contest control of the sector, and conflict between rival gangs can lead to deaths. For example, deaths have been reported in the struggle for control of artisanal chrome mines in South Africa (Trenchard 2023).
- The artisanal and small-scale mining sector is prone to conflict as many of the miners operate outside the law for various reasons (United Nations, Economic Commission for Africa 2012), especially regarding the so-called conflict minerals (gold, tin, tantalum and tungsten). Owing to this concern, the trade in these minerals has been subjected to mandatory due diligence obligations to assess that imports are not from conflict areas or operations controlled by warlords in the United States of America since 2010 (Dodd-Frank Act, United States Securities and Exchange Commission) and in the European Union since 2017 (European Commission 2023). Artisanal gold production is quite widespread in Sub-Saharan Africa, while artisanal and small-scale mining for tantalum and tin are particularly concentrated in the east of the Democratic Republic of the Congo. (Pact Global UK and Alliance for Responsible Mining 2018).
- Artisanal mining also intends to disrupt agriculture. Artisanal miners take over agricultural land and leave behind destroyed landscapes that create problems for those engaged in agriculture. For example, in Zimbabwe chrome mining has left huge pits that have caused loss of livestock for farmers (The Standard 2022).

The financing of artisanal and small-scale mining is discussed in Chapter 7.


Pierre-Yves Babelon © Shutterstock

3.2.6 Conclusions

Capturing the financial benefits of mining will always be contentious. Government clamour for a greater share of resource revenues may chase away investors. Dietsche (2017) argues that for extractives-led development agenda to succeed, mining must lead to increasing productive knowledge and technological capabilities relevant to other sectors. In principle, public authorities have a key role to play in in this process, by reducing transaction costs and addressing structural market failures. Industrial policy defined in its widest sense lies at the heart of that role.

Ensuring a balance between national development aspirations, the needs of mining companies and the needs of local communities is difficult for policymakers. It is still a work in progress. These issues are going to be brought into sharper focus as a new resource boom emerges in the wake of the shift to a green economy.

3.3 WOMEN IN MINING

3.3.1 Introduction

Mining plays a vital role in socioeconomic development as it makes significant contributions to national economies and the Sustainable Development Goals. The potential for mining to help to achieve the Sustainable Development Goals is well known and well documented (United Nations Development Programme [UNDP] nd). There is also some evidence that women play a role as agents of change, especially in respect of their role in sustainable and equitable natural resource management for meeting human needs (Thomas-Slayter and Sodikoff 2001).

The mining sector is, however, characterized by a low level of participation of women at all levels (Monteiro *et al*. 2019). In view of the role of the sector in the economy, it would be beneficial for the sector to increase women's participation, as part of mobilizing their agency in advancing sustainable development. Women in Mining48 acts to promote the participation of women in mining. In South Africa, the available data show that women represent just 14 per cent of the mining labour force out of 450,000 employees, as well as just 16 per cent of top management and 17 per cent of senior management (Louw 2022). Globally, women constitute about 10 per cent of the employees in large-scale operations and only 7.9 per cent of people on the board of directors in the top 500 mining companies (United Nations Entity for Gender Equality and the Empowerment of Women [UN-Women] 2016). Women fare much better in artisanal and small-scale mining, which is highly labour-intensive.49,50 (Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development 2018, cited in IRP 2020a). A recent report by the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (2023) notes that there is a dearth of consistent, detailed and comparable datasets and in-depth analysis regarding the status of employment, by gender, in the large-scale mining sector. Additionally, there is insufficient systemic assessment of women's direct participation in mining operations by occupation, level of education and skills by country, l*et alo*ne their working conditions and salaries. This lack of information on gender equality in mining employment is even more pronounced when data are sought regarding indirect employment along the mining supply chain.

While women are underrepresented in the mining industry, they also earn less for the same job. In Australia, an important mining country, the base salary for a full-time female worker in the mining industry was 10.4 per cent lower than that of her male counterparts in 2020. In Rwanda, women in artisanal and small-scale mining earn 25–30 per cent less than men for the same activities (International Labour Organization [ILO] 2021). Interestingly, in South Africa, women in mining are more qualified than their male counterparts, with 84 per cent of women in mining being more qualified than their bosses (Louw 2022).

The World Bank (2018), referring to the global experience, has shown that the impact of extractive industries is gendered, with men benefiting more from the development of extractive resources than women. This is mainly because men capture more of the direct, employment-related benefits of resource extraction while women bear a disproportionate share of the negative impact, including loss of land, displacement and resulting community fragmentation, and environmental pollution (Eftimie, Heller and Strongman 2009a, cited in World Bank 2018). The United Nations Entity for Gender Equality and the Empowerment of Women (UN-Women) (2016) points that there is a broad consensus in all major studies that if policies and legal frameworks that govern and guide extractive industry activities are gender-blind, women will benefit much less than men.

48 https://www.womeninmining.org.uk/about/.

49 The World Bank estimates that artisanal and small-scale mining employs at least 44.75 million people worldwide and is a source of income for at least a further 134 million people (World Bank 2020a).

50 In Madagascar, Mali and Zimbabwe they make up 50 per cent, while in Guinea they make up 74 per cent of workers in artisanal and small-scale mining (IRP 2020a).

Gender equality in mining can have positive impacts that should motivate both companies and governments to address it. According to Women in Mining UK companies' profit margins are higher for mining companies when women are on the board of directors (Women in Mining (UK) and PWC 2015). Louw (2022) points out that the diversity that women could bring to the sector would make them immensely valuable, boost innovation and contribute to the growth and ongoing relevance of the industry. The World Bank (2015) has found that the inclusion of women has positive long-term effects on the health and education of the families and communities as, in many cultures, women tend to devote most of their income to the food, shelter and education of their families.

A recent study by the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (2023) on women in large-scale mining in 12 countries (Argentina, Australia, Brazil, Canada, Chile, Colombia, Ghana, Mongolia, Peru, South Africa, Sweden and Zambia) finds that although, on average, the share of women's participation in the large-scale mining workforce is gradually increasing, there are several issues that must be highlighted including:

- Women are underrepresented in technical positions and overrepresented in clerical positions;
- Structural barriers, biases, and discriminatory practices and working conditions impeding women's empowerment still largely prevail and need to be concurrently and duly addressed;
- Women are more likely to be laid off during crises, facing the vulnerabilities in sustaining their jobs during economic downturns, downfalls in sectoral performance and global crises;
- The fly-in fly-out model for mines located in remote areas, which is a challenge for women trying to balance responsibilities at home and at work;
- Women lack mining-specific skills and education;
- Women quit large-scale mining at a younger age; and
- The gender pay gap persists in the mining workforce.

3.3.2 Barriers to equal participation

Image of "hypermasculinity"

Mining is consistently characterized in literature and the collective imagination as inherently masculine, demanding strength and courage, as well as resilience to face danger and survival in difficult situations (Benya 2017). Over time, mine culture has been moulded in the image and likeness of hypermasculinity, not only by the sheer number of men that work in mines, but also by their constructed brotherhood of solidarity and sense of belonging (Lahiri-Dutt 2011). Not only was the presence of women in mines perceived as unnatural, but women became feared by many through the dissemination of myths and stories of their presence being the cause of accidents (Perks and Schulz 2020). Such elaborate justifications and discourse – consisting mainly of superstitions, traditions and prejudices – has ultimately normalized women's exclusion from mining.

Culture and traditions

In highly patriarchal communities, ownership of land by women is limited. This is key for artisanal and small-scale mining (ASM) as access to land is central where such activities are regulated. While the share of women working in ASM in the United Republic of Tanzania ranges from 27 per cent to 34 per cent, it is estimated that only 10 per cent of the total licence holders are women (UN-Women, 2016). This means that women in ASM especially must depend on men to access land for such mining. In Madagascar, for example, women engage in temporary marriages with men to secure access to land (Brycesson, Jonsonn and Verbrugee 2014, and Lawson 2016, cited in IRP 2020a).

Even when women have access to ASM, they are affected by cultural attitudes. The pay gap in Rwanda for women in ASM has been attributed to women's limited access to big buyers and markets, as well as to their reliance on middlemen to make up for their lack of bargaining power owing to cultural norms and attitudes (ILO 2021).

Lack of information

Women may have little access to information on their position or rights, or avenues for increasing their influence. A study of women in ASM in northern Ghana found that women were not aware of programmes that could assist them and were disadvantaged in accessing information (Women in Mining Ghana 2020)

3.3.3 Impact of mining on women

While there are significant barriers to the participation of women in mining activities and benefiting from them, they are also disproportionately impacted by the negative impacts of mining activities.

Gender-based violence

The hyper-masculinity of the mining culture leads to certain behaviours, which means that gender-based violence is prevalent in the mining sector (Monteiro *et al*. 2019; Deutsche Gesellschaft für Internationale Zusammenarbeit 2020). This is further reinforced by male solidarity, as well as organizational tolerance of unacceptable behaviour (Benya 2017). The remoteness and relative isolation of mining sites make women more vulnerable to such violence. Women working in mines consistently report unwelcome physical, verbal and non-verbal behaviour that affects their chances of success and advancement in the workplace (Botha 2016). In Canada, a 2017 survey of 540 employees working in management positions within mining showed that 47 per cent of them had experienced harassment (Peltier-Huntley 2019). In its social audit baseline report on South Africa, ActionAid (2018) found that 40 per cent of the women interviewed indicated that jobs in the mining sector were only available through sexual favours.

The ASM sector, with its informality and elements of illegality, is perhaps even more impacted. For example, in the case of ASM, a study from the Deutsche Gesellschaft für Internationale Zusammenarbeit (2020) points out that 74 per cent of women in the east of the Democratic Republic of the Congo have been subjected to sexual violence. Prostitution and human trafficking are also quite rife in the ASM sector. Artisanal and small-scale mining tends to attract huge numbers of immigrants and illegality. The immigration tends to include sex workers, many of whom are trafficked. For example, in Ghana, some of the Chinese miners in an irregular migration situation have also been trafficking Chinese sex workers to Ghana (Aido 2016).

In cases where women have been able to obtain paid employment in mining, some of them have experienced increased gender-based violence at home or in the workplace owing to shifts in gender roles and power structures (The Advocates for Human Rights 2019).

Health

ASM exposes miners to chemical poisoning, most particularly because of mercury use for gold recovery. This is a major hazard, with long-term consequences for the environment and health. Women tend to be more vulnerable to mercury poisoning owing to lower levels of awareness. For example, a study in northern Ghana found that 100 per cent of the women interviewed had no prior knowledge of the extent of the dangers posed by mercury (Women in Mining Ghana 2020).

A lack of maternity, childcare and sanitation facilities also means that women in ASM have their toddlers on site while working, exposing them to any related hazards (Women in Mining Ghana 2020). This makes the children vulnerable to mining-related health challenges from a very early age.

Involuntary resettlement and environmental damage

Mining activities cause involuntary resettlement and environmental damage. The loss of land and water that local populations rely on to grow food will typically have a greater impact on the women and children of a community when they are forced to move by an extractive project; this is because they frequently take greater responsibility for subsistence farming. While men are also affected by displacement and environmental damage, they often have better access to alternative incomes and the ability to move to other locations to seek alternative, and often better, opportunities (Macdonald 2018).

Social disruption

The rapid modernization and monetization of the economy and the injection of a large, mostly male population may lead to social disruption. The injection of mine workers also attracts sex workers, drug dealers and human traffickers, among other criminal activities. This huge influx can potentially destabilize social relations, exacerbate existing gender inequalities and increase incidents of crime, alcoholism, drug abuse, domestic violence, prostitution, trafficking and sexual exploitation, and sexually transmitted diseases in local communities. Women in the community tend to be more affected by these social disruptions (UNDP 2016).

3.3.4 Approaches to inclusion

Enhanced regulatory standards

Governments should introduce minimum legal standards and monitor their implementation for the industry to ensure fit-for-purpose personal protective equipment, safe and separate sanitation facilities, and gender-appropriate health services for women workers. Governments should require the private sector to translate the minimum legal standards into corporate policies. They should also promote the employment of female public officers in key positions related to mining and encourage gender-equal participation and representation in their delegations at events and platforms (Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development 2023).

Internal company policies

Mining companies have a critical role to play in advancing gender equality, not only in their own operations, but also in their supply chains and in nearby mining communities. This would involve actively recognizing women's rights to property and resources; including women as stakeholders in land acquisition, resettlement and consultation processes; addressing vulnerability and gender-based violence in the community; and facilitating inclusive access to jobs and economic opportunities (International Council on Mining and Metals nd). Mining companies can address unconscious gender bias by proactively assessing it in their operations, measuring its impact on workers and taking action to prevent gender bias through recruitment and talent management, training, project assignments and selection for the leadership pipeline (ILO 2021). Mining companies can also increase their support for women-led small and medium-sized enterprises (SMEs) in mining communities. Indeed, they can leverage their buying power and supply chains to promote gender equality by using gender-responsive procurement to support SMEs owned and led by women (ILO 2021). This might involve looking for opportunities in upstream and downstream activities.

Companies need to implement systems for reporting instances of harassment and exploitation for women, as well as for other employees. Gender policy should be required for all companies in extractive industries (UN Women 2016)

Mining companies have made commitments to address gender inequality, as pointed out by Smith (2023). For example:

- BHP wants to achieve gender parity by 2025 (women currently account for 29.8 per cent of employees).
- In 2021, Newmont Mining set a goal of parity in its copper mine in Ghana.
- Teck Resources Ltd. has a goal of 50 per cent participation at its Quebrada copper mine project in Chile.
- Four South African mining companies (Kumba, Anglo-American Plc., Exxaro Resources and Merafe Resources) are led by women.

Despite such examples, women constitute only 14.9 per cent of chief executive officers and hold only 18.1 per cent of board positions.[51]

There are also initiatives at the industry level. For example, the Mining Council of South Africa has created gender-based violence centres in mining communities to help to change the culture and reduce gender-based violence in the community as a whole and not just in mining companies (Smith 2023).

51 https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/despite-diversification-efforts-fewer-than-1-in-5-mining-leaders-are-women-59101897.

However, some have claimed that industry efforts tend to be cosmetic changes around the margins and the objective of frequent industry pronouncements of commitment to gender equality is really to avoid regulation or external intervention (Macdonald 2018). In these regards, the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (2023) recommends that companies should publish their gender performance in their sustainability reports, with breakdowns of age, ethnicity, indigeneity, educational attainment, occupation and pay gaps (including gender breakdown of new hires, promotions, senior leadership, boards and board committees) and the use of International Labour Organization (ILO) or other appropriate international category standards for comparability.

Digitization and automation

Automation and remote operations are opening up new opportunities for women by removing physical strength as part of the requirements of mining work. One area that epitomizes this is drilling operations. Being a drill rig operator traditionally required considerable strength to oversee and load the drill rods and heavy equipment, making it a difficult environment for women to make their mark (Macnamara 2022). The modernization of drilling is changing this. South African drill rig operator Rosond has supplied the Kumba iron ore mine of Anglo American with 28 state-of-the-art drill rigs. The Rosond drill rigs automate most of the heavy duty and dangerous manual tasks, such as managing drill rods, thus opening the operations of these machines to female operators. Rosond has been fully operational for two years at Kumba and currently has just under 30 women on site, with two all-female crews in diamond drilling and one all-female team in grade control (Macnamara 2022).

Indeed, mining is changing in fundamental ways through automation and digitization. The world's first fully automated mine was launched in Mali in 2019. Equipped with driverless trucks and robotic drills, the mine operates around the clock and is up to 30 per cent more efficient than conventional mining operations (ILO 2021).

Automation and digitization will create opportunities in digital jobs that are not tied to traditional perceptions of gender roles in mining, giving women a better chance. Automation is, however, a double-edged sword. It will kill jobs in mining, but this will mostly affect men as they dominate the sector in terms of employment. Cosbey *et al*. (2016) point out that automation can drive many large-scale mine workers to artisanal and small-scale mining. This can create new competition for women in the sector where they have fared better.

Gender in local content policies

In general, the highly mechanized nature of mining means that few jobs are created directly. However, mining companies have tremendous impacts on the economy. ILO (2021) points out that for mining companies, most of the opportunities for women and men in mining are created through local procurement, which creates employment spillovers through opportunities for SMEs to service the mines and manufacture inputs.[52] The Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (2023) shows that the top five countries with the highest number of women participating in large scale mining are Sweden (25 per cent), followed by Canada (19 per cent), Ghana (18 per cent), Mongolia (16 per cent) and Australia (15 per cent).

Governments in Africa are increasingly adopting local content laws to require greater inclusion of local people and firms in the activities of mining companies. For local content laws to be effective in addressing gender imbalances in mining, the laws must also be gender-sensitive. However, examining the local content laws, it is not clear that they are gender-sensitive. For example, the Ghanaian local content law is silent on gender inclusion. It requires mining companies to employ Ghanaians through limitations on the recruitment of expatriates to not more than 6 per cent of the workforce. However, no mention is made of gender balance in the recruitments of Ghanaians. Another key provision is that local companies should be given preference in the award of tenders. In this context, local participation is defined to include ownership or managerial positions occupied by Ghanaians. Again, there is no requirement related to the structure of employment or ownership of local companies giving preference to women (Gatune 2020).

52 Opportunities are also generated in the local community through satellite economic activities, such as transport, hotels, restaurants and shops. The deeper the linkages between large-scale mines and SMEs in the community and at the national level, the greater the impact will be on indirect and induced jobs (Ramdoo 2020).

The South African local content policy is very explicit on gender inclusion. The South African Mining Charter states that a minimum of 70 per cent of total procurement expenditure for mining goods must be for South African manufactured goods. In turn, 5 per cent of that amount must be spent on goods produced by companies owned and controlled by women or young people. Similarly, a minimum of 80 per cent of total expenditure on services must be sourced from companies based in South Africa, 15 per cent of which must be spent on services supplied by companies owned and controlled by women (RoSA 2018, cited in ILO 2020).

Local content policies also need to be accompanied by gender-sensitive supplier development programmes. In this regard, UN-Women (2016) points to the need to empower women through training on negotiation skills, and implementing quotas in tendering for female suppliers and service providers.

3.3.5 Responsible mining initiatives

Beyond industry and government action, civil society can also play a crucial role in influencing mining company policies. There are now many indexes rating companies on responsible mining practices.[53] The 2020 Responsible Mining Index report on 180 mine sites and the policies and practices of 38 large mining companies on ESG issues indicates that "only a small minority of companies take proactive measures to include women in their local procurement support measures, and without such measures, women will most likely be excluded" (Responsible Mining Foundation 2020). Such indexes can perform two roles; they can jolt companies to act, as a low ranking can lead to reputational damage, but more crucially they can highlight what companies are losing by not having more inclusive policies.

The International Finance Corporation, which finances many mining projects, has launched a toolkit of actions and strategies for extractive companies to increase opportunities for women. It has included equal opportunity for both sexes as one of the requirements of its performance standards (International Finance Corporation 2018).

Organizing women

Women, especially those involved in artisanal and small-scale mining, can better benefit from mining by organizing themselves as cooperatives. This can raise their potential to satisfy technical and financial requirements for productive mining (ILO 2021), and allow other partners to provide support, especially in upgrading artisanal and small-scale mining. The World Bank (2020, cited in ILO 2021) points to a case in Nigeria, where the women who formed cooperatives were able to have access to a World Bank-financed grant to purchase equipment. A similar approach has been advocated to support women miners in northern Ghana (Women in Mining Ghana 2020). Childcare cooperatives, which take care of children for an affordable fee while women are working in the mines, can accomplish this goal. Cooperatives have proven to be a particularly powerful way of advancing gender equality (ILO 2021).

Creativity in providing women with information

One of the key challenges affecting women is a lack of information. There are many services available that can help them, but many women are not aware of them. They are not aware of the health and environmental impacts (Women in Mining Ghana 2020) of their work in mining. Creative ways of reaching them are needed to inform them of these issues. Places where women seek various services can be locations for engagement. The report on women in mining in northern Ghana points out that the survey found that women frequent pharmacies, clinics and schools (where they have children of school-going age), which are important potential outlets for giving out information (Women in Mining Ghana 2020).

Better data collection

The absence of gender-disaggregated data is a challenge to designing interventions and for monitoring and evaluation. Better data collection is needed. A recent report (Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development 2023) provides such data.

53 The *Mineral Resource Governance in the 21st Century* report (IRP 2020a) details 89 initiatives that assess companies on various aspects of responsible mining.

Change the perception of women in mining

Nationwide advocacy campaigns are needed to promote changes in the perception of which professions are considered appropriate for each gender. Laplonge (2014), cited in Macdonald (2018), argues that the only way to truly bring about cultural change in the extractives sector that may eventually lead to sexual equality in employment is to challenge both male and female gender stereotypes and the associated sets of behaviour.

The change in perception should also be accompanied by efforts to equip women with the requisite skills required in the sector. Indeed, while digitization can present opportunities for women, the digital divide between men and women will need to be overcome. Science, technology, engineering, and mathematics (STEM) skills will also become increasingly important. The World Bank (2018) points out that women's underrepresentation in professional positions requiring higher education is intricately linked to their low levels of representation among students of STEM subjects.[54]

In this regard, UN-Women (2016) proposes the promotion of women and girls from an early age to enrol in subjects traditionally considered appropriate for men, the provision of scholarship quotas for scholarships for women, the earmarking of budgets and services for women, and the encouragement of women to work in the sector through tax relief.

3.3.6 Conclusions

Women are not receiving equal benefits from the global development of mineral resources, even as they shoulder a greater burden of the negative impacts. Women are underrepresented in employment in the sector and earn lower pay for the same positions, even though, in some cases, they hold higher academic qualifications. The perception that mining is a male domain and a culture of excluding women are entrenched and must be addressed.

Traditional cultures where land ownership is restricted to men means that women are excluded from ownership of artisanal and small-scale mines. A lack of gender-sensitive sanitary and other facilities further excludes women.

The perception of mining jobs as masculine means that women who get into mining are exposed to a toxic masculine culture and at times to gender violence. Beyond the mining workplace, mining activities come with negative spillovers, including social disruption owing to the influx of a large male population, who in turn attract other people including sex workers. The social disruption tends to have a greater impact on women.

The gender imbalance can be addressed in several ways:

- Salaries should be gender neutral and relate only to the job position and employee performance.
- Mining companies can address gender bias by proactively assessing it in their operations, measuring its impact on workers and taking action to prevent it through recruitment and talent management, training, project assignments and selection for the leadership pipeline. They can also favour suppliers who practice gender inclusivity and women-owned businesses.
- Governments can enact local content laws that make provision for the inclusion of women in employment in mining companies and in suppliers for mining companies.
- Digitalization and automation in mining mean that less brawn is required in mining operations. In addition, digital jobs are gender-neutral. However, capturing this opportunity will require closing the digital gap between men and women.
- Perceptions regarding mining need to change across both genders through education and advocacy. Concurrently, empowering women to take opportunities in mining jobs will be key, such as by encouraging more girls to pursue STEM subjects.
- Ultimately, the aim should not be simply to increase numbers and comply with legislation, but to develop career paths for women within the mining sector, with initiatives such as the mentorship of women by women.

54 United Nations Educational, Scientific and Cultural Organization (2017) points out that women represent 35 per cent of all students enrolled in STEM-related fields of study in higher education.

3.4 MINING AND THE ENVIRONMENT

3.4.1 Introduction

The use of minerals and metals in the production of an enormous range of products and services is also a source of multiple potential, mostly harmful impacts on the environment at various levels, from global to local. Environmental impacts include qualitative and quantitative impacts on air, biodiversity, soil and water, as well as the generation of huge quantities of solid waste from mining, ore processing and metallurgical and metal-refining activities (Franks *et al*. 2021).

Greenhouse gas emissions from mineral sourcing and processing are the most prominent global environmental impact, while waste and many chemical and particulate matter emissions generate locally significant impacts on water, soil and biodiversity. Despite technical and technological progress in environmental management, harmless methods of raw material extraction have not yet been developed (Pietrzyk-Sokulska *et al*. 2015).

Environmental pressures caused by mining activities can be expected to increase globally in the future owing to growing demands for minerals (United Nations Environment Programme [UNEP] 2013; Northey *et al*. 2014; Maus *et al*. 2022). The global increase in the demands for metals thus gives rise to the threat of increasing natural habitat loss (Sonter *et al*. 2017) and the pollution of water bodies (Armah *et al*. 2010; Zhou *et al*. 2020). Moreover, mining accidents have resulted in significant unpredicted impacts, and have further increased the negative attitudes towards mining among communities and the public (Cunningham 2005; Andrews *et al*. 2017; Sairinen 2017). Indeed, one of the challenges in assessing the impacts of mining is that the magnitude and severity of the environmental impacts must always be considered alongside risks of accidents and the accumulation of poorly identified impacts. Local-scale mining impacts on biodiversity and environment may also last over 100 years (Beane *et al*. 2016).

While the environmental impacts of mining are a serious governance challenge, minerals and metals-based products and services are also a tool for mitigating some of these impacts. For example, as noted in earlier chapters, the solutions for low-carbon energy designed to tackle global climate change are often highly dependent on minerals. The possible impacts of mining on the environment are reviewed here with respect to greenhouse gas emissions, water use, waste generation (including tailings), land use, degradation of soil and water quality, and biodiversity.

The simplified diagram in figure 3.1 presents the typical production flow of many metals, involving three major stages shown as red boxes numbered 1 to 3: mining a natural mineral concentration; producing a concentrate from the mined raw ore; and extracting the metal, complemented by refining as necessary. On-site impacts sometimes also take place after the closure of the mine, particularly if the closure is not well managed. (The stages of mining in relation to their financing is discussed in more detail in Chapter 5.)

The governance of impacts relies on environmental baseline data acquisition, impact assessments, management plans and high-standard permitting procedures at the local and national levels, as well as corporate ESG management practices, which connect a local sustainable development licence to operate to global value chains. An understanding of the baseline conditions and the risk of the environmental impacts of mining activities is of paramount importance for their technical management and reduction of the impacts to the minimum level possible.

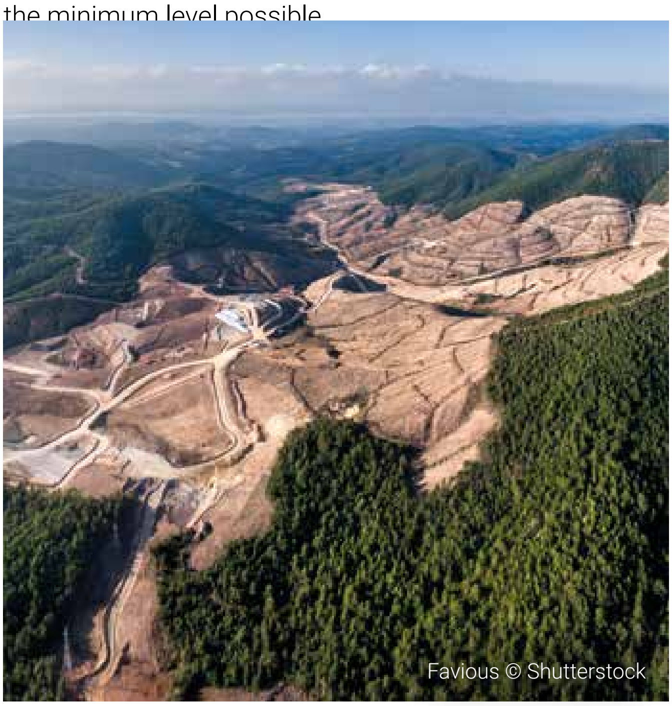
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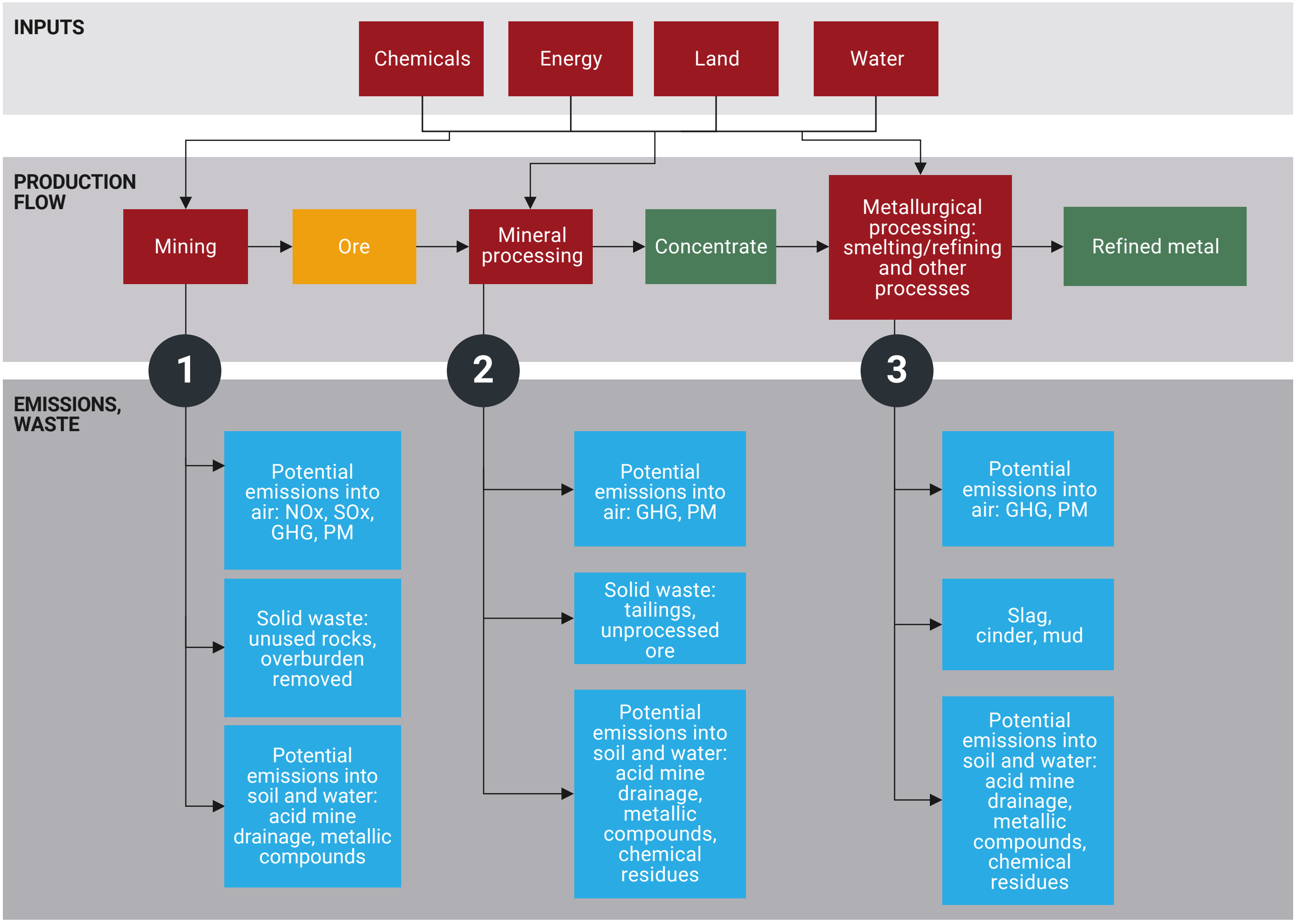
Figure 3.1: A simplified representation of the production flow of metals, with its inputs and related emissions and waste flows



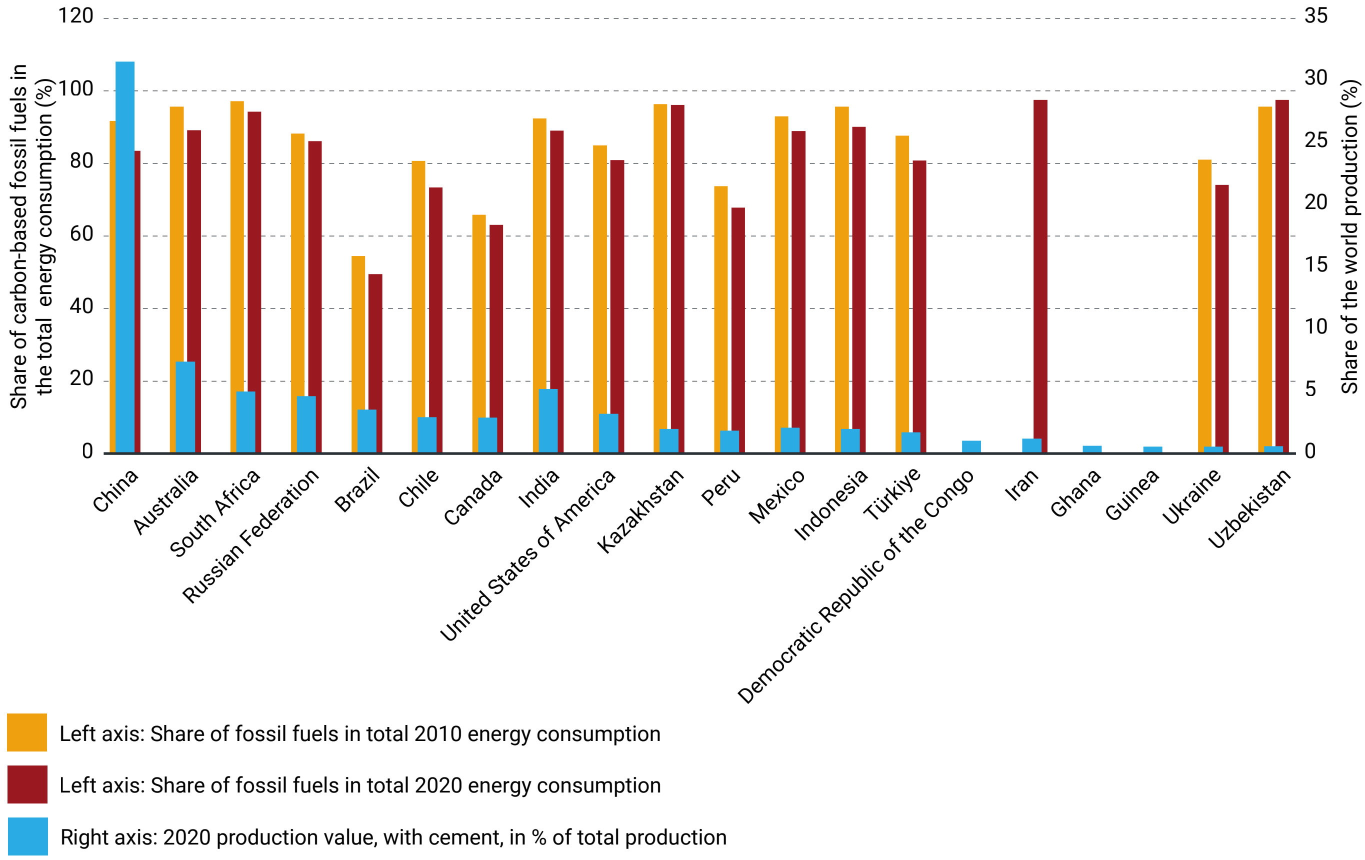
Note: NOx = nitrogen oxides; SOx = sulphur oxides; GHG = greenhouse gases; PM = particulate matter

Source: Authors

3.4.2 Energy consumption and greenhouse gas emissions

The production of minerals and metals (especially steel, aluminium and cement) is a major contributor to global greenhouse gas emissions, estimated to represent 16 per cent (Organization for Economic Cooperation and Development 2019) to 18 per cent (IRP 2020b) of all greenhouse gas emissions. The main reason is that the production of minerals and metals is still based on carbon-based fossil fuels. Figure 3.2 shows an estimate of the share of these fuels in the 2010 and 2020 energy consumption of the world's 20 largest producers of minerals and metals, based on the 2021 Statistical Review of World Energy of BP (2021), with data on the 2020 energy mix for 17 of these countries (no data for the Democratic Republic of the Congo, Ghana or Guinea). On average, in 2020, carbon-based fossil fuels represented 80 per cent of the energy sources used in these countries, with only a few countries (Brazil and Peru) having a somewhat less fossil-based energy production profile owing to their abundant hydropower. On average, the consumption of carbon-based fuels declined from 87 per cent in 2010 to 82 per cent in 2020. However, the consumption of carbon-based fossil fuels significantly increased in some major countries producing minerals and metals during this same period. In the top five countries producing minerals and metals in 2020, representing 53 per cent of the world's production value, carbon-based fossil fuel consumption mostly increased, with only South Africa recording a 3 per cent decrease. The increase was most significant in India (43 per cent) and China (41 per cent), and more moderate in Australia (6 per cent) and the Russian Federation (3 per cent).

Figure 3.2 : The world's 20 largest minerals and metals producing countries, represented by their share of the global production value of non-energy minerals and metals in 2020, including cement (blue bars on the right vertical scale), and by the share of carbon-based fuels in their 2010 and 2020 national energy mixes (left vertical scale, red and yellow bars).



Data sources: Production value: Reichl and Schatz (2022), except for cement: United States Geological Survey (2022); Energy mix data: BP (2021), no data available for the Democratic Republic of the Congo, Ghana, Ukraine and Guinea.

These consumption trends do not bode well for the global transition towards a low-carbon energy or zero-carbon energy world. The huge demand for the minerals and metals needed for this transition may at worst contribute to increasing greenhouse gas emissions, further aggravating sustainability challenges. Decoupling increasing well-being and economic growth from their unsustainable impacts, as advocated by UNEP (2011; 2014), is needed more urgently than ever.

The use of solar and wind power energy coupled with the use of electric heavy machinery offers a major opportunity to the minerals and metals industry and societies to reduce their carbon footprint. However, the high capital cost of mining equipment and the costly management of the intermittent nature of these renewable energy sources are likely to be major hurdles for companies operating on a year-round schedule, wanting to reduce their dependence on carbon-based fossil fuels and their related greenhouse gas emissions. The energy transition in all industries with significant investments in machinery that is not dependent on fossil fuels, including the minerals and metals industry, is likely to progress slowly. For new operations, sustainable energy solutions should be considered from the early planning stage of new projects.

3.4.3 Water use and pollution

The production of some minerals and metals requires large amounts of water (table 3.2, Gunson 2013). The extraction and processing can have significant environmental impacts on waterbodies and groundwater, which can extend to large areas (Ochieng *et al*. 2010; Jain *et al*. 2015; Wolkersdorfer and Mugova 2022). Extreme weather conditions accompanied by climate change can aggravate environmental problems at mines and on processing sites. Water scarcity can be aggravated by droughts and by the excessive extraction of groundwater through boreholes, whereas floods can increase the risk of accidents and uncontrollable discharges to the environment (Green *et al*. 2011; Kossoff *et al*. 2014).

In water-stressed areas, groundwater resources used by the mining industry can be in short supply (Santana *et al*. 2020), Specifically, in areas where groundwater has no or limited natural recharge, mining can drive water scarcity in dramatic ways. Water use to produce minerals and metals can be a source of conflicts in water-stressed areas or in areas with competing water demands, for instance for drinking water supply, sanitation, agriculture, leisure, tourism and biodiversity support. Water scarcity can be a catchment level challenge.

Acid mine drainage can have severe impacts on surface and groundwater, and on soil, as well as on human health (Jacobs *et al*. 2014; Zhang *et al*. 2017; Chen *et al*. 2021), as discussed further in the following sections.

The figures in table 3.2 show large differences in the unitary (m^3 water per metric ton metal contained) water consumption needed to produce the listed metals, with the production of gold requiring much more water than the production of copper, essentially because of the very low grade of gold ores. As water impacts are relatively local or regional, their assessment also needs to be done at the appropriate level. Water use does not necessarily show up as significant in national level water accounts. For example, in Australia, one of the world's most important producers of minerals and metals, mining water use only represented 1.6 per cent of the national primary water consumption in the 2019–2020 fiscal year (Australian Bureau of Statistics 2022). However, the local and regional hydrological impacts can be significant.

The production of minerals and metals can pollute water resources, for instance further to the weathering and oxidation of residual sulphidic or sulphosalt minerals present in the mining waste (Kossoff *et al*. 2014). These pollution impacts are often also associated with the tailings, as the very fine-grained residue of the ore processing can pollute waterbodies and groundwater (Kossoff *et al*. 2014). Pollution is both an operational challenge, with emissions taking place during the lifetime of the mine and after its closure, and a risk management challenge, as accidents can result in irreversible damages. Environmental governance through the permitting or licensing of individual mines often is focused on emissions and assesses them at the mine and along relevant watersheds. Water-related issues are potent drivers of conflicts between minerals and metals producers and local populations. They also often expose the landscape-level impacts of contamination (Budds and Hinojosa 2012).


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Table 3.2 : Water use estimates for the production of selected metals, in m³/metric ton water per metric ton contained metal

Products and related production processes	Ore type	Ore grade	Direct (m^3/t)	Indirect (m^3/t)	Total (m^3/t)	Data sources
Copper cathodes production from ore processing by flotation, followed by pyrometallurgy and refining	Copper Sulfide	0,75% copper (Cu)	91	37	128	a
Copper cathodes production from ore processing by flotation, followed by pyrometallurgy and refining	Copper Oxide	0,75% copper (Cu)	70	198	267	a
Copper concentrates + cathodes production from ore processing by flotation, followed by pyrometallurgy and refining, as well as from solvent extraction fllowed by electrowinning (Hydrometallurgy)	Copper sulfide + oxyde - Chilean 2020 production	0,64% copper (Cu)	96	?		c
Gold produced via the carbon-in-pulp (CIP) process	Gold Non-refractory	3,5 g gold (Au)/t	244 701	69 732	314 433	a
Gold produced via the pressure oxidation + carbon-in-pulp (CIP) process	Gold Refractory	3,5 g gold (Au)/t	284 235	149 112	433 347	a
Nickel, produced via the pyrometallurgical process	Nickel Sulfide	1,3% niquel (Ni)	68	35	102	a
Nickel produced via the high-pressure acid leaching (HPAL) processing roure	Nickel - limonitic ore	1,3% niquel (Ni)	303	1 409	1 712	a
Class I Nickel produced via the high-pressure acid leaching (HPAL) processing roure	Nickel - limonitic ore (laterite deposits)		106	?	?	b
Ferronickel with 27% Ni produced via the pyrometallurgical process, per t vontained Ni	Nickel - saprolitic ore (laterite deposits)		924	?	?	b
Nickel sulphate produced via the high-Pressure Acid Leaching (HPAL) processing route, per tonne nickel sulphate (NiSO4)	sulphidic and imonitic ore from laterite deposits)		80	?	?	b

Sources: a - Northey and Haque, 2013. b - Bonzaier, 2020. c - COCHILCO (2021)

The overall environmental impacts of the production of different metals vary, with the production of copper, gold and platinum being particularly problematic in terms of eco-toxicological impacts (IRP 2019). Mining and mineral treatment approaches depend on the physical and chemical characteristics of the ore, and therefore the composition of wastes generated from mines differs (Falagán *et al*. 2017; Agboola *et al*. 2020). Chemicals, such as flotation agents, are used in beneficiation processes and these chemicals are not usually monitored in waste waters and consequently very little is known about the fate of these chemicals after water is released to nature from water management ponds (Cacciuttolo and Cano 2022).

Environmental impacts depend on the nature and the tonnage of the extracted mineral or ore and the sensitivity of the surrounding environment. However, even low-tonnage unregulated artisanal small-scale mining productions can have severe and long-lasting impacts on water resources and quality, and on human health. These artisanal small-scale mining impacts are mainly caused by using mercury for gold extraction (Markham and Sangermano 2018; Palacios-Torres *et al*. 2018; Macháček 2019; Achina-Obeng and Aram 2022; Gerson *et al*. 2022).

The environmental impacts of artisanal small-scale gold mining are highly significant. This is currently the main global source of highly toxic mercury emissions (Palacios-Torres *et al*. 2018).

However, lithium and copper mines in Chile have also raised concerns about water. In Chile, lithium is mined from underground brine reserves and the extraction of brines is not regulated under the Water Code, but under the Mining Code. The Indigenous communities living nearby blame the depletion of their freshwater and groundwater reserves (as well as associated impacts, such as decreasing agricultural yield and the salination of soil) on the extensive mining of brines (Jerez *et al*. 2021). Copper mining in the Antofagasta region has led to other problems related to freshwater use in mining (Babidge 2016).

Carefully planned and implemented water management can mitigate many of the harmful impacts. For instance, water sourcing can be targeted. Water supply from groundwater should be based on dynamic three-dimensional hydroclimatological modelling to ensure that water withdrawal is sustainably compatible with the characteristics of the relevant groundwater body. Permission for water withdrawal needs to take into account other needs for the same water resource, for instance for human water supply or for agriculture. Process water can be recycled, and wastewater treatment can be carried out in tailored plants to minimize impacts. Investments in reducing water use and contamination risks are costly and can therefore need to be enforced by the government or financiers, or by the public. Overall, water requires systematic governance owing to the multiple benefits and uses of accessible clean water. Management of water impacts is best organized in countries and regions with well-documented surface and groundwater resources, clear and effectively implemented regulations on water use and management, technical competence for management and transparent public reporting practices.

3.4.4 Waste and harmful substances

Tailings from mining are the very fine grained, sand-like, uneconomic residue resulting from the ore processing. They are defined by the European Union as: "The waste solids or slurries that remain after the treatment of minerals by separation processes (e.g. crushing, grinding, size-sorting, flotation and other physico-chemical techniques) to remove the valuable minerals from the less valuable rock" (European Union 2018). Franks *et al*. (2021) estimate that the production of minerals and metals worldwide generates each year about 13 billion metric tons of tailings waste. This inventory is the first of its kind, covering over 1,700 ore tailings disposal sites. Tailings need to be safely stored in perpetuity. Developing safe further uses of tailings constitute a pressing challenge for the mining industry.

Different segments can be an important source of local pollution owing to the presence of harmful unrecovered by-products in the tailings and/or mining waste. Franks *et al*. (2021) estimate that the three largest tailings-producing minerals and metals industry segments are the phosphate, copper and gold production industries. In 2020, the copper production of Chile, the world's largest producer of copper (28 per cent of the 2020 world copper production at the mining stage, according to Reichl and Schatz 2022), will have generated about 890 Mt tailings, a figure calculated based on the average national 0.64 per cent copper grade reported by the Chilean Copper Commission (2021).

In the absence of reuse in other segments of the local economy, tailings are disposed of in tailing ponds, contained by specifically designed confinement structures: tailing dams. The largest tailing ponds can cover areas of 10 km² and more. For cost reasons, the design of tailing dams may involve compromises between cost and reliability over time in given local conditions. Their failure can lead to large-scale impacts on the local environment, for example through river siltation or the release of pollutants. It can also kill workers and local people: in 2019, in Brazil, the Brumadinho iron ore tailings dam failure killed over 250 people and led to major environmental devastation (Silva Rotta *et al*. 2021). This was a major catastrophe in the list of about 130 of major tailings dam failures recorded since 1960 in the regularly updated chronology published by the Wise Uranium Project[55]. This led directly to the launch by the industry (International Council on Mining and Metals [ICMM]), the United Nations Environment Programme (UNEP) and concerned investors of the Global Tailings Review, which is discussed further in later chapters.

The weathering of residual sulphidic or sulphosalt minerals that are considered uneconomical to recover can, especially in humid and warm climates, be a source of one of the major negative impacts of the minerals and metals industry, known as acid mine drainage (Jacobs *et al*. 2014). Acid mine drainage is caused by the development of bacteria with a sulphur-based metabolism, thriving on the surface of these mineral grains, from which they recover their nutrient, releasing sulphuric acid and soluble, potentially hazardous and bio-assimilable, compounds of one or several of the following unrecovered elements that can be present in the tailings, especially from sulphide rich copper, gold or nickel deposits, including arsenic, cadmium, chromium, cobalt, lead, mercury, nickel, selenium, tellurium and zinc. Sulphide-rich mineral assemblages are the main source of acid mine drainage if waste rock piles, tailings and mine structures are not managed. Typically, a low pH may increase heavy metal release into soils and waters (Akcil and Koldas 2006). The processing of phosphate ore can also be a significant source of cadmium, fluorine, lead, mercury or radionuclides releases into the environment or into food produced using fertilizers derived from rock phosphates (Reta *et al*. 2018; Khelifi *et al*. 2021; Silva *et al*. 2022).

55 https://www.wise-uranium.org/

Potentially harmful pollutants can also be disseminated by wind, as very fine-grained particulate matter. Wind-deposited metalliferous mine dust originating from mine tailings can end up several kilometres away from the tailings (Frelich 2019), although the amount of deposited dust decreases with distance (Bussinow *et al*. 2012). Metalliferous mine dust may be hazardous depending on its abundance, particle size, chemical composition, solubility and shape, and surface area (Entwistle *et al*. 2019). Dust contamination from a mine has been assessed, using lichens for example. During the operational phase of mining, lead and zinc concentrations have been observed up to 35 km from the mine. Significantly elevated lead concentrations have been observed within 20 km and zinc concentrations within 5 km from the mine (Søndergaard *et al*. 2011).

Like water issues, soil and air contamination should be addressed in mining permits, with detailed assessments. For example, the heavy metal content of soil in mining areas may be many times higher than national environmental quality standards. This exposes local people to the risk of carcinogenic and non-carcinogenic diseases and causes environmental degradation in the vicinity of mining areas (Li *et al*. 2014).

3.4.5 Biodiversity

In addition to climate change, the loss of biodiversity and habitats has been recognized as one of the most serious threats to humanity (Cardinale *et al*. 2012; Mace *et al*. 2018; Reid *et al*. 2019; Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [IPBES] 2019a). Mining-related impacts on biodiversity may arise from the removal of vegetation and soil on site, leading to habitat destruction and the destruction of ecosystem services, water use in the mining processes, and waste and pollution generation, as well as changes in land use, both at and beyond the site. In addition, metal-mining activities will have indirect influences on biodiversity through climate change, but the strength of these influences will depend on the net impacts of mineral mining and green technologies on greenhouse gas emissions. This section consists of a literature review and a meta-analysis of the potential impacts of mining on the essential biodiversity variables.

IRP (2019) has recognized land use as a major cause of biodiversity loss, with agriculture as the main driver of biodiversity loss and water stress globally. Although metal mining activities, which occupy less than 1 per cent of global land area, do not belong to the top drivers of biodiversity and habitat loss (Murguía *et al*. 2016; IRP 2019), mining is a significant driver of land-cover change and can cause far-reaching impacts on biodiversity (IPBES 2019b; World Wide Fund for Nature [WWF] 2023). Mining-related infrastructure development is not always accounted for when assessing the impacts of operations. Also, at the end of a mine's life cycle, the fragmentation caused by the operation remains with tailings, water storages, buildings, roads, railroads and electricity lines (Renn *et al*. 2022). In addition to the ecotoxicological impacts of mining, the mining effects on biodiversity are often related to land use, with the most significant loss of biodiversity globally associated with coal, nickel and precious metal (e.g. gold) mining (Cabernard and Pfister 2022).

There are approximately 17,000 large-scale mining sites in 171 countries, mostly managed by international corporations, and significant artisanal and small-scale mining. Both mining types and sites are relevant for biodiversity impacts (Bansah *et al*. 2018; IPBES 2019; Marconi *et al*. 2022). Because of the local or regional character of mining impacts on biodiversity, they are often estimated to be moderate (e.g. IPBES 2009; Mykrä *et al*. 2021) or considerable (e.g. Leppänen *et al*. 2017). However, biodiversity impacts have also been characterized as large-scale disasters, particularly following accidents (Koenig 2000; Cunningham 2005; Garcia *et al*. 2016).

Mining projects lead to biodiversity loss, especially when these projects are in ecologically valuable and vulnerable ecosystems. For biodiversity, the impacts of mining are particularly meaningful when mining enters pristine and remote areas, where mineral extraction with associate infrastructure development may inflict significant pressure on the environment and biodiversity (Sonter *et al*. 2017; 2020). Increased demand and the depletion of easily accessible mineral reserves pushes mining activities into new areas, including tropical forests, other vulnerable ecosystems and fragile areas (Sonter *et al*. 2017; IRP 2019). These severe risks occur both through large mining projects and artisanal mining activities. Mining areas of certain metals, e.g. nickel, bauxite and silver, tend to overlap with global biodiversity hotspots (Murguía *et al*. 2016). Some 7 per cent of mining areas are estimated to overlap with key biodiversity hotspots and 16 per cent with remaining wilderness (Durán *et al*. 2013; Sonter *et al*. 2020). Sonter *et al*. (2020) estimate 8 per cent of protected areas to be potentially influenced by mining. This is because an additional 27 per cent of mines are located within 10 kilometres of the boundaries of protected areas. These overlaps are especially high in Europe, where 16 per cent of mines are located inside protected areas and 46 per cent in their vicinity (Durán *et al*. 2013).

Mining actions can pose serious and direct threats to biodiversity and the environment (Sonter *et al*. 2017; IPBES 2019). However, the evaluation of the final global biodiversity and environmental impacts of mining is complex. The final impacts may be less significant than direct biodiversity impacts when considering all the indirect pathways of impacts, which may partly support biodiversity (Sonter *et al*. 2018). Direct impacts, such as hazardous substance emissions to water, are easier to measure than indirect ecosystem impacts (Renn *et al*. 2022). Indirect impacts are not visible and may be long lasting. These could be, for example, changes in soil ecosystems that are dependent on ground water. The strength of impacts depends on the geochemistry at the site, how the extraction of ores is processed (open pit or underground mining) and whether ore concentration is operated at the site, the methods and chemicals used in concentration processes, and the size of waste areas (side rock piles and tailings ponds) on the site. The magnitude of impacts also depends on the sensitivity of the environment. The release of hazardous substances, such as heavy metals, to the environment causes population-level impacts on many organisms, such as fish. Heavy metals are persistent, bio-accumulative and toxic. The most relevant heavy metals and metalloids, in terms of negative environmental impacts, are chromium, nickel, copper, zinc, cadmium, lead, mercury and arsenic (Ali *et al*. 2019). Even though some heavy metals are essential for biological systems as micronutrients, and are thus important for organisms, some are toxic and non-essential, such as cadmium, lead and mercury (Ali *et al*. 2019; Edelstein and Ben-Hur 2018).

Terrestrial habitats

Habitat loss is the most significant pathway of impacts on terrestrial biodiversity caused by mining. Mining drives extensive deforestation in tropical rainforest areas, the Amazon, Africa and South-East Asia.

In addition to the establishment of mining pits and processing infrastructure, transportation infrastructure and urban development associated with mining areas contribute to deforestation (Sonter *et al*. 2017; Kyere-Boateng and Marek 2021). According to the World Wide Fund for Nature (WWF) (2023), mining-related tropical deforestation is growing fast, with a current rate of 3,000 km2 per year, while, according to FAO, the annual deforestation rate has been at 100,000 km2 during the same period. Most mining-related deforestation is driven by coal and gold mining but also some critical minerals result in deforestation in significant amounts, with bauxite, iron ore, copper and manganese accounting for some 2,000 km2 of deforestation over the last 20 years (WWF 2023). This phenomenon links biodiversity loss with climate change driven by land use, as tropical rainforests are the largest global carbon sinks (Brienen *et al*. 2015). Similar impacts of mineral mining on the environment and biodiversity are related to land use, road building and urban development, not only concerning tropical forests, but also other terrestrial ecosystems where mines are established (Rivas *et al*. 2006).

Direct mining impacts on terrestrial biodiversity are generally caused by vegetation and soil removal, increased metal concentrations in soil (Li *et al*. 2014), terrestrial acidification and air pollution (Fugiel *et al*. 2017; Farjana *et al*. 2019). This may result in the loss of all related ecosystem services, many of them little known owing to the lack of in-depth studies. In addition, the composition of vegetation and plant diversity may change because of emissions from mining waste areas (Närhi *et al*. 2012). Changing habitats as a result of mining activities have impacts on herbivorous insects, which vary from negative to positive. For example, Araujo *et al*. (2014) have observed higher species richness of galling insects56 in mining-impacted areas than in areas without mining impacts. Galling insects and other herbivorous invertebrates may be favoured by a pollution-induced decrease in the abundance of sensitive predators, which may result in the creation of an enemy-free space for herbivores (Zvereva and Kozlov 2010). On the other hand, plants may sometimes benefit from metal pollutants (e.g. heavy metals) that can serve as a direct chemical defence function against herbivores (Boyd 2010).

56 Galling insects use plant tissue for development creating a "gall" or abnormal growth on the plant. Such insects include gall wasps, gall midges, aphids and jumping plant lice.

Microbes are essential for soil functions, such as nutrient cycling and mineralization of organic matter. For example, heavy metal and other pollution induced by mining activities may change microbial communities of soil and therefore disturb natural ecosystem functions and processes driven by soil microbes (Brookes 1995; Liu *et al*. 2020). In addition, symbiotic plant-bacteria ecosystem functions, such as atmospheric nitrogen fixation, have been seen to be negatively affected by heavy metal pollution in soil (Giller *et al*. 1998). Närhi *et al*. (2012) have observed that the changes in soil elements, their interactions and species-specific differences of plants in tolerance to toxic elements caused changes in vegetation and the highest concentrations of toxic elements reduced plant diversity by over 50 per cent. High concentrations of zinc, lead and cadmium may decrease plant metabolic activity and induce oxidative damages, which may lead to decreased plant growth (Wójcik *et al*. 2013). The contamination by emissions from weathering tailings has been studied, and high concentrations of calcium, magnesium and phosphorus, as well as toxic elements, such as arsenic, cobalt, copper, sulphur and zinc, have been observed in plumes. Nickel may cause harm to the nutrient balance in plants and high amounts of chromium have a negative impact on photosynthesis. Importantly, plants are one pathway from soil contaminated with heavy metals to exposure of humans and herbivore species with possible health risks (Edelstein and Ben-Hur 2018).

High copper, zinc and iron concentrations have been observed to inhibit growth of algae in soil. Increased and diverse growth of algae has thus been observed in tailing waste areas after decreases in heavy metal contents (Song *et al*. 2014). The growth of algae created suitable conditions for the growth of higher plants (Song *et al*. 2014). On the other hand, some plants accumulate high metal levels in their tissues without symptoms of toxicity. These hyper-accumulator plants are able to take up metals and can be used in the phytoremediation of metal-contaminated soils (Lofty and Mostafa 2014; Mahar *et al*. 2016). For plants, the main route of heavy-metal accumulation is through roots, but some uptake may occur also via leaves.

Freshwaters

In addition to sometimes being responsible for the excessive withdrawal of surface and groundwater, as noted above, mining causes impacts on freshwater ecosystems through emissions and discharges of harmful substances, such as toxins and heavy metals, increasing their concentrations in water, sediments and aquatic biota (Allert *et al*. 2012; Palacios-Torres *et al*. 2018; Zhou *et al*. 2020). Moreover, sulphate emissions from the mining industry may cause unnaturally strong vertical stratification of lakes and major changes in biota owing to increasing salinity towards deeper water layers (Leppänen *et al*. 2017; Leppänen *et al*. 2019; Perrett *et al*. 2021). Heavy metal concentrations in freshwaters tend to be higher in Asia, Africa and South America than in Europe and North America (Zhou *et al*. 2020) and can be increased further by mining activities. The concentrations in developing countries often exceed the health and environmental threshold limits of the World Health Organization and the United States Environmental Protection Agency, whereas concentrations are generally below these limits in Europe and North America. Collectively, global heavy metal concentrations have increased over time from the 1970s and 1980s. Global analysis also showed that sources of heavy metal pollution in rivers and lakes have changed over time. Between the 1970s and the 1990s, mining and manufacturing were the dominant sources of pollution. In the 2000s and 2010s, most of the heavy metal pollution was related to rock weathering and waste discharge with smaller contributions originating from mining and manufacturing (Zhou *et al*. 2020).

Heavy metals have multiple negative influences on freshwater biota. Heavy metal contamination affects the survival, growth rates and welfare of fish, and inhibits the silica uptake of diatoms (Smith and Manyolov 2007, Falasco *et al*. 2009, Lavoie *et al*. 2017, Ali *et al*. 2019). Heavy metal pollution may cause morphological deformities in organisms, such as fish, benthic macroinvertebrates and diatom algae (Martinez *et al*. 2002; Sfakianakis *et al*. 2015; Pandey and Bergey 2016; Lavoie *et al*. 2017). The morphological deformities of organisms, such as fish, are often associated with decreased growth rates, physical conditions, reproduction and survival rates (Sfakianakis *et al*. 2015).

Mining-related increases in the metal concentrations of sediment and water columns result in changes to the abundance, community composition and diversity of freshwater organisms (e.g. Mebane *et al*. 2015; Beane *et al*. 2016; Azevedo-Santos *et al*. 2021; Mykrä *et al*. 2021). The tolerance of species to metal emissions and contamination varies, resulting in the change in community composition along the metal gradients. This is a result of the dominance of tolerant species and the absence of sensitive species at the high metal concentrations, whereas the relative proportions and abundances of sensitive species generally increase with decreasing metal concentrations (Loayza-Muro *et al*. 2010; Mebane *et al*. 2020). In addition to the species-specific tolerance differences to mining emissions within certain taxonomic groups (e.g. benthic macroinvertebrates or fish), tolerance to mining impacts also varies between different taxonomic groups of organisms. Mykrä *et al*. (2021) observed that the diatom species diversity responded significantly to mining effluents, whereas benthic macroinvertebrates were less sensitive without significant species richness or evenness responses. Mining effects were, however, significant on the community composition of both organism groups, but more distinct impacts were observed on diatoms than on macroinvertebrates. Besides impacts on species diversity, metal mining may also affect the genetic diversity of freshwater organisms. Paris *et al*. (2015) observed lower genetic diversity in metal-impacted brown trout (Salmo trutta) populations in areas with a long mining history when compared to unimpacted trout populations. Their analyses also indicated historical population bottlenecks with severe past population declines in populations impacted by mining.

When considering metal toxicities to aquatic organisms, it must be remembered that the toxicity and bioavailability of metals are not only dependent on their concentrations, but are also affected by multiple water chemistry variables and different combinations of interactions with these variables. These connected variables include pH, water hardness, alkalinity and concentrations of organic compounds, such as humic and fulvic acids (Heijerick *et al*. 2003; Magalhães *et al*. 2015). Of these, pH is probably the single most important variable that influences the behaviour of metal in the aquatic environment. Low pH induces the dissociation of metals, increasing their solubility and toxicity. On the other hand, in alkaline pH, most metals precipitate as oxides and hydroxides, thereby becoming less bioavailable and less toxic to aquatic organisms (Cornelis and Nordberg 2007; Magalhães *et al*. 2015). High water hardness generally associates with lower metal toxicity (Mebane *et al*. 2012). This is because calcium ions and magnesium ions in the form of carbonates are blocking entry of metals into organism cells (Magalhães *et al*. 2015). Moreover, high alkalinity in water decreases the toxicity of metal ions by active competition for binding sites in tissues (Santore *et al*. 2001) or by reducing metal concentrations though the formation of insoluble precipitates (Cornelis and Nordberg 2007; Magalhães *et al*. 2015). High organic carbon concentrations in water are also associated with lower metal toxicity to aquatic organisms (Heijerick *et al*. 2003). This is related to dissolved organic matter forming metal ligands that reduce the concentration of free metal cations and bioavailability (Di Toro *et al*. 2001; Magalhães *et al*. 2015). The geology of the catchment and water chemistry of the water body therefore greatly affect its ecological sensitivity to mining impacts.

Mining-influenced water bodies are commonly loaded by multiple metals. When organisms are exposed to mixtures of several metals simultaneously, additive toxic impacts are often observed because species abundances may decrease when there are lower concentrations of a certain metal in the metal mixture, when compared to the situation where a species is exposed singly to this same metal (Mebane *et al*. 2020). On the other hand, in their toxicity tests, Mebane *et al*. (2012) observed higher tolerance of cutthroat trout to zinc in mixtures with lead and cadmium than in the situation where trout were exposed to zinc alone.

In addition to effects from mining-related metal pollution, metal mining in terrestrial and sand mining in aquatic environments are causing suspended solid loads on freshwaters, which consequently increase water turbidity (Affandi and Ishak 2019; Zou *et al*. 2019). The ecological impacts of increased suspended solids include gill damage, as well as a decrease of reproductive success, growth and survival of fishes (Lake and Hinch 1999; Rowe *et al*. 2009; Suedel *et al*. 2017; Affandi and Ishak 2019). Sand mining with increased turbidity in lakes has been observed to decrease the abundance and diversity of aquatic macroinvertebrates, and to change species composition in favour of smaller invertebrate body size when compared to undisturbed reference sites (Zou *et al*. 2019).

Marine habitats

Shallower marine habitats and their biodiversity are threatened by the impacts of sand mining (Trop 2017; Doloksaribu *et al*. 2020; Cho and Kao 2022). These sand mining operations cause changes in water quality (Doloksaribu *et al*. 2020), and the status of benthic habitats and seabed communities, and may also modify hydrological conditions (Trop 2017). Sand mining operations may include the release of harmful or toxic substances, generated by the actual mining activities or through accidental releases from machinery or of materials used in mining (Trop 2017).

The existence of large mineral resources in the deep ocean floor have been known for decades. Earlier exploitation of these mineral deposits has been technically or economically infeasible, but owing to growing demand for minerals and technological development, interests have arisen in utilizing these resources (Koschinsky *et al*. 2018). Deep-sea mineral resources include five types of deposits (Cristiansen *et al*. 2020):

- ferromanganese nodules, which occur on abyssal plains and are especially abundant in the Pacific;
- seafloor massive sulphides, formed at hydrothermal vents, which usually occur on active seamounts and mid-oceanic ridges;
- cobalt rich ferromanganese crusts on seamounts and slopes on sediment-free substrates, which occur mainly at depths of 800–2,500 m;
- phosphorite nodules that occur at upper continental slopes at depths of 200–400 m; and
- metalliferous sediments in brine pools that are only known to occur in the central trough of the Red Sea.

Currently, deep-sea mining is predominantly still in the planning phase and there are not yet any existing commercial deep-sea mining projects (Jones *et al*. 2019; Kung 2021; Leng *et al*. 2021), although exploration licences have been granted across large areas of seafloor habitats of the world's oceans (Marsh *et al*. 2018). In January 2024, Norway became the first country to approve deep-sea mining in principle in a large expanse of the Norwegian Sea.57 Companies are now expected to submit proposals to undertake the controversial practice.

In the current absence of commercial deep-sea mining activity, the ESG risks of deep-sea mining are still largely unknown (Kung *et al*. 2021). Deep-sea mining may, however, be risky as it is planned to occur in deep-sea habitats that are poorly understood in terms of their ecology and sensitivities (Levin *et al*. 2016; Jones *et al*. 2019). Most studies suggest that deep-sea mining causes stress and pollutes deep-sea habitats with likely impacts on marine biodiversity (Hauton *et al*. 2017; Koschinsky *et al*. 2018; Drazen *et al*. 2020; Simon-Lledó *et al*. 2020). Although, the environmental impacts of commercial deep-sea mining have not yet been demonstrated (Koschinsky *et al*. 2018; Simon-Lledó *et al*. 2020), the observations from simulated mining impacts on the seafloor in 1989 and the observations since then have indicated significant and evident changes in seafloor habitats and community composition with decreased diversity and faunal abundance. These observations indicate that deep-sea mining could possibly lead to the irreversible loss of some ecosystem functions (Simon-Lledó *et al*. 2020).

One possible result of commercial deep-sea mining activity is the irreversible loss of particularly important deep-sea biodiversity. Some technical challenges (e.g. energy supply, extraction, vertical transport and mineral processing) need to be solved to enable financially viable deep-sea mining that has lower overall environmental impacts (Leng *et al*. 2021).

Biodiversity conservation

Biodiversity loss has been recognized as one of the major global challenges that can jeopardize life on Earth (IPBES 2019). It is increasingly considered a governance challenge as serious as climate change. Recent highly visible analyses of the value of biodiversity (Dasgupta 2021; IPBES 2022) have challenged traditional biodiversity governance and called for a recognition of the benefits that biodiversity and ecosystems provide. Increasingly, there is an expectation that companies and industries degrading biodiversity take more responsibility and develop solutions that would, ideally, both protect valuable ecosystems and fully internalize the environmental cost, thereby limiting and mitigating harmful activities.

Biodiversity conservation has traditionally been governed by public authorities, through establishing protected areas or through limiting pressure on specific ecosystems via good management practices. Departing from this framing as a constraint on economic activity, conservation policy has increasingly addressed ecosystem services and included incentives and voluntary instruments, such as payments (Wunder *et al*. 2008), alongside the growing use of elaborate data and planning tools (De Groot *et al*. 2010). To complement protection approaches, imitating the ideas of carbon offsetting, there are initiatives for biodiversity offsetting to incentivize the mitigation of negative impacts and compensate those impacts that remain. Indeed, the mining sector has been a piloting sector for this instrument, with its geographically limited impacts and important local social pressure to offset negative impacts (Kujala *et al*. 2015; Droste *et al*. 2022; Kotilainen *et al*. 2022).

57 https://www.bbc.co.uk/news/science-environment-67893808.

Biodiversity conservation is also included in financing criteria and voluntary standards, alongside other environmental impacts. For example, the Biodiversity and Ecosystem Management indicator of the Environmental Responsibility section of the Responsible Mining Index is "the company commits to not explore or mine in World Heritage Sites, to respect other protected areas, and to not use practices that would threaten freshwater, marine, and deep-sea habitats". While measuring biodiversity impacts on the ground can be challenging, this kind of clear criterion is easy to address and evaluate. However, as this section has shown, mining also takes place in protected areas, and mining outside protected areas comes so close that its impact spills over to protected areas. While official guidance may seek to reduce biodiversity loss (e.g. European Commission 2011, for Natura 2000 sites) or enable the mining sector to contribute to halting biodiversity loss, a starting point should be that mining should not take place in protected areas.

Valuation, mapping and payments as instruments for operationalizing biodiversity conservation for governance (Primmer and Furman 2012), have not yet transformed the ways in which resource governance and biodiversity conservation connect. The continuing dilemma is that the economic incentives that stimulate activities have not been successfully tackled, resulting in the overuse of natural resources and land conversion, often by a private sector appealing to consumer demand. The cost of biodiversity loss and ecosystem degradation does not show in the prices of resources. Rather, the costs of both gradual degradation and accidents are still mostly carried by the public sector and society. The ecological cost of land conversion has been acknowledged only after land-use related emissions have gained a status in greenhouse gas calculations. Land-use change is an important proxy for biodiversity and ecosystem service loss that could be governed with more ambition, although the protection of valuable and vulnerable sites must also be included in the policy mix. It is important to keep in mind that habitat loss and degradation are currently threatening over 80 per cent of endangered species, while climate change threatens 20 per cent of endangered species (Maxwell *et al*. 2016).

Governing metal-mining impacts alongside other environmental pressures

A further challenge relates to the coincidence of many drivers of environmental degradation. Owing to global change, many ecosystems face multiple anthropogenic pressures simultaneously (Craig *et al*. 2017; Grizetti *et al*. 2017; Manning 2019). The question therefore arises of what kind of simultaneous and interactive effects does metal mining have with other pressures (e.g. eutrophication, forestry and climate change) on the environment and biodiversity. The meta-analyses of marine and freshwater ecosystems indicate that the net burden of multiple stressors on the environment may be commonly greater than (synergistic stressor interaction) or equal to their summed individual effects (additive stressor interaction), whereas net multiple stressor effects that are less than a potential additive outcome (antagonistic stressor interaction) are less frequent (Harvey *et al*. 2013; Ban *et al*. 2014; Jackson *et al*. 2016). Antagonistic stressor effects generally mean that multiple stressors influence the same set of sensitive species (Jackson *et al*. 2016).

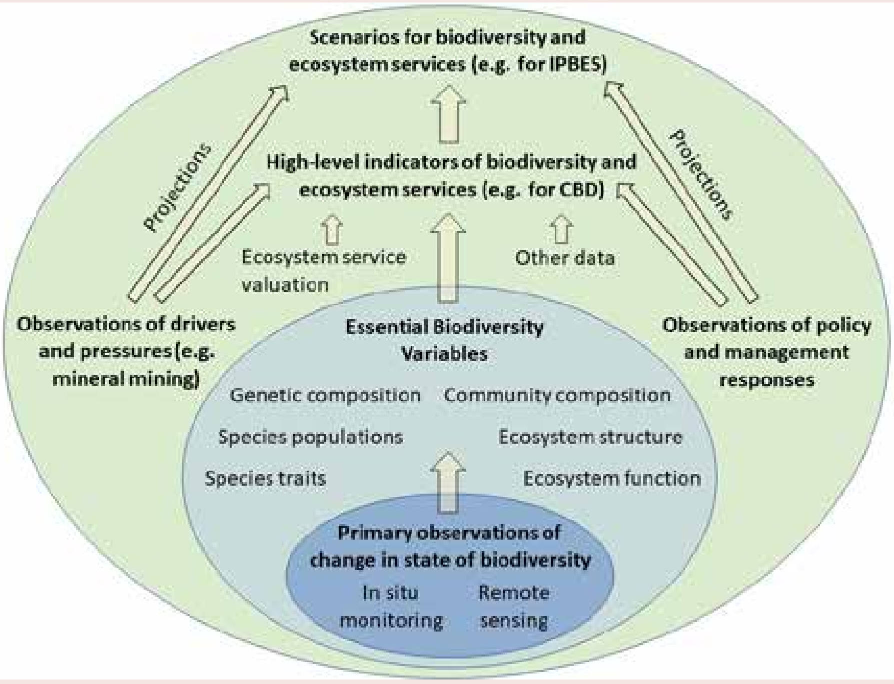
As mineral mining activities together with other stressors have indeed been observed to cause additive or synergistic impacts on the environment and biodiversity (Merriam *et al*. 2010; Raiter *et al*. 2014), it is important to consider and govern the possible multiple stressor effects in the ore-prospecting and planning phases of mineral mining projects, as well as when monitoring and assessing mining impacts on biodiversity and environment. While the magnitude and spatial extent of mining impacts can be controlled by case-specific risk assessment and efficient pollution control (Werner *et al*. 2019), this consideration should be extended to a system-level, in which the impacts of the entire value chain making use of metals would be identified, at least as a causal pathway, and ideally quantified. Together with the location-specific knowledge of sensitive biodiversity – protected or not protected – such understanding could meaningfully be integrated into new standards to be applied in steering and financing mining.

The growing demand for transition minerals will result in an increase in environmental impacts in the future. There is therefore an absolute necessity for careful strategic planning to ensure that these new threats to biodiversity, water and soil will not exceed the positive climate impacts of renewable energy production.

Box 3.2: A meta-analysis of mining impacts on biodiversity

To analyse the impacts that mining has on biodiversity, it is important to draw on recent empirical literature examining this topic. As the literature addresses a range of impacts in varied settings, generalizing and categorizing the impacts is essential. This box summarizes the main results of a meta-analysis that uses so-called essential biodiversity variables, conceptualized and formulated by the efforts of the Global Biodiversity Observation Network (www.geobon.org). Essential biodiversity variables are seeking to support focused, integrated and effective biodiversity monitoring for assessment and policy (Pereira et al. 2013; Jetz et al. 2019). Essential biodiversity variables have been conceptualized to meet the needs of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and the Convention on Biological Diversity (figure 3.3).

Figure 3.3: Schematic vision of the Global Biodiversity Observation Network for the essential biodiversity variables, integrated into the contexts of monitoring, management, pressures, environmental policies, international conventions (Convention on Biological Diversity) and science-policy platforms, such as IPBES



Source: modified from the diagram of the Global Biodiversity Observation Network (www.geobon.org).

The essential biodiversity variables are aimed at capturing critical scales and dimensions of biodiversity, as biological state variables. They are defined so as to be sensitive to change and ecosystem agnostic, as well as be technically feasible, economically viable and sustainable in time. Essential biodiversity variables are categorized into five classes (genetic composition, species populations, species traits (within-species variation), community composition, ecosystem functioning) and into 21 variables with specific descriptions within these classes.

For this meta-analysis, Tolonen et al. (manuscript nd), has examined the impacts of metal mining based on Web of Knowledge-searches of relevant studies published in 2012–2022. The search terms have been selected to focus on essential biodiversity variable classes, except for species populations, for which only species abundance is used, since mining operations with spatially limited and rather local impacts are not expected to affect large-scale species distributions. The review results are indicative, rather than statistically robust, as studies for essential biodiversity variables for each ecosystem type are rather few, but the general observation that can be drawn from this meta-analysis is the clear impacts that mining has on freshwater ecosystems.

This is important as freshwater ecosystems are particularly vulnerable and support disproportionately high levels of biodiversity considering their spatial coverage (Dudgeon et al. 2006). At the same time, species populations in freshwaters are declining more rapidly than those in terrestrial and marine ecosystems (Reid et al. 2019). This is alarming as the ecosystem services supported by freshwater biodiversity are highly valuable, or even essential, for humans, and the contribution of these aquatic ecosystem services to supporting local economies may be high (Dudgeon et al. 2006; Butler 2009; Heino et al. 2021). The meta-analysis shows that the mining industry needs to pay special attention to managing its freshwater biodiversity impacts.

Box 3.3: Mining and the environment in Africa

The environmental cost of mining tends to be quite high, as evidenced by the tragic failure of tailings dams (IRP 2020a). Environmental costs are incurred during all phases of the mining process, from exploration to mine closure. Some areas of particular concern are the direct damage done to water and biodiversity from the mining process, damage attributed to waste produced during the mining activities and damage incurred after the mine has been closed. With regard to transition minerals in Africa, environmental impacts are already being felt.

The development of the Ambatovy Nickel mine in Madagascar has resulted in 2,000 hectares of pristine rainforest being cleared, destroying vital habitat of the endangered indri, the largest living lemur, and thousands of other species (Greenfield 2022).[58] In Ghana, the opening of a bauxite mine led to deforestation that muddied the water for users downstream, making it unusable and forcing more than 2,000 people to rely instead on a borehole. The mine is expected to affect an estimated 17,400 hectares of the protected area (Agbo 2019; Gbadamosi 2020). Similarly, in Guinea, bauxite mining is likely to have huge environmental implications. It is instructive to note that exports to China have risen rapidly in the wake of Indonesia stopping exports to China for environmental and health reasons in 2014, and to Malaysia in 2016. Guinea is now the main supplier of China (Takouleu 2018). In essence, pollution has been exported to Guinea, yet Conservation International has classified Guinean forests as a global biodiversity hotspot.[59] As in Ghana, bauxite is seen as key to the development prospects of Guinea and this might result in less attention being paid to environmental issues.

Macdonald (2018) points to disruptions, including population movements and noise, air and water pollution, that are invariably highly localized close to the resource. At the same time, mining activities tend to be in remote areas where inhabitants depend on direct environmental services for their livelihoods and lack the skills and investment resources to participate and benefit from mining activities. Communities where mining takes place thus bear the brunt of the environmental cost of mining activities.

Mine closure is a huge environmental problem that, if not managed early and proactively, can leave communities vulnerable to dangers from closed mines, including unstable tailing dams that can poison land if they fail, and acid mine drainage. The key challenge here is that mining companies may go bankrupt or cease to exist once the mine is closed. If care is not taken to collect funds to support the rehabilitation and remediation of a closed mine, and in some cases monitor it for stability and the absence of hazardous leakages in perpetuity, society will bear the cost. A better approach is the creation of mine rehabilitation trusts by the mining companies. The board of trustees oversees and administers the trust funds to protect them from being used for other purposes. The mining company drafts the necessary plans and estimates for rehabilitation, and makes periodic payments to the trust, which accumulates adequate resources over time for rehabilitation projects. Recently, several mining companies in Botswana have used trusts as their preferred method of ring-fencing such funds (Dambe 2020)

Although a mine necessarily damages the environment during its operations, remedial measures can restore and even improve the environment. For example, the Ambatovy project has sought to mitigate its environmental impacts by slowing the deforestation driven by small-scale agriculture elsewhere. A study by researchers at Bangor University (Devenish et al. 2022) concludes that there has been no net loss of forest. However, although the number of forest hectares may be the same, there can be enormous differences in terms of biodiversity and ecosystem services between one hectare of rainforest and one hectare of planted secondary forest.

58 https://www.theguardian.com/environment/2022/mar/09/ambatovy-the-madagascan-mine-that-might-prove-carbon-offsetting-works-aoe.

59 http://www.biodiversityhotspots.org.

Just as this report was being finalized in January 2024, the major global association for the mining industry, the International Council on Mining and Metals, set out a new commitment to nature-positive mining[60] at the heart of which is a five-point plan for nature,[61] which is worth quoting in detail. The five headline commitments are:

1. "**Protect and conserve pristine areas of our natural environment:** No mining or exploration in World Heritage Sites and respect all legally designated protected areas.
2. **Halt biodiversity loss at our operations:** Achieve at least no net loss of biodiversity at all mine sites by closure against a 2020 baseline.
3. **Collaborate across value chains:** Develop initiatives and partnerships that halt and reverse nature loss throughout supply and distribution chains.
4. **Restore and enhance landscapes:** Around operations through local partnerships, including with Indigenous Peoples, land-connected peoples and local communities.
5. **Catalyse wider change:** Acting to change the fundamental systems that contribute to nature loss and fostering opportunities for nature's recovery.

These commitments apply to activities across all four realms of nature – land, freshwater, oceans and atmosphere – leveraging companies' areas of influence – from their direct operations, value chains and wider landscapes, through to creating the conditions required to achieve systems transformation. They are supported by transparent disclosures on performance outcomes, including publishing the results of nature-related impact and dependency assessments, and setting targets to address these."

3.4.6 Conclusions

This Chapter has provided a summary some of the important social and environmental issues that will need to be addressed by mining companies and mining stakeholders, including investors, if mining is to contribute to the achievement of sustainable development in host countries and obtain a sustainable development licence to operate, while supplying essential transition minerals to the wider world. Countries are looking for a secure supply of these minerals to contribute to their clean energy technologies and help them to achieve their commitments to reduce their greenhouse gas emissions under the Paris Agreement. Local communities and host governments are looking for real shared value from mining that utilizes their non-renewable resources. They seek to achieve long-term and sustainable growth in their living standards, while also safeguarding their natural environments. Companies and investors are looking for profitability and returns, and ways to manage their risks.

Social and environmental pressures caused by mining activities will increase globally in the future owing to the growing demand for minerals. The global increase in the demand for metals gives rise to increasing carbon emissions from mining and processing. However, as the aim is to balance climate impacts, the even more serious expanding impacts come through the loss of natural habitat and biodiversity and the pollution of water bodies. The impacts vary in their scale. Greenhouse gas emissions from mineral sourcing and processing are the most prominent global environmental impact, while land-use change, waste and many chemical and particulate matter emissions mostly generate locally significant impacts on water, soil and biodiversity. A significant amount of mining occurs in pristine or otherwise valuable biodiverse areas, resulting in proportionally more biodiversity loss than indicated by the small area of mining sites. Deforestation and other impacts driven by land-use change are felt beyond the immediate mining areas, as mining comes with infrastructure development. In addition, there is a particular need for mining to assess the magnitude and severity of the environmental impacts, alongside the risks of accidents and the gradual accumulation of poorly identified impacts.

60 https://www.icmm.com/en-gb/our-principles/position-statements/nature.
61 https://www.icmm.com/en-gb/news/2024/landmark-commitments-nature-positive.

The governance of mining impacts relies on environmental impact assessments and permissions at the local and national level, as well as corporate ESG management practices, which connect a sustainable development licence to operate at the local and company levels to global value chains. To supplement the necessary protection of valuable habitats and regulation-based governance, incentives and voluntary instruments, and innovative instruments, such as offsetting, should be promoted. Biodiversity impacts should be considered in relation to all land conversion driven by mining, and importantly also in freshwater habitats, as they often also transfer impacts in the landscape.

An understanding of the potential environmental impacts of mining activities is of paramount importance for their technical management and reduction to a socially and environmentally acceptable level. Companies and industries degrading biodiversity and ecosystems should take more responsibility and develop solutions. It is to be hoped that the implementation of the commitment of the International Council on Mining and Metals to nature-positive mining, made in January 2024, will show how to realize this concept in practice. Any extra cost of this development and management work should be recovered from the value chain through higher prices.

3.5 CONCLUSIONS OF THE CHAPTER

Mining companies have understood for many years that successful mining requires a social licence to operate. An earlier report, Mineral Resource Governance, by the International Resource Panel in 2020 recommended that this should be extended to a sustainable development licence to operate, so that mining could play an explicit role in contributing to the achievement of the Sustainable Development Goals. This will entail mining making a positive contribution across the economic, social and environmental dimensions included in the Goals.

Mining can play a positive role in economic development by increasing local value addition, by using local companies and employing local people, where possible, by driving technology adoption both in mining and beyond it, and by providing infrastructure that continues to be useful beyond the life of the mine. This Chapter has shown that achieving such outcomes is not straightforward and often requires commitment to capacity-building from local policymakers and international financial institutions. In respect of employment, it was also seen that artisanal and small-scale mining employs far more people than large-scale mining, and that the priority here is to improve working conditions for those involved, including through their sensitive inclusion in the formal economy.

This Chapter has also explored two social issues that are important for sustainable development. The first is land rights, acknowledging that mining often involves a fundamental change of land use and the displacement of people. It is important here for local people to be properly consulted on and compensated for any detriment they may suffer from mining, and that land is restored and returned to them following the closure of a mine, such that it is again in a condition that can be used for other purposes. These considerations are especially important in respect of Indigenous people, who must have an opportunity to give prior informed consent to mining on their territories, as well as having the power to refuse it.

The second key issue relates to women, who tend to be underrepresented in mining, experience disproportionate negative impacts from it and face specific barriers to their involvement in it. The Chapter has indicated a number of ways in which mining can be more inclusive of women through both corporate and public policy, with examples of good practice in some countries and companies showing how greater gender equality can be achieved in this sector.

The last section of the Chapter briefly reviews environmental issues related to mining, but deals in greater depth with mining's impacts on biodiversity. Given countries' commitments at the Fifteenth Meeting of the Conference of the Parties to the Convention on Biodiversity (COP15) to designate 30 per cent of their territory as protected areas, it will be very important to clarify the relationship of mining to these designated. Given the loss of global biodiversity that has already occurred, and the expectation that the protected areas will be those areas that have the most of what is left, the recommendation made here is that mining should not be permitted in protected areas. This goes beyond the most recent welcome the commitment of the International Council on Mining and Metals to achieve "no net loss of biodiversity", "respect all legally designated protected areas" and "restore and enhance landscapes". How companies respond to these new commitments will be critical to determining whether mining and biodiversity conservation really can coexist.

CHAPTER 4

RECYCLING AND THE CIRCULAR ECONOMY

Kseniya Ivashkevich © Shutterstock

CONTENTS

4.1 INTRODUCTION

Earlier chapters have shown that the transition to low-carbon energy technologies is critical to mitigating the impact of climate change, but large quantities of minerals and metals are required to build the necessary infrastructure and technologies, presenting significant challenges for the global mineral supply chain. In the short run, the transition will create immense demand for transition minerals (Hund *et al*. 2020; Gate C and Green Purposes Company 2023).

Whereas circular economy approaches, such as reuse, repurposing, remanufacturing and repair, can prolong the service lives of low-carbon energy technologies and are essential to reduce the demand for primary minerals and metals, ongoing decarbonization pathways will create mountains of waste if the low-carbon energy systems are not sustainably disposed of at their ends of life. Photovoltaic solar module waste is expected to amount to 60 to 78 million metric tons by 2050, while waste from wind turbine will be 43 million metric tons (Robertson-Fall 2022). To put these numbers into context, the combined amount of waste from the solar and wind power industries could match the size of the electric and electronic waste (e-waste) predicted to be generated globally in 2050 (United Nations Environment Programme [UNEP] 2019). Over the next two decades, the cumulative amount of spent batteries from electric vehicles (EV) and storage is expected to surge, reaching 1,300 GWh by 2040 (International Energy Agency 2021).[62]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Against this backdrop, metal recycling emerges as a vital component of the global mineral supply chain. While virgin metals will be needed in considerable quantities for the foreseeable future, recycling could help to meet the demand for transition minerals and put the end-of-life products to a better use than landfill or energy recovery (figure 4.1). While China leads the supply of low-carbon energy technologies materials classified as critical by other large economies, such as the United States of America and the European Union (see table I.2), the United States of America and European Union have recently ramped up the financial measures to support domestic supply routes via secondary production.[63] The issue of financing the supply of transition minerals thus calls for a broader understanding that goes beyond mining. In this sense, taking recycling as the only supply-side circularity approach is particularly relevant to the overarching theme of this report.

Building on existing literature and previous United Nations Environment Programme (UNEP) International Resource Panel (IRP) reports on recycling (UNEP 2011; UNEP 2013), this Chapter explores ongoing and future limitations of the secondary production of transition minerals and how finance can support the recycling industry to overcome these limitations. The first section introduces the concept of recycling as a circular economy pathway, while the second section delves into the major challenges associated with the recycling of transition minerals. The third section is focused on the financing of recycling and its impact on primary and secondary production, as well as the impact of support measures on transition mineral supply chains. The fourth section discusses how financial support can help to address the grand challenges mentioned in the second section. A final section concludes and introduces future research avenues.

62 Assuming that each low-carbon energy technology will be discarded upon completion of its recommended lifespans (see section 2.3).

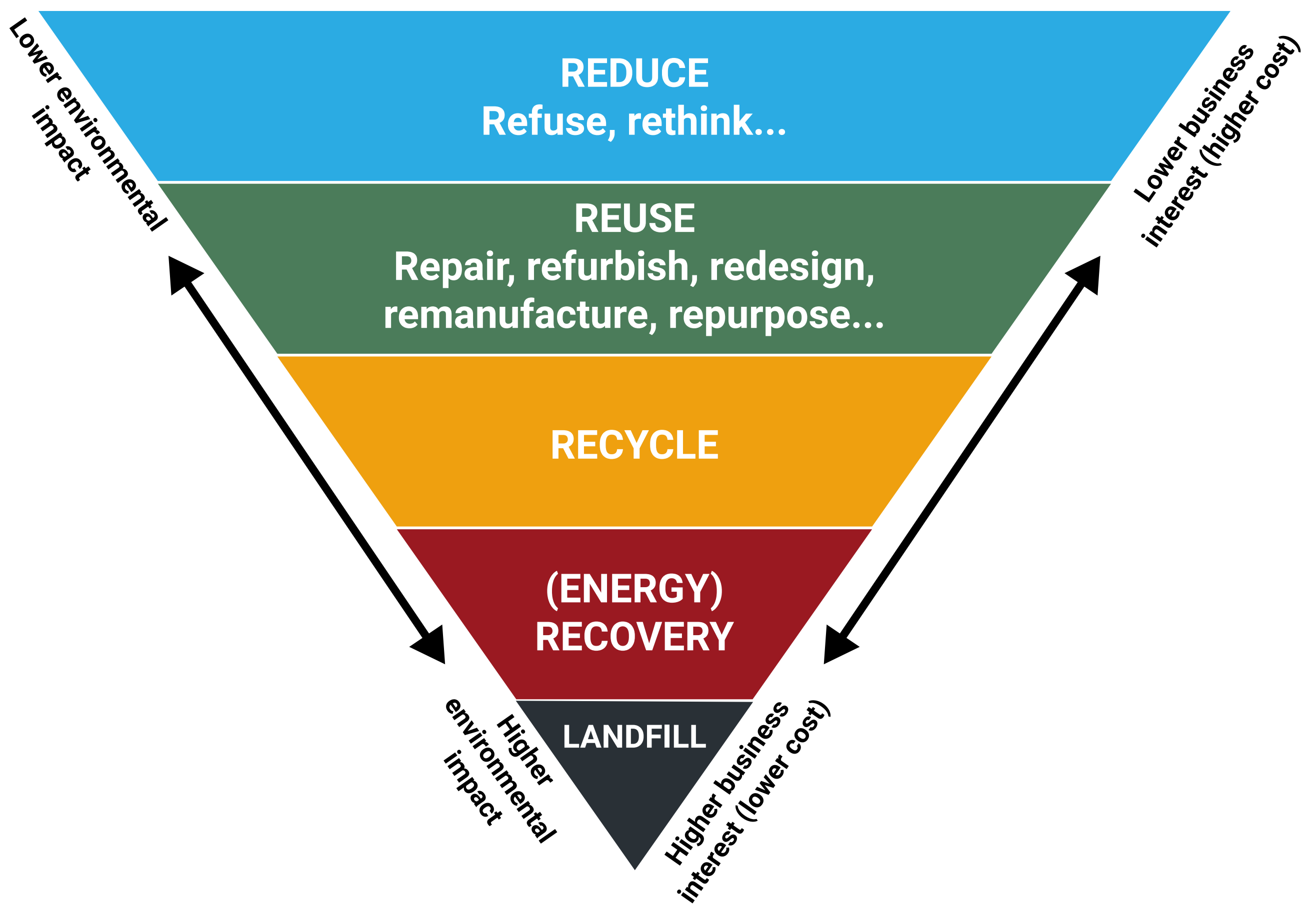
63 The finance of recycling of transition minerals used in electric vehicle batteries is illustrative. The Government of the United States of America introduced US$125 million worth of grants in 2022 for the research and development of circular approaches for battery reuse and recycling (United States Department of Energy 2022). The European Investment Bank pledged €1 billion to the European Battery Alliance to support battery manufacturing and recycling projects within the European Union (European Investment Bank 2020). The European Union also proposed a Circular Economy Action Plan, aiming to reduce the environmental impact of waste generated by batteries. The plan is focused on improving product design, promoting reuse and recycling, and providing incentives for manufacturers to use recycled materials in their products.

4.2 RECYCLING AS A CIRCULAR ECONOMY PATHWAY

Recycling is a key component of the circular economy, alongside other approaches such as reducing (consumption of goods) and reusing (including repairing and repurposing). For better resource conservation and circularity practices, circular economy approaches are typically prioritized from the top to the bottom of the waste management hierarchy (figure 4.1).

The circular economy encompasses various approaches to reduce society's demand for new raw materials, which include reducing consumption (e.g. by sharing a product), repairing the products in use, reusing and repurposing materials (of an end-of-life product), redesigning end-of-life products to be more sustainable or remanufacturing end-of-life products (or their components) to extend their lifespan. These strategies are aimed at keeping materials within the societal in-use stock and minimizing the need for additional raw material extraction (see figure 4.2 for how these circular economy strategies can be applied to electric vehicles). The additional commercial benefits of embracing circularity in business include optimization of value chains, enhanced supply security, improvement of economic performance and resilience against market shocks (Cimprich *et al*. 2023).

Figure 4.1: The waste management hierarchy, from more sustainable resource management practices at the top to less sustainable practices at the bottom



Source: European Commission (2023c); United Nations Economic Commission for Europe [UNECE] (2023a).

Figure 4.2: Circularity in practice: In the case of the life cycle of an electric vehicle, circular economy principles can be implemented through various strategies

By promoting carpooling or shared mobility services, the demand for new electric vehicles can be reduced. Multiple individuals can share the use of a single electric vehicle, maximizing its efficiency and minimizing the need for additional vehicles.

REDUCE

When a battery in an electric vehicle becomes broken or faulty, instead of replacing the entire vehicle or battery, repair options can be explored. Skilled technicians can diagnose and fix the specific issue, extending the lifespan of the electric vehicle and reducing the need for new components.

REPAIR

In instances where the battery of a large high-power electric vehicle loses energy storage capacity, the battery can be repurposed for installation in a smaller, older electric vehicle that needs less power. This practice ensures that the battery's remaining capacity is fully utilized, optimizing resource efficiency and reducing waste.

REUSE

End-of-life or 15-year-old batteries that are no longer suitable for use by electric vehicles can be repurposed for other applications, such as being integrated into home solar panel systems. This repurposing enables the batteries to continue serving a useful purpose and avoids their premature disposal.

REPURPOSE

Electric vehicles can undergo redesign efforts to enhance their energy efficiency and optimize battery usage. Adjustments can be made to the vehicle's components, software and systems to maximize the range and performance of the battery, ultimately reducing overall energy consumption.

REDESIGN

In the context of electric vehicles, remanufacturing involves disassembling the car's battery, electronics and other components. These parts are then thoroughly repaired, cleaned, and reassembled to create a like-new product that can be resold. Remanufacturing minimizes waste and extends the life cycle of valuable components.

REMANUFACTURE

At the end of an electric vehicle's life cycle, when all other circular economy approaches are no longer viable, recycling can be employed. Through effective recycling processes, the materials and components of the electric vehicle, such as the battery, can be recovered from end-of-life electric vehicle, disassembled and used in the production of new products. Recycling ensures the recovery of valuable resources and reduces the need for primary raw materials and helps to close the material loop.

RECYCLE

Source: Author

Circularity strategies should not conflict with each other. For instance, solar photovoltaic panels and wind turbines are often manufactured to operate for a long time. The non-modular design of mainstream photovoltaic panels and turbine nacelles makes repairing them costly and burdensome, making it actually difficult to keep using them through their ex-factory lifespan (Gate C and Green Purposes Company 2023). One circular economy approach (long life) may come at the expense of another (ease of repair) if they are not implemented in a harmonized and consistent way.

It is important to carefully define priorities and consider each case on its own merits when choosing circularity approaches. In some cases, a particular approach in a particular context may not yield the best results for the environment, resource management and human health. For example, where recycling has negative environmental and social impacts exceeding those of landfill, it may not be the best option and another approach should be chosen (van Beukering *et al.* 2014). After optimum cost-benefit levels, pushing for higher recycling rates could end up using excessive inputs (resources, energy, labour) and creating unintended negative impacts (hazardous waste, health consequences), thereby doing more harm than good.

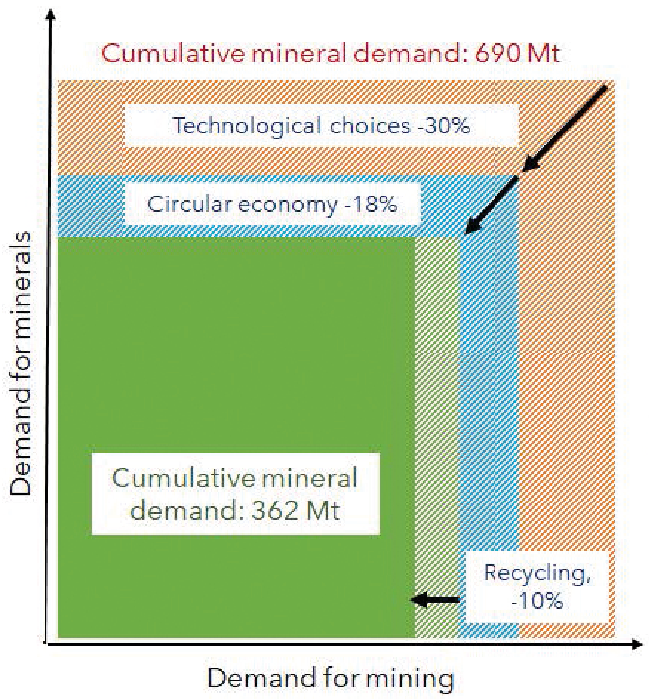
Recycling should be considered a last resort option to reintroduce used materials back into the supply chain. Simas *et al*. (2022) estimate that under net-zero pathways, the cumulative material demand of manufacturers of low-carbon energy technologies could reach up to 690 million metric tons by 2050. They found that technologies that use transition minerals less intensively could curb this demand by 30 per cent, while circular economy strategies could make an additional 18 per cent reduction. Substituting primary extraction with recycled materials can decrease the need for mining by 10 per cent, meeting 20 per cent of the total remaining material demand in a scenario that incorporates advanced technology and circular economy strategies (figure 4.3). A recent report released by Energy Transitions Commission (2023) also estimates that technological advancements, material efficiency and recycling could reduce and meet the cumulative material demand by 2050 between 20 per cent and 60 per cent.

While recycling does not seem to be more effective to meet the net-zero targets compared to demand-side circularity approaches, it has been the most commonly covered strategy in the literature on the circular economy over the past 20 years (Schöggl *et al*. 2020). One possible reason for this focus on recycling is that consumption-oriented markets prioritize ensuring a sufficient supply of raw materials rather than addressing demand-side issues (Allwood 2014), leading to a prioritization of waste management over waste prevention. From a mainstream economics perspective, the former adds more value to the market growth than the latter owing to the discard of a defective product whose components would be recycled (thus generating jobs and new business opportunities) and its replacement by a new one (thus requiring new products to be manufactured and sold), at the expense of non-market impacts from waste generation, and energy and resource consumption. Recycling is thus often prioritized despite not being the most ecological way to manage resources.

Figure 4.3 shows that technology and material substitution and upscaling of new technologies can reduce mineral demand by 30 per cent; in addition, the implementation of circular economy strategies, reducing demand and extending the lifespan of low-carbon technologies can reduce mineral demand by 18 per cent; and improving collection and recycling rates by 2050 to increase mineral recovery from end-of-life low-carbon technologies could reduce demand for primary extraction by a further 10 per cent.

That said, the primary focus of this Chapter is on recycling in order to assess its potential contribution to mineral supply, which is the underlying theme of this report, and to consider the role of finance in addressing challenges and harnessing opportunities for recycling.

Figure 4.3: How the demand for minerals in low-carbon technologies is expected to change from 2022 to 2050



Source: Simas *et al*. (2022, p. 5).

4.3 GRAND CHALLENGES OF RECYCLING TRANSITION MINERALS

The whole process of recycling a material requires energy and resources, even under the best available technology (Allwood 2014). A complete closed loop or cradle-to-cradle recycling of metals cannot be achieved. Losses might be minimized but cannot be entirely avoided owing to systemic and technological shortcomings, as well as other factors, e.g. politics, economics, theft and human factors. Furthermore, the laws of thermodynamics dictate that energy inputs are required at each stage of the recycling cycle, although this could be less than primary resource extraction. Even maintaining a stable stock of metals would thus require energy, resource extraction and use of primary metals to compensate losses, in addition to recycling (UNEP 2013).

Despite such limitations, recycling or secondary production of metals already plays a crucial role in the global economy, particularly for precious metals, aluminium, copper and steel. While it represents only 6 per cent of the total weight of metal trade, the value of scrap metal exports amounted to US$76 billion in 2015, about half the size of primary exports (McCarthy and Börkey 2018).[64]

A variety of economic, technological and societal challenges determines the success of the recycling industry (UNEP 2011). Ten major challenges for secondary producers are summarized below. Some of these challenges are common to all secondary metal producers, while others are more prevalent among recyclers of transition minerals. Examples and short case studies are selected from transition minerals in line with the theme of this report.

4.3.1 Technology and price uncertainties affecting investments

Investors considering entry into the recycling domain seek confidence that their investments will yield a sound return over the years of commitment required. However, this commitment is challenged by a number of uncertainties. To begin with, the dynamic nature of technological change can alter the demand landscape for specific minerals and metals. Indeed, technological advancements enabled substantial reductions of materials used in the low-carbon energy technologies; for example, the thickness of solar photovoltaic panel wafers, which include silver and silicon, was reduced by more than two-thirds since early applications in the 1970s (Louwen and van Sark 2020). On the other hand, technological shifts might mean the complete discarding of certain transition minerals from low-carbon energy technologies, as observed in attempts to reduce the use of cobalt in new electric vehicle batteries (Ryu 2020). This uncertainty poses a risk, as changing demand influenced by technological advancements may lead to lower prices, impacting the overall profitability of recycling initiatives (Christmann and Lefebvre 2022).

Secondly, the economic viability of metal recycling is ultimately dependent on the metal's price. The incentive for recycling would increase when metal prices are high, and in multi-metal products such as batteries the focus of recycling is on those metals with a high economic value. Lithium, for example, has a relatively low economic value compared to cobalt and gold, so that recyclers prioritize these metals, despite lithium making up a larger proportion of the battery weight. A related challenge concerns the high price volatility in metal markets, as seen in Chapter 2. Single-metal oriented recovery facilities can be vulnerable to high price variability.

64 This stark difference in value per unit between metal scraps and ores stems particularly from the difference in metal concentration of the two types of sources (e.g. often higher for aluminium scrap than bauxite ore) and the cost of extracting the metal from them (e.g. often lower for aluminium scrap).

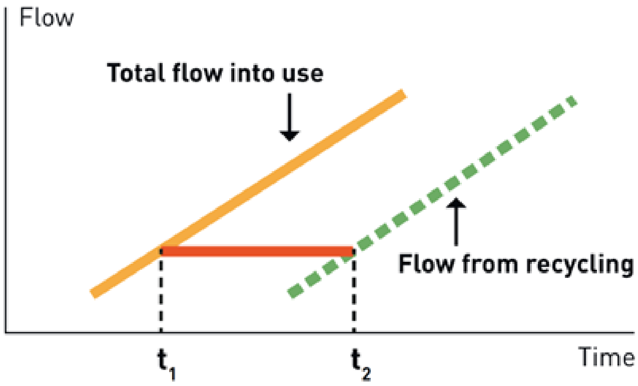
4.3.2 Product design

Many final products present challenges in their design that hinder easy disassembly and (chemical) separation during the later stages of recycling (UNEP 2011). This is particularly evident in the case of electric vehicles, where design choices have a significant impact on the reparability of batteries during their operational life and the recoverability of materials at the end of their life cycle. An example is the design of the batteries in electric vehicles, where evidence indicates that the multiple small cell design, as employed in the Tesla Model S, offers advantages in terms of lower disassembly costs and labour requirements compared to other prominent designs, such as those found in the Nissan Leaf and Porsche Taycan (Lander *et al*. 2021). The implications of product design on recycling processes highlight the importance of considering the entire life cycle of products, incorporating recycling-friendly designs to enhance the efficiency of material recovery.

4.3.3 Long and further extended lifetime of low-carbon energy technologies

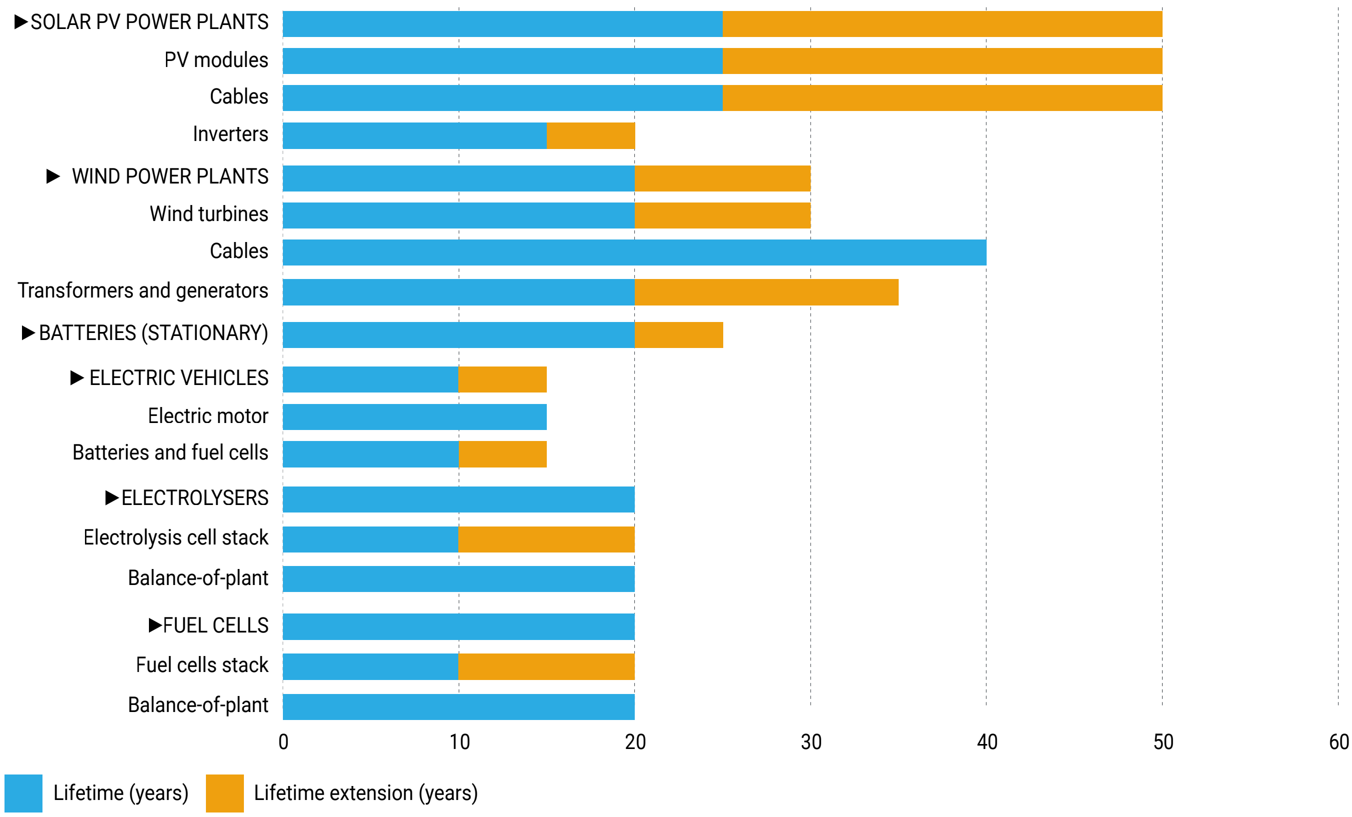
The materials used in current products will not be available for recycling until they reach their end-of-life (figure 4.4). Moreover, in-use dissipation may delay the reintroduction of metals into the supply chains within modern and more useful products (Ciacci *et al*. 2016). Given the long lifetime of low-carbon energy technology products, recycling is therefore not estimated to be able to substitute at scale for primary material until at least 2040 or later (figure 4.5). Whereas this gives stakeholders time to prepare for wide-scale recycling, it means that recycling cannot help much with near-term material supply.

Figure 4.4: The delay of metal flows between current use and future recycling



Source: UNEP (2011, p. 23).

Figure 4.5: Guaranteed lifetimes and extended lifetime assumptions for different low-carbon energy technologies in years



Note: Each technology is noted with an arrow (▸) and its components are indicated underneath.

Data source: Simas *et al*. (2022).

The extension of the lifespan of a product beyond its manufacturer's guarantee may cause delays for the availability of scrap stock for recycling. Moreover, some manufacturers and maintenance companies of low-carbon energy technologies provide lifetime extension services. For instance, Siemens Gamesa does this for wind turbines and add an additional 10 years of lifetime for their products (Pakenham *et al*. 2021).

Another factor is the repurposing of low-carbon energy technologies upon completion of their initial lifespan. Electric vehicle batteries are assumed to reach the end-of-life stage once they lose 20 per cent of their ex-factory capacity. After this stage, users may choose to continue to use their electric vehicle, sell it, change its battery or repurpose the battery depending on the safety and economic returns of each option. Indeed, the batteries can be used for stationary energy storage at homes and industrial sites (Simas *et al*. 2022). Some original equipment manufacturers, such as Renault, 'lease' their cars' batteries as a service and do not sell it as a product, thus retaining the decision over the end-of-life route for spent batteries. Solar photovoltaic panels can retain more than 80 per cent of their ex-factory power generation efficiency even after 25 years. The second-hand market for used photovoltaic panels is already growing and it is very unlikely that panels with a roughly 80 per cent efficiency rate would go into landfill (Gate C and Green Purposes Company 2023). Reducing electricity consumption and personal transportation could also help to reduce the material needed while extending the lifetime of low-carbon energy technologies. Indeed, consumers might use the electric vehicles or home energy storage system years after reaching their design lifetime. The availability of metal stock for recycling can therefore be impacted by other circular economy approaches, such as the extension of the lifetime, the reduction of consumption and the repurposing of end-of-life equipment. There are significant research gaps calling for studies of life-cycle assessment and material flow analysis to guide political and industrial decision-makers as to the most sustainable resource use practices involving low-carbon energy technologies.

4.3.4 Increasing product complexity and obsolete infrastructure

The pace of introducing new products with new materials can quickly render recycling facilities, technologies and infrastructures obsolete. Difficulties with the collection, separation or disassembly, sorting and recycling of new generations of devices can cause many products to end up in litter bins (UNEP 2011; UNEP 2013).

The recycling of some low-carbon energy technology materials can be constrained by quality requirement for high-purity metals. Base metals used for structural parts of the low-carbon energy technology, such as aluminium used in the frames of solar photovoltaic panels and copper in almost every low-carbon energy technology, keep their original quality on recycling and therefore can be recycled without needing cutting-edge recycling techniques (Carrara *et al*. 2020; Hund *et al*. 2020). However, not all recycling processes can achieve high purity levels where required, for example, in respect of silicon, which is used in around 85 per cent of photovoltaic panels deployed annually (Fraunhofer Institute for Solar Energy Systems 2020). In silicon supply chains, the recycling almost always ends up with downcycling. The solar panel industry often uses the silicon downcycled from the electronics industry, which requires the purest silicon available on the market. Solar-grade silicon downgrades to construction-grade silicon on recycling, which is far from achieving circularity for solar panels (Bradford 2008). Similarly, the cobalt used in lithium-ion batteries requires high purity levels (Hund *et al*. 2020), which may not easily be achieved via basic recycling techniques.

Figure 4.6: Differences between a natural ore and human-made 'ore'

NATURAL ORE	HUMAN-MADE 'ORE'
	
A lead-zinc ore with grey galena (lead sulphide) and dark shiny sphalerite (zinc sulphide) crystals. Natural ores frequently comprise less than five minerals (exceptionally up to ten) in frequently geometrically simple assemblages. In this sample, there are two main metals and probable several by-products (cadmium, indium in the sphalerite; silver in the galena).	An electronic motherboard can include 60 different elements, mostly included in very complex, miniaturized assemblies, involving solder, paint, varnishes, ceramics, glass fibre and polymers. This anthropic 'ore' is much more complex and costlier to process than natural ores, except for some easy-to recover metals, such as gold. Nanotechnologies will add to the complexity.

Source: Authors (left photo) and Mewtu, Wikimedia, licensed under the Creative Commons Attribution 2.0 Generic licence (right photo).

Human-made 'ores' have a typically more complex material composition than natural ores (figure 4.6). The former is comprised of a wide range of materials, including metals, plastics, glass and other non-metallic materials, which are often combined in complex ways to create products such as electronic devices. The process of separation can be complicated and challenging owing to the different physical and chemical properties of the various materials in the device. For example, the plastics and glass components of a solar photovoltaic panel can make the device more difficult to process because they can interfere with separation techniques that are optimized for metals. Furthermore, different types of electronic devices can have different compositions and structures, which can further complicate the process of liberating the valuable materials from these products at their end-of-life (UNEP 2013; Richard *et al*. 2005). However, it must also be noted that, despite growing product complexity, the recycling of end-of-life products and 'urban mining'[65] still offer higher metal concentrations than underground ores. As an example, end-of-life lithium-ion batteries contain much higher levels of transition minerals than ores. It is estimated that one metric ton of lithium-ion batteries contains 7-20 per cent of cobalt, compared to 0.3 per cent of cobalt in a natural ore. The lithium content in ore is 0.4 per cent, while it is over 3 per cent in spent batteries (Gate C and Green Purposes Company 2023). There are therefore opportunities to tap resources in end-of-life low-carbon energy technology, if economically feasible processes are available to recycle them.

Moreover, waste that includes reactive transition minerals, such as end-of-life lithium-ion batteries, involves toxicity and other risks (Winslow *et al*. 2018). Lithium-ion batteries can easily catch fire during the recycling process and some pilot lithium recycling plants have been burned down. These cases raise concerns about the health and safety aspects of recycling, which need to be resolved by reliable secondary production (Gate C and Green Purposes Company 2023).

Another problem is that the recycling of complex products often takes place in primary production facilities. This reliance on primary production can have long-term consequences for the sustainability of recycling in a country. For instance, if the expertise on the extraction and refining of a metal is lost, the recycling of the metal is also likely to be brought into question (UNEP 2013).

4.3.5 Logistics of transition mineral recycling

The logistics involved in transporting end-of-life transition mineral scrap present formidable challenges. This is particularly evident in the context of low-carbon energy technologies, where the rapid adoption of these technologies results in the generation of substantial amounts of spent products and components. The sheer volume, weight and varying compositions of these end-of-life low-carbon energy technologies complicate transportation logistics, requiring specialized handling and careful consideration of environmental and safety regulations. Moreover, the lack of standardized processes and infrastructure designed for the recycling of such transition minerals adds layers of complexity to their transportation, underscoring the need for a strategic and comprehensive approach.

A closer examination of the specific case of end-of-life lithium-ion batteries from electric vehicles reveals intricate logistical challenges. The surge in electric vehicle sales will translate into approximately 250,000 metric tons of spent lithium-ion batteries by the early 2030s, creating a demand for efficient collection and transport systems. The distance between end-users and pre-processing and processing facilities could substantially shape the economic and environmental costs of recycling. The irregular shapes and weights of electric vehicle batteries necessitate specialized packaging and transportation, adding to the overall logistical complexity. Furthermore, the current lack of standardized procedures for disassembling and transporting end-of-life lithium-ion batteries poses a challenge in ensuring safe and environmentally sound recycling practices (Nguyen-Tien *et al*. 2022). Addressing these logistical intricacies becomes imperative to streamline the recycling process and harness the value of transition minerals efficiently.

65 While recycling is a key component of urban mining, the concept of urban mining encompasses a broader scope, including the extraction of materials from various urban (waste) sources beyond traditional recycling streams. It is aimed at maximizing resource recovery and promoting circularity by recovering valuable materials from urban waste and reintroducing them into the production cycle. For more information on the applications of urban mining, its potential and limitations, see Arora *et al*. (2021); Kakkos *et al*. (2020); Markopoulou and Taut (2023); and Tercero Espinoza *et al*. (2020).

4.3.6 Variations in (pre-)processing streams

The secondary supply of each low-carbon energy technology raw material is highly influenced by the pre-processing stage for that material. The variation in end-of-life pre-processing routes has a considerable impact on the quality and economic viability of material recovery. If there are too many input streams, the desired quality may not be achieved for scrap. The variability in end-of-life pre-processing routes has a significant impact on downstream processes in the secondary supply of low-carbon energy technology raw materials.

The difference of recovery rates between copper, a ubiquitous transition mineral, and transition minerals with more specialist uses have different challenges associated with their recycling processes. Recent studies projected that recycling can help us to meet 36 per cent of the total global demand for copper (Born and Ciftci 2024), 55 per cent for lithium, 58 per cent for battery-grade nickel and more than the total demand for cobalt (Maisel *et al*. 2023) by 2040 under various demand and use scenarios driven by climate policies.[66] Base metals such as copper are employed in a large number of products and in much higher quantities, leading to numerous processing routes at their end-of-life (Henckens and Worrell 2020). While this would mean that there is already an abundant scrap stock of copper owing to its various applications in vast quantities over a century, this diversified distribution of copper-containing scrap poses challenges and uncertainties about their collection and recycling (Born and Ciftci 2024). For example, it may not be possible or economically feasible to recover some of the old copper scrap owing to its location and now-reduced concentration, such as end-of-life copper pipes under the ground. On the other hand, most of the secondary lithium input for electric vehicle batteries is estimated to come from a single product type, end-of-life lithium-ion batteries, a future stock that began to accumulate in the last decade (Meng *et al*. 2021). Recyclers will thus need to wait until the mass decommissioning of electric vehicle batteries for scrap stock of lithium-ion batteries to become available. However, as opposed to the case of copper, there will be far fewer end-of-life battery streams, meaning that collection and recycling efficiency rates[67] could reach about 95 per cent for lithium, nickel and cobalt-containing components of lithium-ion batteries, meaning end-of-life recycling rates of nearly 90 per cent. These transition minerals are estimated to see an unprecedented demand in the next few decades, mainly concentrated in a few product types. While the capacity of recycling to meet the material demand is estimated to be low in the next decade for ‘niche’ transition minerals, a closed material loop could thus be a more approachable target for them over the long term than base transition minerals.

4.3.7 Target-setting and key performance indicators for recycling

In the metal manufacturing industry, a problematic practice is the material-centric approach. The latter is focused on the recycling rate of a single substance used in different products, such as principal metals, and views other potentially recoverable (companion) metals as impurities or waste. This can result in neglect of the recovery of transition minerals that are found in low quantities. For instance, if the recovery of steel is prioritized in the recycling of automotive components, transition minerals that have been used in alloys, such as niobium, may be lost in the process (van Schaik and Reuter 2014). Moreover, it can be useful to recover and recycle certain components of low-carbon energy technologies as a whole within their recycling loops, for example, the permanent neodymium-iron-boron magnet alloys used in direct-drive wind turbines and electric vehicles (Diehl *et al*. 2018).

The achievement of recycling policy objectives is often measured by the end-of-life recycling rate of materials, which is also used to measure the efficiency of recycling systems. The imposition of minimum recovery requirements can be utilized as a useful approach to

66 The estimate of Born and Ciftci (2024) is based on the stated policies (STEPS) scenario of the International Energy Agency (2023), which mirrors existing policy frameworks, providing an evaluation of energy-related policies on a sectoral and national level, including those in progress. This scenario assumes a relatively conservative progress of decarbonization pathways, which is why the demand for the critical low-carbon energy technology materials is low and the mean share of recycling in the total supply is highest among other (announced pledges, around 34 per cent, and net-zero emissions, around 32 per cent) scenarios, noted above as around 36 per cent. The SSP2 benchmark of Maisel *et al*. (2023) presents a similar ‘bumpy road’ projection for the implementation of climate objectives and presents some of the highest recycling figures when combined with their ‘abundant materials scenario’, which is used above. Recycling rates in both papers correspond to the metals recovered within total end-of-life (old) scrap. See the papers for further estimations under different scenarios.

67 If high material recovery is achieved as suggested by early laboratory experiments (Dominish *et al*. 2019; European Commission 2023b).

reach higher end-of-life recycling rates.[68] However, material recovery is driven by the technologies and economic dynamics of a given time. This means that identical end-of-life products can generate different amounts and quality of metals at the end of recycling processes at different times. It is difficult or impossible to predict economic dynamics (e.g. price movements) or technological developments beyond the short term. Recycling rate targets set by policymakers should therefore be regarded as points in a distribution of uncertain shape (UNEP 2013), the actual outcome of which will depend on economic developments and technological progress.

Furthermore, strict minimum recovery thresholds could lead metal producers to report inflated recovery rates via ineffective approaches. To begin with, recycling may be prioritized over other circular economy approaches for the sake of hitting the recycling targets. For example, perfectly repairable or remanufacturable wind turbines and solar photovoltaic panels could be retired and disassembled for recycling to meet minimum end-of-life recycling targets or minimum recycled content requirements for new products. Second, efficiency indicators for recycling often do not distinguish between new and old scraps,[69] which can be misleading when evaluating the overall effectiveness of recycling efforts. New scrap is relatively easier to collect, transport, separate and process compared to old scrap. While achieving high recycling rates for new scrap is relatively more straightforward, it is important not to overlook the improvement of processing old scrap, which poses greater challenges owing to potential contamination, variability in composition and the need for advanced separation and sorting techniques. Finally, the reporting of inflated recycling efficiency can also occur when crucial metallurgical steps of material recovery are omitted while calculating recycling rates. Current European Union waste legislation, such as the directives on end-of-life vehicles (Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles) and electric and electronic waste (Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE), do not specifically consider the final smelting and refining processes. The rates calculated therefore tend to be higher compared to the actual material recovery rates. To conclude, it is essential to reassess existing practices of using the recovery rates of product masses or particular materials while ignoring key recovery stages.

4.3.8 Public awareness of recycling

The collection of household waste is highly linked to consumer behaviour. Many individuals tend to store unused products at home as backups that never or rarely come to be used, or send them to mixed-waste streams. Depending on the formal or informal character of the routes and the cultural characteristics of a country, policies and public-awareness campaigns can be helpful to reducing losses in the collection of consumer waste.

Policymakers may disregard the recycling of certain metals with a low unit value, when recycling at scale might be economically viable and help to meet the demand for transition minerals. The metal composition in municipal solid waste varies between 3 per cent and 6 per cent in low to middle-income countries, with the latter also generating more municipal solid waste (Goorhuis 2014). Currently, public-awareness projects for recycling hardly extend beyond local campaigns concerning municipal solid waste. At the national level, few information campaigns on recycling are aimed at raising awareness among lower-income and younger groups (Prestin and Pearce 2010). The economic, societal and environmental benefits of recycling must be better communicated and understood to create a more favourable policy environment (Worrell 2014).

68 See e.g. the recently proposed Critical Raw Materials Act (European Commission 2023a), which introduces benchmarks for recycling input rates for strategic raw materials. Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC, in effect since June 2023, specifies end-of-life recovery rates and end-of-life recycling input rates for designated battery raw materials. Similarly, the Republic of Korea also sets minimum recycling rates for its core minerals (Suk-yee 2023).

69 New scrap refers to discarded or waste materials that are generated during the production or processing of a mineral or metal. This waste material may include excess or unused raw materials, by-products or materials that do not meet quality standards. New scrap is distinct from old scrap, which refers to discarded or recycled materials that have completed their useful life cycle and are collected for recycling purposes. New scrap in mining typically consists of materials that have not yet been utilized or incorporated into any final product, and it may be subjected to recycling or waste management practices to minimize environmental impact and maximize resource efficiency.

4.3.9 Social and environmental costs of recycling

In economics, the term 'social cost' refers to an estimate of the economic cost incurred by society owing to an economic activity or policy.[70] The social cost in this sense includes the costs of environmental and other externalities.

Social cost is not necessarily realized but is rather anticipated to manifest upon implementation of an economic decision. While calculating the cost, the social benefit of such a decision is deducted, which could mean a negative social cost in instances where the positive impacts or advantages of the decision outweigh the associated negative consequences, contributing to a net gain for society. Whereas the assessment methodologies could differ, the concept of social benefit typically compares the positive impacts to the costs of alternative (less detrimental) activities.

The social cost of recycling refers to the estimated costs of negative impacts caused by recycling. The social cost can be considered with the economic, societal and environmental benefits generated by recycling to determine its net societal benefit. This net benefit can, in turn, be compared to the societal benefit of mining (also accounting for negative social and environmental impacts) to determine the relative societal cost or benefit of recycling.

Industrial and political actors tend to look at only the economic cost of recycling against the price of a mineral or metal when deciding whether recycling of a metal is an economically viable production option, e.g. as demonstrated by the comprehensive study of Lander *et al*. (2021). However, a purely revenue-oriented approach could bring in revenue in the short term, but may incur high costs in the long run from the impacts of unsustainable mining practices or their remediation. So far, the exclusion of relative social costs in the making of investment decisions has disproportionately benefited primary rather than secondary producers (McCarthy and Börkey 2018).

The impact pathway approach is a method used widely to measure the social cost of recycling.[71] The approach links the impacts of economic processes to their environmental burdens, and then values these impacts economically. It begins by determining the overall emission levels and external effects in physical terms. It then assesses the impacts of these effects on economic activities and human well-being, followed by translating these impacts into monetary values. One advantage of this approach is that it allows the costs of environmental improvements in the waste sector to be compared with their benefits. However, there are challenges in valuing external effects, as they occur outside the market and require special estimation techniques. Additionally, when external effects occur at multiple locations, values estimated at one location must be transferred to others, leading to a high degree of uncertainty in economic valuation (van Beukering *et al*. 2014). Despite its challenges, measuring the social cost can provide decision makers with a more comprehensive assessment of the costs and benefits of recycling.

Recycling metals used in low-carbon energy technologies brings numerous social advantages, spanning environmental conservation, economic efficiency, biodiversity, energy savings, resource conservation, job creation, technological advancements and enhanced resource security. The environmental benefits include reduced emissions, with recycling processes emitting less carbon dioxide than primary production and decreased land use, minimizing the environmental impact of mining (Grimes *et al*. 2008; Grimes *et al*. 2016). Economically, recycling is often more cost-effective than mining, eliminating expensive extraction processes (McCarthy and Börkey 2018). Furthermore, recycling contributes to energy efficiency, requiring less energy than producing new metals, and aids resource conservation, contributing to material security. Support for recycling can help to foster employment in the recycling industry and related sectors, such as transportation. Recycling also drives technological innovation, leading to more efficient recycling processes. Importantly, recycling diversifies supply and increases resource security for transition minerals deemed critical by various nations. It helps to mitigate dependence on

70 Social cost is often calculated in United States dollars and encompasses both private costs and externalities. A comprehensive social cost assessment would also include the estimated benefits (social benefit) of any action or decision taken to mitigate any activity or decision with a social cost. Private costs are the costs directly borne by the individuals or firms engaging in the economic activity, while externalities are the costs imposed on third parties who are not directly involved in the activity. For instance, when calculating the social cost of carbon emissions caused by a coal power plant, the costs of emissions borne by the plant owing to the requirement of increased safety measures for its workers would constitute private costs. The costs that will need to be undertaken by society to address any (physical, health or environmental) impacts of the emissions and other negative externalities caused by the power plant are part of the external costs.

71 See the Appendix (Appendix 4) 4 for a diagram of the impact pathway approach (figure 4.A) by van Beukering *et al*. (2014).

imports, reducing supply risks. Additionally, recycling reduces waste sent to landfill, promoting resource conservation and pollution reduction. Finally, embracing a circular transition, including by acquiring raw materials through recycling, aligns with the ethos of the energy transition by minimizing environmental pollution from mining activities.

The net social benefits of recycling hinge on several determinants, notably labour practices, environmental impact, regulatory standards, scale of operations and geographic location. Labour practices play a critical role; inadequate protection and compensation, along with hazardous working conditions, elevate the social cost. The environmental impact, if not regulated, can result in pollution and health risks, contributing to higher social costs. Regulatory standards and oversight levels strongly influence the social cost; lax regulations can lead to negative social impacts. The scale of recycling operations, while affecting economic costs per unit, magnifies social costs, especially on local communities and the environment. Additionally, the geographic location of recycling operations matters; areas with stringent environmental and labour standards generally incur lower social costs compared to regions with less stringent regulations (Lander *et al*. 2021).

4.3.10 Informal recycling systems

Many of the transition minerals required to produce low-carbon energy technologies can be acquired through e-waste streams other than low-carbon energy technologies from households, end-of-life vehicles and renewable energy generation plants. Experience with consumer e-waste shows that advanced economies tend to use more formal recycling routes, whereas emerging and developing economies opt for more informal recycling systems. Formal systems tend to be more capital-intensive and industrialized, whereas informal routes are more reliant on low-cost labour in most stages. Both systems have their own advantages and disadvantages on the efficiency of recycling stages, as well as sustainability implications.

The literature on informal recycling systems in developing countries presents insights on their benefits and risks. On one hand, the informal sector provides an essential service by collecting waste and generating income. By collecting and removing the potentially hazardous waste from urban areas, they contribute to public health, reduce costs associated with municipal waste management and recover valuable materials that would otherwise be lost (Dias 2012). Panasiuk *et al*. (2022) investigated steel samples from countries with varying levels of gross domestic product (GDP) and observed that nations employing more manual sorting of scrap produced cleaner steel compared to higher GDP countries relying on mechanical scrap sorting. On the other hand, informal waste management poses significant health risks to the workers involved. Workers are exposed to injuries, diseases and acute and chronic effects owing to their daily contact with waste and toxic chemical compounds,[72] as has been observed with electrical and electronic equipment waste streams in China and India (Sangeeta *et al*. 2023; Sepúlveda *et al*. 2010). In addition, informal waste management workers are often ascribed the lowest social status owing to the common association of waste being dirty. Furthermore, without binding rules and regulations, only end-of-life materials with a relatively high economic value are recovered using low-cost technology, labour and practices. Other materials with no monetary incentive are either not collected, get put in landfill or are incinerated, which can have adverse effects on the environment and on human health (Schluep 2014).

While consumers in developed countries indirectly pay for the recycling of their metal waste through their taxes, the collectors usually pay consumers to obtain their scrap in developing countries. It could therefore be assumed that the economic benefits of recycling for consumers is more evident in developing nations. Because many people are willing to be paid for their waste, collection rates can reach up to 95 per cent of the total waste. Furthermore, the informal recycling chain is labour-intensive and composed of a network of businesses and individuals, creating many jobs. As in the collection stage, the pre-processing treatment of metal scrap would involve more manual labour in developing countries than mechanical processes, which are more common in developed countries. The manual sorting leads to higher metal recovery efficiency, low capital cost and more employment. The final scrap processing through the formal route can yield higher recovery efficiency and lower losses than the informal route (UNEP 2013), given that the formal systems often use more sophisticated technology. However, an inherent

72 An example of such compounds is toxic fumes that arise when burning casings or motherboards to recover some valuable metallic compounds.

problem in developed countries is the lack of incentives at the collection stage, which is particularly observed when other waste management options, such as landfill and incineration, incur lower costs or higher profits than recycling (McCarthy and Börkey 2018).

The presence of an open market for recovered metals is key to the achievement of high-purity content in informal recycling streams (Panasiuk *et al*. 2022). In the absence of market regulation and legislation, however, there is a risk that the recycling industry may be susceptible to unethical and unsafe practices (Zhou *et al*. 2019). In particular, workshops with poor qualifications may offer higher prices to collect waste low-carbon energy technology materials as they have lower investment costs in safe and environmentally-friendly recovery technologies. This can lead to these workshops dominating the market of regular recycling businesses, resulting in a situation where 'bad money drives out good money' (Wang and Chen 2013). Such market structure may result in reduced end-of-life material input into formal recycling streams, which already constitutes a great concern for end-of-life electric vehicles (Yu *et al*. 2023). Indeed, between the lack of regulation, the small scale of formal streams and immature technology for intra-electric vehicle industry cycles, some unscrupulous businesses may push electric vehicle batteries into industries such as the electric bicycle industry.

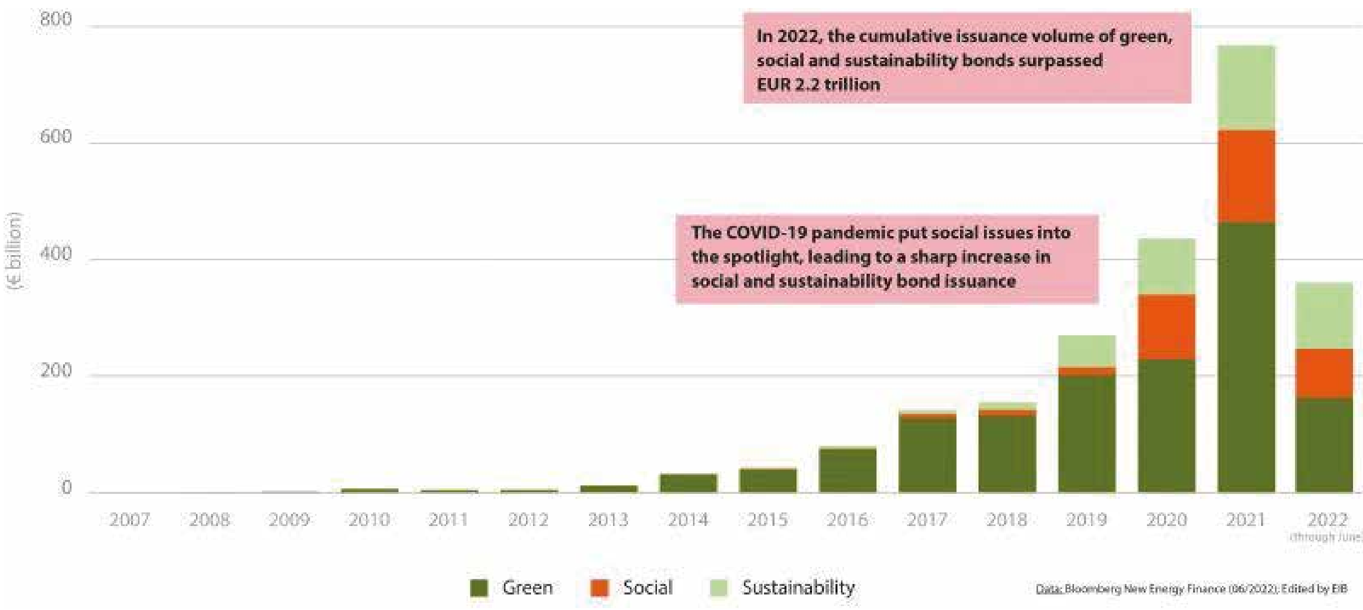
4.4 FINANCE FOR RECYCLING

It is possible to identify at least seven means through which private and public actors could provide support for secondary metal producers. Green bonds are financial instruments issued by governments, municipalities or private entities to raise funds for projects and initiatives that have a positive impact on the environment. Green bonds are different from regular bonds because they have non-financial clauses on the use of proceeds. Public (debt) finance is provided by government and multilateral lenders as part of public investment finance for material sorting, re-melting and reprocessing companies. Public funds could be provided either directly for recyclers or through facilitation of private investment finance. Impact investing, mainly undertaken by private actors, involves investing in companies, organizations or funds with the primary goal of generating a quantifiable and advantageous social or environmental impact while also receiving a financial return. The source of capital can be private banks, pension and wealth funds, financial advisors or family foundations, as well as public investors (government and development finance institutions). Public finance can be strategically combined with private capital to fund recycling and other circular economy projects, in the form of blended finance. The fifth form to be identified is public-private partnerships, which are used by governments to provide public infrastructure or services through long-term contractual arrangements that involve the private partner financing the projects in exchange for long term repayment by governments or users. Government may also introduce tax provisions, such as differential support through corporate income or other taxes in the forms of tax breaks and value added tax (VAT) reliefs, to incentivise the recycling industry. Finally, induced transfers pertain to policies that are aimed at increasing the availability of scrap from municipal solid waste streams, such as the implementation of landfill taxes, extended producer responsibility regulations, and the public provision of waste collection and management services.

What follows in this Chapter is a description of these instruments as they relate to recycling and waste management, Further details of such financing in relation to mining are given in Chapter 6.

Green bonds are specifically earmarked for environmentally friendly and sustainable projects (i.e. sustainability-linked bonds), including those related to transition mineral recycling. The issuance of green bonds has significantly risen in volume since the introduction of the first green bond by the European Investment Bank in 2007, cumulatively reaching €2.2 trillion in 2021, although there was a decrease in issuance in 2022 (figure 4.7). Green bonds can be issued by banks, as well as metal recyclers wishing to finance their new investments. Novelis Inc., one of the largest aluminium processors, announced the issuance of green bonds to finance new recycling projects and low carbon energy infrastructure for its recycling plants in March 2021 and March 2023, reaching a cumulative value of more than €750 million (Novelis 2023).

Figure 4.7: Green bond issuance by year. 2022 data extends until June



Source: European Investment Bank (2022).

Public debt finance is often provided by national budgets and can come in the form of (non-repayable) grants, concessional debt financing or loan guarantees. Such financing helps to fund projects that would not have been funded by capital markets owing to their low 'bankable feasibility'[73] (UNEP 2013). By reducing interest repayment costs, public finance increases the profitability of individual projects, which can encourage firms to enter the market and increase investment in the sector in the short term. This can also serve as a proof of concept, which reduces the risk profile of similar projects and facilitates private investment in the longer term. Government-led investments and finance contribute significantly to the growth of the Chinese recycling industry (Ruan et al. 2023). The Asian Development Bank, the European Bank of Reconstruction and Development, the European Investment Bank and the Just Transition Fund of the European Union are significant regional providers, while the German KfW banking group is among the national providers of public finance for secondary producers (McCarthy and Börkey 2018; United Nations Environment Programme Finance Initiative [UNEP FI] 2020; UNECE 2023a).

Impact investing is a relatively new but fast-growing source of finance available to recycling companies. Impact investors are private sector investors that focus on the potential to generate positive social, environmental and cultural effects alongside a financial return. They accept a below-market rate of return and often lower liquidity in exchange for impact (UNECE 2023a). Provided by a variety of lenders, impact investments are accessible through networks such as the Global Impact Investing Network, foundations and public and private funds. According to a survey by the Network (2017) conducted with 208 respondents with US$114 billion impact investments by 2016, up to 9 per cent of the assets belonged to companies in the sectors, including recycling and waste management.

In a blended finance approach, public funds, often from development institutions or governments, are combined with private sector investments to catalyse and support projects that might otherwise be considered too risky or financially unattractive by private investors alone. Blended finance mechanisms can take various forms, including concessional loans, guarantees, equity investments or other financial instruments that balance risk and return for all involved parties. They can be particularly powerful tools to attract private investors

73 In other words, the return from an investment is reliable and contains low risk. In the case of secondary producers, these refer to risks, such as high price volatility of scrap metal and the use of very recent and unproven methods.

for circular economy projects in low and middle-income countries. The Western Balkans Investment Framework of the European Union provides finance and technical assistance for strategic investments in various sectors, including waste management and recycling (European Commission 2020a; European Commission 2020b).

Public-private partnerships typically involve the joint delivery of large-scale recycling services and infrastructure projects. The private sector often participates in the operational aspects of a project, such as design, financing, construction, operation and maintenance. This business model has already been observed, as in the case of the financing of the Lynas Corporation, a rare earth elements ore processing and recycling company, by Japanese public funds (Reuters 2019; Patil *et al*. 2023). There are several guidelines published to support the implementation of public-private partnerships to achieve sustainability objectives, including the Guiding Principles on Public-Private Partnerships in Support of the United Nations Sustainable Development Goals of the UNECE (2019) and the related public-private partnership evaluation methodology for the Sustainable Development Goals (UNECE 2023b).

Tax benefits are usually provided in the form of corporate income tax reductions, deductions or credits. Tax provisions may not always be considered support measures per se but they can indirectly favour the recycling industry by reducing the cost of scrap and other inputs used for production. The United States of America, the Republic of Korea, China, Brazil and South Africa provide incentives for recycling waste or reducing material use. In this area, European countries appear to focus more on penalties than incentives (KPMG 2013). Recycling firms can also benefit from relief from VAT, e.g. VAT refunds and credits. Examples of VAT incentives for recycled goods (to be sold or used as inputs) are common in the United States of America, Mexico, China and the Republic of Korea (International Solid Waste Association [ISWA] 2015). Nevertheless, secondary producers benefit from tax holidays, corporate income tax reductions and tax credits to a much smaller extent than primary producers (McCarthy and Börkey 2018).

Induced transfers include landfill taxes and bans, sorted waste collection for recycling and extended producer responsibility requirements. Such waste management policies are designed to reduce the amount of waste sent to landfills or incinerators. Combined with reasonable minimum content requirements, these policies lead to an increase in the quality and quantity of scrap materials available for recycling, particularly in market conditions where recycling and take-back schemes are more lucrative than landfill. In the long-run, extended producer responsibility can also encourage manufacturers to develop less material-intensive and complex product designs. Induced transfers can be useful to tap into reserves of municipal solid waste, which are becoming an increasingly important source of transition minerals owing to the electronic content of household waste. Increasing public recycling services, such as kerbside collection and drop-off points, can have a positive impact on household recycling (Goorhuis 2014). Export restrictions ranging from documentation to taxes and bans applied by major ore and scrap producers can constitute another induced transfer. Indeed, major primary producers of transition minerals and metals, such as China, Indonesia, India, the Russian Federation and the Democratic Republic of the Congo, have employed restrictions on the export of metals including rare earth elements and cobalt in the 2010s, and germanium and gallium in 2023.[74] Even a minor change in the export tax rates or quotas could have major implications for global supply chains and metal prices, In turn, rising metal and commodity prices may increase the production capacity of recyclers owing to rising profit margins. Bans and quotas on metal scrap, the key input for secondary producers, typically have a limited impact on metal prices and availability compared to export restrictions on virgin materials. Export restrictions on metal scrap have been mostly applied by emerging economies, which accounted for only around 20 per cent of all scrap exports (by value) in 2014 (McCarthy and Börkey 2018).[75]

The support measures for recyclers are not exhaustive, but the list above specifically highlights the practical support provided, not merely theoretical options.
In recent years, private finance opportunities have significantly improved, with the United Nations Environment Programme Finance Initiative (UNEP FI) offering detailed documentation on available finance opportunities for businesses transitioning to a circular

74 https://www.reuters.com/world/china/china-exported-no-germanium-gallium-aug-due-export-curbs-2023-09-20/.

75 Note that some restrictions on scrap can take an indirect form. For example, end-of-life vehicles and specific types of electronic waste are classified as hazardous waste by European waste regulations, and it is forbidden to export them outside European Union member States. This policy effectively serves as a ban on exporting certain types of metal scrap but is not always considered as such.

economy, including recyclers of transition minerals and materials (UNEP FI 2020). The report not only outlines existing measures but also recommends extraordinary actions during crises, such as post-pandemic economic support programmes. Subsequent reports delve into frameworks for target setting and performance measurement (UNEP FI 2021; UNEP FI 2023) and illustrate the progress of banks, which are committed to the Principles for Responsible Banking, in incorporating circularity principles into their financial decisions (UNEP 2021; UNEP 2023).

4.4.1 Impact of support for primary and secondary production

Theoretically, low input costs and higher metal prices benefit both primary and secondary producers and most of the finance mechanisms available to primary producers are also available to secondary producers. In practice, however, secondary re-melters and smelters are less able to take advantage of lower input prices or higher output prices compared to their primary counterparts. There may be several reasons for this. Other than the technical limitations of the recyclers and market power of the mining industry, lower input prices have a limited impact if recycling plants are operating at a high capacity and the supply of scrap is limited. Moreover, only limited returns can be achieved by support measures that are aimed at increasing the secondary production of metals with already high recovery rates. Regarding the returns from investment, the same amount of support per unit made available for both primary and secondary producers does not result in similar levels of increase in the downstream output and yields better returns for the extraction sector (Zink *et al*. 2016). In other words, the provision of the same type and level of support to both industries tends to widen the gap between them in favour of mining firms.

Although the typologies of the support vary for primary and secondary production, extractive industries globally receive a lot more support from governments in relative (per unit of output) and absolute terms, reaching to the levels of billions of dollars.[76] Johansson *et al*. (2014) demonstrate that, regardless of their form, the subsidies introduced by the Government of Sweden are significantly higher for primary metal manufacturers. In the case of fiscal support mechanisms, a study by Scharf (1999) concluded that the Canadian tax system substantially favours using virgin materials rather than recycled materials for metal products. Fiscal assistance mechanisms are usually not targeted; they are therefore theoretically available to recycling companies. In practice, however, they are rather used by extractive industries. For instance, prolonged tax loss carry-forward frameworks are particularly favoured by primary producers to offset their current taxable income using their previously incurred financial losses in lengthy pre-production stages (McCarthy and Börkey 2018).

It appears that recycling support measures address market failures more effectively than those in the primary sector, where the measures often seem to be designed to attract investment. Moreover, the support measures for the secondary sector put less pressure on public budgets. A landfill tax generates revenue, extended producer responsibility schemes and recycled content labelling are budget neutral, and public recycling collection is usually covered by the sale of recyclables and municipal waste charges (McCarthy and Börkey 2018).

The effect of support for primary and secondary production may vary in the short and long runs. Let us consider the use of export restrictions as an induced transfer. In a domestic setting, implementing restrictions could initially reduce the availability of metal feedstock to foreign companies, potentially lowering metal prices and benefiting downstream processors in the home market. However, in the long term, decreased prices might disincentivize both primary and secondary producers from maintaining production levels. Moreover, domestic support measures can have global implications when the support mechanisms are introduced by a major mineral or metal producer. For example, reduced metal flows owing to export restrictions introduced by a significant primary producer could lead to global price increases, enhancing the competitiveness of secondary producers compared to primary ones in the short run. If the restrictions stay in place for a long period, the infrastructure could adapt to the conditions, e.g. by increasing investment into secondary production or exploration of new mines.

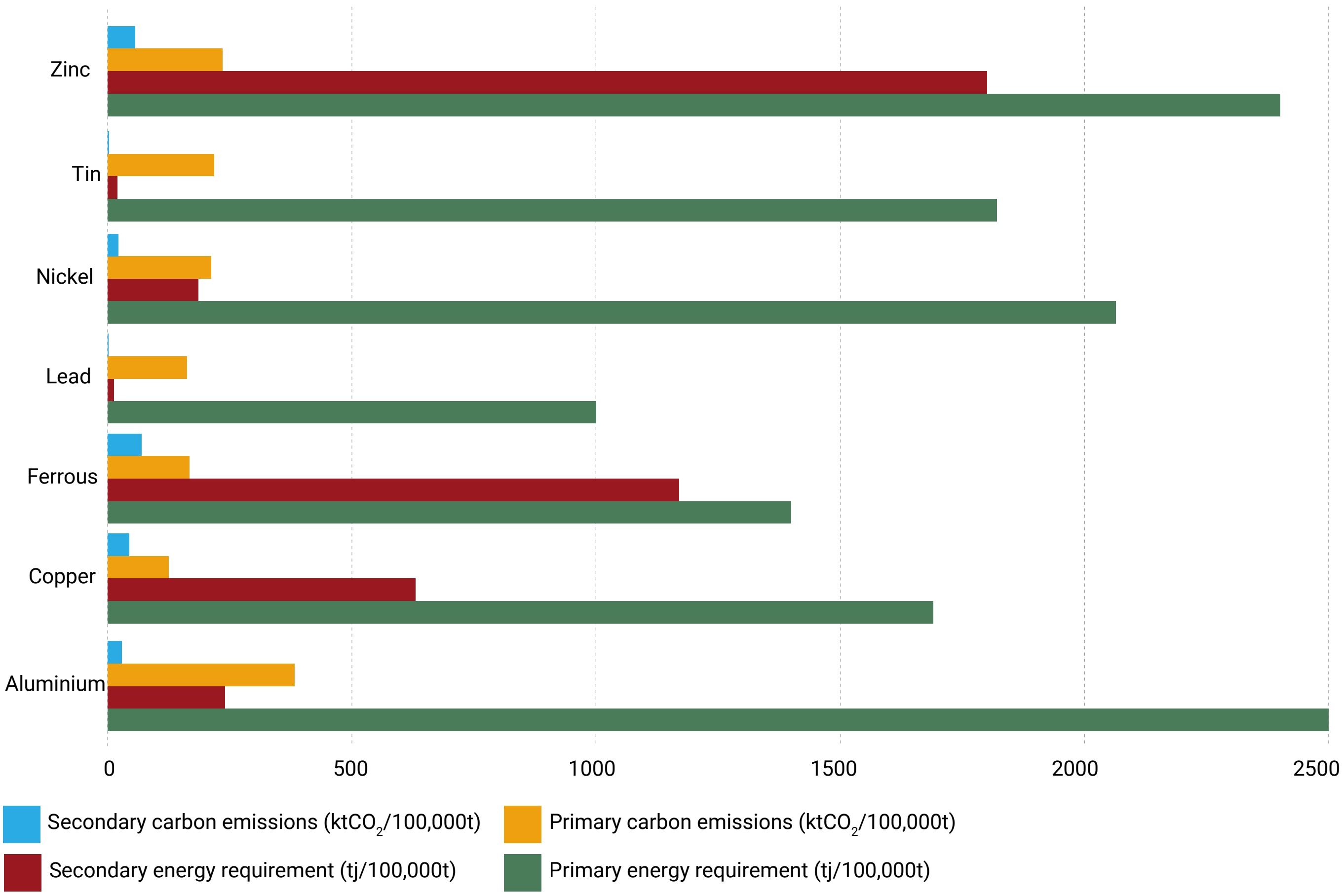
Financial support mechanisms for primary and secondary productions also have environmental impacts. The environmental footprint, water and energy consumptions of mining are generally much higher than those of recycling. Primary production processes often lack adequate regulation of environmental externalities but the available evidence indicates that the industry

76 See Chapter 5 for a more detailed review of finance of primary production.

often has higher carbon and energy footprints than recycling. Figure 4.8 shows that in the production of key transition minerals such as aluminium, copper and nickel, extractive activities respectively consume 10, 3 and 11 times more energy than recycling and have 13, 3 and 10 times the carbon footprint of recycling. The widening of the gap between primary and secondary production (e.g. by using indiscriminate support measures) can thus actually serve to increase the negative externalities of the former on the environment. Such effects need to be laid out more clearly in evaluations. While there are assessment methods for potentially environmentally harmful subsidies for European energy, agriculture and fisheries sectors, there are currently no quantitative cross-country evaluations for environmentally harmful subsidies provided to mining and recycling industries.

The effects of past recycling support experiences on the overarching resource management objectives and the environment could provide useful guidance for stakeholders when designing new mechanisms and revising existing ones (see table 4.1). Owing to the difficulties associated with quantitative measurement of the impacts of support,[77] an overview of actual and potential effects is presented here.

Figure 4.8: Energy consumption and savings (in terajoules/100,000t) and carbon footprint and savings (kilotons of carbon dioxide/100,000t) required per 100,000 metric tons of primary and secondary productions for 7 selected transition minerals



Source: Grimes *et al*. (2008).[78]

77 For example, the landfill taxes may provide indirect benefits to recycling companies by increasing the size and quality of feedstocks. However, the exact impact of a tax raised on feedstock (price, quantity and quality), and metal collection and processing rates is difficult to quantify and measure.

78 The Bureau of International Recycling released an updated version of the 2008 report in 2016 using data collected by literature review (Grimes *et al*. 2016). Although the data from two versions is very similar (which also shows the accuracy of the authors' conclusions), the 2008 version based on real data collected from the industries is used here.

Table 4.1: Review of the impact of economic instruments to support recycling

Subject of research	Main findings	Reference and type of research [empirical/theoretical]*
Quality promotion and information campaigns	Quality promotion and targeted information campaigns can improve recycling rates, especially among lower-income and younger recycling groups. Crowding-out effects and reduced service quality observed in mandatory recycling, especially when expanded to new materials in high-burden areas.	Halvorsen (2012) [empirical]
Virgin material taxes	Taxes reduce the extraction of virgin materials but prove ineffective in stimulating recycling, reducing extraction externalities or preventing the import of untaxed resources.	Söderholm (2011) [theoretical and empirical]
Welfare gains from reduction and recycling strategies	The benefits of reducing greenhouse gas emissions in the production of consumer goods are as significant as or greater than those of reducing solid waste disposal. Cost-optimal waste reduction levels vary widely by material. Direct recycling subsidies are less cost-effective than deposit or refund or advance disposal fees in achieving emissions reductions.	Acuff and Kaffne (2013) [theoretical]
Extended producer responsibility	In the long run, optimal efficiency is achieved through a subsidy on recyclability and a tax on the purchase of durables. On the short-run adjustment path, policy instruments may have different signs, harming recyclability while promoting demand for durables. A deposit–refund system is demonstrated to achieve efficient allocation both in the short and long run.	Eichner and Runkel (2005) [theoretical]
Legislation impact on profitability and feasibility	Constraints on recycling operations and the use of recycled materials owing to legislation that has an impact on various aspects, including landfill costs, transportation costs, energy costs and limitations on waste import and export. The balance between labour and energy costs affects technology choice and the profitability of using new versus recycled inputs. Supporting innovation in technological development or commercial applications can introduce new and more efficient technology.	UNEP (2013) [empirical]

** Theoretical papers denote those developing their findings through models or equilibrium frameworks, exploring hypothetical scenarios to derive insights. Empirical papers are those relying on the analysis of adopted policies, investigating the real-world impact through data, observations and practical evidence.*

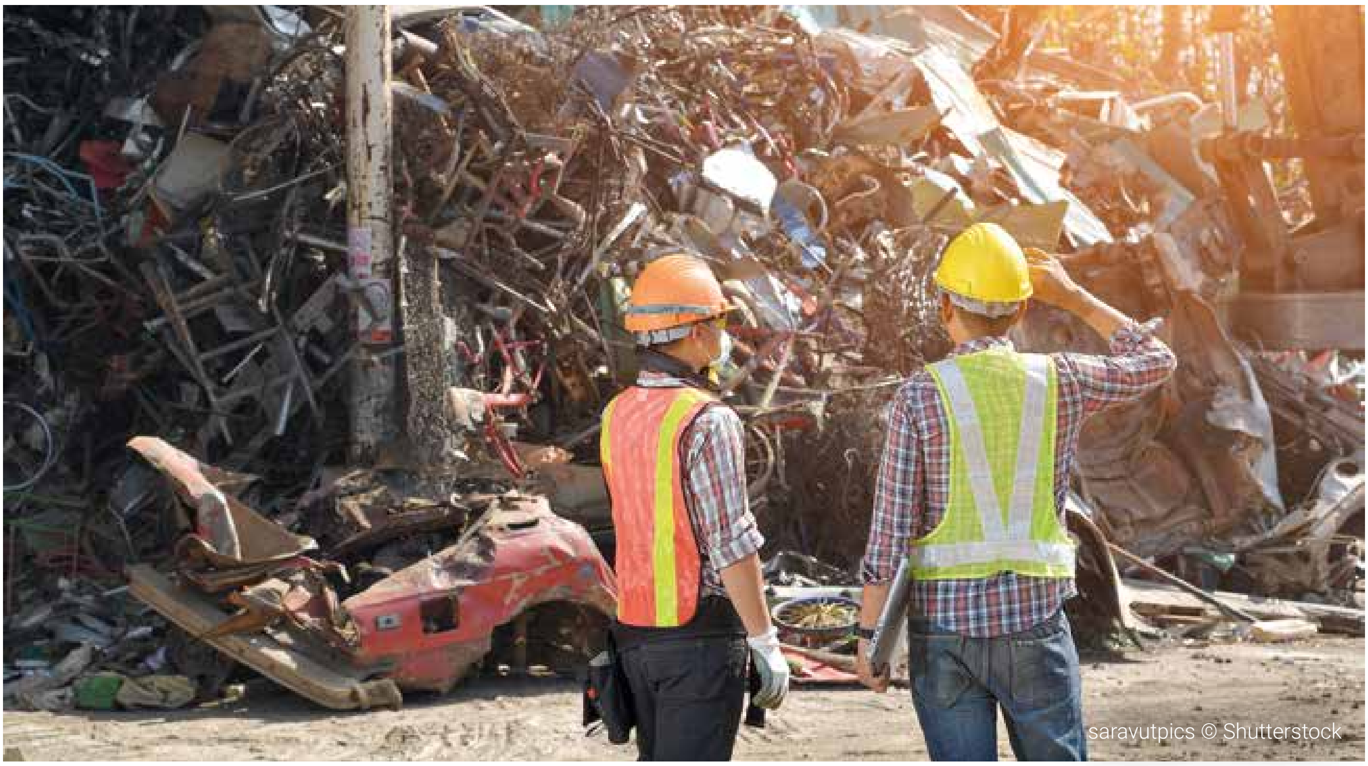
Source: Authors

4.4.2 Financial support for the recycling of transition minerals

Financial support is of vital importance for transition mineral recyclers at the early stages of their business. Lander *et al*. (2021) estimate that (particularly domestic) recycling of batteries can be a profitable business if it is scaled up. However, the economies of scale could mean that incumbent companies and countries would be in a favourable position in the future. This could in turn pose high barriers to entry for new companies and countries wishing to develop their own recycling business and policies. Policy support, particularly in forms of tax reliefs, subsidies and financial incentives would be crucial to sustain the market entry of new players.

To increase the end-of-life recycling rates of copper and nickel, certain policy measures can be implemented to ensure positive financial returns. One measure involves holding the producers of copper- and nickel-containing products accountable for recovering these materials from their products (Henckens *et al*. 2019) . Another measure includes mandating the recycling-oriented design of such products (van Schaik and Reuter 2014). In addition, support for the innovation of electronic labelling of parts within copper- and nickel-containing products can help to facilitate their separate collection and selective dismantling. The disposal of copper- and nickel-containing products can be strictly limited or taxed, while subsidies can be given for the use of recycled copper and nickel. Taxing the sale and import of primary copper and nickel could also be an option to dissuade buyers from relying on virgin raw materials in their supply chains.

Table 4.2 presents an overview of some recent funding arrangements for recycling facilities around the world. The table includes funding agreements that were concluded between 2020 and September 2023 (compiled through desktop research of publicly available sources in English). The contracts for the creation of joint ventures or a company's subsidiaries in other countries are not included. Based on the table, it can be said that there is a growing trend in funding deals for recycling facilities around the world, with several countries investing in the recycling of metals used in electric vehicle batteries, permanent magnet metals such as rare earth elements, and solar photovoltaic panel materials. The facilities are receiving public finance, including grants and debt finance, as well as private investment, including impact investing. The amount of finance provided to secondary producers generally varied from US$500,000 to US$40 million, with some exceptional projects in the United States of America and China receiving finance worth hundreds of millions of dollars. The capacity of these recycling facilities is expected to increase over the next few years, with operational targets set for 2023 to 2027.



saravutpics © Shutterstock

Table 4.2: Examples from recent funding deals for metal recycling facilities for low-carbon energy technologies around the world (2020–2023)

Location	Companies	Financier	Metals covered	Size and other information about the facility	Types of finance	Source[79]
Australia	Lynas Corporation	Japan Oil, Gas and Metals National Corp (JOGMEC) and Sojitz Corp	Rare earth elements	US$ 147 million low-interest loan to be repaid by 2030, aiming to provide rare earth elements to Japanese customers	Public-private partnership	1
Canada (Quebec)	Geomega	Investissement Quebec (Government of Quebec)	Permanent magnet metals (Rare earth elements)	Can$ 1.72 million to equip a new facility	Public debt finance	2 3
China (Hubei)	Contemporary Amperex Technology Co Ltd	Undisclosed (self-owned or self-raised funds)	Electric vehicle (EV) battery metals such as cobalt and lithium	RMB 32 billion (US$ 4.96 billion)	Information not available	4 5
Estonia	Neo Performance Materials	European Commission Just Transition Fund	Permanent magnet metals (Rare earth elements)	€18.7 million to construct a vertically integrated rare earth magnet manufacturing and recycling facility. Operational target is 2025.	Public finance	6
Europe	European Battery Alliance	European Investment Bank	Electric vehicle battery metals	€1 billion support for Europe-wide battery projects, including recycling	Public finance	7
France	MagREEsource	Tangent Line (PFR Poland), Finindus (ArcelorMittal and the Flemish Region), EIT Raw Materials, and private investors	Permanent magnet metals (rare earth elements)	€5 million for a plant with a capacity of 50 tons by 2023 (to be upgraded to 500 tons by 2027)	Public finance	8 9
Germany	HyProMag (based in the United Kingdom of Great Britain and Northern Ireland)	European Regional Development Fund and the Ministry of Economic Affairs, Labour and Tourism, Baden-Württemberg	Permanent magnet metals (rare earth elements)	€3.7 million (€2.5 million from the European Union and €1.2 million from the Ministry) – initial production of 100 metric tons of neodymium magnets in 2024	Public finance (grant)	10
Japan	Sumitomo Metal Mining, JX Nippon Mining and Metals, Sumitomo Chemical, Kanto Denka Kogyo, Jera, Nissan Motor	Nedo (state-owned energy research agency)	Electric vehicle battery metals Rare metals	The consortium is aimed at establishing the technology to achieve a recycling ratio of 70 per cent for lithium, 95 per cent for nickel and 95 per cent for cobalt by the April 2030–March 2031 fiscal year.	Public finance	11
Malaysia (Kuala Lumpur)	Ni Hsin EV tech Berhad	SIRIM Berhad (state-owned company of Malaysian Government)	Lithium-ion battery metals	The pilot plant will be fully operational in 2023, with an annual recycling capacity of 550 metric tons of lithium-ion batteries.	Public finance	12
North America	Cirba Solutions	EQT Infrastructure V fund	Electric vehicle battery metals	US$ 245 million minority investment	Impact investing	13
United Kingdom of Great Britain and Northern Ireland (Teeside)	Altilium (Green Lithium)	British Government Automotive Transformation Fund	Electric vehicle battery metals (old scrap), gigafactory scrap (new scrap) and nickel and cobalt (primary feed)	£3 million	Public finance (grant)	14

79 See the Appendix (Appendix 4) for the list of URL links corresponding to the source numbers in table 4.2.

Location	Companies	Financier	Metals covered	Size and other information about the facility	Types of finance	Source
United States of America	Redwood Materials	Amazon (Climate Pledge Fund) Capricorn Investment Group (CIG) Breakthrough Energy Ventures[80]	Electric vehicle battery metals	Redwood is one of five companies Amazon is investing in as part of its US$2 billion Climate Pledge Fund. Also received US$40 million from CIG.	Impact investing	15
United States of America (Atlanta)	Novelis Inc.	Self-issuance	Aluminium	US$ 280 million in March 2023, €500 million in March 2021	Green bonds	16
United States of America (Odessa, Texas)	Solarcycle (based in California)	Fifth Wall and HG Ventures (The Heritage Group). Also, Prologis Ventures and existing investors Urban Innovation Fund and Closed Loop Partners	Solar photovoltaic panel materials	US$ 30 million (in addition to US$ 7 million raised since January 2022), aiming to grow the plant's recycling capacity from 500,000 to 1 million panels per year and support research and development.	Impact investing (fundraiser)	17
United States of America (Pittsburgh)	Metalico	State (Pennsylvania Department of Environmental Protection) Volkswagen	Aluminium, brass, bronze, copper, stainless steel, nickel alloys and steel	US$ 500,000 investment will be used to electrify the vehicles and infrastructure of the company. VW is the supplier of state funding.	Public finance (grant)	18 19

Overall, the table suggests that funding for recycling facilities for transition minerals is increasing in Europe, North America and Asia, indicating a growing interest in sustainable and circular material management. While the list is not meant to be exhaustive, notably, there do not seem to be many financial support examples in Africa, South America or Oceania, despite these regions including leading primary source countries of many transition minerals, such as lithium, copper, nickel and aluminium. Given their significant role and expertise in primary production, companies operating and based in countries and territories such as Chile, Argentina, South Africa, Australia and New Caledonia could also potentially become involved in the establishment of certain downstream ore-processing projects. Indeed, some of the funded recycling projects listed in table 4.2 are already being led by companies with backgrounds in extraction, such as the Canadian mineral exploration company Mkango being a majority stakeholder in HyProMag. The extractive industry possesses valuable expertise in processing natural ores and there are many companies whose workflows go beyond upstream activities to include secondary production stages such as mineral and scrap metal processing, as well as smelting, remelting and refining of metal scrap.

Significant environmental, social and economic benefits can be achieved if public and private financiers could further explore the untapped potential of vertically integrated recycling projects involving manufacturers (including those of low-carbon energy technologies) and primary production firms from mining regions further downstream.

Another area where secondary and primary producers may collaborate to address a crucial problem linked to the mining industry is the treatment of mine tailings. They could be another source of transition mineral scrap that can be fed into recycling streams (Araya *et al*. 2021). There are thousands of tailings dams around the world that contain post-extraction waste. This 'waste', in turn, may contain a lot of valuable transition minerals that were not separated from the ore owing to their low economic value or insufficient technology at the time of the extractive operations. The separation and processing of the tailings can be a lucrative business for secondary and downstream primary metal producers (Araujo *et al*. 2022). Moreover, the treatment of the mining waste through circular economy strategies could reduce the environmental impact of past, present and future mining operations and encourage businesses and policymakers

80 Capricorn Investment Group: a sustainability-focused venture capital firm. Breakthrough Energy Ventures: an environmental fund backed by Jeff Bezos, Bill Gates and several other billionaires, mostly from the world of technology.

to monitor more closely the potentially hazardous facilities that might have been neglected owing to their remoteness or obsolescence (Kinnunen *et al*. 2022). There are successful experiments of recovering nickel and cobalt via 'bioleaching', i.e. the remediation of tailings via microorganisms resistant to heavy metal toxication (Dong *et al*. 2023). The mining of waste that has already been dug up could reduce the need for highly energy-, water- and carbon-intensive stages of primary production, such as drilling, crushing and grinding.[81] Secondary producers could potentially work with the mining industry to locate and ensure the safety of the tailings facilities, while processing the tailings and turning this challenge posed by the primary producers into an opportunity to reduce the environmental footprint of former and ongoing metal production. The Regulation on critical raw materials (Regulation (EU) 2024/1252)[82] (European Commission 2023a) requires current operators to evaluate the potential for recovering materials from mine tailings and collect data on critical raw materials in the waste they generate. For closed or abandoned mines, European Union member States are mandated to compile this information from permitting records and targeted sampling, making it available in an openly accessible database. This enables prospective operators to identify viable sites for recovery projects in collaboration with public authorities.

4.5 RECYCLING CHALLENGES AND FINANCE

This section discusses the role of the different measures of financial support for secondary production, presented above, in the delivery of policy and business-driven solutions designed to tackle the above-mentioned grand challenges, highlighting the responsibilities of public, private and scientific actors in addressing them.

Technology and price uncertainties. Navigating uncertainties demands not only financial commitment, but also strategic agility to adapt to evolving technological trends and ensure sustained viability in the recycling sector. Projections informing investors require detailed assessments of potential technological shifts and advances and research needs to be funded by sustainability and climate funds to better account for this complex uncertainty in estimations (Christmann and Lefebvre 2022). Metal prices are one of strongest determinants of investment flows into secondary production (as shown in Chapter 2). Governments can enable finance for investments in recycling infrastructure, such as recycling facilities and waste management systems, to lower the cost of recycling and make it more economically viable. In particular, financial incentives for integrated metal production can be crucial to reducing vulnerabilities related to volatile metal prices.

The collaborative work of public and private investors and contribution of researchers can help to address price-related and technological uncertainties. Following comprehensive technological assessments, impact investments led by flagship sustainability funds, as well as public-private partnerships and blended finance initiatives led by well-established public and private investors, could help to secure the investment, ensuring trust in the recycling projects by providing their vote of confidence.

Product design challenges. The design of products is critical in ensuring that they can be easily disassembled and recycled by downstream secondary metal processors. It is desirable for the companies at each stage of the value chain to make the job of those in the next stages easier by designing their products and using materials that can easily be collected, dismantled and sorted. This requires more supply chain collaboration by mechanisms, such as cost-sharing of the recycling-oriented design or vertical integration between manufacturing and recycling industries. From the design stage, the materials used in low-carbon energy systems need to be labelled for future use and recycling. The labels could contain material information, e.g. in the case

81 Indeed, such stages of mining are responsible for about one third of the carbon dioxide emissions (per ton) in the production of some critical energy transition metals such as lithium, nickel, praseodymium and neodymium, and more than two thirds in the case of copper (Conte 2022). The energy intensity of the mining stages in copper production is also estimated to be up to 40 per cent in the hydrometallurgy method (Moreno-Leiva *et al*. 2020). At the country level, a United States-wide study showed that crushing and grinding used on average about 44 per cent of all the energy used for mining in the United States of America at the time of that survey (United States Department of Energy 2007).

82 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02024R1252-20240503

of lithium batteries, detailed specifications, including of the materials used in the anode, cathode, electrolyte and separator. Such labelling can be useful for the recyclers after the end-of-life of a product. The development of digital passports needs to be an integral part of products' design before they enter the production stage to facilitate their disassembly, sorting and processing for recycling (UNEP 2013). Blockchain technology could be used for labelling before assembling products (Raja Santhi and Muthuswamy 2022) in order to create a product passport. One finance option that can help to address this challenge is eco-design financing. This type of financing provides financial incentives to companies that design products that are environmentally friendly and easy to recycle. By providing financial incentives, eco-design financing can encourage companies to use materials that can be easily collected, dismantled, and sorted. The proposal of the European Commission regarding eco-design requirements (Proposal for a Regulation of the European Parliament and of the Council establishing a framework for setting ecodesign requirements for sustainable products and repealing Directive 2009/125/EC)[83], offers financial support for micro, small and medium-sized enterprises ranging from fiscal advantages to the provision of physical and digital infrastructure investments to meet eco-design requirements, including labelling, set out by the legislation.

Long lifetime of products. Extension of the (already quite long) lifetime of durables may present a challenge for closing the low-carbon energy technology loops via recycling. However, material-oriented recycling rates should not be the ultimate objective when determining circularity policies and supporting secondary production projects; recycling should be supported only if it is the best available option compared to other circular economy approaches. In such cases, extended producer responsibility can yield many benefits in the long-term, such as reduced product complexity and material inputs, and the organized collection of materials from decommissioned low-carbon energy technologies. The burgeoning literature on life-cycle assessment and material flow analysis in the last decade underscore the need for further studies to reconcile the Sustainable Development Goals with circular economy pathways (Schöggl *et al.* 2020). In this regard, the finance of research on material flow analysis and life-cycle assessment in relation to low-carbon energy technologies, their input materials and supply chains would help to make more informed decisions about most sustainable circular approaches.

Increasing product complexity and inadequate infrastructure. Green bonds can be used to fund the development of new recycling facilities and infrastructure that are designed to handle the increasing complexity of modern products. Green bond financing can also be used to fund private research into new recycling technologies and development of such technologies. These efforts should be complemented by government finance for public and academic research for the development and assessment of new recycling methods and streams, including urban mining. Secondary producers could make use of support measures such as extended tax loss-carry forward to delay the repayment of their debts in early stages of commercialization (also see below).

Logistics of recycling. Policymakers should focus on incentivizing the development of standardized procedures for the collection, disassembly and transportation of end-of-life lithium-ion batteries. This involves creating a supportive regulatory environment that encourages industry collaboration and adherence to best practices. In addition, investments in research and development for innovative packaging and transportation solutions tailored to the unique characteristics of end-of-life lithium-ion batteries are essential. Regarding the location of facilities, Nguyen-Tien *et al.* (2022) discuss a hub-and-spokes model for lithium-ion battery recycling, with batteries removed at 'spokes' and recycling at central hubs, but note uncertainty about the durability of this model as the industry develops. The establishment of efficient hub-and-spokes systems requires both domestic and international financial support. Local collection, sorting and transfer centres and processing facilities could benefit from tax provisions, green bonds and public debt finance, as well as public-private partnerships, to be facilitated by national governments and domestic finance providers. In addition, international financial frameworks need to be enabled for all of the companies taking part in the global recycling value chains of end-of-life lithium-ion batteries and other low-carbon energy technology components, including logistic and safety providers. In this regard, the public and private financiers of countries hosting the logistics and recycling activities could collaborate to offer specific multinational green bonds, blended finance and impact-investing options to all the companies involved in their recycling value chains. Establishing a robust logistical organization necessitates collaboration between governments, recycling and logistics companies, financiers and research institutions to create sustainable and standardized practices for transporting and recycling transition mineral scrap.

83 https://eur-lex.europa.eu/procedure/EN/2022_95

Variations in processing streams. The variabilities in low-carbon energy technology metals require tailor-made recycling pathways for almost each of them. The constraints on recycling and the policies required to tackle them vary significantly across different metals. The limited availability of scrap is the main obstacle to the expansion of secondary base metal production. In the case of 'niche' transition minerals, the economic feasibility of recycling processes remains crucial to boost secondary supply. Here, policy could be the key to unlocking the potential of the recycling industry by mitigating the obstacles to its competitiveness and restructuring the support mechanisms for primary metal production (Compañero *et al*. 2021; McCarthy and Börkey 2018). Impact investing can be used to fund companies that are developing new recycling technologies to handle different processing streams and that are working on new ways to recover metals from products that are difficult to recycle. Moreover, support mechanisms such as extended tax loss carry-forward systems and accelerated depreciation provisions might be of use for recycling companies of transition minerals, as they are for mining companies. Although these are generally favoured by primary producers, the secondary producers have similar pre-production costs involving experiments with new methods and technologies, which can be remedied by tax provisions at the early stages of commercial production.

Target setting and key performance indicators. Targets need to be set in the light of the best available technologies for recycling, considering both the physics and the economic and environmental costs and benefits of recycling. The material-centric approach needs to be replaced with the product-based approach oriented towards the holistic recycling of all components of a product. Without reliable and realistic measurement of past and current recycling efforts, it becomes extremely difficult to make decisions on recycling policies and finance for stakeholders. It would be beneficial for policymakers to explore this initiative as a way to advance the incorporation of circular metrics into financing strategies. Further elaboration of key performance indicators should be undertaken to encompass distinct stages within the recycling process. This involves identifying and recommending specific key performance indicators tailored to each phase, from collection and sorting to dismantling, chemical separation, and final material processing. By tailoring key performance indicators to the unique challenges and objectives of each stage, a more comprehensive and nuanced evaluation framework can be established, enhancing the effectiveness of monitoring and improving recycling processes. Public and private finance organizations must thus support the research and development of product-based performance indicators. The recent progress report of UNEP FI underlines that the banks financing recycling and circular economy approaches are "(…) making progress in measuring their performance in various impact areas [but] the methodologies are still in their early stages" and it is highly recommended that they lead the innovation in the development of performance measurement (UNEP FI 2023b, p. 15). UNEP FI (2023a) provides detailed circular economy target-setting guidance for private financiers who aim to achieve or increase their positive impact, which can also be applicable to recyclers and other businesses working in the field of the circular economy. To increase transparency, enable external verification and avoid greenwashing, circular metrics must be embedded into financing. The Government of the Netherlands has taken significant steps towards achieving a fully circular economy by 2050. Its Financing Circular Economy working group has developed a pathway for integrating circular metrics into financing practices (Fischer and Achterberg 2022). Governments, businesses and independent organizations can set specific recycling targets and track progress towards those targets using key performance indicators, such as the amount of waste diverted from landfill or the percentage of recyclable materials recovered. This can help to focus efforts and resources on achieving recycling goals. Governments can use pay-for-performance systems to incentivize waste management companies to meet or exceed recycling targets, encouraging them to invest in recycling infrastructure and improve recycling rates.

Public awareness about recycling. Governments need to finance awareness campaigns for household recycling with a particular focus on lower-recycling groups in the population (Prestin and Pearce 2010). Public awareness is significant not only for household recycling, but also for investing in future industrial-level recycling policies. This could include providing incentives for households to recycle, such as tax breaks or discounts on utility bills. Governments should also ensure that recycling facilities are easily accessible and that recycling options are properly communicated to the public and to the businesses in industrial zones with metal scrap generation.

Social cost of recycling. A better understanding of the comparative social costs of mining and recycling required to produce transition minerals is necessary to make better-informed investment decisions for sustainable resource management. Financing of the development of methods such as the impact pathway approach is needed. Furthermore, the development of assessment methods for environmentally harmful subsidies in mining and recycling industries could help policymakers to choose more eco-friendly support measures. The social cost of metal recycling can be high, particularly in emerging economies where informal recycling systems are prevalent. One finance option that can help to address this challenge is impact investing. By investing in formal recycling systems and technologies that prioritize worker safety and environmental sustainability, impact investors can help to improve the social cost of metal recycling.

Informal recycling systems. Public-private partnerships can be used to set up more formal recycling systems to help to increase the recovery efficiency of metals and reduce the environmental harm caused by informal recycling systems. The support for public-private partnership initiatives can be rallied via multilateral lenders such as the World Bank, in addition to relevant government agencies. Moreover, public-private partnerships can also be used to provide incentives for scrap collectors in developing countries. Effective monitoring measures must also be introduced and funded to ensure the safety and regulation of informal waste streams. To incentivize formal collection in developed countries, a deposit on the end-product might be useful. This deposit would need to be adjusted to the level of prices on the return date of the product. The black market for metal scrap is a significant challenge in many countries and can lead to the theft of valuable metals, as well as hazardous recycling practices. Financing for formal recycling systems can help to reduce the incentive for harmful and illegal recycling practices, as formal systems typically offer higher prices for scrap metal and adhere to higher environmental and safety standards. In developing countries, where informal recycling systems play a crucial role in waste management, the emphasis on formalizing recycling sectors should be balanced to avoid marginalizing informal recyclers. The informal sector, while presenting challenges like health risks, also contributes to waste collection, income generation and job creation. Selective and moderate deployment of subsidies and penalties to formal and informal recycling routes can help to reduce some of the negative impacts of recycling practices harmful to health and environment (Yu *et al*. 2023). To effectively address the risks associated with informal recycling, financial support could be provided for the establishment of public-private partnerships and for policy measures, such as training for scrap collectors and the supervision of incentives and penalties.

As a final note on the (re-)mining of tailings, this chapter calls for the creation of a global database for former and operating mine tailings facilities in order to make use of the mineral potential of these facilities while drawing the attention of governments and mining industry to their safety (see International institutions in Chapter 8 for details). This recommendation aligns with some of the existing efforts in this area, such as the Critical Raw Materials Act of the European Union (European Commission 2023a). There are several crucial considerations that need to be highlighted regarding the mining of tailings. Ensuring safety and preventing risks, such as potential collapses, should be of paramount importance throughout the entire process. Additionally, it is essential to establish oversight and regulation of the database by an international body, as suggested in the recommendations in Chapter 8 for the establishment of an international minerals and metals agency. The creation of such a database should build on existing databases, such as the Global Tailings Portal, by employing a combination of data scraping (potentially using artificial intelligence to capture locational patterns) and qualitative research to collect historical data on tailings dams, including potential material gains from tailings.[84] Lastly, the mining sector and financiers, being the primary beneficiaries of this new mineral resource, should take the lead in developing finance and risk prevention strategies pertaining to the mining of tailings. It may also be possible to generate some degree of self-funding from the sale of data or licensing of developed data, methods and technologies to third parties.

84 To the best of our knowledge, there is no known initiative to recover transition minerals from a mine tailings facility or any principles published to achieve this. The recent publications of the International Council on Mining and Metals (https://www.icmm.com/en-gb/our-principles/tailings/global-industry-standard-on-tailings-management, https://im-mining.com/2022/09/22/the-icmm-addresses-mine-tailings-reduction-ambition-with-new-roadmap-and-initiative/), the Initiative for Responsible Mining Assurance (https://responsiblemining.net/wp-content/uploads/2018/07/IRMA_STANDARD_v.1.0_FINAL_2018-1.pdf) and the Global Tailings Review (https://globaltailingsreview.org/) address issues such as the environmental and social risks linked to tailings facilities, increasing mining efficiency to reduce the size of the tailings, and locating and assessment of risks of former facilities.

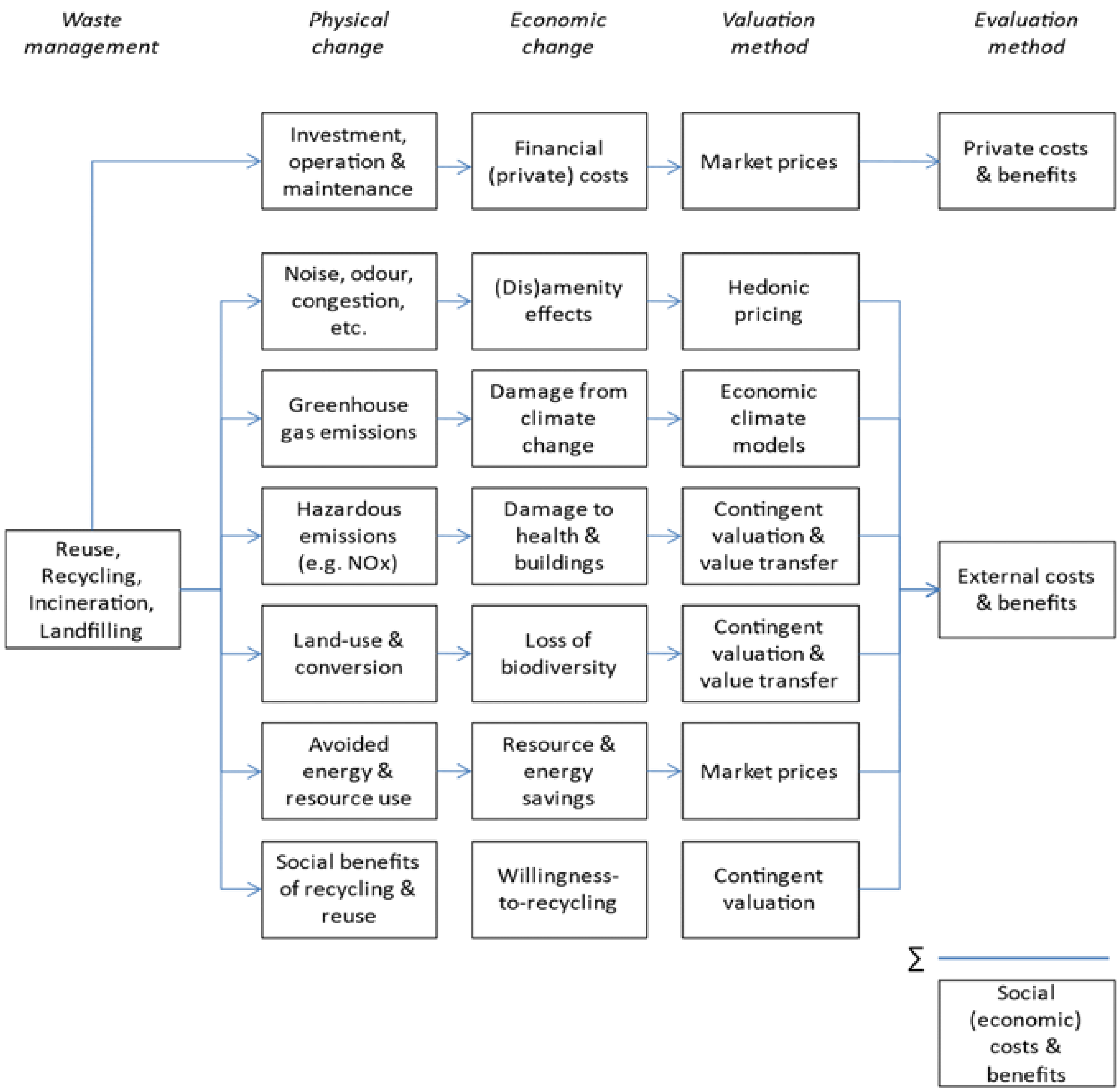
4.6 CONCLUSIONS OF THE CHAPTER

When implemented in harmony with other circularity strategies, recycling presents an effective pathway for the supply of transition minerals. However, there are a number of challenges that must be addressed for effective secondary production to be achieved. This Chapter outlined a multifaceted approach to address the grand challenges of transition mineral recycling, offering policy and business-driven approaches underpinned by financial instruments. Metal pricing, a key determinant for investment in secondary production, can be influenced by government-backed financing for recycling infrastructure, reducing costs and making recycling more economically viable. Eco-design financing, with financial incentives, helps to overcome product design challenge and encourage environmentally friendly and easily recyclable designs. Green bonds serve to fund the development of recycling facilities and infrastructure to tackle increasing product complexity, complemented by government financing for research into new recycling technologies. Impact investing is crucial for handling varied processing streams and developing methods for recovering metals from challenging products. Extended tax provisions and accelerated depreciation support the early stages of commercial production for recycling companies. Social cost challenges in metal recycling, particularly in emerging economies with informal systems, can be addressed through impact investing, prioritizing worker safety and environmental sustainability. Informal recycling systems can benefit from the establishment of public-private partnerships, supported by training and a mechanism of subsidies and penalties to promote less harmful recycling practices. Governments, businesses and financiers should collaborate to set specific recycling targets (for whole products, as well as specific materials, as appropriate), focusing on key performance indicators to track progress and incentivize investments in recycling infrastructure. Public awareness campaigns financed by governments can promote household recycling. Addressing the above-mentioned limitations and providing adequate financial support for recycling would contribute to the efforts for the implementation of circular economy principles and meeting material demand driven by global climate objectives.

In addition to those avenues already mentioned, a few further research avenues informed by the findings of this Chapter are presented here. There is a limited amount of research that has comprehensively investigated the various types of financial assistance for secondary metal production. This could be attributed to several factors, such as narrow definitions of government support, challenges in measuring many forms of secondary support or the fact that support is provided at different levels of administration (McCarthy and Börkey 2018). For a better impact assessment, further research is recommended in the areas of fiscal policies, subsidies and global impact on metal markets and supply chains. One area of research could be to analyse the impact of different fiscal policies, such as landfill tax, on primary and secondary production. Another area could be to investigate the impact of subsidies favouring primary production on the reduction of secondary production, owing to the increased costs or competitiveness of recycling. Case studies could also be produced on the global impact of subsidies and finance provided to the mining industry by a significant mining company, such as a substantial subsidy introduced by the Chinese government for the rare earth element mining industry. The case countries can be determined among the top producers of a mineral for which the production is highly concentrated, using the Herfindahl-Hirschman Index score as a metric (e.g. see Nassar *et al*. 2015) or the approach outlined in Chapter 1. Once there is a stock of individual country case studies, qualitative and quantitative cross-country studies could also be conducted for a better comparative assessment of different policies. The creation of a global database for former and operating mining tailings facilities could be a major step towards achieving more sustainable transition mineral production. In-depth qualitative and quantitative investigations into the mineral stock of these sources are needed, as well as financial support to unlock their potential for economically viable and sustainable metal production. Further research in these areas could provide valuable insights into the effects of fiscal policies, subsidies and mining practices on global metal markets and supply chains, as well as inform policies to promote sustainable recycling practices.

4.7 APPENDIX

Figure 4.A.1: Economic valuation and the impact pathway approach



Source: van Beukering *et al.* (2014, p. 483).

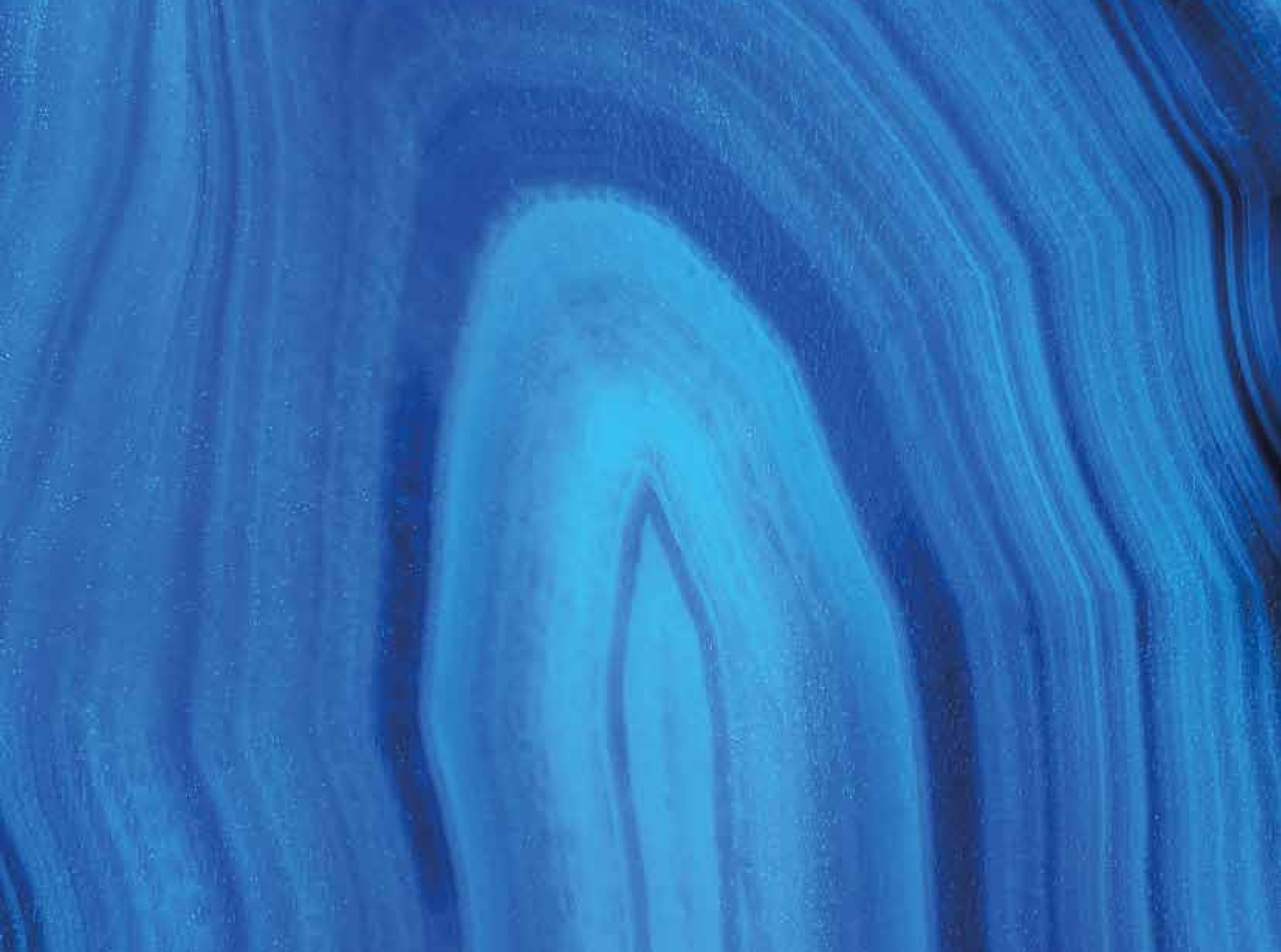
Table 4.B: URL links for sources used in table 4.2

1.	https://www.reuters.com/article/us-lynas-corp-japan-debt-idUSKCN1TS00Q/
2.	https://www.recyclingproductnews.com/article/32987/geomega-secures-financing-for-rare-earth-magnet-recycling-demonstration-plant
3.	https://finance.yahoo.com/news/geomega-announces-3m-funding-government-191600996.html?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAADPQbnKK8-UovOn5wa9w2JyTsR7ITkIWCgbSkyzi5Vi6HEvKTgPZiqfR32lykBrPg66Dw0VbIbMFBDNpzfip6uCba65eDqsvWqwwSPMLVx5qMXbEaU55cLnsURuKqISW79ds8RVGCo9lHx26G-BWEMUDcjAj3S4E9mPOjCrBiED-
4.	https://www.reuters.com/world/china/ev-battery-maker-catl-plans-5-billion-china-recycling-facility-2021-10-12/
5.	https://www.catl.com/uploads/1/file/public/202110/20211013094320_eoielp3aer.pdf
6.	https://www.neomaterials.com/neo-performance-materials-to-receive-first-ever-grant-under-europes-just-transition-fund-for-neos-planned-sintered-rare-earth-magnet-manufacturing-plant-in-estonia/
7.	https://www.eib.org/en/press/all/2020-121-eib-reaffirms-commitment-to-a-european-battery-industry-to-boost-green-recovery
8.	https://jimdo-storage.global.ssl.fastly.net/file/a8b67f72-b983-4eb7-91d4-83ae47d98601/CP_MagREEsource_Eng_final.pdf
9.	https://www.greencarcongress.com/2023/02/20230207-magreesource.html
10.	https://www.mining-technology.com/news/hypromag-rare-earth-germany/
11.	https://www.argusmedia.com/en/news/2400483-viewpoint-battery-recycling-key-to-net-zero-in-japan
12.	https://www.nst.com.my/business/2022/12/861114/ni-hsin-groups-unit-collaborates-sirim-setup-lithium-ion-battery-recycling
13.	https://www.recyclingtoday.com/article/cirba-solutions-secures-245-million-dollar-investment-for-battery-recycling/
14.	https://atfpro.co.uk/altilium-metals-have-selected-teesside-for-the-uks-largest-ev-battery-recycling-plant/
15.	https://www.electrive.com/2022/12/09/accurec-announces-new-proces-to-recycle-lithium-from-old-batteries/
16.	https://investors.novelis.com/2023-04-21-Novelis-Second-Green-Bond-Report-Demonstrates-Commitment-to-Meeting-Sustainability-Goals
17.	https://www.forbes.com/sites/jeffkart/2023/03/15/solarcycle-plans-to-recycle-1-million-panels-a-year-with-help-from-30-million-in-financing/?sh=2a4540635406
18.	https://www.cbsnews.com/pittsburgh/news/pittsburgh-scrap-metal-company-getting-electric-trucks-with-state-help/
19.	http://www.metalicopittsburgh.com/services

Source: URL links (accessed on 20 April 2023)

PART 2:

FINANCING THE PRODUCTION OF MINERALS AND METALS



CHAPTER 5

FINANCING THE PRODUCTION OF MINERALS AND METALS TODAY

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CONTENTS

5.1 FINANCE AND THE MINERALS AND METALS INDUSTRY: BOUNDARIES OF THE DISCUSSION

This Chapter introduces and discusses the current state of the linkages between the financial sector, the financing needs of the minerals and metals industry, and the production of mineral commodities, with respect to the major sustainability issues related to the production and use of minerals and metals, given their key role in the provision of goods and services essential to human well-being. These services include the critical role of transition minerals.

As stated by Wellmer and Hagelüken (2015): "the trilemma of security of supply under conditions of economic viability and environmental sustainability also needs to be addressed in order to achieve sustainable development". Finance and the choices and values of finance suppliers, both public and private, are of major importance in this context.

The minerals and metals industry is a highly diversified and complex[85] industry requiring billions of dollars in annual investment to finance mineral exploration (see table 5.7 and figures 5.8, 5.9 and 5.10) and the commissioning of new production sites (mines, mineral processing plants, smelters and refineries). The largest capital investment reported so far needed to launch an industrial-scale project is the Simandou iron ore project in Guinea, which would require an estimated US$20 billion of initial capital investment to develop the mine and its related facilities (Engineering and Mining Journal 2022), including a 600 km railway line and a deep-sea harbour, for the export of the iron ore to the world markets.

Investors therefore play an important role in the delivery of minerals and metals to society, but the world of finance is itself very diversified (figure 5.1, left side), including actors that only seek a rapid profit, whatever the consequences of their actions on sustainability. These actors essentially use minerals- and metals-related activities as a vehicle for their essentially short-term speculative moves, while others look for long-term opportunities that will provide credible returns for the assets they manage, including public savings and pension funds. The informed choices of investors and of the finance industry are therefore one of the key engines to drive progress towards sustainable development, possibly to the same extent as the regulatory actions taken by public authorities at the national or regional levels.

Public policies and regulations have an essential role in informing finance decisions, e.g. through disclosure requirements that improve the availability, quality and comparability of data, and to attract finance, especially private finance, through policies contributing to increasing the economic and financial viability of projects without jeopardizing environmental and social sustainability. They also are an essential ingredient of fostering trust among the multiple stakeholders who have to concur to make responsible mining projects possible (figure 5.1).

The analysis and discussion presented here is focused on the industry producing non-energy minerals and metals and on industrial-scale operations, which require large-scale investments for the development of new production sites, and for which public data and information are available. It does not cover the hydrocarbons-producing industry or radioactivity-related issues in the uranium industry.


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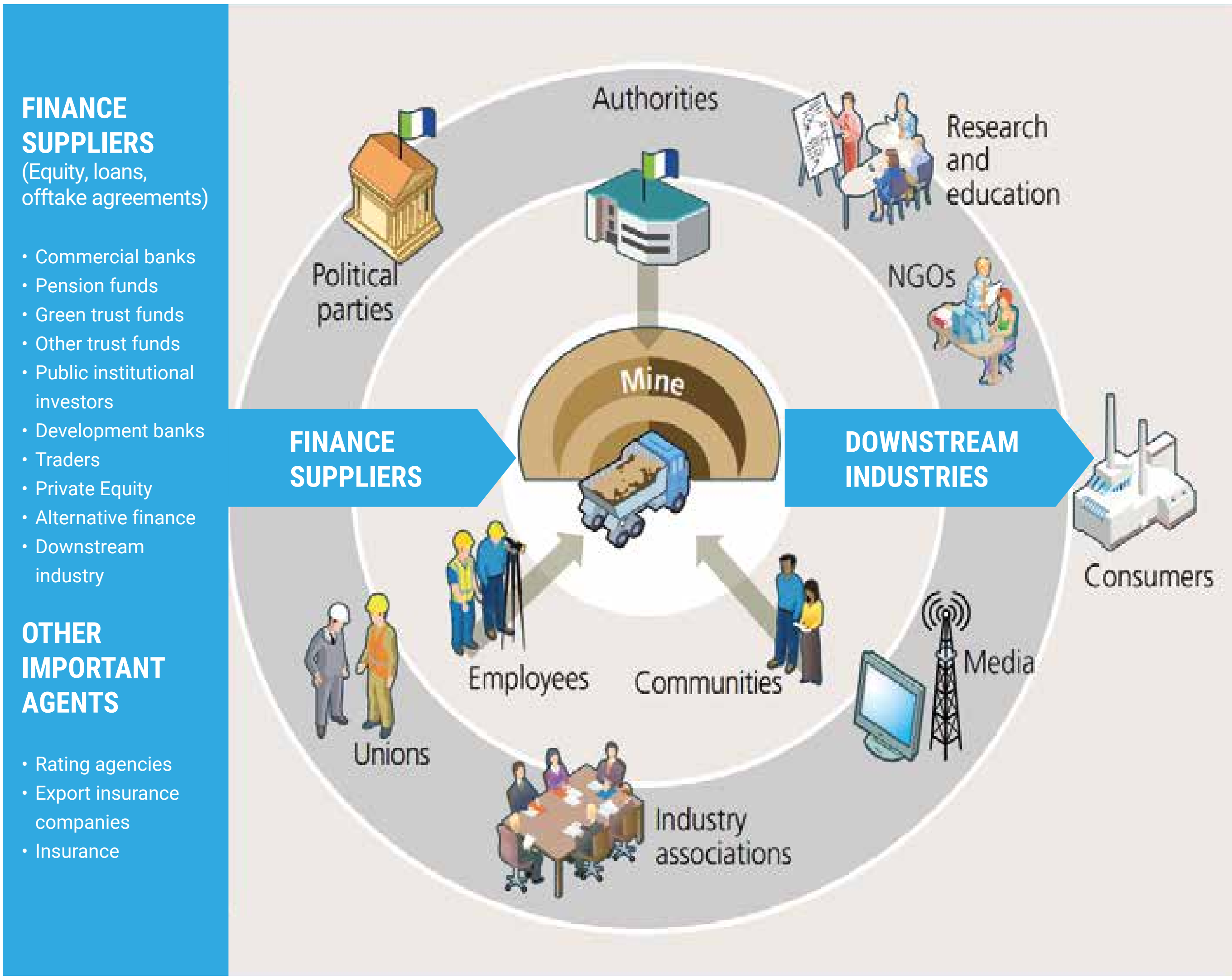
85 Overviews of the diversity and complexity of this industry, and of its essential roles in support of human development are available from multiple sources, including the annual editions of the United States Geological Survey Minerals Yearbook, the final report of the Mining, Minerals and Sustainable Development Project (Mining, Minerals and Sustainable Development 2002); Halland et al. (2015), the International Council on Mining and Metals (2016a and 2016b), Cameron and Stanley (2017); Christmann (2019); Ericsson and Löf (2019) and International Resource Panel (2020a).

Figure 5.1: **Stakeholders in the minerals and metals industry. The production of minerals and metals also requires other suppliers not shown on the figure, such as technology, equipment and service providers**



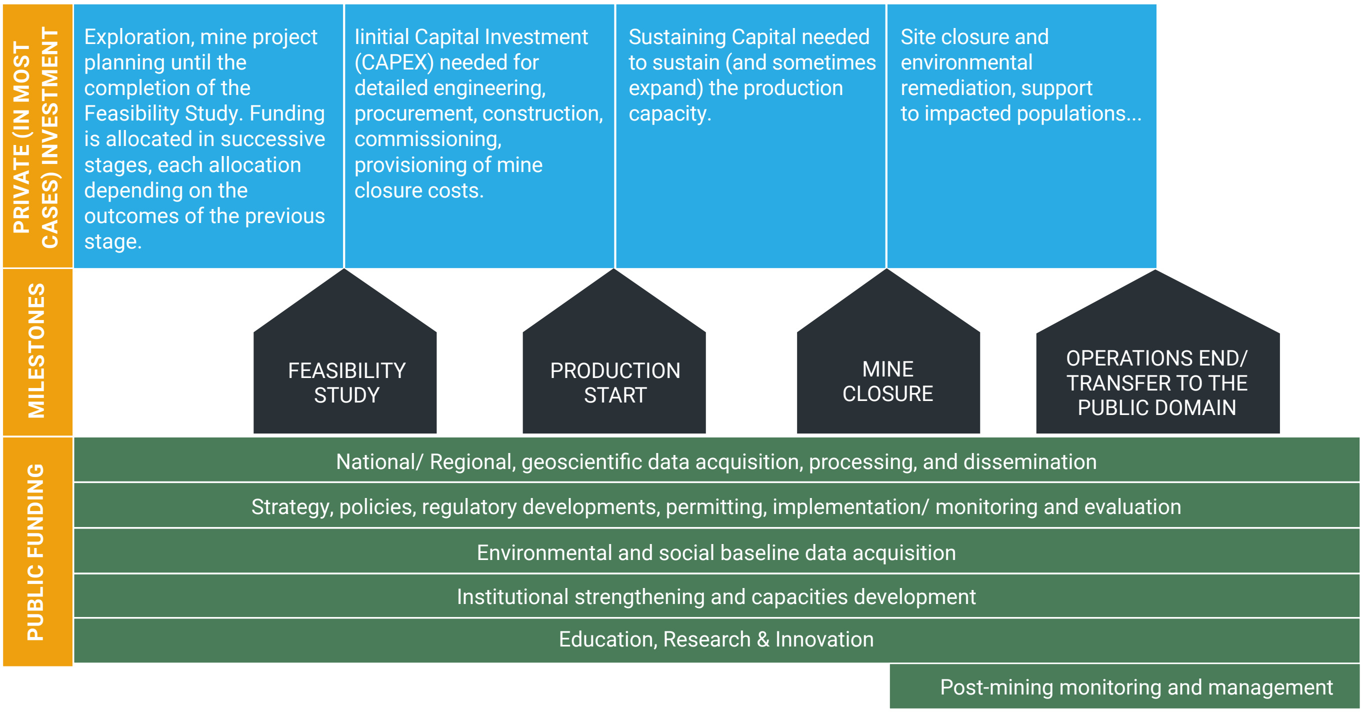
Source: Authors

Artisanal and small-scale mining is only marginally discussed in this chapter. Many such operations are family businesses or individual undertakings, of an informal, unregulated and sometimes illegal and even criminal nature. Their capital requirements are comparatively modest, and they are discussed in greater detail in Chapter 7.

The financing needs for industrial-scale minerals and metals production are diverse, as summarized in figure 5.2. and are further detailed in section 5.3, as well as in figure 5.5 and table 5.6. The financing of extractive activities from cradle (exploration) to mine closure, highlighted in green in figure 5.2, is mostly from private sources, through project specific combinations of equity and debt finance provided by a great diversity of private and institutional investors, development banks and, sometimes, State-controlled banks and investment funds. The latter have a pre-eminent role in more centrally planned economies. The main financing needs are the initial capital investment needed (section 5.3.1.1), after the completion of a feasibility study demonstrating the economic attractiveness of the project, for detailed engineering, procurement and construction, as well as for the commissioning activities needed to start production.

The financing needs highlighted in yellow relate to the role of public authorities in promoting, enabling, permitting, monitoring and overseeing mining activities (see section 5.3.3).

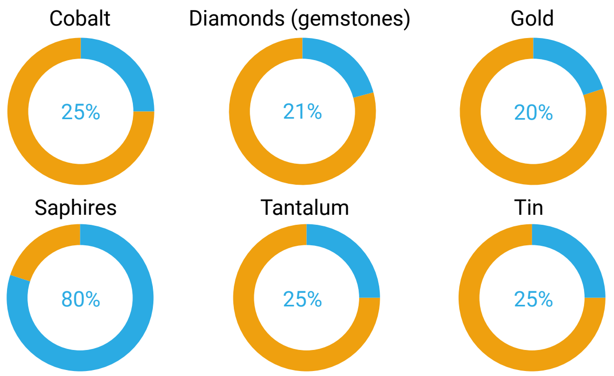
Figure 5.2: Summary representation of the financing needs at the various stages of minerals and metals related activities



Source: Authors

The formalization and the development of this specific segment of the mining industry, on which many millions of people in poorer countries depend for their living, would greatly benefit from the establishment of a specific funding mechanism to foster the development of mining small-and-medium sized enterprises (SMEs) operating in a formal, regulated framework (International Resource Panel [IRP] 2020a). Despite the small size and production capacity of operations essentially based on the use of muscular force, the artisanal and small-scale mining sector plays an important role in the production of several minerals and metals of great economic importance, especially cobalt, gold, tantalum, tin and precious stones (including diamonds, sapphire and jade). This importance is depicted in figure 5.3. A detailed overview of the artisanal and small-scale mining segment of the minerals and metals industry is provided in World Bank (2021) and in the abundant literature partly accessible via the Artisanal and Small-scale Mining Knowledge Sharing Archive (http://artisanalmining.org/). As already noted, the provision of finance for this sector is the subject of Chapter 7.

Figure 5.3 : Estimated share of artisanal and small-scale mining (in blue), as compared to industrial scale operations (in orange), in the world production of selected minerals



Source: Authors

Data from the European Commission Raw Materials Information System, accessed on 22 July 2022 (https://rmis.jrc.ec.europa.eu/?page=artisanal-and-small-scale-mining-a6f8a3). The European Commission states that the data are an average between estimates from BGR (Bundesanstalt für Geowissenschaften und Rohstoffe German Federal Institute for Geoscience and Raw Materials) (2019), the Organization for Economic Cooperation and Development (2019) and representatives from civil society organisations consulted within the European Commission Joint Research Centre project Surebatt (Reference year: 2019). Sapphires, Gold, Tantalum, Tin and Diamonds – (Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development 2017). (Reference year: 2009 for gold, tantalum and tin; 2017 for diamonds; 2013 for saphires).

Similarly, owing to the lack of suitable statistical data, the production of construction materials and of many industrial minerals and their financing are not issues developed in this report. Construction materials are traded over shorter distances because they are bulky in nature (such as sand, limestone and cement) and have lower intrinsic value. Their financing and management are also relatively localized.

The analysis and discussion in this Chapter are therefore essentially focused on documented large-scale formal industrial operations, supplying the world economy. This largely excludes operations from companies that are not compelled to report their activities, or do not voluntarily report on their operations. This opaqueness remains particularly important in companies financed by private equity or operating in or from countries that have not yet made public disclosure an important component of their public governance framework.

This, for instance, makes it particularly difficult to analyse finance issues related to the Chinese minerals and metals industry, within China or beyond its borders. This is an important issue, as seen in Chapter 1, because of the dominant share of Chinese domestic production in the global production of many minerals and metals essential to the global economy (figure 1.3), in addition to the rising share of minerals productions controlled by Chinese companies operating abroad. The rapid evolution since 2000 of Asia in general, and of China in particular (table 1.1), as the leading drivers of the global minerals and metals industry is the major development that has happened since 2002. The high rate of growth of the Chinese minerals and metals industry observed since 2000 is of a magnitude and speed without precedent in human history, with huge impacts on the global economy and sustainable development issues. It is further covered in Chapters 1 and 2 of this report.

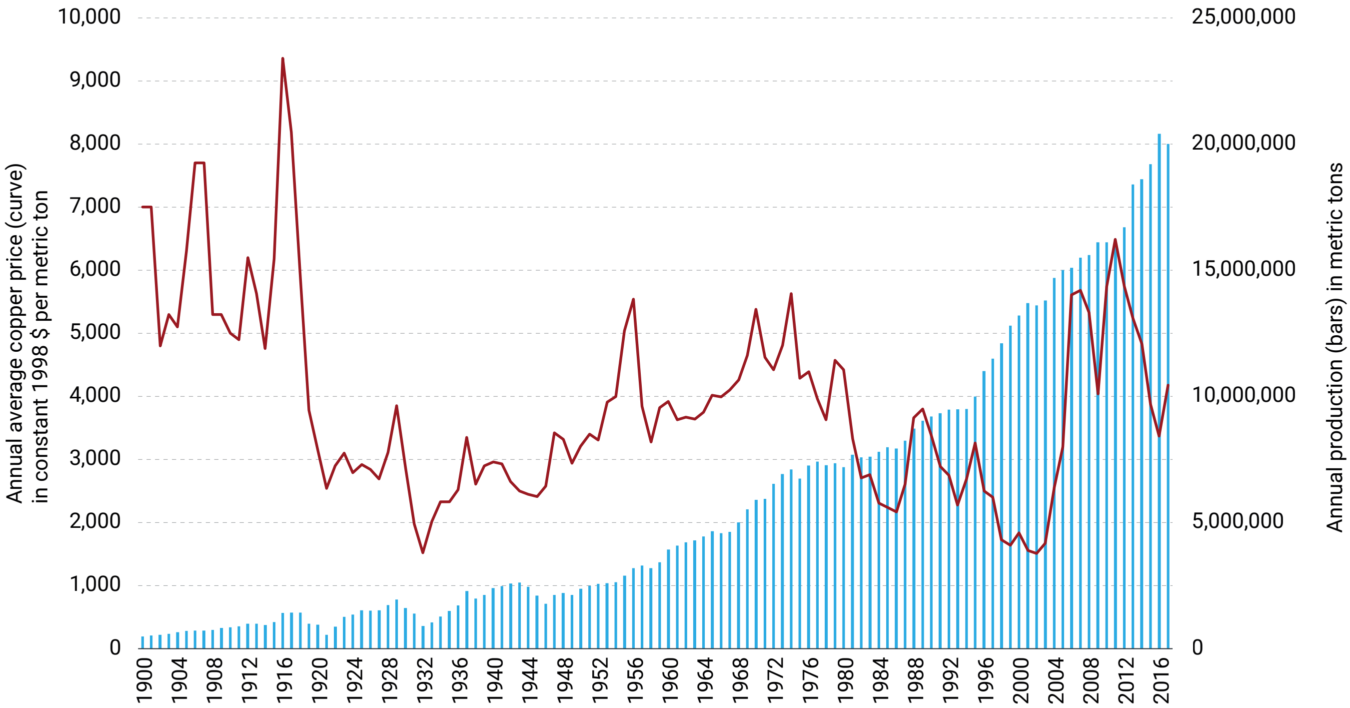
The production of minerals and metals can be technologically highly complex and knowledge-intensive, requiring the combined use of different mineral exploration methods (Jébrak 2012; Bustillo Revuelta 2017; Haldar 2018; Okada 2022) and mining engineering techniques, and the selection of the most appropriate biological, chemical or physical methods for ore-processing and metallurgical technologies (Darling 2011; Wills and Finch 2016). Advanced digital technologies, such as real-time production management relying on sensor webs, the Internet-of-Things and continuously updated digital twins of the operations, big data and artificial intelligence play an ever-growing role in industrial-scale operations, deeply modifying the industry (Moore 2018). However, the implementation of state-of-the-art technologies by individual, especially smaller, companies can be hampered by issues such as their capital cost and the availability of the technical skills necessary. This considerably slows down the use of the currently best available technologies, which can take decades to become widely used in the case of major capital items, such as ore-processing plants or smelters. It must also be noted that once a company has chosen the technologies and equipment most appropriate for the mining and the processing of its resource, with its mineralogical and geochemical specificities, it will be likely to wait until its capital-intensive equipment needs replacement before considering whether to invest in some newer technology offering efficiency gains.

Technological and managerial innovation are key drivers of profitable large-scale industrial operations (Vidal and al. 2013a; European Technology Platform on Sustainable Mineral Resources 2015; Schodde 2019; Ali *et al*. 2018; Smith and Wentworth 2022). Innovation plays a crucial role in keeping production costs below market prices, arising from the enhanced efficiency of geological resource use, the reduction of energy and water use, the reduction of emissions and waste production, and the efficient use of labour and machinery. Innovation and cheap, abundant and concentrated carbon-based energy sources have made it possible to efficiently bulk mine large tonnage and low-grade deposits, such as porphyry copper deposits, leading to an apparent ore grade decline that does not reflect geological scarcity.

Together with the availability of abundant and cheap carbon-based energy, innovation has allowed the massive increase of the world production of metals observed since the onset of the twentieth century, and particularly after the Second World War. For many minerals and metals, innovation and cheap carbon-based fossil fuels allowed massive increases in production, without a comparable growth of minerals and metals prices, as exemplified in figure 5.4 for copper.

In the 1900–2017 period, world copper production grew by a factor of 39, while the copper price, expressed in constant United States dollars, was lower at the end of that period than it was at its beginning.

Figure 5.4 : Global copper production (in metric tons copper contained in the mined production (right axis and blue bars) and average annual copper price, in 1998 constant United States dollars (left axis and red line)



Source: Authors.

Data from Data source: United States Geological Survey Data Series 140 (Porter et al. 2022). The deflator used to calculate the constant 1998 United States dollar values is the United States Consumer Price Index for All Urban Consumers published by the United States Bureau of Labour Statistics.

5.2 THE KEY ECONOMIC FEATURES OF THE MINERALS AND METALS INDUSTRY

This section sets out some of the fundamental characteristics of large-scale mining: how it is organized and the processes that it uses. These characteristics are of great relevance to whether and how mining operations are financed.

5.2.1 Extractive activities can only take place where economically recoverable deposits of minerals occur

The location of minerals is the result of a specific geological process that took place at a given moment in the Earth's billion years of history. The geographical distribution of these processes is highly uneven, meaning that no country can expect to have domestic economic concentrations of all the minerals and metals its economy requires. This is a fundamental reason for the existence of geographically disconnected and complex supply chains for minerals and metals, which depend on trade (see Chapter 1) to overcome this geographic disconnect.

In this context, trading houses and individual traders play an important role in connecting supply sources with downstream industrial users. Some trading houses are also mining companies. Glencore, the world's third largest mining company by market value in early 2023,[86] is also a leading global minerals and metals trading house. Trading houses and traders are one of the components (figure 5.1) of the multi-faceted finance industry that funds mineral exploration and the development of new production facilities. So far, the commitment of individual trading houses (as well as other components of the finance industry) to sustainable development ethics, accountability and transparency is highly variable, as documented in a report by the World Resources Forum and the Responsible Mining Foundation (2023) assessing the sustainable development-related due diligence and public disclosure practices of a sample of 25 trading houses, including some of the world's largest trading houses specializing in the minerals and metals trade. The report states that "many companies are unable to show that they are taking action to prevent supply chain risks from human rights abuses, illicit financial flows, and environmental damage. Due diligence systems on these issues are generally weak, often limited to the initial step of setting expectations for suppliers. Only rarely do companies' systems extend to the critical stages of risk assessment and mitigation. Without these elements the due diligence systems will never contribute to the prevention of these significant supply chain issues. Alongside these weak results, there is little sign that companies are making efforts to review and improve the effectiveness of their due diligence systems. For example, about two-thirds of the companies show no evidence of tracking and reporting their performance on managing human rights risks in their supply chain.". However, it also shows that some major minerals and metals traders have much improved their transparency and disclosure practices.

5.2.2 The production of metals involves several stages

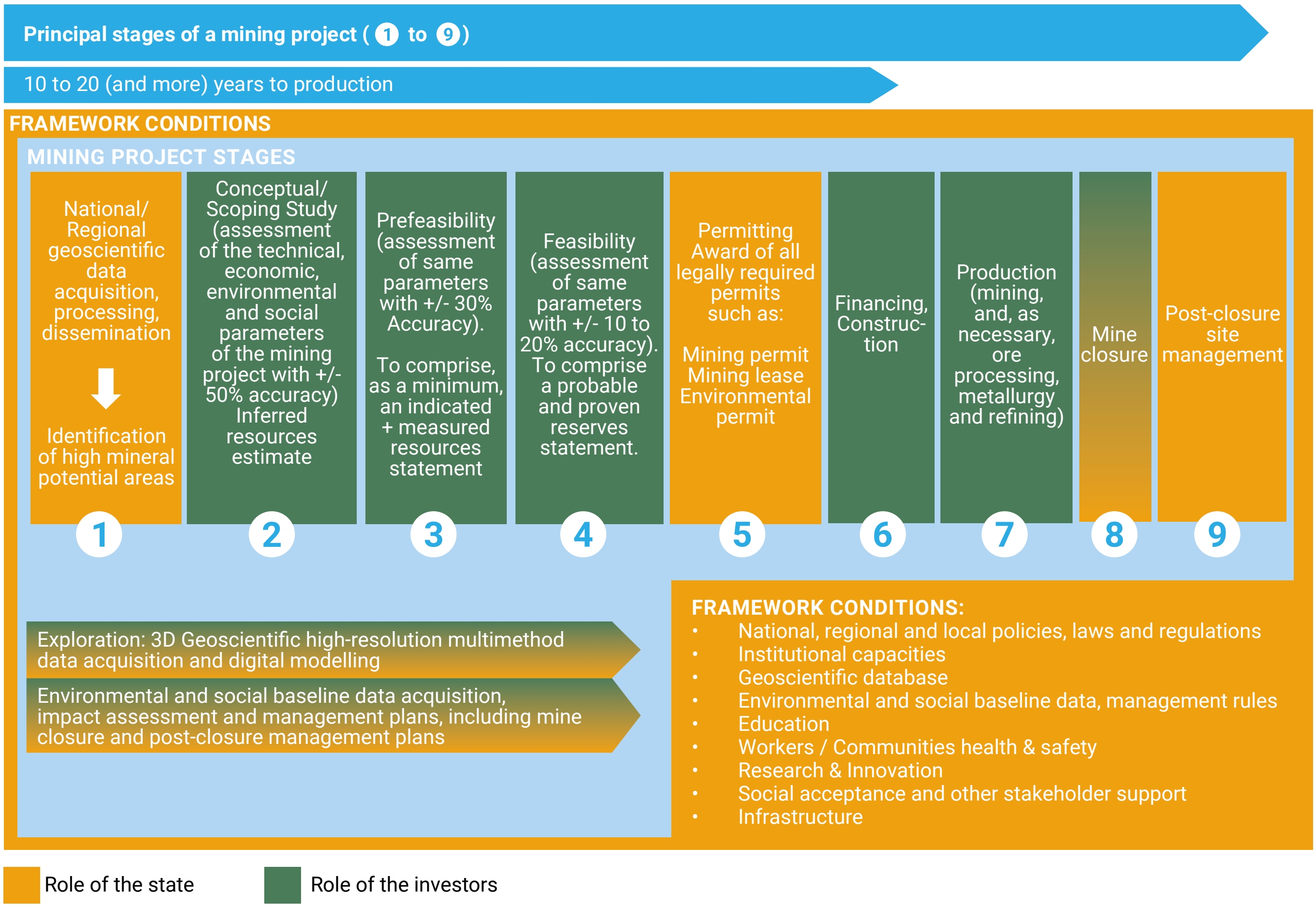
Figure 5.5 shows the nine stages involved in the production of metals. Each of these stages needs to be financed, often by different financial sector actors.

There are six stages that need to take place before production can start: (1) data acquisition from a geological survey; (2) a scoping study; (3 and 4) pre-feasibility and feasibility studies; (5) permitting; and (6) financing and mine construction. These stages are discussed in more detail later in the chapter.

In the production stage (7), ore must be extracted from the Earth's crust by some form of mining, essentially from open-pit or underground mines, with the choice of the mining method dependent on the nature of the ore and on the detailed geometry of the mineral concentrations. The contained metals will then be extracted by physical, chemical or microbiological methods (or a combination thereof) to produce a concentrate of the economically valuable minerals contained in the ore, in preparation for the later extraction and, as needed, the refining of the contained metal(s) by a metallurgical process and, in many cases, a refining process tailored to the physical and chemical characteristics of the concentrate.

86 Source: https://www.mining.com/top-50-biggest-mining-companies/.

Figure 5.5: Main stages of an industrial-scale mining project



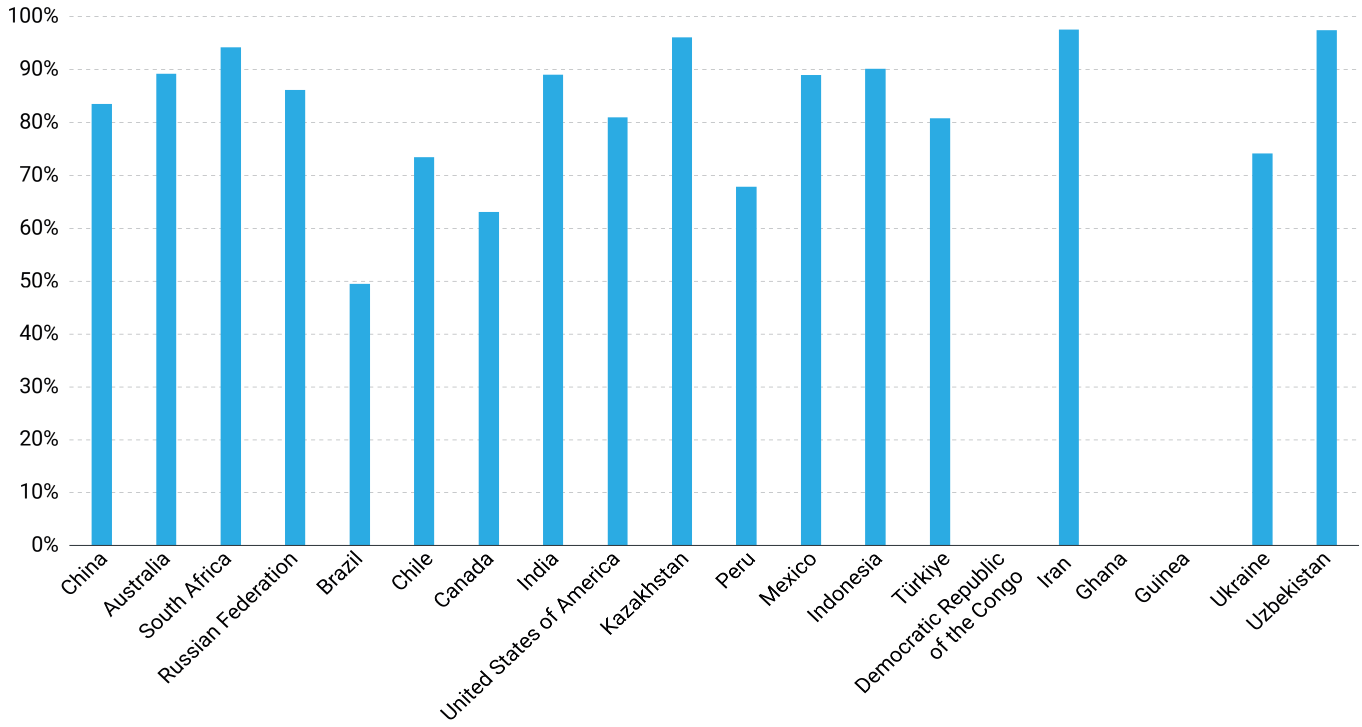
Note: Gold backgrounds indicate publicly funded activities and green backgrounds indicate activities funded by investors, which are predominantly private in countries with liberal economic regimes. Depending on a country's specific policy, public funding may support some activities, as highlighted by a combination of gold and green colors.

Source: Authors, modified from IRP (2020a).

In most cases, the valuable minerals will be separated from the mined ore by a specific concentration process that needs to take place near the mine to avoid, in the case of low-grade ores, the cost and impacts of handling and transporting waste materials over long distances. For instance, in 2014, Northey *et al*. estimated the average global copper ore grade to be 0.62 per cent. This means that for every ton of copper in an average ore, there are about 150 metric tons of uneconomic minerals extracted. Transporting the latter over long distances makes no economic or environmental sense. The resulting concentrate offers several advantages: the volume of material to be transported is much reduced, while its contained metal value is increased. This makes it possible to transport materials by sea to far away smelters, generally located in places where abundant and cheap energy sources, and other competitive advantages (infrastructure, qualified manpower and sometimes lax environmental or social practices) are available. Abundant and cheap energy frequently remains synonymous with the predominant use of carbon-based fossil fuels (figure 5.6) in the most important minerals- and metals-producing countries. Globally, the Organization for Economic Cooperation and Development (OECD) (2019) estimates that the minerals and metals industry is the source of about 16 per cent of global greenhouse gas emissions, with the production of aluminium, cement and steel being the main contributors to these emissions. The high greenhouse gas emissions for these three mineral raw materials relate to the metallurgical production stages of alumina and aluminium and of steel and to the manufacturing of cement, which can be compared to a pyrometallurgical process in some of its aspects. One of the causes of these high greenhouse gas emissions may be the nature of the material handled (limestone as a feedstock for cement production, liberating carbon dioxide in the cement production process), the need to use coking coal as a reducing agent in steel-making or the use of coal as an energy source for the energy-intensive production of alumina and aluminium. Important greenhouse gas emissions related to the production of many other minerals and metals arise if carbon-based energy sources are used to drive the crushing and grinding operations necessary in ore processing. In 2007, an analysis of the energy consumption of the mining industry in the United States of America (United States Department of Energy 2007) estimated that crushing and grinding operations required about 44 per cent of industry's total energy use (1,246 trillion British Thermal Units/year, equivalent to 1,315 TW/year.

Detailed overviews of ore-processing are available from Gupta and Yan, 2016, and Wills and Finch, 2016, and of metallurgy from European Commission (2013a; 2013b;2013c) and Vignes (2011a; 2011b; 2011c).

Figure 5.6 : The world's 20 largest minerals and metals producing countries in 2020: share of carbon-based energy sources in the national energy mix.



Source: Authors

Data source: BP (2022).

Alexey Asanov © Shutterstock

5.2.3 Large-scale projects can have lead times of 30 years and more from initial discovery to production.

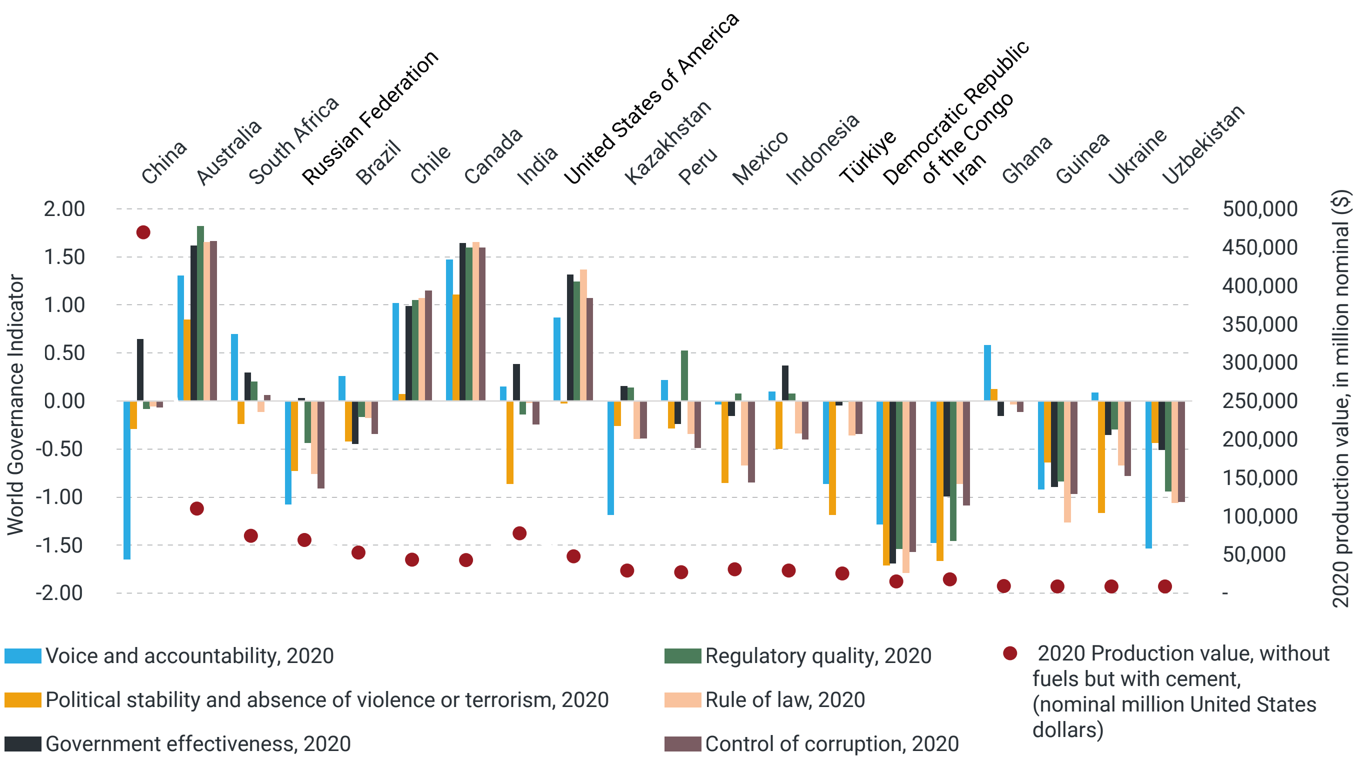
The lead time is the time needed to perform the stages 2 to 6 in figure 5.5 if the quality of a discovery justifies the rising investment needed to perform each successive stage. Long lead times, exceeding two decades are quite common, especially for large-scale projects. Hinde (2020), considering the 45 largest mines put in production between 2010 and 2019, as documented in the S&P Global Market Intelligence database, notes that on average it took 29 years from discovery to the startup of the mining operations, with an average of 24 years from discovery to the completion of the feasibility study. Data compilation from the 2012, 2017 and 2022 annual surveys of the world's main projects published by the Engineering and Mining Journal shows that out of the 190 projects listed in 2021 for which an initial capital expenditure estimate is available, 48 (25 per cent) projects were already listed in 2016 and 25 (13 per cent) were already listed in 2011.

Table 5.1 (see Section 2.8) on copper deposits indicates the year of each deposit's discovery, and shows the long lead times of large-scale industrial scale mining projects. Some 16 of the 20 listed projects were discovered over 30 years ago. None of these deposits, which are of major importance to meet the copper demand foreseen including for the low-carbon energy transition (International Energy Agency 2021; Marscheider-Weidemann 2021), are yet in production, and some of these projects may be further delayed for many years, without any certainty as to their future start date. This situation concerning long lead times confirms the observations made about 271 copper deposits by Ali *et al*. (2017).

Long project lead times can result from a combination of several factors:

- A decline in the economic merits of the project, caused for instance by a demand decline, which can itself relate to a technology shift or to a broader economic downturn. It can also be caused by the complexity of a given project, putting its anticipated profitability at risk (see the discussion on risks, Section 2.6).
- The complexity of environmental and of mine-permitting procedures, as, in several jurisdictions, authorities pay growing attention to the environmental and social impacts of minerals and metals production. For new mining projects, obtaining the informal sustainable development licence to operate advocated by IRP (2020a), involving support from all the project's stakeholders (figure 5.1), is likely to become an issue of rising importance and complexity worldwide, except in countries where autocratic regimes may push new minerals and metals production projects whatever their impacts.
- Environmental and social issues, sometimes translating to active opposition by local populations to the development of a mining project. Water use, cultural heritage, biodiversity conservation and the sharing of the wealth that minerals and metals production is supposed to create can become contentious issues, leading to opposition and, in the worst cases, even to open conflict.
- Weaknesses in the institutional capacities needed to evaluate the complex and large technical documentation submitted by mining companies to obtain their mining permits (feasibility studies) and environmental permits (environmental baseline data, environmental and social impact statements and management plans, mine closure plans). For a public authority, such as a mining directorate or an environmental agency, the assessment of such large and complex documentation (a single project may have many thousands of pages of technical reports, spread over many different reports), requires the availability of qualified and well-experienced staff and political support.
- This can be problematic, including in some developed countries. Lower-income countries can face great difficulties in recruiting sufficiently qualified professionals and keeping them in employment, a source of recurring budgetary costs that some governments find it difficult to cover. This situation is further aggravated in countries with governance issues. Figure 5.7 provides a broad indication of the governance conditions prevailing in 2020 in each of the world's largest 20 minerals and metals producing countries. It shows that of the 20 main minerals- and metals-producing countries, 16 have a comparatively weak governance framework, aggravating the weakness in institutional capacities.

Figure 5.7: The world's 20 largest minerals and metals producing countries in 2020, by production value (including cement) (right vertical axis) and the 6 governance sub-indicators forming the World 2020 Governance Indicators of the World Bank for the selected countries (left axis, maximum theoretical values are +3 for the best performance, and – 3 for the worst performance).



Source: Authors

Data sources: Reichl and Schatz (2022) and United States Geological Survey Mineral Commodity Summaries, 2022 edition for production values; Kaufmann and Kraay (World Bank), 2022 for the World Governance Indicators used.

5.2.4 Minerals and metals production is a commodities-producing industry

Apart from construction materials (sand and gravel, ordinary clay for brick making, stone), which have a per metric ton value too low to be globally tradeable, as discussed in Section 2.1, minerals and metals are globally traded commodities (Trafigura 2019). Trade implies that the traded products are well specified, preferably by means of internationally recognized standards. To be a tradeable commodity, a mineral or a metal must meet chemical or physical specifications defined by their customers, which is widely the case for industrial minerals, by traders or by exchanges specialized in the trading of metals, such as the London Metal Exchange (LME), the New York Mercantile Exchange and the Shanghai Futures Exchange.

An example of the specifications to be met by metals to be tradeable is provided, for the metals traded at the London Metal Exchange, by the LME Rulebook (London Metal Exchange 2022a). These specifications do not include environmental or social criteria. In other words, this means that global minerals and metals exchanges have no role in furthering the contributions of the minerals and metals industry to sustainable development. Their only contribution is the provision of reference prices and volumes for the minerals and metals they trade, as well as information about future contracts and the stocks in their bonded warehouses. They also provide information about the market sentiment at a given point in time, through their disclosure of futures contracts and the related anticipated prices of metals. Producers can, on a voluntary basis, disclose their sustainability metrics using specific services such as the LMEpassport;[87]

87 https://www.lme.com/Trading/Initiatives/LMEpassport

these sustainability disclosures are then made public via a web service, such as the London Metal Exchange Live Sustainability Disclosures.[88] What is reported and according to what format or standard is left to the decision of the volunteering companies. The earlier attempt of the London Metal Exchange to introduce a specific trading platform for "green" (low carbon) aluminium had to be abandoned, in view of industry opposition (Jamasmie 2020).

The commodity nature of minerals and metals has several consequences related to sustainable development:

- **The full production cost (full cash-cost) of any mineral or metal produced by an operation must be below the market price, or the producer will incur a loss.** This cost includes all cost elements of the traded commodity, including mining and, as applicable, processing, melting, refining, depreciation, depletion, interest rates, amortization, taxes, royalties, levies and duties.

- **These production costs must, in principle, integrate the cost of fulfilling any obligations set out in national or regional laws and regulatory frameworks applicable to minerals- and metals-producing activities.** From a sustainable development perspective, any weaknesses, loopholes or exemptions, sometimes granted by authorities in confidential agreements, can be detrimental to the sustainable development goals, as can be the lack of well-qualified and resourced personnel needed to effectively implement existing regulatory frameworks. Shortcomings may be further aggravated in countries with insufficient public income to fund the core public institutions needed to promote and regulate the development of their minerals and metals industries or by weak public governance.

- **Voluntary pro-sustainability measures are likely to be considered by investors and individual companies only if they allow a reduction of their production cost.** The reduction of input use, such as chemicals, energy (such as electricity, explosives and fuel) allow such win-win situations where sustainability gains and reduced production can be obtained. Similarly, the reduction of internal conflicts (between employers and employees) and external conflicts (between companies and local populations) may reduce costs, but individual companies may evaluate the bottom-line benefits of proactive approaches to conflict management differently. Companies' environmental, social and governance performances are, however, emerging as a separate material consideration for some investors, as discussed in Chapter 6.

- For investors, the stakes are high, as the value of their investments can be severely hit by the materialization of one or several risks described in the appendix (Appendix 5). They have much to win, in the long term, by supporting the development of sound environmental, social and governance practices and transparent, public, quadruple bottom-line reporting, including the economic, environmental, social and governance performances, based on internationally recognized standards, which so far are missing, but with important developments in progress.

5.2.5 Large-scale production projects are technically complex projects

Large-scale industrial projects are technically complex operations at all stages, from exploration to mining, ore-processing, and, for metals only, metallurgical extraction and refining. This complexity is reflected in detail in the public feasibility reports available for many projects, but not all by any means. Process selection, continuous process control and optimization to save on costly inputs, such as chemicals or energy, for example, are important factors to maximize the profitability of a mining operation.

Technological innovation helps to reduce production costs and environmental impacts, thanks for instance to more efficient or reduced use of chemicals, energy and water. A modern large-scale mine requires a well-coordinated use of competences in geology, geochemistry, geophysics, mineralogy, geotechnics, mining engineering, drilling, sampling, laboratory techniques, explosives and blasting, heavy machinery operation and maintenance, automation, robotics, hydraulics, electrics, welding, surveying, logistics, trading, information and communication technologies (ICT), administration, environmental management and social sciences. ICT plays a major role in modern exploration, mine planning and through all the stages of the industrial production of minerals and metals, as represented in figure 5.5.

88 https://www.lmepassport.com/#/public/live-sustainability-disclosures.

Exploration requires advanced geological knowledge and experience, as it is the detection of specific geological conditions that is the main guide towards the discovery of a potentially valuable mineral concentration. The first step towards the production of minerals and metals always starts with the compilation and interpretation of existing geological data, and then with field observations, soon to be complemented by some drilling, as a three-dimensional understanding of the mineral concentration will be necessary.

At the exploration stage, visual observations are in most cases complemented by the use of satellite imagery and a wide, and growing, range of sensors used to acquire georeferenced digital geochemical, mineralogical or geophysical data, either by means of portable field equipment (such as X-Ray fluorescence analysers and hyperspectral analysers), or helicopter or airborne data acquisition campaigns. All observations and data serve to progressively build a high-resolution three-dimensional digital geostatistical model of the ore deposit (Sirelda and Resmi 2017; Carvalho *et al*. 2020, Arias *et al*. 2021), an essential tool in support of later mine design and planning that allows various mine designs and production schemes to be virtually tested, in support of the selection of the optimal production scenario, which is a crucial component of feasibility studies.

At the production stage, process optimization at every single step is key to the efficient control of production costs, in order to save on input costs, such as chemicals (including explosives), energy and water, and to increase productivity, for instance through automation or preventive, planned maintenance of machinery. In modern, state-of-the-art production facilities (mines, ore processing, smelters and refineries) sensors and sensor webs continuously feed data into digital twins of the operations, allowing precise control of all the unitary operations, with significative sustainability benefits (Haüpl 2021). They also enable the remote automated operation of production facilities, keeping personnel away from potential sources of harm.

Sánchez and Hartlieb (2020) and research agendas jointly developed by academics, researchers and industry representatives (Vidal *et al*. 2013b; European Technology Platform on Sustainable Mineral Resources 2015) provide an overview of the critical role and the trends in research and innovation as one of the important drivers of the enhanced sustainability of minerals and metals production.

5.2.6 Metals production is a high-risk industry

The commitment of private investment depends on an acceptable risk-return ratio, whereas minerals and metals exploration and production activities are exposed to a wide range of risks (Paithankar 2011; Badri *et al*. 2012; Maraboutis *et al*. 2022), as detailed in Appendix 5. Individual investors have variable risk acceptance. Some investors may accept certain risks, for instance governance-related risks, but shy away from others, such as economic risks. One of the consequences of this exposure to multiple risks is that the expected returns from mining projects need to be quite high, as shown by the key economic parameters discussed below that a project needs, on average, to meet in order to attract the initial capital investment required for its construction and commissioning.

Risks can impact the various stages of the mining life cycle:

- Exploration-related risks (Section 2.6.1)
- Production-related risks (Section 2.6.2)
- Post-mine closure risks (Section 2.6.3)

The exploration for minerals and metals (Stages 2 to 4, figure 5.5), the permitting (Stage 5), construction and commissioning of new production sites (Stage 6), and the production (Stage 7), mine-closure and the post-mining stages (Stages 8 and 9) are exposed to multiple risks, or can cause risks to local populations or local and global ecosystems. Risks can be categorized into several classes: economic/business, governance, environmental, technological and social risks, as shown in Appendix 5.

In 2022, the European Commission worked on the elaboration of best risk management approaches in the extractive sector, with the support of consultants. The study was finalized in September 2023 (Eco-Efficiency Consulting and Engineering 2023) and is currently available from the competent national authorities of the European Union member States. It provides information on important aspects for how to undertake risk management within the on-shore extractives sector with a focus on environmental risks and selected aspects of occupational safety and health.

5.2.6.1 Exploration related risks

Economic risks

Exploration activities require significant capital investments over many years. Table 5.6 provides the order of magnitude durations and the costs of mineral exploration stages, while Section 5.3.4, provides a broader economic overview of global mineral exploration and of its financing.

The main exploration-related risk is the economic risk of never recovering the investment made in mineral exploration, as funds invested in mineral exploration will not generate economic returns until an exploration project turns into a profitable production operation. Schodde (2022a), based on 2022 metal prices (see table 5.7), estimated that over the 2011–June 2022 period, the average value of the discoveries made as a result of worldwide mineral exploration was only US$0.64 per dollar invested in mineral exploration, with important regional differences. This does not mean that investment into mineral exploration activities cannot be highly profitable. The gains can be huge in the rare case that a top-tier deposit is discovered. Profits can also be made further to active trading in any shares with high volatilities, and shares of junior mining companies are no exception to this common practice.

Economic risks are aggravated by the frequently long lead times of exploration projects (see Section 5.2.3)

Long-term investors supporting mineral exploration projects manage the economic risks by implementing a stepwise approach to exploration funding, with the main steps outlined in figure 5.5 and table 5.6. At the end of each step, a "stop-or-go" decision is taken in view of the results of the completed stage, the economic potential of the project and broader economic considerations. Uncertainty about a project's merits is very high during early-stage exploration and progressively decreases up to the completion of the feasibility study. However, even then, there remain risks that will be discussed in the next section. Some amount of uncertainty is inherent to the minerals and metals industry. Uncertainty can only be reduced; it never can be eliminated.

To reduce their exposure to economic risks, investors in mineral exploration favour brownfield exploration projects over greenfield ones (see Glossary for these expressions), looking for extensions of known deposits or deposits located in the district, with the same geological context as already profitably mined deposits (brownfield exploration). Investors tend to be shy of the cost of exploring areas that are as yet unexplored, where less data may be available to guide exploration towards promising targets. According to S&P Global Intelligence (2022), only 26 per cent the total estimated global exploration funding allocation (US$11.2 billion) went to grassroots exploration, while 36 per cent of this budget went to late-stage projects and feasibility studies, and 38 per cent went to mine site exploration, directly looking for extensions of a known ore-body in production.

Environmental and social risks

The environmental and social footprint of mineral exploration is mostly minor, and only temporary. It cannot be compared with the environmental risks and impacts of the production stage and the post-mine closure stage. Early-stage exploration (definition: see Glossary) has no significant environmental impacts as the activities in the field are limited to the temporary (generally for a few weeks or lasting as long as some months) presence of a field team, with no heavy equipment involved. Some impacts may occur if vegetation must be removed to provide access by car, and temporary localized disturbance of biodiversity may occur. In most cases, the natural recovery of exploration areas is rapid, and if there are no further activities, such as advanced exploration (definition: see Glossary) or later mining, the recovery of the natural environmental is likely to be completed in a few years.

Advanced stage activities can have higher impacts owing to the operation of heavy machinery, such as drilling rigs and bulldozers, which may affect biodiversity or fertile soil, which may be removed from a small area to access the bedrock. Accidental spills of fuels or oil used to operate vehicles and machinery are a source of localized impacts, calling for careful supervision of exploration operations by both the companies engaged in them and the public institution in charge of the supervision of mineral exploration and mining activities.

5.2.6.2 Production related risks

The production of minerals and metals is one of the human activities most exposed to multiple, complex forms of risk (see Appendix 5). Appendix 5 consists of a table providing a semi-detailed compilation of risks specific to the minerals and metals industry, assessed from a broader sustainable development perspective. The identification and evaluation of these risks, and of the impacts they may have, not only on future production activities but also on local communities and on local and regional ecosystems and the services they provide, requires close attention at the planning stage of new projects. Ideally, risk identification and the definition of prevention and management strategies call for close cooperation between the companies developing new projects, the relevant regulatory authorities, and the communities that may be affected.

Economic risks are diverse. Inflation, unanticipated increases in the cost of labour, energy and other inputs may have an impact on an operation's viability. Among these risks, the decline of demand and thus of a commodity's market price, may seriously jeopardize a mine's economic viability. Operations producing minerals or metals for a market dominated by a single or a few applications are particularly vulnerable to rapid demand and correlated price declines in the case of technological shifts. As an example, this happened to cobalt, the price of which peaked at over US$80,000 per ton in April 2022, in view of strong demand for the production of lithium batteries cathode material. Since then, the price of cobalt has declined to slightly above US$30,000 per ton in view of a growing substitution of cobalt by nickel in cathode materials and of open questions regarding the pace of the future development of electromobility in China. Minerals and metals producers can to some extent manage this category of economic risk by hedging the prices of their products (Trafigura 2019; London Metal Exchange 2022b) and by entering prepayment agreements with trading houses or the end users of their products (Trafigura 2020).

Environmental and social risks, if they materialize, may translate into negative impacts, sometimes lasting for decades, even centuries, after the closure of a given productive activity. Risk assessment and management are of major importance to all minerals and metals industry stakeholders (figure 5.1), especially companies developing production projects or operating production sites, the investors invested in these activities, the local communities that may be affected by the activities and, finally, various components of the global and the local environment, the environment on which humanity's fate greatly depends, which is a silent stakeholder in any project or operation.

The materialization of risks can badly affect operations and ruin investments, cause fatalities and injuries, destroy buildings and infrastructure, and cause major environmental and lasting reputational damage to a company and the industry in general. The financial consequences of major events resulting from weak risk management can, in some cases, be counted in billions of dollars. The consequences of poorly assessed or managed risks are illustrated by the Brumadinho tailings dam failure. This happened in January 2019 at one of the iron ore operations of Vale in Brazil, killing 259 people, with 11 still missing, in addition to large damage to buildings and infrastructure, as well as to the local environment, particularly the local river system. In 2021, Vale agreed to pay about US$7 billion in settlement for the damage it caused (Andreoni and Casado 2021). The final cost to the company could be significantly higher. Its further consequences are presented in Chapter 6.

5.2.6.3 Mine closure

The Brumadinho case is an extreme illustration of the need for formal and adequately funded mine closure procedures, and the potentially dire possible consequences of the absence or poor implementation of such procedures.

Depending on the specific national or regional legislation, and of its effective implementation, once an operation stops, whatever the cause, a formal closure process that normally involves the operating company, as well as public authorities, should take place. The aim is to ensure that the land where the past operations took place is handed back to the authorities or original landowners, without any attached biological, chemical or physical issues, to allow the use of the derelict industrial site for other purposes. Local populations should be closely associated with the closure process as they are likely to suffer most from any problems developing after the mine-closure.

Mine closure comprises diverse site-specific actions such as:

- social support measures to ease the transition of affected communities towards new activities supporting their livelihoods;
- dismantling of facilities and the removal, recycling and reuse of their materials and equipment;

- site remediation that may include soil treatment to remove pollutants, the removal and reprocessing of waste, the reintroduction of vegetation or reforestation, development of alternative post-mining land-uses, such as recreational facilities, environmental conservation areas (for instance thanks to the development of ecologically valuable wetlands or of equally valuable fauna or flora conservation areas at the location of former open pits).

Several jurisdictions with important mining activities, as well as institutions, have developed guidelines on mine-closure management that are of value to any party confronted with this particularly important stage of any mine. Examples are Québec, Canada (Ministère de l'Énergie et des Ressources naturelles, 2017), Papua New Guinea (International Institute for Sustainable Development 2019), Western Australia (Government of Western Australia, Department of Mines, Industry Regulation and Safety 2020), India (Indian Bureau of Mines 2022) and Nevada, United States of America (Nevada Division of Environmental Protection 2022). In addition, the World Bank Group (Parshley *et al*. 2021) and the International Council on Mining and Metals (2019) provide detailed guidelines that are not country-specific.

A central guiding principle in mine closure strategies is, after mine closure, to ensure a smooth social transition to local communities that were dependent on the mining activity for their living, and to enable alternative sustainable land uses where a production facility was once located. Mine closure is the pivotal moment where the company that leased the land needed for its production activities will transfer its rights and obligations back to the authorities or the original landowners. Mine closure planning should be closely integrated into an operations feasibility study and in the related Environmental and Social Impact Assessment to be submitted to the regulatory authorities as part of the mining permitting and environmental licensing processes. The costs foreseen by the mine closure plan must be budgeted for in the feasibility study and adequately provisioned, with a proper financial guarantee being provided to the authorities. The mine closure plan should not be an afterthought, but should be considered at the initial stages.

Hidden or underestimated mine closure costs may expose investors to considerable financial risks, as mine closure is an extremely challenging task with multiple intertwined technical, environmental and social issues. The insufficient provisioning of capital needed for this delicate stage of a mining operation's life or planning of the necessary, potentially costly, operations can lead to legal tangles, or even conflicts, with the authorities or local populations. The International Council on Mining and Metals (2023), on its website dedicated to mine closure notes "closing a mine poses a material financial and social risk that puts broader economic survival and future investment in mining in jeopardy. In response, mining companies are seeking to better integrate ESG [environmental, social and governance] and closure considerations into their mine plans to optimise closure performance and costs." In view of the potential long-term consequences to local communities and to the natural environment they depend on, mine closure issues are receiving significant attention.

An extreme example of issues related to mine closure is the Giant Mine closure case. This was a large gold mine near the city of Yellowknife, Northwest Territories, Canada. The mine closed in 2004, leaving behind 237,000 metric tons of arsenic trioxide (Crown-Indigenous Relations and Northern Affairs Canada 2021), not only an economically worthless by-product of the metallurgical process (ore roasting) used to recover gold from the ore, but also a deadly poison. This powdery residue is stored in underground chambers from where it may leak into groundwater and surface water, a deadly threat to local populations and the regional environment. The only solution to avoid a catastrophe is to build a frozen underground bubble to confine the toxic material. In 2012 (Aboriginal Affairs and Northern Development Canada 2012), the initial cost of this solution was estimated to be Can$ 903 million (US$ 686 million, at the 15 September 2023 exchange rate), over the 2006–2025 period. In addition, the annual recurring cost of operating the system and proper site monitoring was estimated to be Can$ 1,982 million (US$ 1,506 million) for the 2025–2037 period. The final costs could be much higher, as the confinement and monitoring system on the site will need to be operated for perpetuity. This burden will have to be borne by future taxpayers who have not at all benefited from the past mining activities.

Since the 1990s, a growing number of jurisdictional authorities are developing mine closure regulations to protect taxpayers and local communities from the potential impacts from mining legacies (see figure 2 in Parshley *et al*. 2021).

5.2.6.4 Post-mine closure risks

Depending on whether a mine closure is carried out successfully, in the worst but not infrequent case, long-term risks related to derelict minerals and metals production may include one or several of the following items:

- Ground instability: land subsidence and, in the worst case, land collapse into underground cavities related to past mining activities;
- The release of potentially harmful chemical compounds from mining waste, such as tailings, toxic heavy metals and potentially bio-assimilable compounds, into the air (via dust), soil and surface or groundwater;
- Tailing dams failure.

These risks may be aggravated in the case of the exposure of improperly closed mining sites to natural hazards, such as extreme weather conditions (rainfall or drought), landslides or seismic or volcanic activities.

5.2.7 Risk assessment and management practices

Risk assessment has a long history in mining, as mining projects are exposed to a wide range of complex intertwined political, economic or business, environmental and social risks with the existence of feedback loops, for instance between commodity prices and the capacity of a given company to engage in the costly management of the ore-processing tailings it generates.

The risks of engaging in a particular operation have always been more or less considered by operators and the investors supporting them. The assessment of any political, regulatory, economic, environmental and social risks that may have an impact on the viability of a future operation is a core component of feasibility studies and of their preceding stages (scoping studies, preliminary economic assessments, prefeasibility). Risk assessments can be highly empirical and skewed towards an investor's or an operator's short-term interests, owing to the need for the operator to keep its full cash cost (see Section 5.2.4) below the market price(s) of the commodity(ies) being produced. This may lead to a reduced consideration for the lasting environmental or social consequences the materialization of a specific risk can cause, and the temptation to leave unsuspecting future taxpayers to cope with legacies many years after the closure of the operation that generated the problems.

There is a lot of literature on risks specific to the minerals and metals industry, including on transition minerals and their management, as seen from the perspective of a given stakeholder, mostly from an industry or business perspective (Darling 2011; Gonen 2020) or related to a specific risk category, such as operational risks (Paithankar 2011).

In their review of risk assessment methods in the mining industry, Tubis *et al*. (2020) identified over 100,000 records of publications of all sorts, published in the 2010–2020 period, matching the search expression "risk in mining industry", using the Primo search engine. Among the authors' findings and conclusions, two risk categories were found to be of particularly high importance, warranting further research and knowledge development:

- The impacts of mining on the environment and the impacts of the environment on mining,
- Financial and economic risk assessment issues, a domain that the authors consider of great importance but on which they could not identify any literature.

The perception by mining companies of the top 10 business risks to mining projects has been assessed annually for over 10 years by EY (formerly Ernst & Young). In its 2023 Edition, EY (2022a) ranks environmental and social issues as the top risk, and the closely related issues related to obtaining the informal licence to operate (the unwritten consensus of all stakeholders, including local communities and workers, in support of the given project, see figure 5.1), as the third-biggest risk.

Throughout the full lifetime of a production project, from the construction to the post-closure stages (Stages 6 to 9, figure 5.5), the detailed assessment of hazards, risks and the potential impacts that may result from a production project, along with the related impact monitoring, mitigation and reduction strategies and mitigation plans, needs to be an essential component of the exploration activities leading to the preparation of a project's feasibility study (Stages 2 to 4, figure 5.5). They have a major impact on the project's economics and its contribution to sustainable development.

Hazards and risks (see Glossary for a definition of these terms) specific to the production of minerals and metals may be perceived differently by different stakeholders. Investors are, for instance, likely to be concerned about the relevance and the profitability of their investment, or about the consequences for their investment of the materialization of a risk through circumstances, such as an accident, a tailings dam failure, a conflict with local communities or air, soil and water pollution.

Companies are also likely to be concerned about their reputation and, for publicly listed companies, about a decline of their market value and rising difficulties in attracting the investment necessary for their future projects.

Local communities are likely to be concerned about the consequences on their economic viability, their health or the impacts on local environmental components their living depends on, such as the availability of sufficient good quality water resources, clean air or fertile soil. They may also be highly concerned about the conservation of their cultural heritage.

So far, there is no mandatory international standard for risk assessment, reporting and public disclosure for minerals and metals production projects. There are no international requirements for minerals- and metals-producing companies to perform risk assessments and disclose their outcomes in a specified format. Current practice varies from opaqueness to transparency regarding the risks related to individual projects and operations. Transparent risk assessment should be considered as a good governance practice, but governance practices are diverse and none of them are broadly internationally recognized and implemented, with the current state of affairs having been described in detail in the IRP report on mineral resources governance in the twenty-first century (IRP 2020a).

No statistical review of the current situation regarding risk assessments and reporting practice could be identified. Public documents presenting the risk assessments performed for individual mining projects are essentially limited to:

- Feasibility studies made public in compliance with the Canadian NI-43-101 standard disclosure obligations, applicable to all companies listed on the Toronto Stock Exchange, the world's largest exchange for exploration and mining companies. So far, the NI 43-101 has established the world's most stringent disclosure obligations, which are applicable to about 1,200 companies listed on the Toronto Stock Exchange, including reporting on risks. Its requirements applicable to written disclosure of mineral resources and mineral reserves include: "… the identification of any known legal, political, environmental, or other risks that could materially affect the potential development of the mineral resources or mineral reserves" (Canadian Institute of Mining, Metallurgy and Petroleum 2011).
- The disclosure obligations for companies listed on the second largest exchange specialized in equity-raising for minerals- and metals-related projects, the Australian Securities Exchange, are less stringent. The Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (JORC Code) describes its intents as follows: "to provide a minimum standard for Public Reporting, and to ensure that such reporting contains all information that investors and their professional advisers would reasonably require, and reasonably expect to find in the report, for the purpose of making a reasoned and balanced judgement regarding the Exploration Results, Mineral Resources or Ore Reserves being reported". Its definition of risks is also narrower, as the standard only calls for the identification and reporting of "any identified material naturally occurring risks" that could impede the demonstration of the existence of proved reserves.
- The compliance by mining companies with national and regional legislation and regulations making public consultations prior to the environmental permitting of projects mandatory. Some countries and regions provide public access to registries that allow any filed document can be retrieved and downloaded. Examples are the Environmental Protection Authority of Western Australia,[89] the Environmental Assessment Office Project Information Centre of British Columbia, Canada[90] and project-specific registries for companies that must seek an Environmental Impact Statement under the United States National Environmental Policy Act, one example being the large-scale Resolution Copper mining project in Arizona.[91]

89 https://www.epa.wa.gov.au/epa-assessment-reports.

90 https://www.projects.eao.gov.bc.ca/projects-list.

91 https://www.resolutionmineeis.us/.

As noted above, the European Commission published its elaboration of best risk management approaches in respect of environmental risks and selected aspects of occupational safety and health in the extractives sector in September 2023 (Eco-Efficiency Consulting and Engineering 2023).

5.2.8 Minerals and metals production is a capital-intensive industry

The production of minerals requires an initial capital investment before any productive activity can be started. The amount of initial capital is extremely variable, depending on the size of the production operation, the technologies used to produce a marketable mineral product, the project-specific risks and their management costs, and the provisions made for mine closure. Initial capital expenditure requirements vary from several billion dollars for large-scale base metals or iron ore production projects to a few dollars for rudimentary small-scale individual artisanal operations, where equipment may be limited to a pick, a shovel and a metal pan needed to produce the mineral concentrate (mostly a heavy – high-density – mineral such as coltan (a tantalum ore), cassiterite (tin ore), gold or precious minerals). Figures 5.8 to 5.10 provide an overview of the initial capital requirements of the world's main mining projects, derived from the 2021 annual survey of mining projects, the Global Mining Investment Outlook (Govreau 2022), published every year by the Engineering and Mining Journal. According to this source, at the end of 2021, 221 projects were earmarked for investment into their development, totaling US$270 billion in capital expenditure needs, some of them over many years. This figure is likely to be significantly underestimated, as many projects remain unreported or undisclosed, as explained in Section 5.2.9. Not all important mineral production categories are covered, most probably owing to the lack of public data on individual projects. Industrial minerals (such as rock phosphate, potash and sulphur) and projects related to construction materials or development minerals are not reported.

Table 5.1 indicates the initial capital expenditure and resources estimates (in metric tons of contained copper) of the world's 20 largest undeveloped copper mines. The actual initial capital expenditure that will be required for the construction of these projects is often higher than stated in published feasibility studies (definition: see Glossary) (Mackenzie and Cusworth 2007; Mackenzie and Cusworth 2016), owing to a wide range of causes. In addition, many years may elapse between the completion of a feasibility study, and the decision to commit the required initial capital expenditure and to start building a new production site. EY (2022b) states that "a June 2021 study of 192 global mining and metals projects worth more than US$1b found that 64% ran over budget or schedule – or both – with the average cost overrun sitting at 39%."

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Table 5.1: The world's 20 largest undeveloped copper deposits (those of greatest importance to the global economy; as of August 2022)

Ranking by copper contained in the stated resources	Deposit name	Country	Deposit type	Owner	Discovery year	Capital expenditure (in nominal million dollars)	Copper contained in the indicated and measured resource or in the reserves (metric tons)	Projects on hold or facing major uncertainties as to their future development
1	Pebble	United States of America (Alaska)	Porphyry copper	Northern Dynasty Minerals	1987	4,500	25.82	X
2	Udokan copper	Russian Federation (Transbaïkalia)	Sediment-hosted	Udokan copper/ USM Holding	1940	1,350	18.67	X
3	Tampakan	Phillippines	Epithermal deposit + porphyry copper	Alcantara Group/ Sagitarius Mines	1992	5,900	14.99	X
4	Reko Diq	Pakistan (Belouchistan)	Porphyry copper	JV Barrick (50 per cent) and Pakistani partners.	1974	4,150	14.40	
5	Mes Aynak	Afghanistan	Sediment-hosted	Jiangxi Copper/ Metallurgical Corporation of China	1973	Unknown	12.31	X
6	Resolution Copper	United States of America (Arizona)	Porphyry copper	Rio Tinto/ BHP	1995	6,000	10.18	X
7	Cascabel/ Alpala	Ecuador	Porphyry copper	SolGold	2011	2,540	9.85	
8	Taca Taca	Argentina	Porphyry copper	First Quantum	Mid-1960s	3,275	9.47	
9	Frieda River (Horse-Ivaal-Trukai-Ekwai-Koki (HITEK) deposits)	Papua New Guinea	Porphyry copper	Frieda River Ltd. (PanAust Mining)	1964	3,600	8.74	X
10	Los Helados	Chile	Porphyry copper	NGEX Minerals	2008	Unknown	7.98	
11	Golpu	Papua New Guinea	Porphyry copper	Harmony Gold/ Newcrest	1983	2,825	7.59	
12	Twin Metals (Maturi and Maturi SW deposits)	United States of America (Minnesota)	Mafic to ultramafic intrusion	Antofagasta	1954	2,775	7.37	X
13	Onto/Hu'u	Indonesia	Porphyry copper	Sumbawa Timur Mining	2013	Unknown	7.07	
14	Baimskaya (Peshanka deposit)	Russian Federation (Tchoukotka)	Porphyry copper	KazMinerals	1972	8,500	6.61	
15	Ann Mason	United States of America (Nevada)	Porphyry copper	Hudbay	1956	1,351	6.44	
16	Kerr-Sulphurets-Mitchell	Canada (British Columbia)	Porphyry copper	Seabridge Gold	1960s	5,005	6.38	
17	Galore Creek	Canada (British Columbia)	Porphyry copper	Teck/ Newmont Mining	1955	2,200	5.19	X
18	Los Azules	Argentina	Porphyry copper	Andes Corporation Minera and McEwen Mining	Mid-1980s	2,363	4.62	
19	Bougainville (Panguna mine)	Papua New Guinea	Porphyry copper	Bougainville Copper Limited	1969	1,800	4.61	X
20	Casino Copper	Canada (Yukon)	Porphyry copper	Casino Mining/ Western Copper and Gold	1965	3,251	3.48	
	Total (in metric tons contained copper in published indicated and measured resources) >>>					**61,385**	**191.76**	
	of which, projects that are facing significant development issues >>>						**107.89**	
	of which, projects that are facing significant development issues, as a percentage of the total resources of the listed deposits >>>						**56 per cent**	
	Deposits discovered over 30 years ago >>>						**10 out of 20 (50 per cent)**	

Note: They represent a total resource of 180 metric tons of copper, about nine years' worth of the current world production. Putting them into production would require at least $61 billion.

Deposits with a discovery year highlighted in gold were discovered more than 30 years ago. Projects shown to be on hold are currently blocked in their development owing to one or several issues, such as the award of an environmental or the mining permit, or environmental or social issues including open conflicts or political instability.

Source: Authors

Data sources: Company reports (up to August 2022), United States Geological Survey.

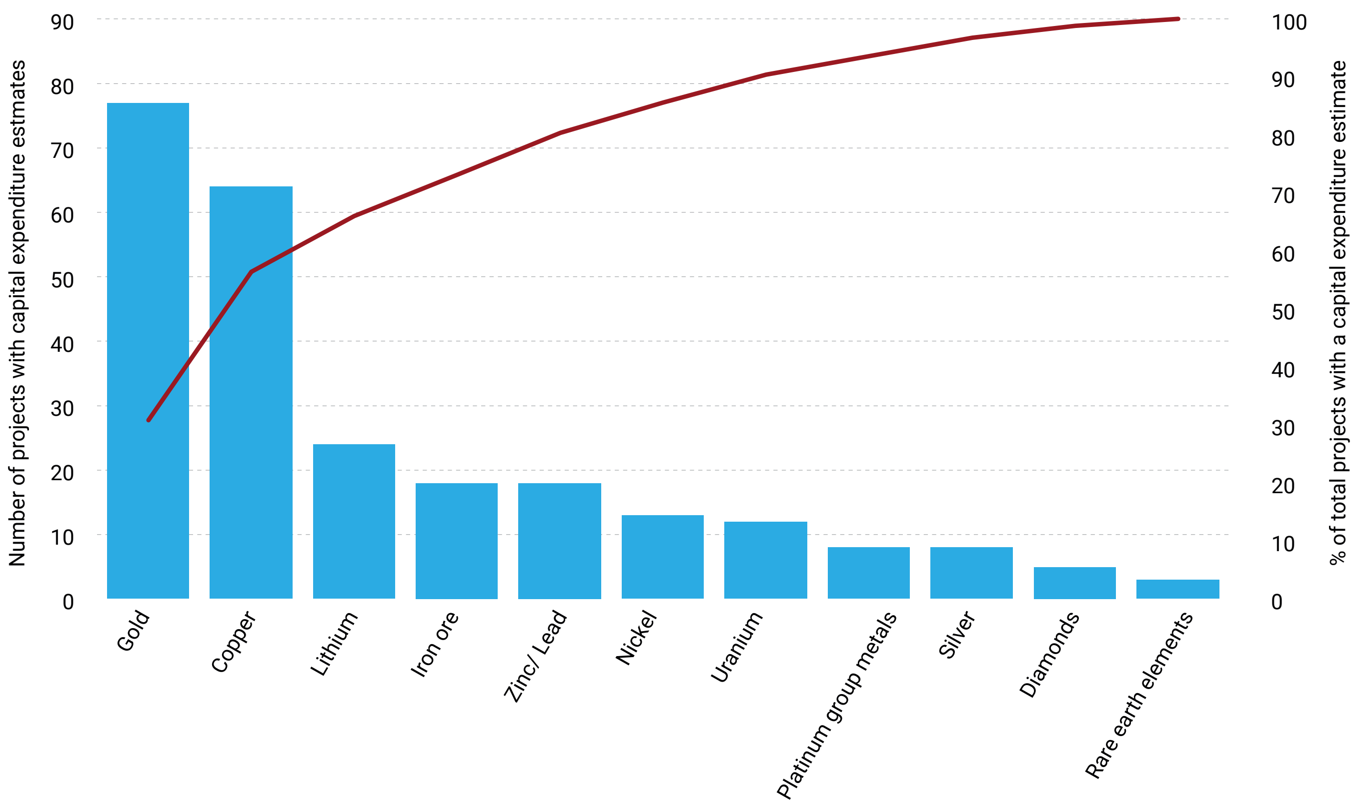
See also: Valenta, R.K., Kemp, D., Owen, J.R., Corder, G.D. and Lèbre, É. (2019). Re-thinking complex orebodies: Consequences for the future world supply of copper. *Journal of Cleaner Production* 220, pp. 816–826. https://www.sciencedirect.com/science/article/pii/S0959652619305359?via%3Dihub

Figures 5.8 to 5.10 provide a synthetic overview of the initial capital requirements needed to launch new mining production, as estimated by Govreau (2022) at the end of 2021. Figure 5.10 shows that, on average, iron ore (average capital expenditure requirement: US$3,255 million) and copper (average capital expenditure requirement: US$1,985 million) production projects are those with the highest capital expenditure requirements. This is related to the large tonnage of ore that needs to be extracted, processed and transported to meet world demand.

Commercial databases also provide such information; for instance, S&P Global Market Intelligence (https://www.spglobal.com/marketintelligence/en/) and OPAXE (https://www.opaxe.com/).

An analysis of the 2,178 scoping, preliminary economic assessment, preliminary feasibility and feasibility studies listed by OPAXE[92] for the period from 4 September 2014 to 23 September 2022 shows that 1,368 (63 per cent) of these reports were produced using the Canadian NI 43-101 reporting standard, 761 (35 per cent) were produced using the Australian JORC Code and only 5 (less than 1 per cent) were produced using the South African Code for the Reporting of Exploration Results, Mineral Resources and Mineral Reserves (SAMREC Code). While there are other national reporting standards recognized by the Committee for Minerals Reserves International Reporting Standards (CRIRSCO),[93] they do not appear to have any impact on the information available on the global minerals and metals industry.

Figure 5.8: Major mining projects in the year 2021, with reported capital expenditure estimates, by number of projects



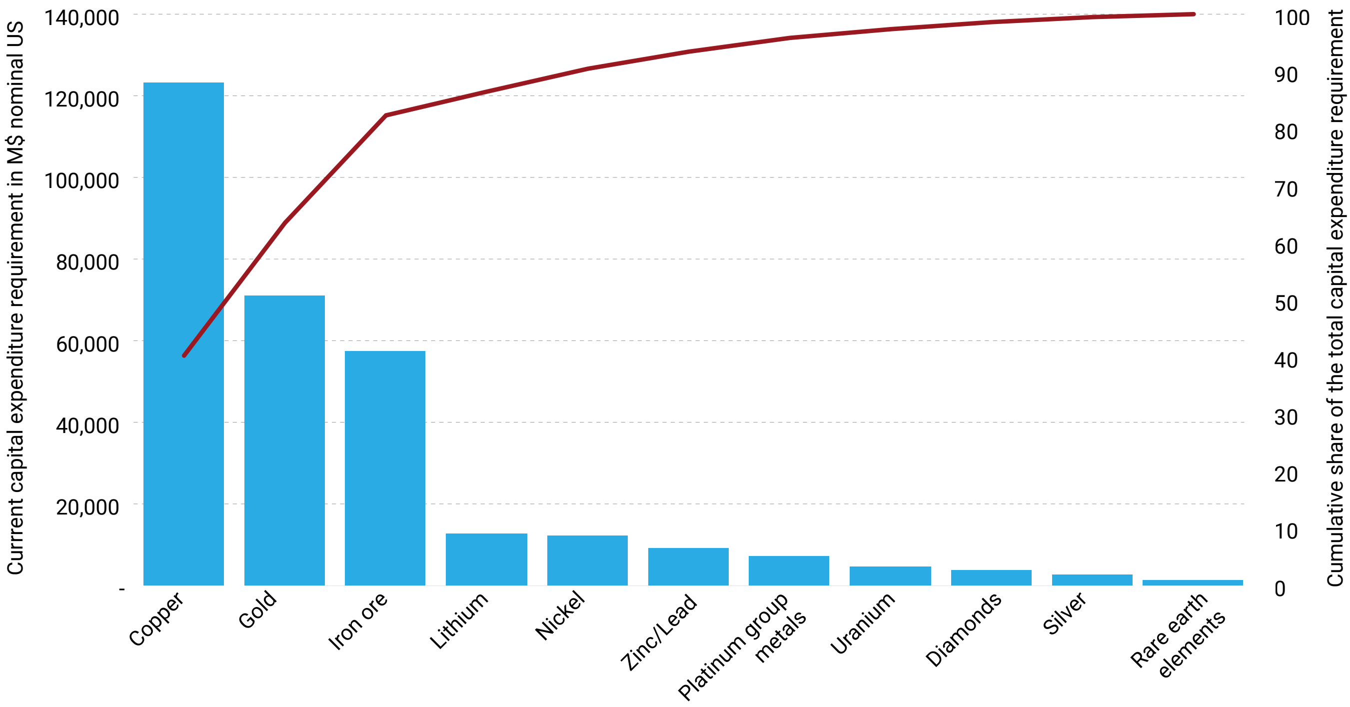
Source: Authors

Data source: Engineering and Mining Journal (2022).

92 https://www.opaxe.com/.

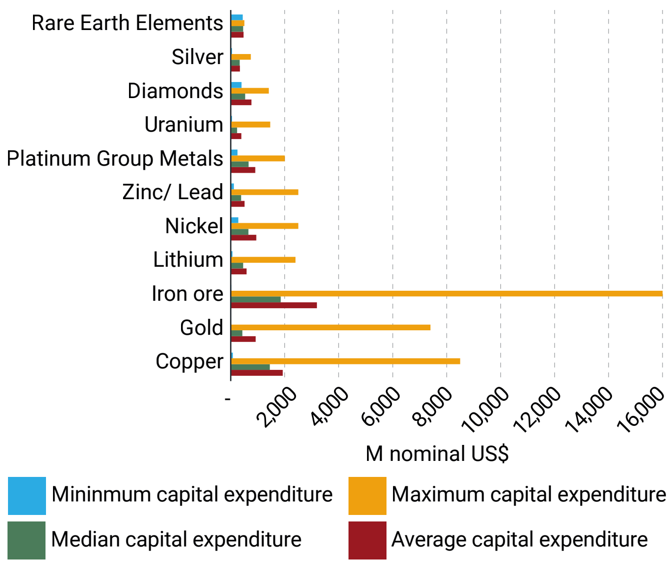
93 www.crirsco.com.

Figure 5.9: Major mining projects in the year 2021, total capital expenditure estimate by mineral resource category, in current million United States dollars



Data source: Engineering and Mining Journal (2022).

Figure 5.10 : Major mining projects in the year 2021: minimum, maximum, average and median capital expenditure requirement by mineral resource category, in current United States dollars



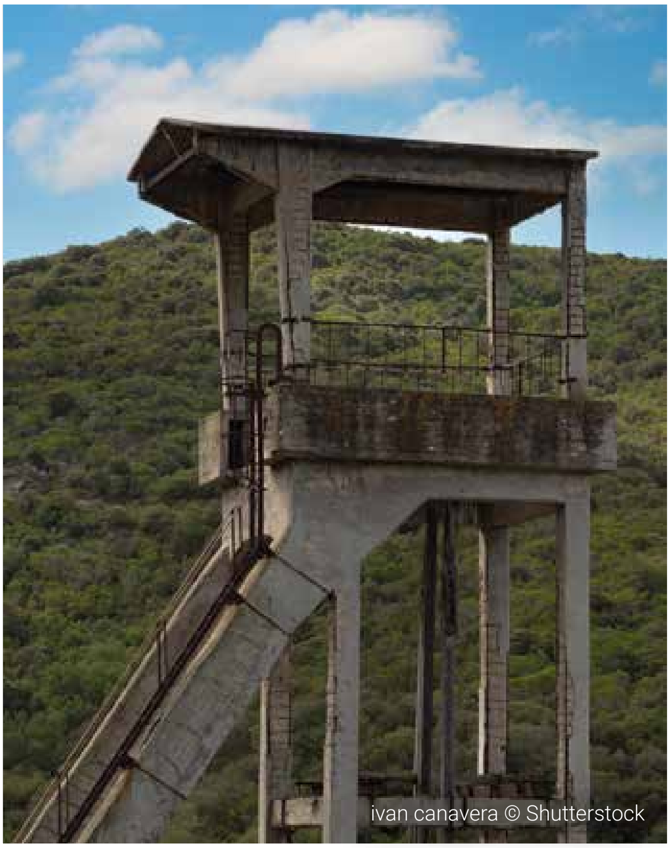
Source: Authors

Data source: Engineering and Mining Journal (2022).

As noted above, the mentioned databases only provide an incomplete overview of the financing of the global mining minerals and metals industry as much data remains undisclosed. Several important limitations of what is known, in detail, about the global minerals and metals industry are as follows:

- Limited data and information are available on construction minerals and development minerals (sand and gravel, ordinary clay, slate, dimension and ornamental stone) and industrial minerals production, as many companies engaged in these sectors of the minerals and metals industry are not publicly listed or have no public reporting obligations.
- Unlisted companies, for instance private equity companies, also have no public disclosure obligations, a situation that is aggravated by the fact that many of them are also headquartered in countries with little commitment to transparency.

- Countries with limitations on the public disclosure of their companies. The case of China is of particular importance, as it is the world's largest producer of a range of minerals and metals (see Chapter 1). So far information available in English on the huge Chinese minerals and metals industry is limited. In addition to a mine and its necessary auxiliary installations (access roads, energy and water supply, explosives storage and in some cases on-site production, offices and other facilities), large-scale industrial operations may also include some additional project-specific facilities, such as an ore-processing plant, a metals foundry and refinery, a railway or a deep-sea harbour. This explains why in several cases the initial capital investment ranges from US$10 billion to US$16 billion. Top-tier large-scale industrial projects are those which matter most for the global production of most ferrous (chromium, cobalt, iron, manganese, nickel, tungsten and vanadium) and several non-ferrous metals (aluminium, copper, lead, zinc) that are produced in larger tonnages. Data on the initial capital investment required to put specific projects into production is part of the mandatory public disclosure requirements for projects owned by companies listed on the relatively few stock markets where disclosure is mandatory for exploration projects, in various degrees of detail, which are essentially Canada and Australia.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5.2.9 The long road towards transparency and accountability

For many centuries, mining and metallurgical activities were considered as highly strategic by the rulers of the different countries endowed with mineral deposits, and wars were fought to secure these resources, or control resources located in other countries. For these rulers, minerals and metals were a major source of wealth and of dominance over other countries. This remains the case in some countries where policymakers see rapid industrialization and infrastructure development dependent on minerals and metals as key drivers of economic and social development, and do not put information about this sector in the public domain.

Historically, the public disclosure of mining and metallurgical activities was essentially limited to financial and economic data, including data on production, resources and reserves published by publicly listed companies in their annual reports. The history of minerals and metals not only includes great industrial achievements, but also frauds, scams and multiple counts of negative environmental and social impacts.

As recently as 2004, in a country as economically and socially advanced as Canada, it was possible for the company operating a mine that closed to declare bankruptcy, leaving environmental burdens from past operations to the local communities and authorities to cope with (the Giant Mine case, a large gold mine that operated near Yellowknife, Northwest Territories (Canada, Government of the Northwestern Territories, Indian and Northern Affairs Canada 2010; Sandlos and Keeling 2012). Poor environmental and social conditions still prevail in mining operations in many parts of the world, but no global site-specific overview of environmental and social impacts of minerals and metals production is yet available. The most advanced development in this direction is the environmental, social and governance assessment of 40 large mining companies and 250 individual mining sites based on a wide range of indicators in the Responsible Mining Foundation 2022 report (Responsible Mining Foundation 2022c; see Chapter 6).

From a sustainable development perspective, the lack of transparency and of extended disclosure obligations enhances the opportunities for wrongdoing, such as poor environmental and social practices, taxation base erosion, transfer pricing (Guj *et al*. 2017; Pun 2017, Readhead 2018a), corruption ("Congo Hold-Up"[94]) or money-laundering. The accurate and detailed reporting of impacts from the mining industry are an essential first step if investors are to be able to invest in responsible mining companies. The absence of information also contributes to the development of numerous environmental, social and governance-related conflicts between local communities and companies pursuing mineral exploration or actual mining. Figure I.12 in the Introduction shows the location of minerals and metals exploration projects or production sites where conflicts have been identified in Latin America by the Environmental Justice Atlas.[95] The high number of minerals- and metals-related conflicts all along the Andes mountain range is caused by two factors, underlining the importance of environmental, social and governance-related aspects to the future of the minerals and metals supply and the global low-carbon energy transition:

- The Andean region is one the regions with the highest densities of mineral deposits, especially copper deposits, in the world. It is the world's largest source of copper, a metal of the highest importance to the global low-carbon energy transition.
- Water and fertile soil are particularly scarce resources in most of the Andes, and of vital importance to local, generally poor, communities, especially on the western side of the cordillera and on its plain along the Pacific coast. The competition for the use of these resources is an important cause of conflicts.

Illicit financial flows are a major and continuing problem plaguing the minerals and metals industry in many countries or regions that suffer from poor governance frameworks, undermining the industry's contributions to the Sustainable Development Goals and depriving them of much needed public revenue, i.e. opportunities to offer a sustainable future to their populations (Cobham and Janský 2018; African Union and United Nations Economic Commission for Africa 2021; Albertin *et al*. 2021).

To help to combat this situation, the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development and OECD have developed analysis and a toolkit to address taxation base erosion and profit shifting in developing countries (Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development and OECD 2019).

Over the last two decades, two major events have catalyzed progress towards greater accountability and transparency of some part of the global minerals and metals industry (this is described in detail in the IRP report *Mineral Resource Governance in the 21st Century* (IRP 2020a)):

- The shockwave from the Bre-X gold-mining scam (Nicholls 1999; Desjardins 2015) led the stock market to the publication and enforcement:
    - In 1999, of the Australian JORC Code developed by the Joint Ore Reserves Committee of the Australasian Institute of Mining and Metallurgy, the Australian Institute of Geoscientists and the Minerals Council of Australia; and
    - In 2001, of the NI 43-101 Standards of Disclosure for Mineral Projects, developed by the Canadian Securities Administration.
- The strong distrust of civil society and local communities caused by the negative environmental and social impacts of the minerals and metals industry's activities. Already widespread in the 1990s, this led a group of nine major companies to launch an in-depth independent multi-stakeholder assessment of the linkages between the minerals and metals industry and sustainable development, the Minerals and Mining for Sustainable Development project, the report of which found that "minerals companies as a group have a poor record of safe and healthy working conditions" and "even the best modern operations may have some undesirable environmental impacts, and good practice has far to go before it spreads to all parts of the industry" (Mining, Minerals and Sustainable Development 2002). The report strongly advocates for greater transparency and dissemination of information on projects as an effective way to reduce transaction costs and obtain the support of the local communities that may be affected by mining projects.

94 Website with case histories of corrupt practices in the mining sector of the Democratic Republic of the Congo: congoholdup.com
95 https://ejatlas.org/.

These important milestones on the long and windy road towards consolidating mining's contribution to sustainable development had important positive consequences that are presented in detail in the IRP report *Mineral Resource Governance in the 21st Century* (IRP 2020a). The key developments from a financial and investment perspective are outlined here in two parts: exploration activities, up to the definitive feasibility study (Stages 2 to 4, figure 5.5); and production activities (Stages 6 and 7).

5.2.9.1 Progress related to the public reporting of exploration activities

Since the early 2000s, there have been important developments in the data and information available on the exploration activities of some important parts of the global minerals and metals industry. Stock market authorities introduced requirements for much improved reporting practices of mineral exploration projects, up to the definitive feasibility study. Publicly listed companies were compelled ensure that their reporting practices on their exploration projects conformed to national standards, with a key role given to named qualified or competent persons, who either prepare or supervise these reports, putting their professional standing at risk in the event of malpractice. Some non-listed companies joined this move towards greater transparency by voluntarily reporting their exploration activities using the same reporting procedures as listed companies.

The obligation for companies listed on some major stock markets to report their exploration activities, up to and including the Definitive Feasibility Study, in a format described by relevant national reporting standards and recognized by the relevant stock market regulatory authority (Committee for Mineral Reserves International Reporting Standards [CRIRSCO][96], is a game changer, but one with important limits.

S&P Global IQ, a subscription-based service, has identified 422 feasibility studies on individual projects being reported according to a national reporting code since 2001. Of these, 55 per cent were reported according to the Australian JORC Code and 42 per cent according to the Canadian NI 43-101 standard. Only seven feasibility studies (2 per cent of the total) were reported according to the South African SAMREC Code; two were reported using the Securities and Exchange Commission SEC code of the United States of America; two using the Russian National Reporting Organization (OERN)[97] code of the Russian Federation; and one using a Chinese code not yet recognized by CRIRSCO. The national reporting codes of Brazil, Chile, Colombia, Europe, India, Indonesia, Kazakhstan, Mongolia and Türkiye so far have no impact on the progress of public disclosure of mineral exploration and development projects. While China is the world's largest minerals-and-metals-producing country, no feasibility study prepared by a Chinese company for a project within China could be identified, at least not in the English language.

Figure 5.11 shows the annual progress made since 2001 in the publication of feasibility studies compliant with one of the reporting codes recognized by CRIRSCO, as recorded in the S&P database.

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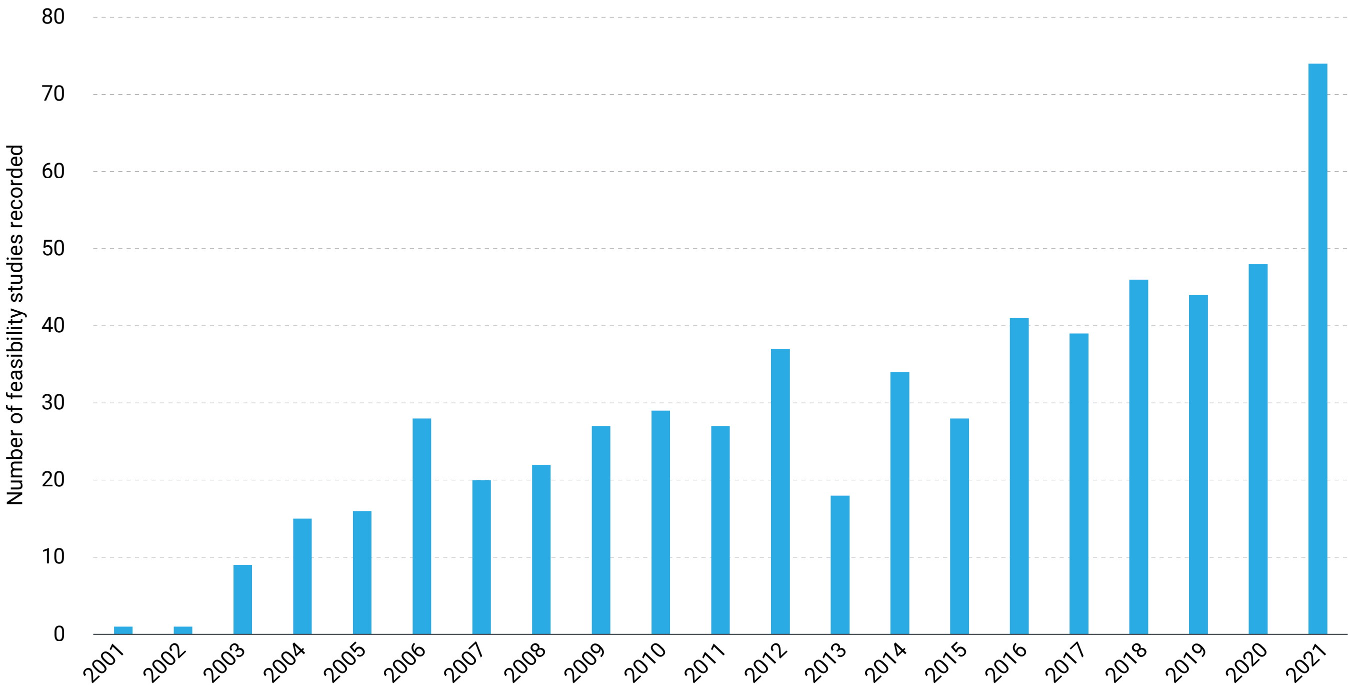
96 https://crirsco.com/

97 From a CRIRSCO presentation: https://crirsco.com/wp-content/uploads/2024/04/15_Russia_NAEN_Update-GMalukhin_OIllyin.pdf

Figure 5.11: Annual count of feasibility studies compliant with a national reporting code recognized by CRIRSCO



Source: Authors

Data source: S&P Global IQ subscription-based global minerals and metals industry database

The obligation for nearly 2,000 companies listed either on the Toronto Stock Exchange (NI 43-101 reporting standard) or the Australian Securities Exchange (JORC Code), to report on their mineral exploration projects worldwide under one of these reporting codes has much improved, quantitatively and qualitatively, the data and information publicly available on a significant part of global mineral exploration activities. In particular, as intended by these reporting standards, the reports from these companies provide resources and reserves data with the highest current confidence level, as the data they provide is much less prone to embellishment or manipulations than data from other sources. The latter are hardly verifiable, leaving their users no other option but to accept or reject such data.

Feasibility studies also provide valuable analysis of the minerals and metals market. They also provide detailed insights into ore deposit geology, mining, ore processing and, sometimes, metallurgical technologies.

However, despite progress since the late 1990s, important limits remain concerning the disclosure of reliable data and information on mineral exploration projects:

- There are major differences between reporting and disclosure obligations under the Canadian NI 43-101 standard and the Australian JORC Code, and limits to the sustainable development relevant knowledge that can be derived from the reports produced using these national reporting standards (Forest 2013). Disclosure obligations regarding sampling procedures, the determination of indicated or measured resources, or of reserves, are extensive under NI 43-101 and must include information on the sampling and analytical procedures applied, the security of the sample storage and the modifying factors (see Glossary; textbooks on mineral exploration and mine valuation provide much further detail, e.g. Australasian Institute of Mining and Metallurgy 2014; Bustillo Revuelta 2017) applied to resources for their conversion into reserves. JORC reporting obligations (Australian Institute of Geoscientists, AusIMM Mineral Institute, Minerals Council of Australia (JORC) 2012) are of a more limited scope. Furthermore, it leaves reporting companies the choice to exclude from their disclosure some commercially sensitive information, replacing such information with "summary information (for example the methodology used to determine economic assumptions where the numerical values of those assumptions are commercially sensitive) and context for the purpose of informing investors or potential investors and their advisers" (Australian Institute of Geoscientists, AusIMM Mineral Institute, Minerals Council of Australia (JORC) 2012). Consequently, the data and information available from JORC-compliant reports are frequently of a much more summary nature than in NI 43-101-compliant reports.

- At the global level, the United Nations Economic Commission for Europe (2019a, 2019b) has developed a unified, harmonized, multilingual resources and reserves reporting framework. It was initially developed to allow governments to gain a harmonized overview of national oil and gas resources and reserves. This framework is being extended to mineral resources to produce the United Nations Framework Classification for Resources (*UNFC*) United Nations Economic Commission for Europe (2019a, 2019b)) and work is in progress to develop its full compatibility with the CRIRSCO Reporting Template (CRIRSCO 2024). The CRIRSCO Reporting Template provides guidelines for countries developing their national reporting standards for public reporting on mineral exploration projects, up to the completed feasibility study, including resources and reserves reporting. UNFC has thus far provided a convenient tool to governments wanting to have a unified system to document their resources and reserves. The African Union has developed the African Minerals Resources and Energy Classification System (AMREC) based on UNFC; and an example of the use of UNFC at the national level is provided by the Geological Survey of Finland (Michaux 2021). UNFC is not used by the mining industry for reporting purposes, and it is not a mandatory reporting framework. So far, when compared to the NI 43-101 or JORC national reporting standards, UNFC has had little impact on the development of publicly available information and data on mining projects.

- Despite the progress made so far, efforts to link existing best practices in transparency and public disclosure would much benefit from effective support from the governments and industry of all the important mineral-producing countries that re lagging behind in the development of transparency and public disclosure on exploration and mining activities. China, in particular, as the world's most important minerals- and metals-producing country, would be well placed to take the lead in this respect.

- Where disclosure does take place, the quality of the reports, whatever the reporting format being used, is highly dependent on the intents of the reporting company and the competences of the parties involved in the preparation of these reports. There remains much scope to improve and standardize feasibility studies, according to McKinsey (Dussud *et al*. 2019), who notes that more rigorous feasibility studies "help to prevent cost and schedule overruns and maximize value". Depending on how external stakeholders, especially communities that are likely to be impacted by a future operation, are associated in a transparent, auditable manner at all stages (figure 5.5) leading to the preparation of a feasibility study, the process is critical to developing trust among stakeholders, with significant potential to facilitate the obtention by the informal, but vitally important sustainable development licence to operate project (IRP 2020a).

5.2.9.2 Progress related to public reporting of the environmental, social and governance performance of minerals and metals production activities.

In parallel to the development, for companies publicly listed on some major stock markets (essentially the Toronto Stock Exchange and the Australian Securities Exchange), of codified, mandatory reporting on mineral exploration activities, environmental, social and governance reporting has developed over the same period, with close to 90 voluntary initiatives worldwide seeking to promote the transparency and accountability of minerals and metals production activities (IRP 2020a). However, none of these initiatives, either developed by some part of the minerals and metals industry or some non-governmental organizations, addresses the need for standardized, transparent, operation-level reporting of environmental, social and governance-related aspects, along with economic performance.

The United Nations Environment Programme (UNEP) (2020) in its report on Sustainability Reporting in the Mining Sector notes: "The management of environmental and social aspects, and sustainability reporting of mining companies, is currently not meeting the expectations of interested stakeholders, notably communities affected by mining operations and investors. In general, governments have not specifically targeted sustainability reporting of the mining sector, but the sector often falls under wider policies, including regulations that address sustainability reporting of large or publicly listed companies".

Despite all the good intentions of the mining companies that supported the Mining, Minerals and Sustainable Development project 20 years ago, much remains to be done to bridge the wide gap remaining between the recommendations laid out in Breaking New Ground, the final report of the Mining, Minerals and Sustainable Development Project (Mining, Minerals and Sustainable Development 2002) and the achievements so far. The Global Reporting Initiative is currently the most widely used voluntary environmental, social and governance performance reporting standards framework (Global Reporting Initiative 2022a) used by an unspecified, but probably significant number of mining companies listed on the stock markets of OECD countries.

The Responsible Mining Foundation (2022), discussing the Global Reporting Initiative, notes important shortcomings in the standards-based environmental, social and governance reporting of the Initiative: "The fundamental problem in the GRI [Global Reporting Initiative] framework is the fact that it relies on reporting companies selecting which issues to report on. The only information required for a sustainability report to be in accordance with GRI are general disclosures on governance and corporate organisational matters, with very little ESG [environmental, social and governance] substance." And "In addition, the kinds of data requested by the GRI framework are of little meaning in indicating companies' ESG impacts on the ground. The problems in this respect include the following:

- **Aggregate statistics:** Quantitative indicators focus on statistics aggregated to a company or regional level, with no mine-site-level reporting requested. On water discharges for example, companies are asked to report company-level consolidated data on the total aggregate levels of pollution parameters in their water discharges, and on local procurement, company-wide aggregate spend on local procurement is the required information.
- **Relative data:** Some GRI indicators require only rates rather than absolute figures. This is the case, for example, with injuries and occupational disease, which are reported as fractions of total hours worked.
- **Lack of contextual data:** GRI indicators rarely require statistics to be accompanied by information to put the figures into context. So for example, companies are asked to report the number of environmental incidents but not with any details such as the location and severity of these events."

In 2020, the IRP report *Mineral Resource Governance in the 21st Century* depicted a fragmented landscape of environmental, social and governance practices and reporting, with close to 90 different initiatives aimed at documenting certain environmental, social and governance-related aspects of minerals and metals production projects (Chapter 7, IRP 2020a).

In October 2021, at the 26th United Nations Climate Change Conference of the Parties (COP26), the International Financial Reporting Standards Forum introduced the International Sustainability Standards Board. Its objective is to develop, in the public interest, high-quality, understandable, enforceable, and globally accepted sustainability reporting standards (International Financial Reporting Standards Foundation 2021). These standards will complement the existing International Financial Reporting Standards that have widely replaced national accounting standards, with the important exception of the United States of America where the national Generally Accepted Accounting Principles remains the mandatory reporting standard. The International Sustainability Standards Board and Global Reporting Initiative are seeking to coordinate their work programmes and standard-setting activities (Global Reporting Initiative 2022b). It will take years before the impact of this initiative on global environmental, social and governance reporting practices and quality will be measurable.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The road towards transparency and accountability remains steep and winding. It is critical to build trust among stakeholders to enable the further rise of transition minerals production needed to meet clean energy transition goals (International Energy Agency 2021, International Renewable Energy Agency 2022). There is much that industry, governments and the finance industry could and should urgently do, in a globally coordinated effort, to progress towards transparency and environmental, social and governance accountability at the operational level. The current developments are contrasted.

On the negative side:

- Political regimes, based on national myths and massive disinformation, and the risks of global international confrontation, are on the rise, and may further develop in the coming years as nationalist dystopian narratives provide the illusion of easy solutions to complex problems.
- The Global Reporting Initiative no longer provides transparency on the progress of environmental, social and governance reporting by the minerals and metals industry. Up to 2013/14, it provided free access to a database recording the environmental, social and governance reporting of individual companies under the Initiative, rating their compliance level to the reporting standard of the Initiative (then named "Guidelines") and stating whether the environmental, social and governance report for each listed company was externally audited. The Global Reporting Initiative then introduced a paywall, only providing a list of companies quoting the Initiative in their environmental, social and governance reports. As at 2022, the Initiative does not provide information on the use of its standards by individual companies.
- In an effort to develop the much-needed site-level transparency, the Responsible Mining Foundation,[98] a Switzerland-based non-governmental organization, has been developing a unique methodology to develop site level environmental, social and governance reporting since 2012 (Responsible Mining Foundation 2022b), with a wide set of indicators that offer the most detailed environmental, social and governance relevant indicator set on mining activities to date. As at 2022, based on publicly available data and additional data contributed by companies, it could provide site-specific data and analysis on 40 assessed companies and 250 mine sites in 83 countries around the world (RMI Report 2022, Responsible Mining Foundation 2022c, individual mine site and company specific reports are accessible at: https://www.responsibleminingfoundation.org/rmi-report-2022/). On 6 April 2022, the Foundation reported (Responsible Mining Foundation 2022b) that it would close and cease its activities owing to a lack of independent long-term co-funding, with the Foundation declining to accept industry-related contributions.
- At the 2021 Roundup Conference of the Association for Mineral Exploration of British Columbia, Robert Friedland, the billionaire founder and Chair of Ivanhoe Capital, and one of the world's best-known and most influential mining industry financiers, highlighted the central importance of environmental, social and governance performance to meeting the challenges of the minerals and metals demand arising from the low-carbon energy transition (Ivanhoe Mines 2021).

On the positive side, some initiatives are developing with a potential for global reach if they receive support from all stakeholders, with the commitment of governments, industry and investors playing a central role in their ongoing development and success:

- In 2006, the Initiative for Responsible Mining Assurance was launched by a coalition of non-governmental organizations, minerals and metals traders, representatives from some communities impacted by mining companies, labour unions and mining companies.[99] In 2018, the Initiative published the first version of its Standard for Responsible Mining (Initiative for Responsible Mining 2018), which details a number of important requirements for any company volunteering to seek auditing and certification from the Initiative:
    - The need to acquire environmental and social baseline data (Section 2.1.4.1 of the Standard) as part of the Environmental and Social Impact Assessment preparation process;
    - The need to geochemically and mineralogically characterize any solid waste streams (section 4.1.3).

98 https://www.responsibleminingfoundation.org/.

99 https://responsiblemining.net/.

The Initiative for Responsible Mining Assurance proposes companies to be audited on a voluntary basis against the Standard for Responsible Mining, with a choice between a self-assessment and an independent auditing process. Audit reports are made public. As at August 2023, 15 mine sites in Africa and in Central and Latin America are at various stages of progress in obtaining certification from the Initiative. The certification states the level of compliance of the audited operation with the Standard.

- In early 2023, the Church of England, an important global institutional investor, launched the Global Investor Commission on Mining 2030 initiative, which it defines as “a collaborative investor-led initiative”, that “recognises the mining industry’s important role in the transition to a low carbon economy, and considers key systemic issues faced by the mining sector that currently challenge, or could challenge, existing good practice and the sector’s social licence to operate”.[100] Such an action, if it attracts sufficient participation from other important institutional investors could lead to significant progress regarding the transparency, accountability and environmental, social and governance practices of the global mining industry.

Transparency and accountability are not in contradiction with legitimate business interests. On the contrary, in a world where, thanks to the Internet, millions of people and organizations can actively spread data and information in real-time across the world, transparency and real environmental, social and governance accountability are in the best interests of industry and its investors. The example of the Canadian NI 43-101 reporting standard shows that reporting obligations do not deter investment in mineral exploration. On 31 December 2011, the Toronto Stock Exchange listed 1,646 mining companies, mostly junior exploration companies, on its TSX and TSX-V markets, with a total of about Can$ 427 billion market value. About 10 years later, on 31 March 2022, this number had declined to 1,162 companies, but with a higher total market value (Can$ 668 billion, equivalent to US$ 501 billion).[101] The reduction in the number of listed companies rather reflects the reduction in mineral exploration budgets observed since 2012, the record year for mineral exploration investments, rather than companies trying to escape reporting obligations through delisting. The market value increase probably reflects a better average profitability of mining companies and a greater appetite of investors for mining-related investment.

5.3 FINANCING NEEDS AND THE ROLES OF PUBLIC FUNDING AND OF INVESTORS

Several forms of financing are needed to support responsible minerals and metals production activities that support sustainable development.

Public financing is needed for activities with a gold background colour on figure 5.5, while activities with a green background are mostly financed by investors, which in market economies are essentially private.

Some activities are shown with a combined gold and green background, meaning that in market-oriented countries where governments strongly promote the local minerals and metals industry, some activities that are usually left to investors, such as mineral exploration and the acquisition of environmental and social baseline data, are sometimes partly or totally taken on by public authorities using their financing resources.

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100 https://mining2030.org/.

101 Data source: https://www.tsx.com/listings/current-market-statistics/mig-archives.

5.3.1 Key economic parameters of industrial-scale mining projects

In market-oriented countries, investors mostly make their decisions based on definitive feasibility studies. They are also called bankable feasibility studies, as banks and other investors require them as a key element to inform their decision-making processes. Most investors are likely to examine an investment opportunity in relation to the risks and of the potential economic returns. They are also likely to compare the opportunity to invest in a mining project with other investment opportunities.

Investors need as much reliable data and information as possible to evaluate the merits and the risks of any specific mining project investment proposal. This evaluation process is described in detail in several handbooks on mineral economics (e.g. Darling 2011; Wellmer *et al*. 2011; Rudenno 2012; Buchanan 2015; Halland *et al*. 2015; Queen's University 2022). The Canadian Institute of Mining, Metallurgy and Petroleum (2014) provides authoritative definitions of the key expressions used for the evaluation of mining projects, such as "resource", "reserve", "modifying factor" and "pre-feasibility" and "feasibility" studies. These definitions are used in the Canadian NI 43-101 Standards of Disclosure for Mineral Projects, which are applicable to the projects of the companies listed on the Toronto Stock Exchange. Comparable definitions are also used in the other national reporting codes listed by CRIRSCO.

This section only highlights some key economic aspects of mining projects. Textbooks such as those of (Gocht *et al*. 1988), Wellmer *et al*. (2008), Darling (2011), Rudenno (2012) and Jones *et al*. (2019) provide in-depth introductions to mineral economics and project valuation.

This section is based on the analysis of data related to 835 public feasibility studies, published over 20 years, between October 2001 and October 2022, compiled by S&P Global Market Intelligence, a commercial information service on the global mining industry.[102] The detail of the economic data available for individual projects is variable, as reflected below by the numbers of studies that could be used to calculate the average and median values mentioned. The S&P database only includes industrial-scale projects. Artisanal and small-scale mining activities generally do not report on their activities. In the event that several successive feasibility studies were performed for the same project, only the most recent version was considered. This database served for the production of Tables 5.2, 5.3, 5.4 and 5.5 below.

The treatment of mining finances that follows does not include any need to pay taxes and royalties owing to the host government, an issue that was discussed in some detail in Chapter 2 in relation to South America. These requirements differ greatly from country to country and will not be addressed further here.

5.3.1.1 Initial capital expenditure

Initial capital expenditure is the upfront capital needed to start production at a new facility and comprises all fixed expenditures (capital items) needed to start production activities. Additional capital, known as sustaining capital, may also be needed by some projects to finance later production expansions or the acquisition of new capital items. This section only discusses initial capital requirements.

The initial capital needed to start production at a new mine is extremely variable. It depends on the size of the reserves that will be mined, the production rate, and the complexity of the technologies and equipment needed to mine and process the extracted minerals up to a stage where they will meet the criteria to be marketable. The processing of most minerals will require some form of plant, and in the case of metals production it may include the construction of a smelter and a metal(s) refinery. Otherwise, ore or concentrates will have to be transported, sometimes over many thousands of kilometers, to such facilities. Projects to produce metals in large tonnages are the most capital-intensive for copper projects, as shown in table 5.1: Each of the world's 20 largest currently undeveloped copper projects have an initial capital expenditure requirement of over US$1 billion.

The initial capital expenditure requirement will also depend on the need for auxiliary facilities such as storage facilities for chemicals, explosives, fuels and water, the need for an on-site explosives production plant, an equipment maintenance facility, energy and water supply and sanitation, waste storage facilities, access roads, housing and recreational facilities. In some cases, such as the giant Simandou ore deposit in Guinea, a deep-sea harbour will need to be constructed to transport the ore to the customers' steel plants, as well as a 650 km railway line to connect the mining area with the harbour area.

102 https://www.spglobal.com/marketintelligence/en/campaigns/metals-mining.

In the case of artisanal and small-scale mining operations, capital expenditure can be limited to the purchase of some picks and shovels needed to start digging and to some steel pans for concentrating native gold grains or other high-density minerals, such as colombo-tantalite (the main tantalum ore). Finance for artisanal and small-scale mining operations is discussed in Chapter 7 and is not discussed further here.

The S&P database provides capital expenditure figures in nominal United States dollars for 659 feasibility studies. Capital expenditure requirements vary from US$0.35 million to over US$18,000 million.

The average capital expenditure value of this dataset is US$689 million, and its median value is US$185 million.

5.3.1.2 Discounted cash flow analysis, discounting rates and net present value

By far the most widespread economic valuation method for a mine project is the discounted cash flow analysis method. In feasibility studies it is the economic summary of the project. Based on the reserves calculation and on the modifying factors, it takes into account the value of money over time by estimating future annual production value and cost over the lifetime of the productive activities.

In feasibility studies, an annual cash-flow is, for a given year, the difference between the income before interest, taxes, depreciation and amortization minus all operating costs. This defines the operating profit.

For metals, the operating income is the net smelter return perceived by a company, not the market price of the metal(s) contained in the ore. Using copper as an example, the market cash price of copper on 24 November 2023 was US$8,295 per metric ton. The operating income of a mining company would be that copper price minus the cost of transporting the ore concentrate it produced to a smelter, as well as the costs of smelting the concentrate and refining the metal(s) contained in the ore. Any credits paid by the smelter to the mining company for the co- or by-products[103] contained in the ore will increase the net smelter return.

The discounted cash flow analysis is performed in annual increments, from initial production up to mine closure, over the full life of the mine. The discounted cash flow analysis is a core component of pre-feasibility and feasibility studies compliant with national reporting standards such as NI 43-101 or the JORC Code. To perform a discounted cash flow analysis, the prior determination of a deposit's indicated and measured resources and reserves is necessary. Resource modelling nowadays relies on computer-assisted three-dimensional digital modelling of the ore body, itself widely based on observations and multi-element analysis of drill-hole cores, and geostatistical, probabilistic interpolation of the observed data. The three-dimensional digital representation of the geology and mineralization grades is the basis for the application of the modifying factors, the process by which a resource becomes a reserve.

Consequently, reserves vary over time, especially depending on changes in economic factors such as demand, the market prices of the mineral(s) or metal(s) produced and the cost of the inputs needed (energy, chemicals – including explosives – and water), transport, metallurgical and refining processes (in the case of metals production), as well as of waste disposal and management.

Pre-feasibility studies will normally consider several scenarios, assuming different sets of modifying factors, especially minerals and metals prices and demand, throughout the life of the mine, and identifying the economic sensitivity of the project to these variations. During the feasibility study stage, the most credible scenario (baseline scenario) will then be selected and assessed in detail to determine a few key economic parameters, including risks, that will inform potential investors about the potential economic returns that the project is anticipated to deliver over the life of the mine. According to the Queen's University Mine Wiki[104], a feasibility study should include a cost estimate (initial capital cost and operating cost estimates) of accuracy in the order of +/- 10 per cent to 20 per cent and it may comprise a contingencies provision of +/- 15 per cent.

103 See Glossary for a definition of these terms.

104 Queen's University. (2022). Discounted Cash Flow Analysis - Methodology and discount rates. Online article, with the link now discontinued.

Discounted cash flow analyses are normally performed in two separate stages:

- The pre-tax discounted cash flow analysis only considers direct operating costs, excluding interest paid on loans received, taxes and royalties paid to public authorities, and financial provisions made for amortization and depreciation of capital equipment.
- The post-tax discounted cash flow analysis, which includes interest paid, taxation, depreciation and amortization.

The discounted cash flow analysis performed during the feasibility study requires the definition of a discount rate that reflects the risk perception by the top management of the company that is developing the project. These risks are then compared to an investment in a supposedly risk-free investment vehicle, under no-inflation conditions (Park and Matunhire 2011). The most common "risk-free"[105] investment used for the purpose of this comparison is the Treasury Bonds of the United States of America. The selection of the discount rate directly impacts a project's net present value, which is the sum of the discounted annual cash-flows over the project's full life of the mine, as defined above.

The net present value of a project is defined as follows:

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+d)^t}$$

Where:

- R_t is the net cash inflow or outflow during a single year.
- d is the constant discount rate applied to the project.
- t is the several years between the initial capital investment and the mine closure (assuming that no further cash-flows will occur after the mine closure).

The choice of discount rate by a project proponent is a delicate balancing act, based on the assessment of the project-specific risks. Park and Matunhire (2011) provide a calculation example for the Ambatovy nickel mine (Madagascar). For the same series of future cash-flows, the higher the discount rate, the lower the net present value of the project. While offering a better economic protection against risks, a high discount rate may reduce a project's attractiveness to investors.

Examples of the present values of annual US$1,000 cash flows over time, using different discount rates, are given in table 5.2, showing the much lower value of distant cash flows compared to the cash-flows in early production years.

From an economic point of view, the cash flow generated during the first few production years matters much more than cash flows generated many years after production starts. The consequences of this will be further discussed under "payback period" (Section 3.1.4).

Table 5.2: Calculation of the net present value of annual future positive US$1,000 cash flows, using different discount rates

Year of the cash flow		Discount rate applied (%)					
		5	6	7	8	9	10
1	Net present value (NPV) of a $1,000 cash flow generated in year N	952	943	935	926	917	909
2		907	890	873	857	842	826
3		864	840	816	794	772	751
(...)		(...)	(...)	(...)	(...)	(...)	(...)
10		614	558	508	463	422	386
20		377	312	258	215	178	149
30		231	174	131	99	75	57
40		142	97	67	46	32	22

Source: Authors

105 "Risk free" is put in double quotation marks as it relates to sovereign bonds that may also prove to be risky assets in view of the high public debt/gross domestic product ratios in many OECD countries, in the event of a major systemic financial crisis.

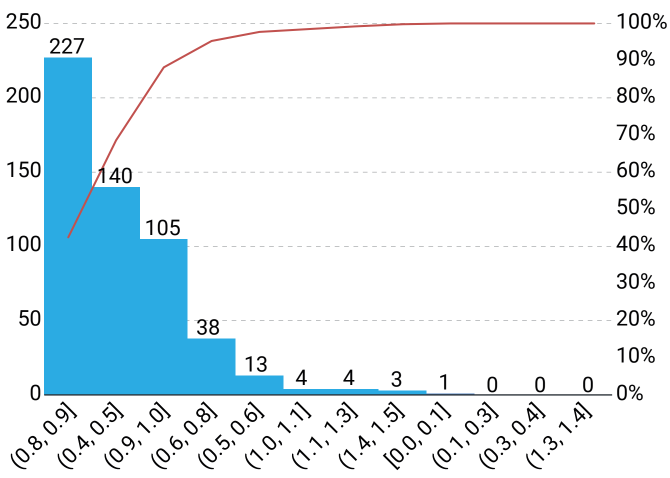
The S&P database mentioned above provides the base discounting rate applied in 535 feasibility studies. The average applied discount rate was 7.56 per cent, a rate quite comparable to the 7.18 per cent average observed by Ovalle (2020) among only 100 projects.

Figure 5.12 provides the Pareto distribution diagram of this dataset. The x-axis provides ranges of discount rates applied to the project. The first bar therefore means that 226 projects had a discount rate of between 7.5 per cent and 8.8 per cent.

About 69 per cent of the 535 projects have a discount rate ranging from 7 per cent to 10 per cent. The effects of the recent return of inflation and the related interest rate increases by central banks, especially the United States Treasury, cannot be measured yet, but they may trigger a rise in the discount rates applied to mining projects.

An analysis of the average discount rates applied for projects in different world regions with a sufficient number of published feasibility studies to be statistically significant (n >20) shows no major regional differences in the discount rates applied (table 5.3), with projects in North America and South America having discount rates only about 1 per cent lower than those for projects in Europe, the Asia and the Pacific region and Africa.

Figure 5.12: Pareto frequency analysis of the discount rates applied to 535 individual mining projects, as stated in their feasibility studies



Source: Authors

Data derived from the S&P database.

Table 5.3: Average discount rates applied to projects in different world regions

Region	Average discount rate (per cent)	Number of feasibility reports with data
Africa	7.7	147
Asia and the Pacific	8.1	165
Europe (including the 27 member States of the European Union)	7.6	51
European Union	7.6	25
Latin America	6.8	114
North America	6.9	174

Source: Authors

Data derived from the S&P database.

5.3.1.3. Internal rate of return

The internal rate of return, as calculated in the feasibility study, provides investors with an estimate of the future profitability of their investment, and is therefore an important metric for evaluating the attractiveness of new minerals and metals projects. Together with the discount rate and the net present value, it allows investors to estimate the returns they may obtain against the risks they are taking.

The internal rate of return of a project is the discount rate at which the net present value of all annual cash flows will be zero.

It is defined as follows:

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+IRR)^t} = 0$$

Where:

- R_t is the net cash inflow or outflow during a single year.
- *IRR* is the constant internal rate of return applied to the project, over the life of the mine.
- *n* is the number of years between the initial capital investment and the mine closure (considering that no further cash flows will occur after the mine closure).

As stated above, cash-flows can be calculated "pre-tax" or "post-tax". This of course impacts the calculation of the internal rate of return. The database includes 211 projects with pre-tax and post-tax figures from feasibility studies prepared in compliance with one of the CRIRSCO-compliant national reporting standards. On average, their pre-tax internal rate of return is 59.2 per cent, while the average post-tax internal rate of return is 48.9 per cent. Median values for the internal rate of return are 36.5 per cent and 29 per cent respectively. Some 44 projects (21 per cent of the projects for which both internal rate of return values were available) have a post-tax internal rate of return below 20 per cent.

The analysis of the average internal rates of return applied for the projects in world regions with sufficient published feasibility studies to be statistically significant (n >20), shows some regional differences in the average internal rates of return (table 5.4). These differences could be the result of several factors. For instance, the attractive average internal rate of return of 61 per cent for the 145 projects in the Asia and the Pacific region is likely to reflect the fact that 121 (83 per cent) of these projects are in Australia, a country with excellent infrastructure and a specialized workforce, as well as a well-developed institutional framework and a long track record of mining and metallurgical activities. The explanatory factor for the high average internal rate of return of Africa (48 per cent) probably relates to the quality of the resources and reserves of projects being developed in the continent, as its geological resources are still widely underexplored and thus underexploited, making it a world region where major discoveries of near-surface, or outcropping, high-grade mineral deposits are still possible.

Table 5.4: The average internal rate of return of mining projects, by world regions

Region	Average internal rate of return (%)
Africa	48
Asia and the Pacific	61
Europe (including the 27 member States of the European Union)	35
European Union	35
Latin America	39
North America	39

Source: Authors

Data derived from the S&P database.

5.3.1.4 Payback period

The payback period, expressed in years, is the time needed to recover the initial capital investment. This period is the one where an investment is extremely vulnerable to the materialization of risks, whether foreseen or not, as the viability of the operation may be called into question. Investors are therefore favouring projects with payback periods as short as possible.

The anticipated payback period of new projects is documented in their feasibility reports. Actual payback times may differ by some additional years, because of technical difficulties requiring complex operational procedures, processes or equipment adjustments during the production ramp-up stage (the period running from the start of production to the moment where the production will meet the nameplate capacity stated in the feasibility study).

This has consequences on mining practices, as well as on the revenue that governments may earn during the early years of a new operation. These consequences are further compounded by the logic of discounted cash flow analysis, especially in the cases where the discount rate is at the higher end (8 per cent and over) of the range mostly applied for minerals and metals production projects: the economic logic pushes operators to maximize positive cash-flows in the early production years. This can lead to mining the higher-grade parts of a deposit, leading to downgrading the economic value of remaining reserves, a practice known as high-grading. This may compromise the long-term viability of the operations, for instance in case of a decline of the market price of the produced mineral(s) and metal(s) prices.

Governments, hoping to promote new employment opportunities and to earn revenue from minerals and metals production activities, may provide new operations with tax holidays, contributing to maximizing the positive cash-flows during the early years of production. This may aggravate the risk of high-grading or lead to abusive transfer pricing (Readhead 2018), and from there to taxation base erosion. Companies may be tempted to increase their production as much as possible during the tax holiday period, depriving governments of potentially substantial later income.

The analysis of the average anticipated payback time of the projects in world regions with sufficient published feasibility studies to be statistically significant (n >20) shows no significant regional differences in average payback times (table 5.5), which average about three years in every region.

Table 5.5: Average payback times of projects, by world regions

Region	Average payback time (years)
Africa	3.1
Asia and the Pacific	2.7
Europe (including the 27 member States of the European Union)	3.5
European Union	3.5
Latin America	3.4
North America	3.6

Source: Authors

Data derived from the S&P database.

5.3.1.5 Conclusions on the key economic parameters of industrial-scale mining projects

In conclusion, as a rule of thumb, projects that, after applying a 7 per cent to 10 per cent discounting factor, have a post-tax internal rate of return of less than 30 per cent and a payback time of more than three years have reduced chances of securing their capital expenditure financing, with the investment decision also dependent on the existence of country- or project-specific risks (see Appendix 5).

While there are no specific rules defining which minimum parameters are to be met by a project to secure the funding of its initial capital expenditure requirement, investors are likely to be selective in their decisions, making the funding of large-scale mining projects in countries exhibiting political instability, poor governance or weak institutional capacities a process that can delay the commissioning of new mines for many years.

5.3.2 Global inflation and the economic performance of China create uncertainty for the global minerals and metals industry.

The coronavirus disease (COVID-19) crisis, the vigorous rebound of the world economy after two years of COVID-19 crisis, and the war in Ukraine have created considerable global economic uncertainty and a rapid rise in energy prices and metal prices. The increase in inflation and interest rates in 2022–2023 caused yields on United States 10-year Treasury Bonds yields to increase to 4.016 per cent on 29 October 2022,[106] a level not seen since the 2008 financial crisis. At the same time, the inflation (United States Consumer Price Index) rate in the United States of America was 8.2 per cent year-on-year for September 2022, according to Trading Economics,[107] with further hikes in T-Bond yields likely. In the Eurozone area, inflation reached 10 per cent. In the first quarter of 2023, the GDP growth rate of China was 4.5 per cent, according to the Chinese National Bureau of Statistics, well below the two-digit growth rate observed before the COVID-19 crisis. This reduced growth rate has a negative impact on the minerals and metals demand of China, and from there on the world economy as China is the world's largest producer of many minerals and metals (see figure 1.3 and table 1.1 in Chapter 1).

Such developments may discourage investment in exploration of minerals and metallic ores and in the commissioning of new production facilities worldwide, especially owing to the higher cost of capital. This would reduce the chances of meeting the levels of demand for the minerals and metals needed to achieve the global low-carbon energy transition goals, as outlined in scenarios published by Hund *et al.* (World Bank) (2020), the International Energy Agency (2021), the German Raw Materials Agency (Marscheider *et al.* 2021), the Geological Survey of Finland (Michaux 2021) and Watari *et al.* (2020) (see Introduction and Chapter 1 for examples).

Mining companies will face higher capital costs, owing to likely increases of the price of equipment, and increases in their production costs, particularly the cost of the fossil fuels still predominantly used in the mining industry. Moreover, the increase in sovereign bond yields, if it lasts, will make investment in mining projects less attractive to investors, as the difference between the yield of "no-risk" of United States Treasury Bonds and the discount rates applied to risky minerals and metals production projects declines.

106 http://www.worldgovernmentbonds.com/bond-historical-data/united-states/10-years/.

107 https://tradingeconomics.com/united-states/inflation-cpi.

5.3.3 Financing requirements specific to the minerals and metals industry development

In any jurisdiction where the minerals and metals industry is properly developed, or seen as a development objective, specific financing is needed for four different categories of interrelated activities, which are detailed in subsections 3.3 to 3.6:

1. **Public funding is needed for the development of the public geoscientific database to co-fund the acquisition of baseline environmental and social data** in areas with high mineral potential and to develop the institutional framework for all other activities needed to develop, implement, manage and evaluate the specific framework conditions (see box in the right corner of figure 5.5) under which mining and metallurgical operations will operate in a specific jurisdiction. This activity is the first step in mineral exploration (Stage 1 in figure 5.5 and table 5.6), whereas baseline data acquisition may continue up to the feasibility study (Stage 4).
2. **Mostly private funding is needed for the exploration activities** (Stages 2 to 4 in figure 5.5 and table 5.6).
3. **Mostly private funding of the initial capital expenditure** is needed for mine development and other production activities, such as ore-processing or metallurgical facilities (Stages 6 to 8 in figure 5.5 and table 5.6).
4. **Public funding is also likely to be needed to monitor and manage old, derelict mining sites, after the end of mining activities once the areas leased by the State for these activities are handed back to the State** (Stage 9 in figure 5.5 and table 5.6). In the event of problems occurring during the post-mine closure stage (see Section 5.3.6), recurring annual public funding will be needed, potentially for centuries and more, for the assessment of derelict facilities (one-off cost item) and any possibly needed monitoring or control activities of high-risk or high-potential impact areas. Funding may also be needed for remediation or ground or tailing dams stabilization works. This can put a high burden on public budgets, as shown by the extreme Giant Mine example, p. 18, and can be problematic in countries and regions with limited budgetary resources and many other needs to address.

Table 5.6: Main stages of a mining project, with average cost and duration estimates of individual stages

	Stage	Activity	Stage in figure 5.5	Government approval	Cost estimate ($)	Typical duration
Mineral exploration	Geological infrastructure	Regional air- borne geophysics, geochemistry, and geological surveys	1		10–100/km^2	10–20 years, national program cycles
	Mineral resource assessment	Regional data inte- gration, ore deposit modeling, prospectivity assessment	1			10–20 years, national program cycles
	Reconnaissance	Semi-regional airborne and ground surveys to identify targets	2		0.5–2 million	1–3 years
	Exploration	Drilling, trenching, surface and down-the-hole geophysics, detailed geological mapping and geochemistry, sampling and analysis. 3D orebody modelling, Environmental and social baseline data acquisition	2	Exploration permit/license, Exploration ESIA	0.1–50 million	1–10 years
	Advanced exploration	Drilling, pilot ore processing and metallurgical tests, geotechnical studies, prefeasibility study	3		0.5 to 2.0 per cent of the initial Capital Expenditure (Queens University, 2022), including supporting studies and test work.	
Mine development	Mine planning	Feasibility and engineering studies, mine closure and post-mine management plan, ESIA and ESMP	4		4.0 to 8.0 per cent of the initial Capital Expenditure (Queens University, 2022), including supporting studies and test work.	1–3 years
	Permitting	Review of the feasibility study, of the ESIA and ESMP by the authorities. May include public consultations and lead to the request for additional studies.	5	Mining license; ESIA and others (for example, water permits)	Cost depends on the nature of requested additional studies.	0.5 to sometimes 10 years and more, in case of environmental and social issues/ conflicts
	Construction	Infrastructure and mine development, processing and auxiliary facilities construction	6		50 million–15 billion	1–5 years
Mine operation	Mining	Ore production (open pit, underground, or alluvial mining)	7			10–100 years
Mine closure	Closure	Final closure and decomissioning	8	Release of license	1–50 million	1–5 years
	Post-closure	Monitoring/occasional observation and maintenance	9		0.1–0.5 million/year	Perpetuity

Source: Authors, adaptation of an original work by the World Bank (Halland *et al*. (2015), table 4.1 in Chapter 2). Views and opinions expressed in the adaptation are the sole responsibility of the authors of the adaptation and are not endorsed by the World Bank.

5.3.4 Public financing of the institutional framework

Countries and governments engaged in the development of minerals and metals production activities need to develop and maintain the framework conditions (see figure 5.5) to turn their natural mineral capital into a source of sustainable development (Halland *et al*. 2015; IRP 2020b). To this end, a framework comprising several core institutional capacities is required:

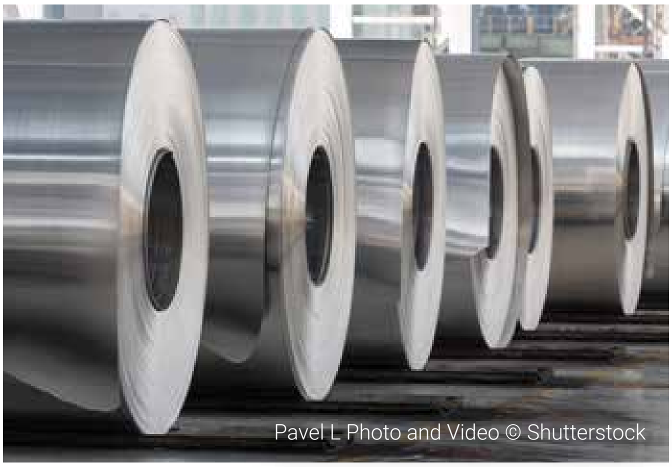
- **A policymaking, legal framework and regulatory development and enforcement capacity to promote and regulate mineral exploration and all downstream minerals and metals production activities (mining directorate capacity).** This specific capacity covers a wide range of activities, such as the preparation of a draft national policy statement on minerals and metals and any other sectoral policy document; the drafting of mining law proposals and related regulations; the allocation and management of exploration licences and mining permits (the latter based on a critical review of the documentation, including the feasibility studies and any other mandatory documentation prepared by the companies applying for a mining permit); the capacity to negotiate with national and global investors and companies; the allocation of mining leases, the monitoring of minerals and metals production activities, particularly from a health and safety angle; the preparation and publication of statistics and of strategy and policy papers; and market analysis.

- A geological survey capacity for the acquisition, processing, modelling, conservation and dissemination of the geoscientific digital data documenting a country's subsurface and its related resources, such as minerals, energy (oil, gas, coal, radioactive elements, geothermal) and groundwater resources (and their three-dimensional temporal dynamics), as well as on-surface inventories (e.g. biodiversity). This inventory should also include the assessment of natural hazards such as ground instability, landslides, seismic and volcanic hazards and gas emissions (methane, carbon monoxide and carbon dioxide, radon). This data should be considered a public good (Bernknopf and Shapiro 2015) and be made available to all other authorities as a component of their own information systems, such as the public environmental information system. The public availability of digital georeferenced geoscientific data documenting a country or region's mineral potential is a major asset to attract investment into mineral exploration (Otto 1995; Duke 2010). Public digital geoscientific data coverage of a sufficiently high resolution (geological, geochemical, alluvial sampling and geophysical data sets) is a powerful catalyst of private sector investment in mineral exploration. International data-sharing can foster trust, promote investment and shorten long project development lead times, helping to expand the existing supply expand the existing supply of mineral raw materials (Energy Transitions Commission 2023)Moreover, the capacity of a geological survey to keep highly specialized geoscientists in employment acts partially as a buffer against the "boom and bust" periods of mineral exploration (see figure 5.14), with the "bust" periods frequently leading to the dismissal of geoscientists and other scientific staff by exploration companies needing to cut their budgets. As expert knowledge is vital for the transformation of geoscientific data and field observations (including observations of cores recovered from drill holes) into an exploration success, specialized human resources are as important as advanced exploration technologies.

- An environmental surveying and management capacity (environmental agency capacity). This is needed in support of environmental and sustainable development policymaking and legal framework development and enforcement: preparation of the draft national environmental and sustainable development strategy and any other sectoral policy documents; the drafting of environmental law and regulations; the allocation and management of environmental permits based on a critical review of the documentation submitted by mining projects, including baseline data, environmental and social impact assessments, management plans and feasibility studies; the allocation of mining leases, and the monitoring of minerals and metals production activities particularly from the environmental and social angles.

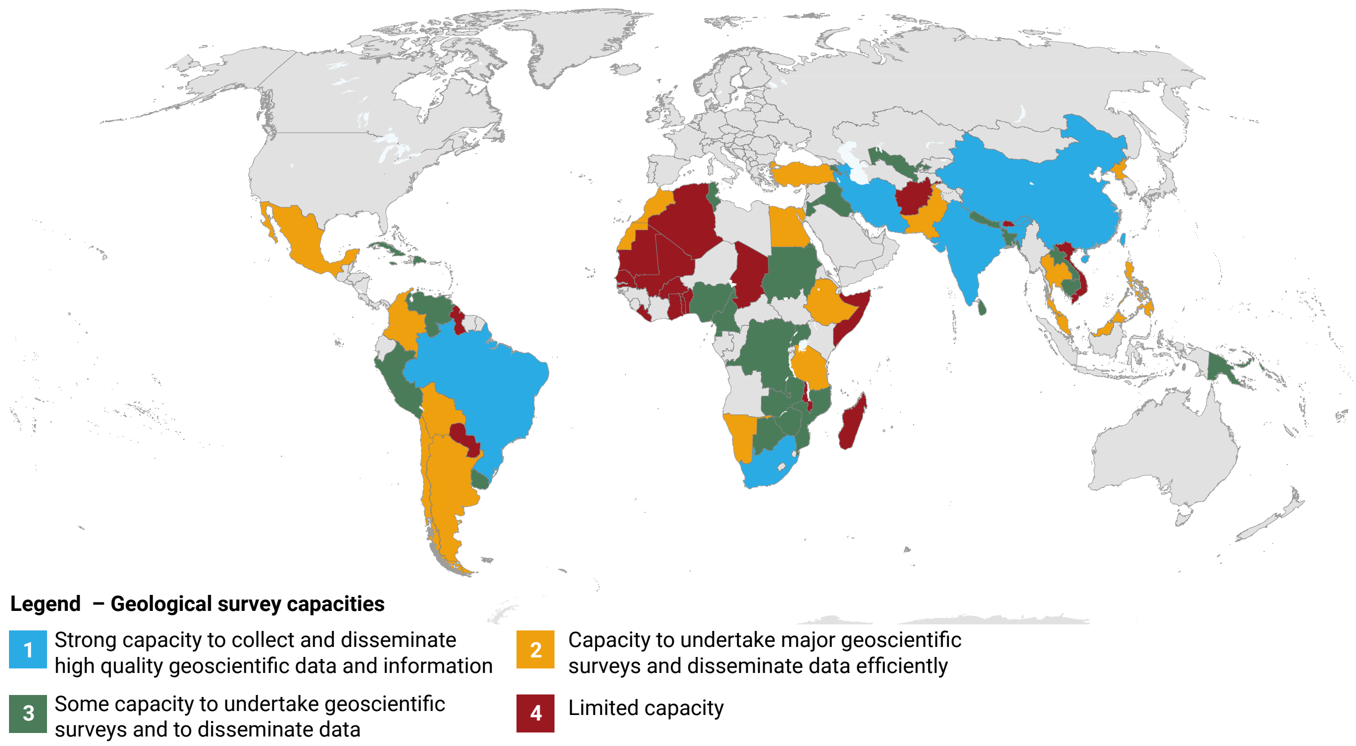
These core institutional capacities can be organized as components of a unique public institution or as separate institutions, with the most important points being the good coordination of their activities, an adequate and secure public funding of their activities and the technical competence of their human resources.

The development of these institutional capacities requires recurring annual public funding to support the work of highly qualified and experienced human resources. This can be problematic in developing countries (low-income countries and lower middle-income countries under the World Bank country classification by income level (Hamadeh *et al*. 2022)), with low budgets and high demands for better education, health or social services. In 2012, the Australian Geological Survey (Kay et al. 2013) published an assessment of the geological survey capacities from 71 countries belonging to the African, Asian, Latin American and Pacific regions, with no information available for 23 additional countries. Figure 5.13 provides a cartographic overview of this assessment at the country level.



Pavel L Photo and Video © Shutterstock

Figure 5.13: Geological survey capacities in the African, Central American, Latin American, Asian and Pacific regions



Source: Authors, derived from Kay *et al*. (2013).

The capacities of many African geological surveys appear limited. In 2022, the budget of the whole Ministry of Mines of the Democratic Republic of the Congo was about US$16 million (Democratic Republic of the Congo 2022), of which only an unspecified part funds the above-described institutional framework. In 2020, the Democratic Republic of the Congo was Africa's second largest minerals and metals producer by value. Reichl and Schatz (2022) assessed the value of its non-energy minerals production to be US$15.4 billion, of which only 0.1 per cent was allocated for the budget of the Ministry of Mines.

In contrast, the United States of America, with a 2020 non-energy mineral production value of US$26.7 billion, allocated US$86 million to its federal Mineral Resources Programme (0.56 per cent of the minerals and metals production value of the United States of America), operated by the United States Geological Survey. Additional resources to support the acquisition and dissemination of mineral resources data were allocated at the State level. This strong contrast reflects the fact that the Democratic Republic of the Congo is a low-income country with a population of nearly 100 million people, most of whom are poor, with many pressing social and security issues, and with the eastern part of the country having been the theatre of the criminal operations of warlords for decades.

In such a situation, a government is likely to allocate its modest resources to priorities other than funding the institutional framework needed by its booming mining industry.

Reedman *et al*. (1998), analysing the activities, budgets and staffing of 55 geological surveys across the world, notes "a relative deficiency in graduate employees in the Geological Survey organisations of the low and lower-middle income countries with the overall situation being worst in Africa and the greatest variation being seen in Asia and the Pacific". Some 20 years later the United Nations Economic Commission for Africa (2018), assessing the capacity of African geological survey organisations to meet the geological needs of individual nations, notes that "African states lack basic geological mapping or, at best, are poorly mapped.". The situation relative to environmental and social baseline data coverage is likely to be equally unsatisfactory, depriving many African countries of the opportunities the development of their mineral wealth could offer, if activities were carried out according to high standards compatible with sustainable development.

The World Bank Group (especially through the International Development Agency), the United Nations Development Programme (UNDP) and the European

Commission have provided their support to developing the geoscientific database and the minerals- and metals-related institutional capacities of lower-income countries. While the European Commission was a major donor up to 2000, through the now discontinued SYSMIN Special Financing Facility (€575 million for the 1995–2000 period) and the European Development Fund, its support was almost completely halted owing to the then prevailing political disinterest, both among member States and at the level of the European Commission itself. Support has resumed over about the last 10 years, but at a much-reduced rate (Christmann 2021).

Regional cooperation can partly help to overcome shortcomings in institutional capacities. The main developments of regional institutional cooperation involving some developing countries are:

- In Africa, since 2010, the African Development Bank hosts the African Legal Support Facility[108] to support African States, some of which have limited in-country capacities, in their complex negotiations for instance with foreign companies seeking to invest in the development of mineral exploration or production facilities. The Facility also provides training to reinforce national legal capacities.
- In East and South-East Asia, the Coordinating Committee for Geoscience Programmes[109] was established in 1966 with the support of the United Nations Economic and Social Commission for Asia and the Pacific; it was initially intended for the joint prospecting of onshore mineral resources and became an intergovernmental organization in 1991. A progressive enlargement of the scope of its activities to the multiple facets of geoscience in service of society led to the efficient development and sharing of knowledge and experience, and the development of common databases and information systems, strengthening the institutional capacities of each of its member States.
- In Latin America, the Association of Ibero-American Geological and Mining Surveys[110] was created in 1993, with a scope quite comparable to the current scope of activities of the Coordinating Committee for Geoscience Programmes, to foster networking, cooperation and the exchange of experience and data integration among Latin American geological surveys and mining directorates.

5.3.5 Mineral exploration financing

Mineral exploration activities can either be focused on the search for extensions of already known deposits, or those in their close vicinity with a comparable geological context, or be focused on new areas, away from known comparable deposits. The former are named "brownfield" exploration projects, while the latter are "greenfield" exploration projects. Exploration costs include all costs incurred from the early-stage exploration work (see Glossary) of Stage 1, figure 5.5, and table 5.6, up to the completion of the feasibility study (stage 4, figure 5.5).

For example, for a project requiring an initial capital investment of US$500 million needed for the construction and commissioning of the production facilities and related infrastructure, the investment in exploration can be as high as 10 per cent, i.e. US$50 million of the required initial capital investment.

Table 5.6, provides an order of magnitude estimate of mineral exploration costs, from early-stage exploration projects (Stage 2 in figure 5.5) up to the completion of the feasibility study stage (Stage 4 in figure 5.5). Investment in mineral exploration is a high-risk form of investment, as it only generates negative cash flows unless a discovery is made that will, years after the exploration investment was made, eventually turn into a productive operation generating enough positive cash flows to balance the initial investment and then, and only then, generate a monetary surplus that will be used to pay taxes, royalties and levies and returns to the investors. Moreover, the probability that an exploration project will ever lead to a new mine is low, although estimates available from literature are variable, as the success rates are estimated on a different basis. While Natural Resources Canada (2013), the Canadian government department in charge of minerals and metals, estimates that 1 in 10,000 showings (outcropping mineralized occurrences) will become a mine, McCrae (2015), quoting the famous exploration geologist David Lowell, mentions that "only one out of three hundred to five hundred attractive targets become a mine". Whatever the unspecified nuance between a "showing" and an "attractive target" (which may already have undergone the exploration work needed to determine the attractiveness), exploration is a high-risk investment, with potentially high financial risk.

108 https://www.afdb.org/en/topics-and-sectors/initiatives-partnerships/african-legal-support-facility.
109 https://ccop.asia/.
110 https://asgmi.org/en/.

The high risk of mineral exploration activities makes it difficult for junior exploration companies to obtain loans to finance their projects, with banks generally avoiding the high risks related to mineral exploration activities coupled with the unavailability of positive cash flows that can serve to pay back loans.

The mineral intelligence expert Richard Schodde has published several estimates at the regional level, based on his own database, of the value of the discoveries made (based on the market value of the marketable metals contained in the discoveries made). His 2022 estimate is shown in table 5.7.

Table 5.7: Cumulative investment in mineral exploration from January 2011 to the end of June 2022, by world regions, in nominal United States dollars and with the estimated value of the metals and minerals deposits discovered over this period, based on June 2022 market prices

Region	Exploration spend (June 2022 US$b)		Est No of discoveries #		Tier 1+2 discoveries		Estimated value (June 2022 US$b) #		Value / spend
Indonesia	$3.2	1.5%	17	1.7%	2	3.1%	$4.1	3.1%	1.3
Pacific / South East Asia	$9	4%	30	3%	2	3%	$5	4%	0.55
Australia	$25	12%	191	19%	17	27%	$30	23%	1.19
Canada	$27	13%	115	12%	10	16%	$19	14%	0.7
United States of America	$14	7%	30	3%	3	5%	$8	6%	0.6
Latin America	$41	20%	124	13%	7	11%	$13	10%	0.32
Africa	$24	12%	234	24%	10	16%	$23	18%	0.97
West Europe	$5	2%	26	3%	2	3%	$2	1%	0.4
East Europe	$3	1%	10	1%	1	2%	$3	2%	1.06
Former Soviet Union + China	$54	26%	200	20%	11	17%	$27	21%	0.5
Rest of World	$5	2%	21	2%	1	2%	$1	1%	0.18
WORLD	$207	100%	981	100%	64	100%	$132	100%	0.64

Note: Includes Bulk Minerals, excludes satellite deposits found in existing camps - # Includes an adjustment for unreported discoveries.
Caution: Values are indicative / approximate-only
Source: Schodde (2022a).

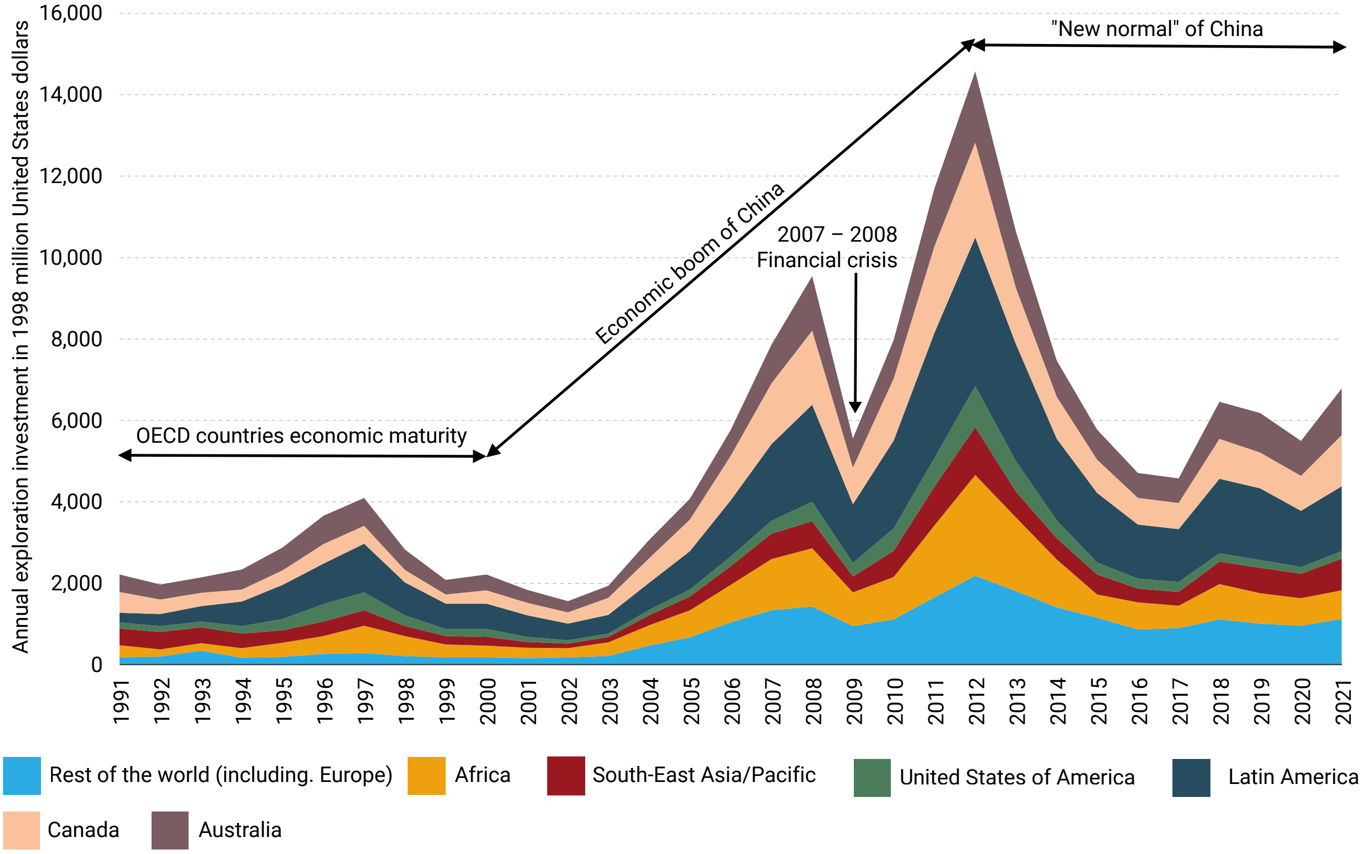
A comparable estimate, for the 2009–2018 period (Schodde 2019) showed an even lower return (US$0.55 per dollar invested in exploration, compared to US$0.64 per dollar in table 5.7), reflecting lower average metal prices at the time of the estimate, rather than variations of exploration success.

This estimate accounts for as yet unreported discoveries, as it may take several years for a company to be able to report a discovery according to one the reporting standards recognized by the Committee for Mineral Reserves International Reporting Standards (CRIRSCO). This time is needed by companies in mineral exploration to acquire enough data, essentially by drilling operations, and to process the data to develop three-dimensional digital probabilistic models from which resources can be reliably calculated, and, once the mining method would have been defined and integrated into the three-dimensional model and reserves.

Table 5.7 shows a clear regional variability of the return on mineral exploration investments, possibly reflecting the fact that in as yet underexplored regions, such as Africa, China, South-East and Central Asia, and Europe beyond the limits of the European Union (figures 5.14 and 5.15), there is a higher probability of discoveries of outcropping, or near-surface mineral deposits that are easier to discover than in regions with a much longer exploration history, where future exploration successes are more likely to be hidden deep-seated deposits that are much more difficult and costly to discover.

The regional and annual variability of mineral exploration investments is shown in figure 5.14. Annual mineral exploration investment estimates are highly variable. Over the 1991–2021 period, in constant 1998 United States dollars, the annual exploration investment estimates varied between approximately US$2 billion and US$15 billion, the high variability of annual mineral exploration investments reflecting varying perceptions of the attractiveness of mineral exploration as an investment opportunity. This perception was driven by the market outlook for the main minerals and metals attracting exploration investments (figure 5.15), with gold having historically received most of the investments.

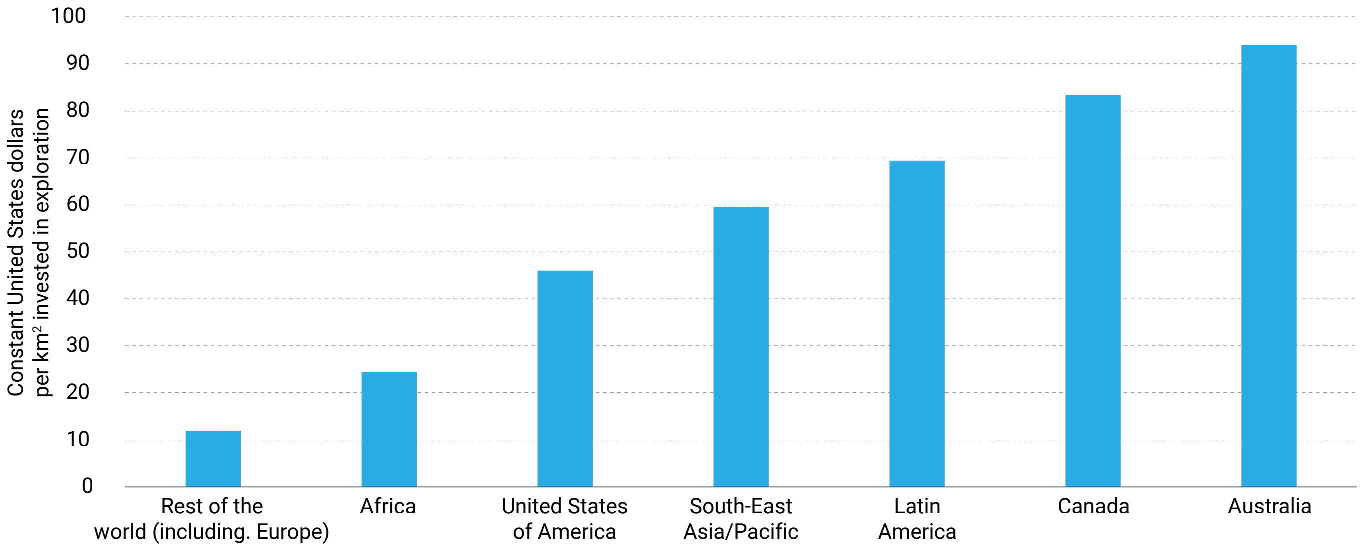
Figure 5.14: Annual non-energy mineral exploration investments by world regions between 1991 and 2021, in 1998 constant million United States dollars, using the Consumer Price Index of the United States of America as deflator



Source: Authors, compiled from annual reports on global mineral exploration published by various sources, the diagram shows alternating boom and bust periods, as well as the decline in mineral exploration investment since 2012. (Compiled from Raw Materials Data, SNL and S&P data).

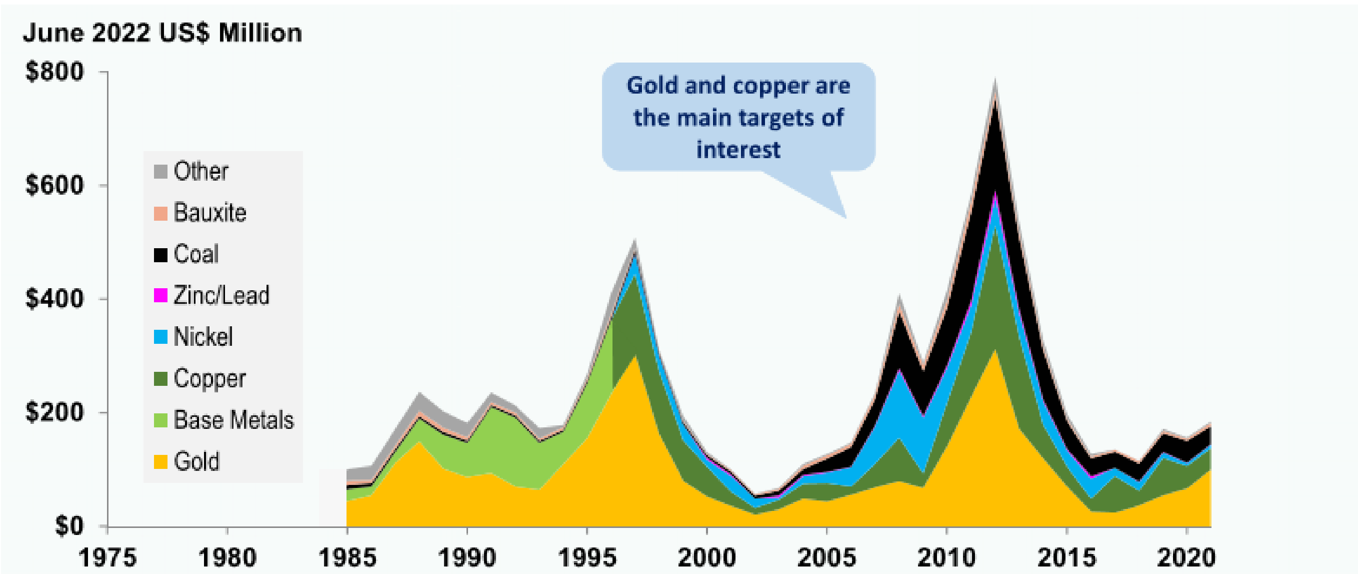
Figure 5.15 shows the variability of mineral exploration investments across the world's main geographic regions, expressed as average constant 1998 United States dollars invested per km² over the 1991–2021 period. The value of constant 1998 United States dollars was calculated using the Consumer Price Index of the United States of America as deflator, conforming to the method of the United States Geological Survey for the calculation of annual average metal prices since 1900 (Kelly and Matos 2022). It clearly shows major differences in the exploration investments made in the different regions. Although Africa, broadly speaking, has a geological potential comparable to Australia and Canada, it attracted much less investment than Australia or Canada. Moreover, owing to this comparatively much lower exploration rate, there is a higher probability of discovering large near-surface deposits than in much more explored countries or regions. This situation relates to a range of issues that vary from country to country. There can be issues related to the framework conditions highlighted in figure 5.5 or to issues related to governance, social acceptance and security. Every year, the Canadian Fraser Institute publishes a survey of the perceptions of investment framework-related conditions by mining-related companies. This survey only represents the views of the companies that voluntarily respond, which is likely to introduce considerable bias into the analysis of the responses received. Its latest survey, related to 2021, reveals the lack or limited nature of public investment in the development of a sufficiently high-resolution geoscientific data infrastructure and the lack of interoperability of existing digital databases.

Figure 5.15: Average 1991–2021 exploration investment per km², in constant 1998 United States dollars, by world regions



Source: Authors, compiled from annual reports on global mineral exploration published by various sources (Raw Materials Data, SNL and S&P).

Figure 5.16 : The respective weight of investment into mineral exploration of specific mineral raw materials, from 1975 to 2021

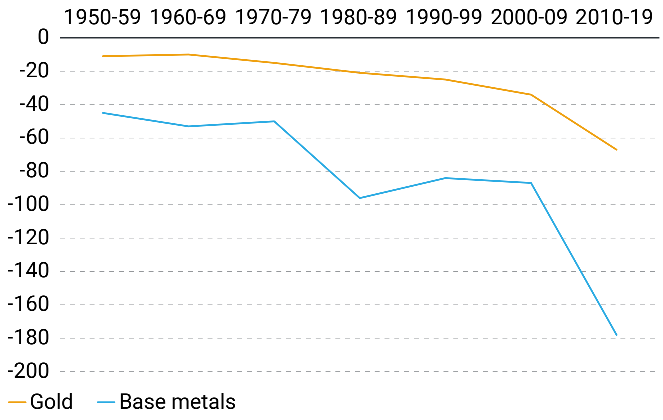


Note: Unlike in Figure 5.14, the annual investments are shown in nominal United States dollars and integrate data other than S&P data.

Source: Schodde (2022a).

Figure 5.16 shows the relative underfunding of mineral exploration for copper and base metals, one of the important problems that may harm the long-term availability of metals of major importance to the clean energy transition. This is a worrying trend as the exploration success rate appears to have declined over the last 10 years, and exploration is also becoming more difficult and costly. As the probability of discoveries of large-size outcropping deposits is declining in historically highly explored districts, the trend is to search for deeper-seated ore deposits, hidden under a cover of non-mineralized rocks (figure 5.17), a trend that accelerates over time, especially for base metals (copper, nickel, zinc, lead).

Figure 5.17: Trend in the average depth of gold and base-metals (copper, nickel, zinc, lead) discoveries over the period from 1950 to 2021



Source: Authors. Data from R. Schodde (2020).

Mineral exploration investments are funded in several ways, with considerable variations in the 1975–2021 period (figure 5.18, from Schodde 2022b):

- From the cash reserves of active mining companies. The role of major, moderate and small producers in the discovery of mineral deposits is shown in figure 5.18. Their role has declined significantly since the 1960s, this decline being particularly marked over the last 15 years. Producers may prefer to secure the stability of their shareholding by paying out dividends or boosting their share's value by investing parts of their profits in repurchasing their own shares, rather than investing in risky mineral exploration projects. For them, it appears less risky to leave mineral exploration to junior companies, and to take a share, or even control, of the most attractive projects once a solid feasibility study has demonstrated their attractiveness. In 2020, active mining companies were only responsible for 17 per cent of the reported discoveries.

- Buy junior mineral exploration companies that do not yet have any productive activities. Since the 1980s, the role of these companies in mineral deposit discoveries has steadily grown up to the present day. In 2020, junior companies made 66 per cent of the reported discoveries (figure 5.18). A few of these companies may become a moderate or major producer. In most cases, in the event of a discovery, their assets will be bought by an existing producer with sufficient experience and financial standing to raise the initial capital expenditure needed to develop a new production facility.A junior exploration company, after initial early exploration work funded by the resources of its project promoters, will seek funding for further exploration work by becoming listed on the stock markets of countries with liberal economic systems and a strong historical mineral exploration culture, including an ecosystem of universities, mining schools, research institutions and industry associations, essentially Canada or Australia. Funding of exploration activities will then be based partly or totally through floating the company's shares, mostly on the Toronto Stock Exchange (TSX and TSX-V) and the Australian Securities Exchange. About 1,900 companies are listed on these two stock exchanges, most of them junior exploration companies. Some other stock exchanges, including those of Frankfurt, Johannesburg, London and New York, also list junior exploration companies, but at a reduced scale. Multiple listings are quite frequent.

- Private equity, trust funds and offtake agreements with traders or downstream industrial minerals and metals users may play a role in mineral exploration, but the role of these alternative financing modes in mineral exploration, although fairly undocumented, is likely to be of minor importance in the funding of mineral exploration projects.

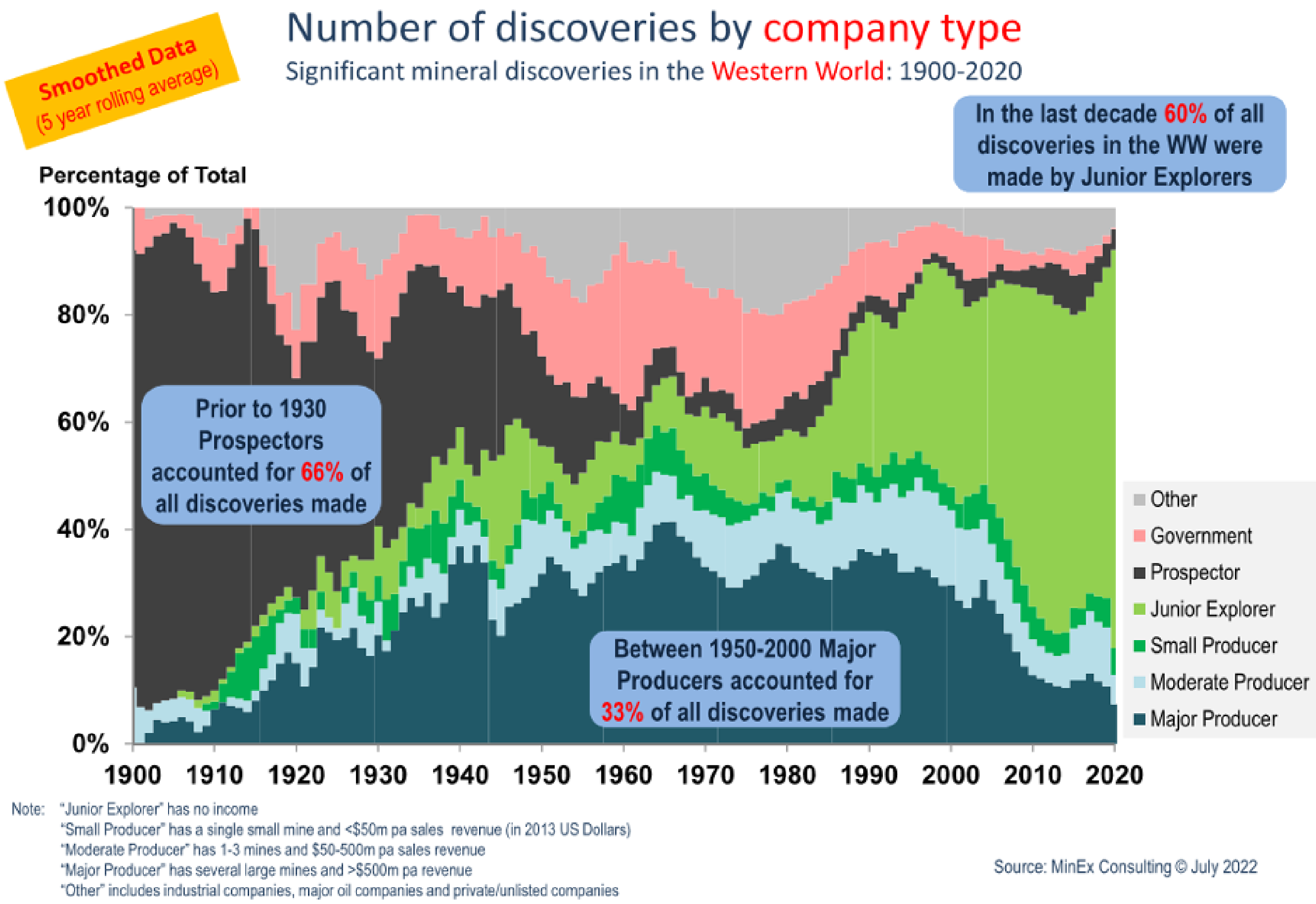
- Governments, mostly via their geological survey organizations, were the second most important discoverers for several decades after the Second World War, but many had to reduce their exploration activities in the late part of the twentieth century as governments with liberal economic systems, at times of low metal prices and abundant supply, lost their political interest in publicly funded activities related to minerals and metals. In 2020, only 1 per cent of the discoveries were made by governmental organizations.

- Even in China public investment significantly declined over the last decade (China, Ministry of Natural Resources 2021, and see Chapter 2). While the total mineral exploration budget reported for 2012 was RMB 51 billion (equivalent to US$7.4 billion at the average RMB/US$ exchange rate in 2020 of US$0.145 per RMB), it was down 68 per cent to RMB 16.2 billion in 2020 (US$2.3 billion), of which only 51 per cent (US$1.2 billion) was invested in mineral exploration. This represents about
8 per cent of the world's exploration budget assessed by Schodde (2022b), or about 11 per cent of the world's total exploration budget assessed by S&P Global Market Intelligence (2022). However, this reduction in

mineral exploration budgets may be, at least partly, offset by the improving efficiency of Chinese mineral exploration activities, as the use of modern state-of-the-art exploration techniques seems to be developing in the country (no English-language data is available to support or invalidate this point of view).

- After many years of disinterest in mineral resources-related issues, the wind is changing as several jurisdictions dependent on minerals and metals imports are struggling with supply issues and fearing that growing geopolitical tensions may disrupt some vital supply chains on which their economies, and social well-being, depend. The launch of multiple critical minerals-related initiatives in France, the European Union, Germany, Japan, the United Kingdom of Great Britain and Northern Ireland, the United States of America and possibly elsewhere (see Introduction) is an illustration of this new geopolitical nervousness. It may signal a new age of government interest in minerals and metals and the urgent need for new initiatives related to the global governance of mineral resources, as outlined by the IRP report *Mineral Resource Governance in the 21st Century* (Chapter 12, IRP 2020a).

Figure 5.18: Mineral deposits discoveries made over the 1900–2020 period, by nature of the economic agent that made the discovery



Source: Reproduced with permission, personal communication with Richard Schodde, MinEx Consulting (2022).

- Finally, prospectors made about 1 per cent of the discoveries in 2020. Prospectors used to be iconic figures of the Australian, Canadian and United States of America mining industries. Working in the field, frequently under extreme hardship, with little or no technical equipment and quite frequently no degree in geology or mineral engineering, they looked for signs of outcropping mineralization such as mineralized outcrops or mineralized boulders and were reputed for their flair for spotting geological potential. Many discoveries made during the first part of the twentieth century were made by prospectors, but nowadays they have been almost completely replaced by junior companies with highly educated staff able to efficiently implement state-of-the-art mineral exploration technologies described in recent handbooks (e.g. Moon *et al*, 2009; Haldar 2018; Gonzalez-Alvarez *et al*. 2020).

5.3.6 Initial capital expenditure financing

This is by far the most capital-intensive of all stages of a mining project (see Section 3.1). Initial capital expenditure is secured through a combination of equity and debt that varies from project to project.

Capital expenditure requirements can be met by any mix of:

- public equity raising, by listing the company on a stock exchange and floating shares to investors, or from raising capital from private sources (private equity); and
- loans.

Key investors are varied. Commercial banks, development banks (e.g. the World Bank Group, the European Investment Bank, the Inter-American and African Development Banks), trust funds, private equity funds and special purpose acquisition companies all play an important role in the funding of initial capital expenditure requirements. Governments also contribute to funding new production capacities through their national development agencies and funds.

Owing to the size of initial capital expenditure requirements (see section 3.1.1), capital quite frequently comes from a roundtable of different investors, providing a specific combination of equity and loans. For projects in low-income countries, the participation in capital expenditure financing of one, or several, development banks is an important catalyst, as it is a sign of trust in the projects' potential that encourages other investors to contribute to the financing.

As a result of the high demand for minerals and metals critical to the global low-carbon energy transition, companies at the very end of minerals and metals supply chains, traditionally far from mining activities, such as car or battery manufacturers, wanting to secure their strategic minerals and metals supplies, have recently become significant shareholders of mining companies. In 2023, General Motors invested US$650 million into the mining company Lithium Americas (Lithium Americas 2023) to speed up the production launch of the large-scale Thacker Pass (Nevada, United States of America) lithium deposit (Lithium Americas 2023) and secure future supplies from it. Ford is involved in a US$4.5 billion initial capital investment, together with Vale (Brazil) and Zhejiang Huayou Cobalt (China), to build a new nickel-producing plant in Pomalaa, Indonesia (Reuters 2023b). In 2023, car manufacturer Stellantis bought a 14.2 per cent stake in McEwen Mining Inc., a mining company owning the Los Azules advanced copper exploration project in Argentina (Attwood 2023) and holds an 8 per cent stake in Vulcan Energy (an Australian junior company developing a major lithium production project in Germany) (Reuters 2023a).

This new trend with downstream industries becoming financiers of mineral exploration and the development of new production facilities also materializes through a flurry of offtake agreements whereby the downstream industrial investor will obtain a predefined share of the production as repayment of a loan. A number of car manufacturers are discussing offtake agreements with companies that have mining projects still at the development stage. Examples of this are the offtake agreements separately signed by Renault (Reuters 2021a) and Volkswagen (Basov 2021), two leading car manufacturers, with Vulcan Energy, a junior company developing a lithium production project from brine in Germany. This project had not completed its feasibility study by the end of October 2022. Ford has signed off-take agreements with Ioneer, a junior company developing the Rhyolite Ridge project in the United States of America (Ioneer 2022) and Lake Resources, another junior company, developing the Kachi lithium project in Argentina (Randall 2022). These are just a few examples.

The engagement of the downstream manufacturing industry with the financing of new production facilities is an important strategic development, as it can broaden the financing sources needed to develop the many mining projects that will need to be put in production for the low-carbon energy transition. Moreover, manufacturers can play an important role in fostering the contribution of the minerals and metals industry to sustainable development, and particularly its transparency and reporting practices.

No globally consolidated statistical data is available on the financing of initial capital expenditure requirements. S&P Global, as part of its subscription service, provides a monthly and annual review of mining project financing, but this includes exploration as well as mine development projects and the database is likely to only cover a part of global mining financing. Some key economic agents (including some governments and public bodies, as well as offshore economic agents operating from tax havens via sometimes opaque holding structures) report nothing, or close to nothing, about their activities.

In 2021, S&P identified 2,684 instances of financing, worth $21.55 billion, in the global minerals and metals industry (Manalo 2022). Some 40 per cent of these reported financings were raised via the Toronto Stock Exchange, 36 per cent via the Australian Securities Exchange and only 0.3 per cent via the London Stock Exchange. This underlines the importance of equity in financing the minerals and metals industry and the role of Toronto and Sydney as key financing hubs of a large part of this industry. Gold and base metals (copper, lead-zinc, nickel*,[111] cobalt*, molybdenum* and tin), as well as non-gold precious metals (platinum group metals* and silver* in the S&P classification), received 36 per cent each of the financing, while speciality metals projects (mostly lithium projects) received 28 per cent of the financing.

However, despite all these recent trends in investing, there are serious concerns about insufficient funding of new productive projects. Figure 5.19, published by mining.com and BMO Capital, shows that, since 2012, the global mining industry has much reduced the share of its annual earnings before interest, taxes, depreciation and amortization it reinvests into expansion projects, favouring the payment of dividends to its shareholders or share buybacks designed to boost the value of their shares. This article states that “given it has never been harder to build a new mine owing to capital expenditure escalation concerns, shareholder resistance and environmental, social and governance challenges, we see companies looking towards buying rather than building any growth”. This analysis is consistent with the decline in mineral exploration investment out of their profits by minerals- and metals- producing companies, noted in figure 5.18 (Schodde 2022b).

At a time when the demand for minerals and metals will continue to grow, especially the demand for transition minerals that is expected to boom over the next two or three decades, underinvestment in mineral exploration and the development of new production facilities may soon create severe supply bottlenecks that can jeopardize the achievement of a net-zero carbon world by 2050–2060, calling for global coordinated action to overcome any shortage of supply. The low average price/earnings ratio observed for publicly listed mining companies signals the relatively low interest of investors to invest in mining, with some remarkable exceptions. On the basis of financial data from 206 publicly listed mining companies, companiesmarketcap.com,[112] in August 2023, estimated that the average price/earnings ratio for these mining companies was 5.94, against 28.2 for the 684 pharmaceutical companies or 34.1 for the 403 software companies it assessed.

In August 2023, BenchmarkSource stated that the lithium industry alone needs between 116 (high case scenario) and US$54 billion (base case scenario) in investment to meet automaker and policy targets by 2030 (BenchmarkSource 2023).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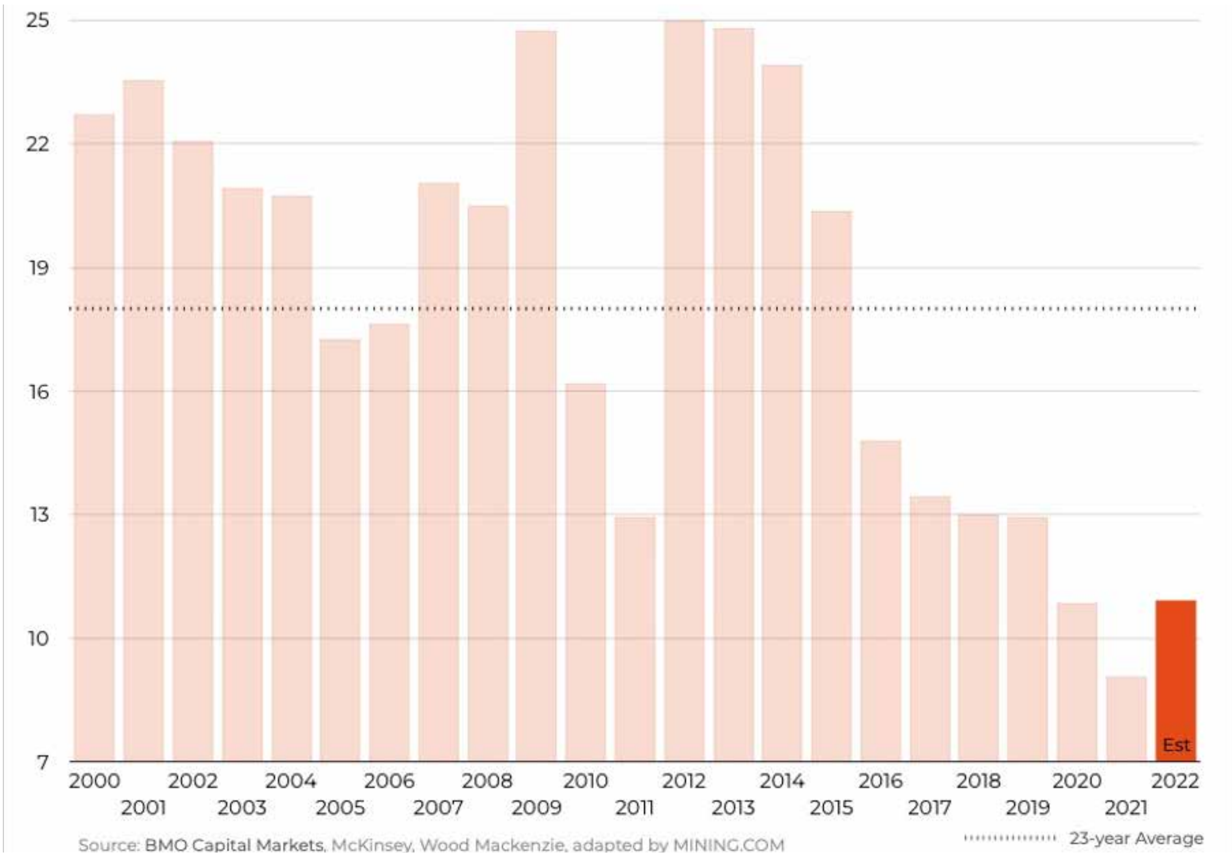
111 Starred (*) elemental symbols indicate elements that in other literature, for instance Reichl and Schatz (2022), are categorized in other mineral product groups. This underlines the semantic heterogeneity prevailing in minerals- and metals-related literature, one of the problems on the long road towards transparency.

112 https://companiesmarketcap.com/mining/largest-mining-companies-by-market-cap/.

Figure 5.19: Expansion capital invested as a percentage of global mining sector earnings before interest, taxes, depreciation and amortization



Source: Els (2023), reproduced with permission from mining.com.

5.3.7 Financing post-closure monitoring and management

After the completion of the formal closure process, or the abandonment of operations deemed unprofitable by their owners, the land used by past operations will now be handed back to its original owners. As in many countries energy and metallic minerals resources are owned by the State, and not by the landowner owning the surface, national or regional authorities may have to cope with any issues remaining or arising after mine closure.

In many countries, mine closure procedures were non-existent or lax until about 20 years ago when the authorities of various jurisdictions introduced mandatory mine closure procedures, with the result that derelict mining, ore-processing and metallurgical facilities and their related waste can be a lasting source of negative impacts (see Section 2.6.3 for additional details).

As a consequence, public funding may be needed:

- To make a digital inventory of the localization, nature and extension of derelict sites and to assess their potential or measurable impacts on local communities and ecosystems.
- On this basis, to identify and implement specific actions necessary to address the most pressing issues, such as the remediation of derelict sites or the infilling of some underground cavities, as well as the need for long-term monitoring and site management activities. The latter may be necessary to process acid mine drainage or runoff water contaminated with radionuclides. The former may be necessary to verify the stability of tailing dams, if the tailings they withhold cannot be used as inputs for some economic activities.

In the cases where long-term site monitoring or management is necessary, recurring annual public funding may become a necessity, potentially for centuries or longer.

5.4 CONCLUSIONS OF THE CHAPTER

The global energy transition to net-zero carbon energy production, including required additional facilities such as energy storage or back-up production facilities (to overcome the intermittent, non-programmable nature of solar and wind energy) and intelligent distribution networks will require a massive development of transition minerals production over the next three or four decades, as shown in many published scenarios. The future demand of specific transition minerals such as cobalt, lithium or nickel will be highly dependent on the nature of the technologies that will be used in the future to produce the different components of the global energy system. Energy-related technologies are continuously shifting, for instance the technologies and raw materials used for energy storage, including in the electromobility sector.

Whatever the future variations over time of the transition minerals mix needed to build the future global energy system, and despite all the vast possibilities offered by the circular economy concept, the demand for minerals and metals is likely to continue to grow exponentially over the coming decades.

Meeting this demand will require many billions of dollars of investment in mineral exploration and in the development of new production facilities such as mines, mineral processing facilities, metallurgical plants and metal refineries. Securing the necessary investments in mineral exploration, mine development, well-managed mine closure and the institutional capacities needed to develop global responsible mining is a major challenge. Failure to address it adequately could derail the global energy transition and lead to regional or global resource conflicts.

At times where access and production of mineral resources is confronted with important environmental, social and governance issues, a well-coordinated, continued, global effort, building on the recommendations of this IRP report, and of international institutions such as the International Energy Agency, the International Renewable Energy Agency, OECD and the World Bank, appears to be an absolute necessity, along with all the efforts needed to progress as far as technically possible and socially acceptable towards a more circular economy. The production of minerals can be much more responsible than it currently is. A paradigm shift is needed at the level of all stakeholders if humanity is to benefit from the promises of the global energy transition.

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5.5 APPENDIX: SUMMARY LIST OF MINERALS AND METALS PRODUCTION- RELATED RISKS

Risk category	Short risk description	Suggested mitigation actions
Economic/Business risks	Community or NGO opposition to the project. Failure to gain the sustainable development licence to operate	• Whatever the financing mode of a project (publicly listed company, private equity, state-owned enterprise, etc.), make public, under the supervision of designated qualified persons, all data documenting the economic, environmental, governance and social dimensions of the project, with full consideration of its inputs and outputs and their impacts and related issues. Fully report performance at the operational level using indicators that correctly describe emissions and waste, impacts on land use, water resources and biodiversity. Support and contribute to international initiatives developing full reporting frameworks at the project development and operating stages. A commitment to transparency and building trust among stakeholders are essential to the long-term success of mining operations and their maximum contribution to the Sustainable Development Goals. • Proactive, documented dialogue with the local communities from the beginning of exploration activities, with the support of cross-cultural communication experts if cultural differences exist. • Associate, if needed, with the support of an external facilitator, local communities and NGOs in your risk assessment process. • Proactive engagement with NGOs. • Identification and implementation of actions that can provide long-term benefits (beyond mine closure) to local populations. • Publication of all project and operations-related economic, environmental, social and governance data and of summaries in a format accessible or understandable to laypersons.
	Construction and commissioning delays	• Develop and implement an operational readiness plan, based on risk assessment and a mitigation strategy.
	Geological risk: overestimation of reserves	• Perform sufficient pre-production drilling within the mine planning footprint and perform three-dimensional geostatistical modelling to document the reserves with a high probability factor, at least for a production time equal to the payback period.
	Poor understanding of the existence and spatial distribution of penalizing elements in the ore	• Sufficient pre-production drilling within the mine planning footprint to understand the three-dimensional distribution of penalizing elements and their mineral carriers through sampling and multi-element geochemical analysis, as well as mineralogical determinations and three-dimensional geostatistical modelling.
	Volatility of commodity prices	• Identify the economic sensitivity of the project to price variations of mineral raw materials during the preparation of the feasibility study. Elaborate hedging strategies.
	Persistent economic downturn leading to decreased commodity prices or decreased demand	• Perform mineral intelligence analysis to identify possible future market trends and potential 'black swans' that may disrupt market trend scenarios. This includes the identification of potential future technological shifts or other circumstances that can disrupt the future demand/supply balance. This assessment should be performed no later than the feasibility study. • Perform an analysis of the sensitivity of your project to the variations of the prices of the minerals and metals you plan to produce.
	Underperformance (against the production schedules defined in the feasibility study) of the mining, ore processing or metallurgical operations	• Implement sensor-web-based real-time monitoring of all operations, at the level of individual equipment and processes, to identify productivity issues, define and implement preventive maintenance schemes (with the support of the equipment suppliers) to avoid unscheduled downtime. Elaborate and use a digital twin of the operation(s).
	Insufficiently skilled and experienced personnel	• Develop a hiring and incentivization strategy from the early project planning stage (as early as the pre-feasibility study). If relevant, consider with the authorities, opening a local or regional professional training facility.

Risk category	Short risk description	Suggested mitigation actions
Governance risks	Weak corporate practices	• For governments: make it compulsory for companies to publicly report their site-specific economic, environmental, governance and social performance according to a (currently non-existent) internationally recognized standard, ensuring the reliable documentation of all positive and negative immediate and possible long-term impacts, including those related to energy and water use; the emissions (including fine particulate matter) in air, soil and water; the production of mineralogically and geochemically characterized solid waste streams). • Make public reporting rules compulsory, whatever the type of project financing used to fund their initial capital expenditure requirement. Adapt the reporting rules to the size of the reporting companies and of the potential risks related to their production. • Encourage the development of an international comprehensive operation-level environmental, social and governance reporting framework. • For companies: engage proactively in this development. Link the remuneration of top management to the verifiable implementation of these enhanced environmental, social and governance reporting obligations.
	Sudden, unpredictable changes of the regulatory framework or the taxation rules applicable to mineral exploration and actual mining and metallurgical operations	• For governments: ensure the stability and predictability of the regulatory and taxation framework. Ensure the transparency of all activities from exploration to production. Frequent changes of government, with the resulting changes of political perceptions and attention given to the minerals and metals industry, is a major challenge for the planning and the investment of projects that may span decades. • For companies: assess the political stability, regulatory quality, institutional capacities and governance performance of the jurisdiction in question. Multilateral investment guarantees and national or regional risk insurance systems may offer coverage of some risks. Adjust the discounting factor used to perform the discounted cash-flow analysis of the project during the feasibility study, to reward countries offering a verifiable, transparent good governance investment framework.
	Weak regulatory framework	• Consider mining laws, codes and environmental law reforms necessary to fully integrate sustainable development goals based on transparency (mandatory public disclosure of the data and reports on exploration and production activities) and full integration of the economic, environmental, governance and social impacts of the production of minerals and metals. • Seek external support to strengthen institutional capacities (development banks and donor countries may support actions in support of developing countries. Consider pooling the necessary capacities at the regional level (e.g. the Legal Support Facility of the African Development Bank and the African Mineral Development Center).
	Insufficient institutional capacities	• Ensure the proper budgeting of the core institutional capacities needed (environmental agency, geological survey, mining directorate) to conceive and implement the transparent regulatory, monitoring or reporting framework applicable to the production of minerals and metals. For developing countries, sharing the efforts at regional levels can reduce costs. Examples of this are the Legal Support Facility of the African Development Bank and the African Mineral Development Centre.
Environmental risks	Insufficient transparency obligations	• Build on current best practice in reporting on mining projects (Canadian NI 43-101 reporting standard) and on operations (Global Reporting Initiative), develop comprehensive reporting and public disclosure frameworks covering all quantitative and qualitative sustainable development-related aspects. Reporting should be produced under the supervision of qualified persons (see glossary) as defined in the Canadian NI 43-101 standard. • Apply mandatory disclosure obligations to all projects and operations, whatever their financing mode.
	Lack of proper mineralogical and geochemical characterization of waste streams, particularly of tailings. Leaching of harmful metallic compounds in the environment.	• Perform Mineralogical and geochemical three-dimensional modelling of the ore body to determine the presence and distribution of minerals and potentially harmful elements that may cause acid mine drainage or leak into the environment. • Continuously monitor waste streams and carry out periodical public reporting needed if sulphides or sulphosalts are present in the processing waste, as part of the strategy to reduce the acid mine drainage problem. • Monitor and publicly report tailings mineralogy and geochemistry.
	Production of acid-generating tailings	• In case of the presence of sulphides or sulphosalts in the mineralization, ensure that acid base accounting and a net acid generation calculation is performed and reported as part of the ore processing pilot tests (pre-feasibility and feasibility stages). In view of the results, decide and report on optimal tailings disposal strategy to ensure the long-term absence of acid mine drainage.
	Health impacts related to dust (fine particles) emissions	• Mineralogical and geochemical characterization of dust particles. • Avoidance of dust emissions from mining activities and by wind erosion of tailings or waste materials.

Risk category	Short risk description	Suggested mitigation actions
Environmental risks (continued)	Mine closure and post-closure issues (ground stability, acid mine drainage, tailings dam failure, unsuitability of mined land for other purposes, loss of activity or revenue for local populations, etc.)	• Identify any possible environmental and social issues that may arise during mine closure and post-closure and develop and make public the remediation and monitoring plan, in close collaboration with authorities and local communities. Detail the actions planned to enable the use of the past production area for other purposes, including for biodiversity conservation. Budget for the required actions and provide a financial guarantee that covers the costs up to the moment where the former production area, including any waste accumulations, can safely be used either for new economic or environmental purposes.
	Greenhouse gas emissions from the use of carbon-based fossil fuels	• Consider the use of non-carbon sourced energies and energy-efficient production processes and equipment. Consider the opportunity to use electrical machinery and vehicles. Set targets and monitor and report on your performance.
	Water use or pollution issues (surface and groundwater)	• Prevent the overdraft of surface water resources or groundwater bodies with limited or non-existent recharge, conflicting use of water resources needed by other stakeholders (agriculture, animal farms, urban water supply, fire hazard control, fisheries, recreational water uses, etc.) • Perform hydrological and hydrogeological baseline data collection, and three-dimensional or four-dimensional groundwater modelling if significant groundwater use is required, especially in water-stressed areas and areas with competitive water uses. Qualitative (geochemical) and quantitative monitoring and public reporting of groundwater and surface water bodies affected by the operations should be considered. Establish a budgeted post-closure monitoring plan of the water bodies affected, with related reporting, until it can be demonstrated that no further effects on water resources occur or will occur in the future.
	Lack of proper mineralogical and geochemical characterization of waste streams, particularly tailings. Leaching of harmful metallic compounds in the environment.	• Perform mineralogical and geochemical three-dimensional modelling of the ore body to determine the presence and distribution of minerals or potentially harmful elements that may cause acid mine drainage or otherwise leak into the environment. • Continuously monitor of waste streams and periodical public reporting needed if sulphides or sulphosalts are present in the processing waste, as part of the strategy to reduce acid mine drainage problem. • Monitor and publicly report the mineralogy and geochemistry of tailings.
	Threats to or losses of biodiversity	• Perform baseline data collection on flora and fauna, providing a comprehensive inventory of species existing within the operations area and in areas, such as areas of specifically developed infrastructure (roads, power transmission lines, etc.) serving the operations. Identify threatened or fragile species and develop a plan protecting those species, in cooperation with local communities and NGOs. Develop a soil protection plan in areas where fertile soils are either scarce or particularly vulnerable (e.g. tropical rainforest soil).
	Harmful gas emissions (methane, radon, etc.)	• An inventory of the risks of potentially harmful gas emissions, such as methane or radon emissions, needs to be performed as part of the environmental impact assessment. In case of risk, establish a mitigation strategy (ventilation, remote robotic operations, etc.)
	Exposure to natural hazard (landslides, flooding, droughts, seismic or volcanic activity, natural hazardous gas emissions (CO_2, methane, radon, etc.)	• The inventory of historical occurrences, with an estimate of their magnitudes and impacts, should be part of a project baseline data acquisition and integrated into the environmental impact assessment. Clearly documented mitigation strategies and the funding they need to be prepared and published.
	Dust emissions (fine particulate matter)	• The sources, intensities, the mineralogical or geochemical nature, and the related potential health impacts of potential dust emissions should be identified as part of the environmental impact assessment. Potential sources to be assessed include mining, processing and metallurgical operations, tailing and other mine waste storages, as well as off-site dirt roads used for frequent transport by heavy trucks of inputs to and outputs from the mining and ore processing. Clearly documented mitigation strategies and the funding they need are to be prepared and published. Monitoring and periodical reporting of indicators are needed.
	Noise and vibrations	• Identification of noise and vibration sources, frequency and intensity of noise and vibrations at the operation(s) site(s) and at the level of off-site transport infrastructure (transport of inputs and outputs) should be documented in the environmental impact assessment. Clearly documented mitigation strategies and the funding they need are to be prepared and published. Their implementation is to be monitored and publicly reported.

Risk category	Short risk description	Suggested mitigation actions
Technological risks	Inadequate design of the ore processing or metallurgical and refining process leading to excessive consumption of inputs or excessive emissions	• Ore processing and metallurgical pilot tests performed during the pre-feasibility or feasibility stage should make it possible to identify the best process available to process the ore or extract or refine the metals contained. This is of importance to reducing energy and water use, as well as keeping emissions and waste generation to a minimum while maximizing the recovery rate of the valuable mineral component(s). The best available technologies should be selected for the project design and documented in the feasibility study.
	Poor design of tailing dams or compromises with monitoring or inspections and their findings: risks of tailing dam failure or leakage of harmful compounds to the environment.	• Best practice needs to be used in tailing dams design and documented in the environmental impact assessment and the feasibility study. Monitoring of the stability of the structure needs to be performed and the results publicly reported.
Social risks (note: many of the other stated risks can also translate into social risks)	Damages to cultural heritage	• A mandatory baseline study identifying and cataloguing any heritage site or site of particular cultural importance to local populations should be completed during the pre-feasibility or feasibility stage. The involvement of participants from the local communities is of great importance. Solutions to avoid the destruction of cultural heritage need to be identified and transparently implemented and reported on.
	Environmental degradation affecting local populations	• Dust, noise, pollution of water resources or soil, and the loss of fertile soil used for food production can all lead to conflicts, which may spiral into violence. All potential environmental impacts need to be identified no later than during the feasibility stage, together with relevant mitigation strategies, indicators and public reporting commitments.

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CHAPTER 6

SUSTAINABLE FINANCE FOR RESPONSIBLE MINING

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CONTENTS

6.1 INTRODUCTION TO SUSTAINABLE FINANCE AND FRAMEWORKS

6.1.1 General context

As has been seen in earlier chapters, the mining industry that extracts and processes the critical minerals required for the low-carbon energy transition raises environmental, social and governance concerns throughout mining life cycles, especially in vulnerable contexts (Columbia Center on Sustainable Investment *et al.* 2016). Mining operations, if not properly designed, operated and managed, can be associated with environmental contamination accidents including ecosystem disruption (Arendt *et al.* 2022), water pollution (Wang *et al.* 2021), land and habitat degradation (Sonter *et al.* 2018), greenhouse gas emissions (Azadi *et al.* 2020) and deterioration of air quality (Batur and Babii 2022; Stewart 2020). Meanwhile, conflicts with local communities are not always solved by corporate efforts to obtain a social licence to operate from local stakeholders (Owen and Kemp 2013; Vanclay and Hanna 2019). Safety, gender, equity, Indigenous and labour interconnections are rarely addressed comprehensively (Ali 2003; Verrier *et al.* 2022). These issues have given rise to an enormous number and range of civil society initiatives and proposals that seek better outcomes from mining for both the environment and host communities. The mining industry is under pressure to obtain a broader sustainable development licence to operate in line with the Sustainable Development Goals (Pedro *et al.* 2017).

Mining involves huge investments, which puts the financial sector in a strong position to drive improvements in the environmental, social and governance performance of the sector. The finance sector has also a vital role in enabling societies to respond to the challenges of metals and minerals supply. It can provide the capital needed to support the transition to low-carbon and sustainable economies, mitigate the adverse consequences of mining and adapt to the impacts of climate change. Beyond capital provision, the finance sector can direct investments towards responsible good practices in mining, exert a positive influence on governmental actors and influence the policy agenda. In short, finance has a key role to play in pressuring companies and stakeholders to include sustainability factors in their business practices.

When deciding about financing mining activities, investors are discouraged both by environmental, social and governance risks from existing unsustainable practices (International Energy Agency 2022c; Bloomberg 2022), and the extra costs that might be entailed in new, more sustainable practices. Investments in the energy transition are more urgent than ever (International Energy Agency 2021), and the need to provide large amounts of capital to the mining industry on an environmentally and socially sustainable basis has become increasingly acute (Lee and Suh 2022). The financial sector could also be a powerful ally of civil society organizations in incentivizing fewer damaging mining activities.

The finance sector is diverse, with many different actors playing different roles in capital provision (figure 6.1).

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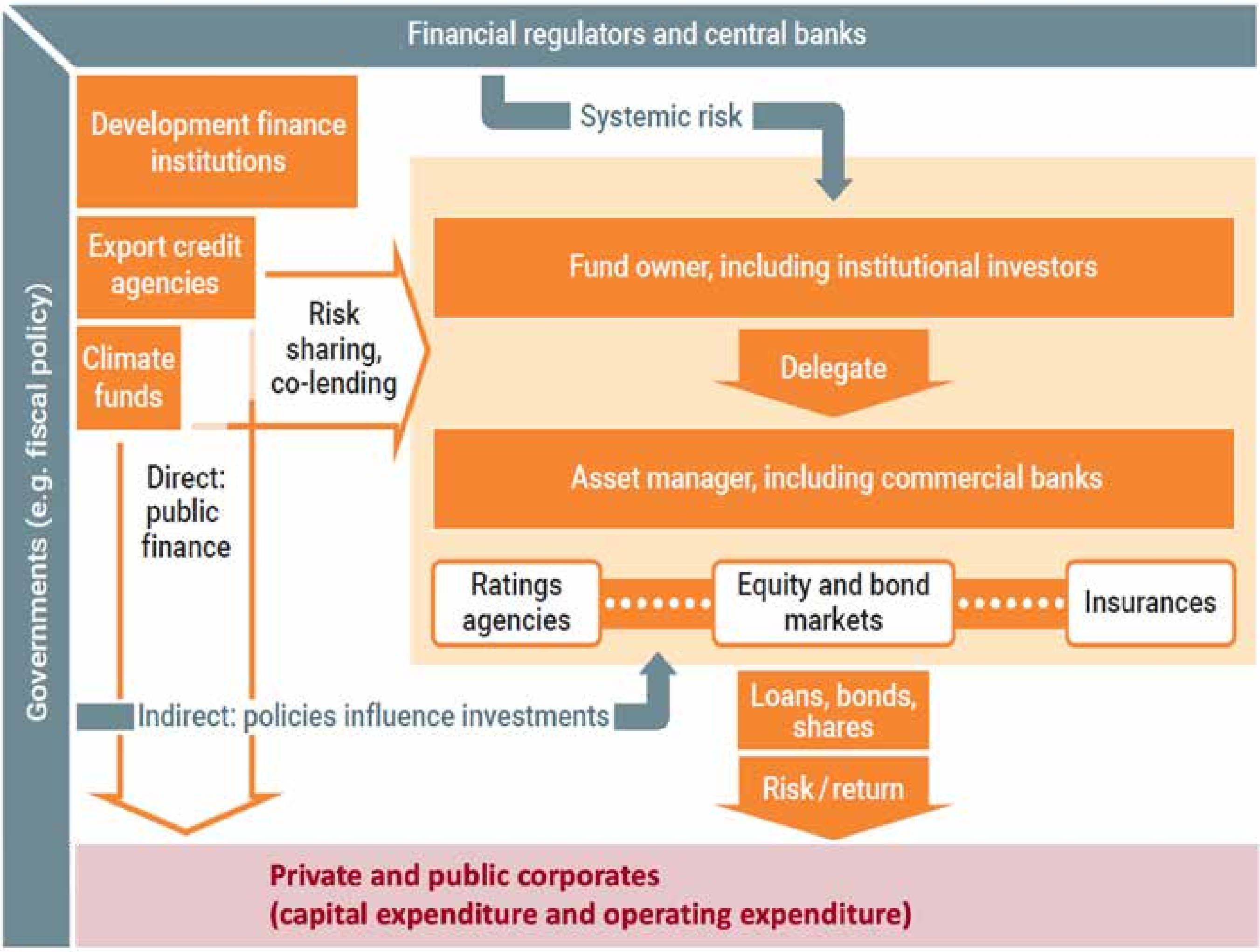
Figure 6.1: Schematic of the financial sector



Source: Adapted from United Nations Environment Programme (2022, figure 7.2, p. 68).

At present, there are more than 12,000 active capital and maintenance projects in the mining sector globally. They cumulatively represent approximately US$1.2 trillion, US$231.1 billion of which are devoted to mines currently under construction.[113] The average 2023 mining spending will increase as the energy transition and energy security issues become more pressing. As costs are projected to rise, the expansion of existing facilities is becoming the preferred option for most miners across the globe: 30 per cent of the value of 2023 planned projects is related to mine expansion (Govreau 2023). A favourable policy environment can contribute to strong mining economies. In its Policies Database, the International Energy Agency lists 35 instruments such as grants, preferential loans or loan guarantees to support the development of mining value chains (International Energy Agency 2022b). On top of these, the Critical Minerals Policy Tracker of the Agency highlights 11 tax incentive mechanisms across nine countries (in North and South America, Asia, Europe and Australia) in the policy area of "promoting exploration, production and innovation" to support projects in the development and mining phase. Countries may use taxation measures and incentivizing domestic production or deductions for chosen investments (International Energy Agency 2022a).

113 S&P Capital IQ Global Mining Intelligence, https://www.spglobal.com/marketintelligence/en/campaigns/metals-mining accessed 2022

In recent years, many financial companies have committed to sustainability and fuelled the sustainable finance debate. Banks, insurance companies and investors have strengthened their approach to sustainability. Many have made formal commitments. Some have delivered on them by funding companies that produce positive socioenvironmental impacts. Through their action, financial operators have encouraged the uptake of responsible practices. The finance sector has also been and continues to be learning how to identify, assess and disclose the environmental, social and governance risks to which they are exposed. By including environmental, social and governance factors in their strategies, financial operators and investors have also increasingly responded to clients' demands[114] and intergovernmental programmes (United Nations Environment Programme [UNEP] 2023), proving there is a growing business case for sustainability.[115] Sustainable finance is also paramount to curbing illicit financial flows, as discussed further below.

As repeatedly noted in this report, the industry producing minerals and metals is fundamental to sustainability and sustainable development: mineral resources are and will be ever more essential to promoting the low-carbon economy (International Energy Agency 2021). The market size of key energy transition minerals reached US$320 billion in 2022, doubling over the past five years, bringing broad-based price increases and strong volatility in 2021 and 2022, as well as potential new revenues and development opportunities (International Energy Agency 2023c). The newly released critical minerals data explorer of the International Energy Agency showcases the evolution of demand projections under various energy scenarios and technology trends (International Energy Agency 2023b). Extraction and refinement processes that are not properly designed, operated and managed can face severe social and environmental impacts that have to be mitigated, and companies are increasingly working to promote a sustainable value chain (Extractives Global Programmatic Support 2017). The proliferation of schemes, alliances, principles and standards is a sign that environmental, social and governance factors, alongside traditional economic considerations, are attracting increasing attention. This Chapter explores the mechanisms under which sustainable finance can support and improve the environmental, social and governance performance of the mining industry.

This Chapter begins by reviewing the existing definitions and frameworks promoting sustainable finance. As sustainable finance involves mechanisms to promote sustainable investments, but also tools to finance sustainability, the Chapter reviews how ambitious policy objectives are translated into operational practices. The Chapter then sets out the various financial instruments that are used along the various stages of the mining value chain. The focus here is on mining rather than the further refining and processing of ores because mining faces its own special circumstances, while the challenges involved in the later stages of metal production are common to many industries. The Chapter considers how sustainable finance, along with corporate environmental, social and governance efforts, affects environmental, social and governance performance across the board. In reviewing different national approaches, the Chapter shows that there are conflicts between different jurisdictions, and calls for an integrated and universal approach that will be instrumental in valuing and supporting responsible practices in mining and the pursuit of sustainable development.

6.1.2 Sustainable finance guidelines and objectives

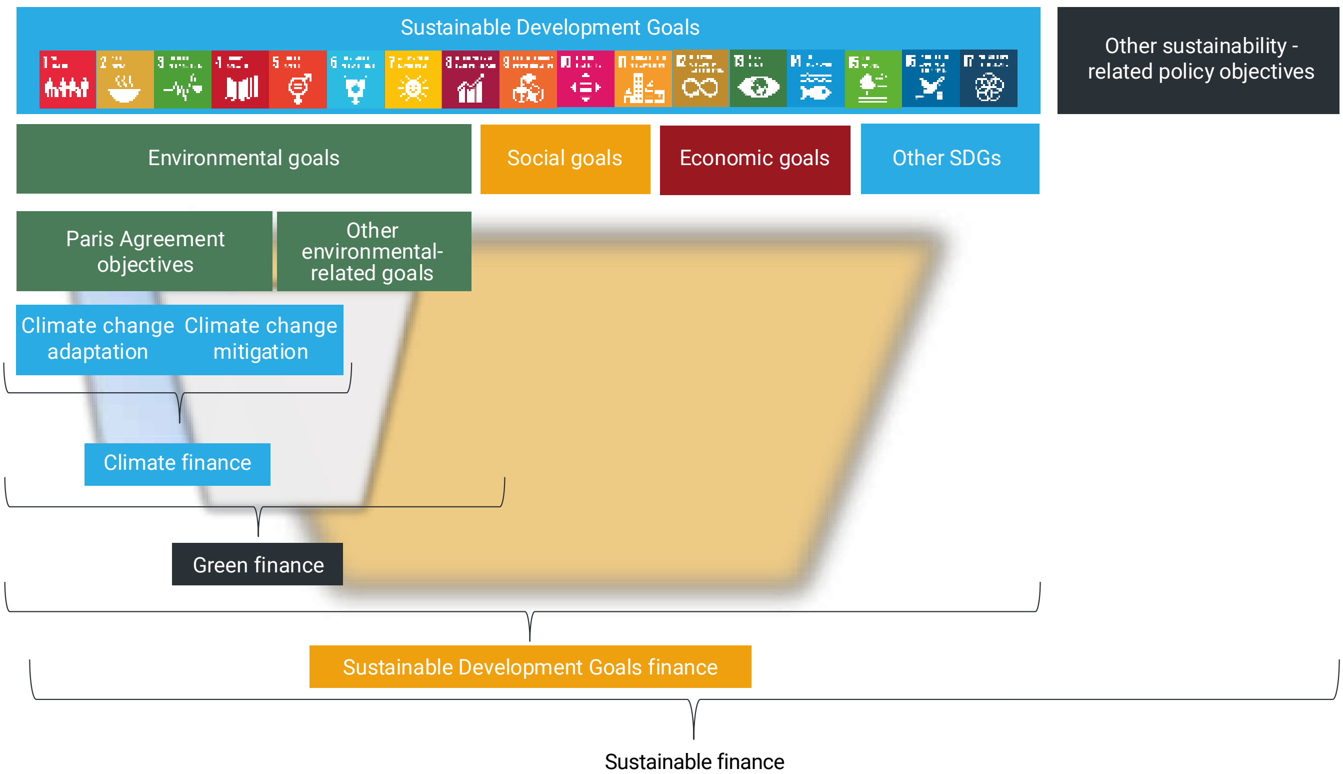
There is no unique definition of sustainable finance. Guidelines have emerged and consolidated across different industries, touching on "ethical", "socially responsible", "green" and "sustainable" factors that shape how financed is deployed. The scientific literature shows that there is a lack of a shared definition, mainly because frameworks are focused on different environmental, social and governance dimensions and tend to have diverse motives. Migliorelli (2021), Widyawati (2020) and Sparkes (2008) explore the historical and conceptual assessments of sustainable finance initiatives. International organizations, financial institutions, governments and regulatory bodies have created definitions, standards and rules that reflect multiple coexisting motivations. The outcome of this two-decade process is a proliferation of heterogeneous terms and concepts (figure 6.2). The lack of a shared and unique definition affects comparability and thus accountability of investments.

114 A recent report by the CFA Institute (2020) reports that that better management of investment risks (64 per cent) and clients' demands (59 per cent) are the top two reasons to include environmental, social and governance factors in investment decisions. The report surveyed more than 7,000 industry professionals across the globe. See https://rpc.cfainstitute.org/-/media/documents/survey/future-of-sustainability.pdf.

115 For instance, see the United Nations Environment Programme Principles for Responsible Banking (https://www.unepfi.org/banking/bankingprinciples/) and referenced progress report released in September 2023.

The European Commission refers to sustainable finance as "the process of taking environmental, social and governance considerations into account when making investment decisions in the financial sector, leading to more long-term investments in sustainable economic activities and projects" (2022). Sustainable finance also includes transparency efforts especially in risk assessment and risk disclosure relevant to environmental, social and governance aspects. This approach is shared by other major multinational institutions such as the European Central Bank, the World Bank,[116] other development banks and the International Monetary Fund.[117] The Group of 20, through its Sustainable Finance Study Group, embraces a broader concept and includes "financing as well as related institutional and market arrangements that contribute to the achievement of strong, sustainable, balanced and inclusive growth, through supporting directly and indirectly the framework of the Sustainable Development Goals" (Group of 20 2018). Broadly, sustainable finance is understood as inclusive of different themes: reporting and disclosure, institutional responsibility, capital allocation (investments), risk management practices, standardization processes, financial innovations, research and capacity-building.[118]

Figure 6.2: An overview of sustainable finance and its components



Source: Adapted from Migliorelli (2021).

116 Sustainable Finance, the World Bank. https://www.worldbank.org/en/topic/financialsector/brief/sustainable-finance.

117 Global Financial Stability Report, Chapter 6 (2019). https://www.elibrary.imf.org/display/book/9781498324021/9781498324021.xml.

118 A recent report by the Coalition of Finance Ministers for Climate Action charted the different existing approaches of national sustainable finance roadmaps. The report is available at: https://www.financeministersforclimate.org/sites/cape/files/inline-files/Sustainable%20Finance%20Roadmaps%20Report%20-%20Nov%202021.pdf.

Using a synthesis of multiple existing frameworks and definitions, in this report sustainable finance includes social, green (and climate) finance, while also incorporating considerations about the economic sustainability of the whole financial system (International Capital Market Association 2020). In general, sustainable finance is supported by frameworks comprising principles followed by financial institutions using existing or novel instruments to finance sustainable assets. The rationale behind sustainable finance lies in the perception that the actions taken by financial actors can improve the performance of the companies in which they invest (Whelan and Fink 2016; Madaleno and Vieira 2020) while generating benefits for the planet and society, as well as private returns to investors.

Under the sustainable finance umbrella, responsible and sustainable investing occupies a central role. In this context sustainable investing is an "approach that considers ESG [environmental, social and governance] factors in portfolio selection and management" (Global Sustainable Investment Alliance 2018). For the purpose of this report, we consider sustainable investing to be the use of one or more strategies out of the following:[119]

1. *Exclusionary screening:* the portfolio composition excludes pre-determined sectors as they are not compliant with environmental, social and governance paradigms.
2. *Best-in-class screening:* the portfolio composition includes investments in environmental, social and governance-compliant sectors and projects.
3. *Norms-based principles:* investments are screened against a set of norms that follow a set of standards or recognized best practices (i.e. the Cyanide Code and the European Union Best Available Technique Reference Documents [BREFs]).
4. *Environmental, social and governance assessment integration:* investment managers include environmental, social and governance indicators, metrics and considerations in their financial analyses and assessments. Reporting and transparency practices (including public disclosure) also support environmental, social and governance integration (for instance, see details on European Union taxonomy-related disclosure tools in Section 4.3.1).
5. *Sustainability-oriented investments:* investments targeting sustainability (i.e. green technologies, cleantech innovations, sustainable practices).
6. *Impact investing:* investments target specific environmental, social and governance problems and communities may be involved. Capital is provided to businesses and projects that can prove a clear and tangible environmental, social and governance purpose.
7. *Corporate and shareholder action:* the use of shareholder influence on corporate decisions and actions (namely, active ownership).

The landscape for environmental, social and governance investment is growing fast. Between 2012 and 2020, total "sustainable investing" assets grew from US$13.3 trillion to US$30.7 trillion (Schumacher 2020), the most famous of such funds being the Norwegian Oil Fund, worth US$1.3 billion.[120] Markets, investors and shareholders are increasingly conscious that a strong sustainability orientation can also be a source of good economic returns. The environmental, social and governance world is dominated by a plethora of standards, initiatives, regulations, principles and good practices that may generate confusion among market operators. Moreover, research has detected divergence in measurement and scope (Berg *et al.* 2022; Kotsantonis and Serafeim 2019). A systematization and assessment of existing practices is urgent, and may be offered by the release in June 2023 of new standards by the International Sustainability Standards Board.[121]

The environmental factors of the term 'environmental, social and governance' can cover a wide range of issues, such as energy use (fossil resources), greenhouse gas emissions leading to climate change, surface water and groundwater (quantitative and qualitative issues), soil, biodiversity, waste and emissions, and long-term management of derelict mining and metallurgical sites. However, the most attention has been given to climate change, such that climate finance is now seen as a special category of finance (box 6.1).

119 The sustainable investment strategies were detailed by the Global Sustainable Investment Alliance, a membership-based collaboration among sustainable investment organizations.

120 See Norges Bank Investment Management website: https://www.nbim.no/

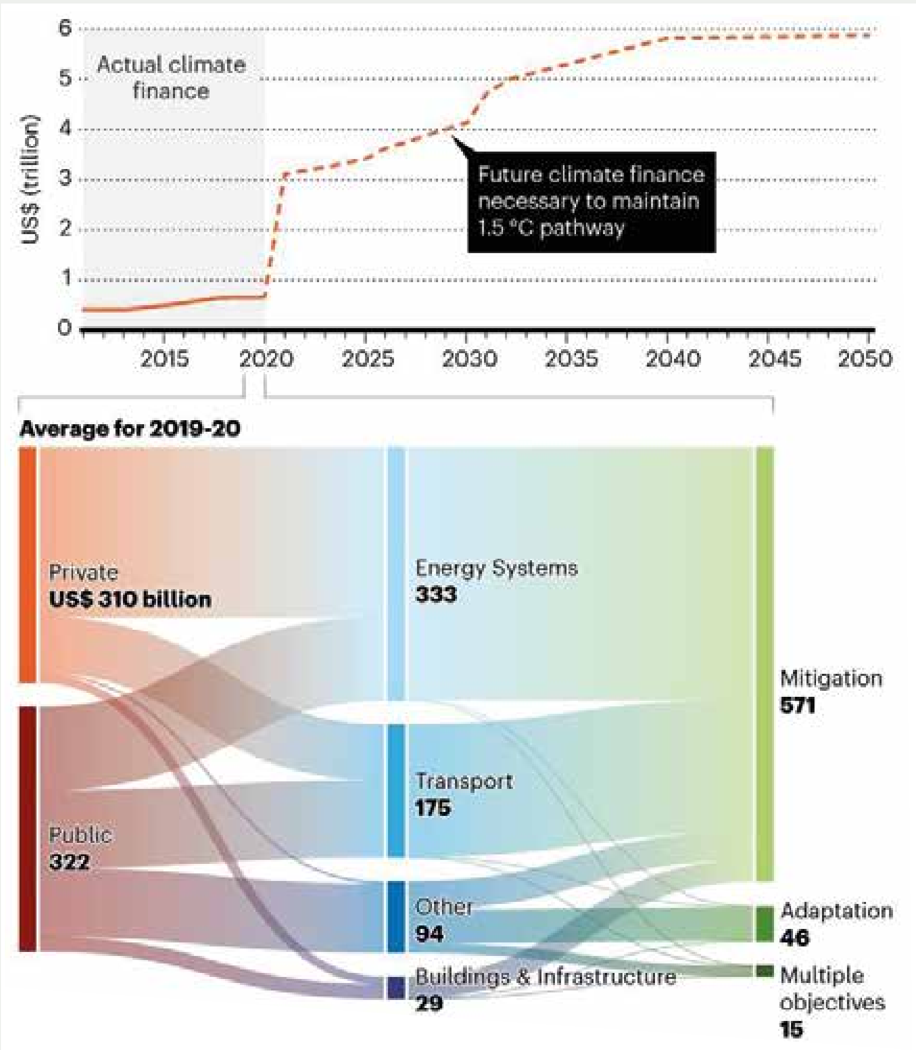
121 https://www.ifrs.org/news-and-events/news/2023/06/issb-issues-ifrs-s1-ifrs-s2/. Accessed 18 July 2023.

Box 6.1: Climate finance: a new financial flow

Sustainable development and climate change are strongly linked: developing countries are the most affected by adverse climate impacts while also being the least able to adapt to them. In the 2030 Agenda for Sustainable Development (2015), United Nations Member States committed to take action to tackle climate change and protect the planet from what was described as "one of the greatest challenges of our time". The set of skills, tools and resources available to move towards a climate-resilient future are restricted in the most vulnerable areas of the world, despite their limited contribution to the problem.

Climate finance refers to "local, national or transnational financing—drawn from public, private and alternative sources of financing—that seeks to support mitigation and adaptation actions that will address climate change" (website of United Nations Framework Convention on Climate Change 2022[122]). Article 9 of the Paris Agreement (2015) marked a milestone for climate action. Rich nations pledged to transfer US$100 billion per year to less wealthy countries by 2020 to assist in mitigation and adaptation. At the 26th United Nations Climate Change Conference of the Parties (COP26) in Glasgow, it became apparent the promise had not been fulfilled and parties renegotiated to meet the target by 2025. Some issues remain open, including the post-2025 finance landscape: an assessment by the Standing Committee on Finance of the United Nations Framework Convention on Climate Change remarked that developing countries will require up to US$6 trillion up to 2030 (figure 6.3).

Figure 6.3: Climate finance needs for future mitigation and adaptation (top); source of climate financing 2019–2020 (bottom)

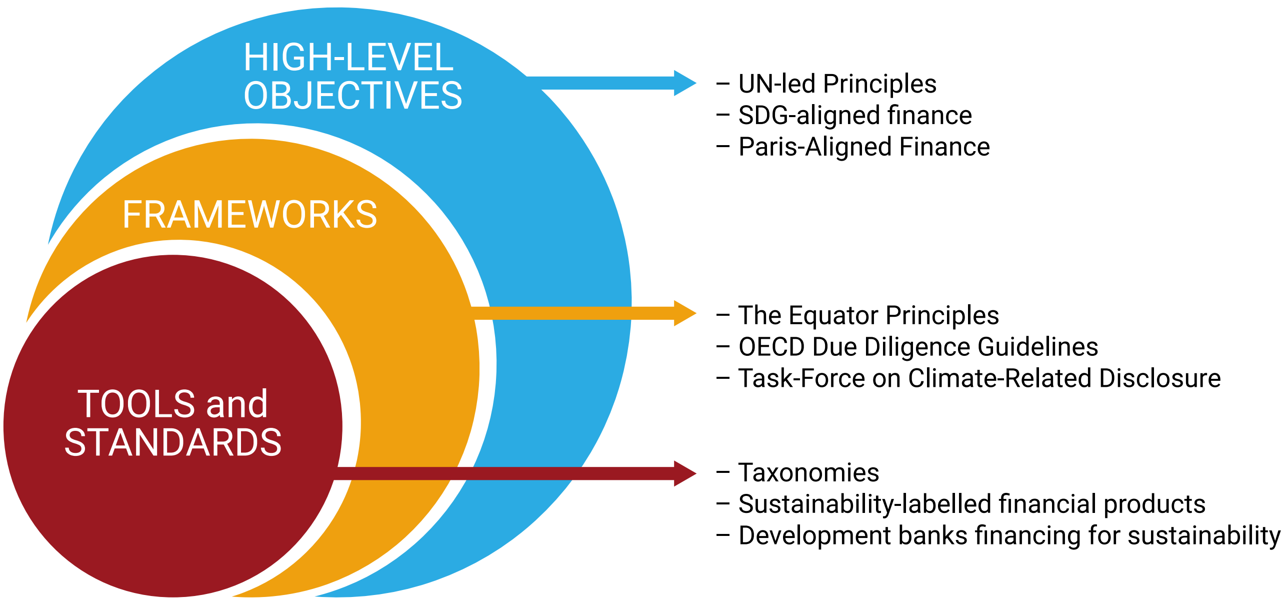


Source: Nature (2021). https://www.nature.com/articles/d41586-021-02846-3.

122 https://unfccc.int/topics/introduction-to-climate-finance

There exists a strong business case behind the channelling of more financial resources towards climate-resilient activities. Scientific evidence shows that with no greater climate action, temperature could rise above pre-industrial levels by around 4°C, exposing the world to an estimated US$23 trillion in global economic losses (Kompas *et al.* 2018). From an investor's point of view, assets are not just exposed to physical risks (i.e. arising from climate change impacts and leading to disruption and physical damages to assets and people), but also to transition risks (i.e. the impact of climate change and other environmental policies regulations and changing technology costs). Investments in a climate-resilient economy offer opportunities for economic growth and increased competitiveness as this market becomes more prominent, and the demand for sustainably produced products is on the rise. Finally, climate finance widens the spectrum of potential investments by opening up product innovations and markets. The involvement of market actors in rather economically neglected areas of the world opens up possibilities for innovation by valuing diversity.

Figure 6.4: Sustainable finance as detailed in three nested layers



Source: Authors.

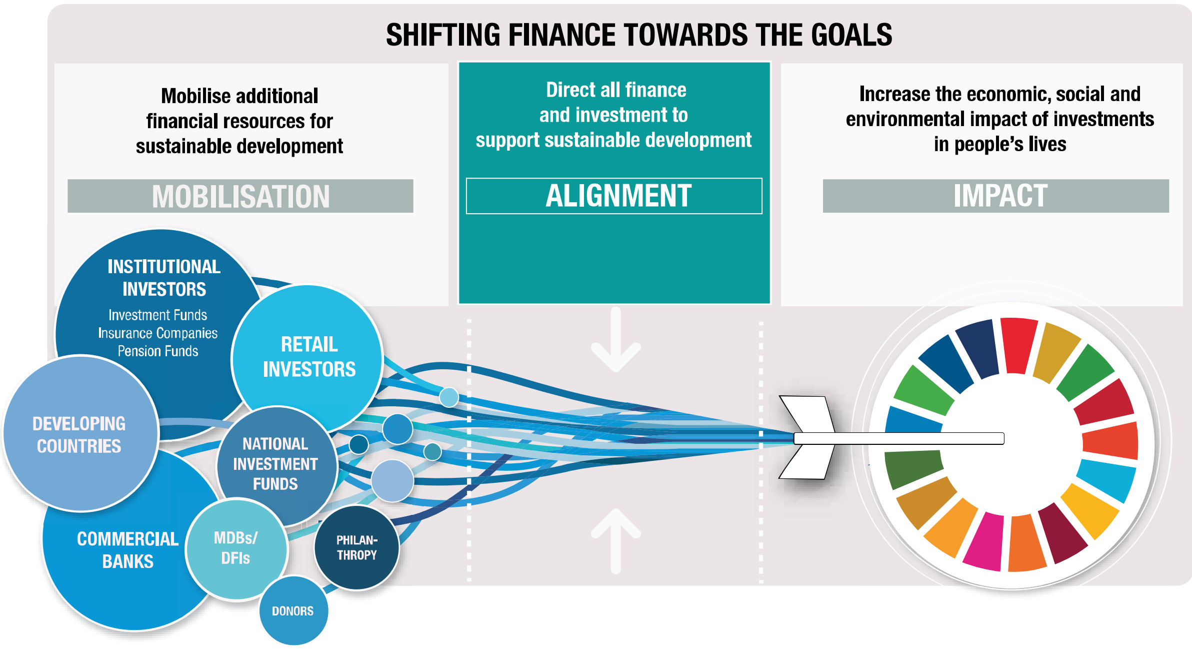
Sustainable finance initiatives are defined at and operate through three levels: high-level objectives that influence industry-relevant frameworks that are ultimately translated into applicable tools and standards (figure 6.4). However, as noted above, the sustainable finance landscape is fragmented, with common policy objectives having multiple understandings that can constrain the financing of assets for sustainable development.[123] This fragmentation can be a deterrent for companies to engage with environmental, social and governance reporting and initiatives, but there remain effective options to finance the extractive industry under a sustainable finance framework.

123 The Organization for Economic Cooperation and Development (OECD) explored the barriers to scaling up green and sustainable investments in its OECD Business and Finance Outlook Series. The lack of a universal definition of "sustainable" assets is frequently mentioned as a limitation for market operators. See OECD (2016) and OECD (2017) for a detailed discussion.

6.1.3 High-level objectives

The 2030 Agenda for Sustainable Development and its Sustainable Development Goals, the Paris Agreement, and the recent Kunming-Montreal Global Biodiversity Framework and Global Framework on Chemicals[124] are international landmarks of a journey towards a sustainable future. Many Sustainable Development Goal-inspired financing initiatives have been initiated at the international, national and sectoral levels. Together with an ensemble of United Nations-led principles, supranational institutions and countries have undertaken initiatives for financing sustainability. These initiatives allow for the mobilization and alignment of private and public financial resources and they ensure that these flows are directed towards priorities relevant to the Sustainable Development Goals (figure 6.5).

Figure 6.5: The process of redirecting finance towards the Sustainable Development Goals



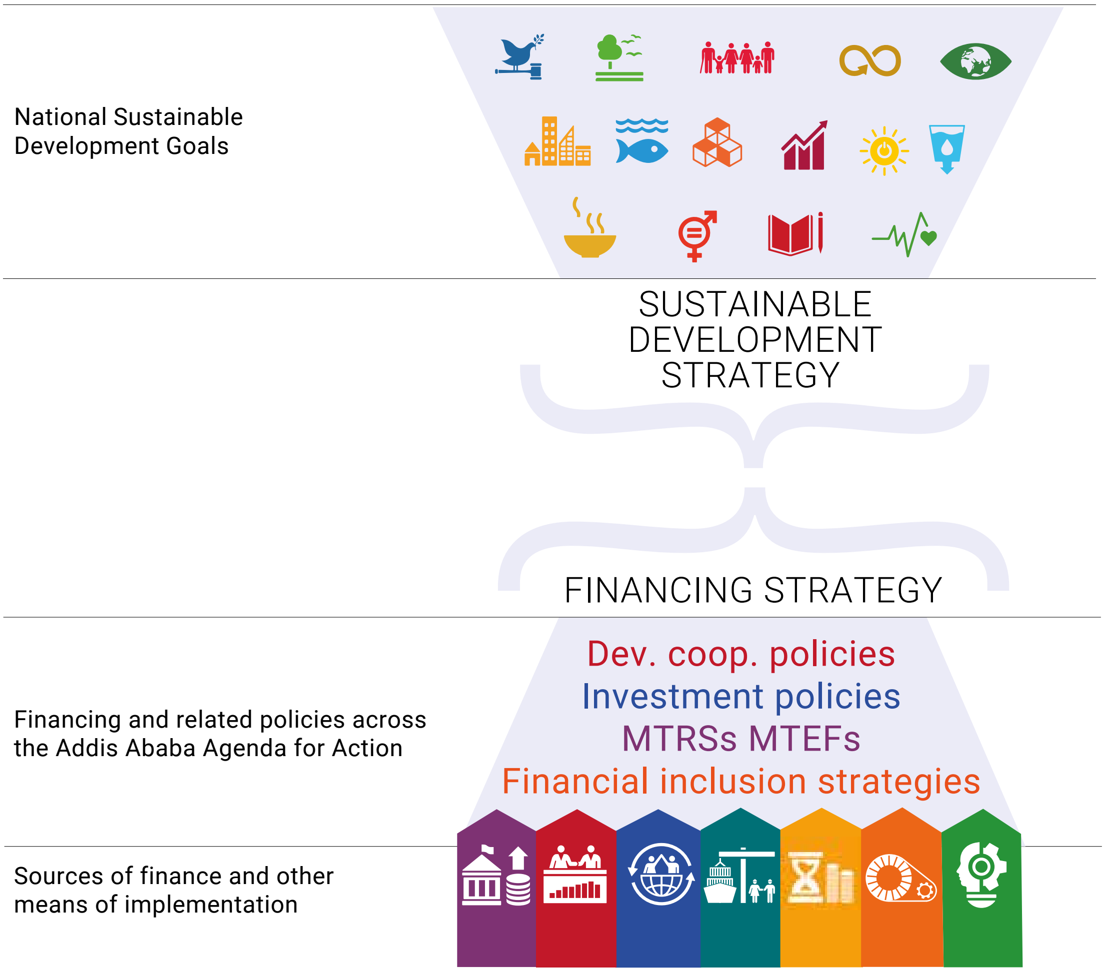
Source: Organization for Economic Cooperation and Development (2021).

6.1.3.1 Sustainable Development Goal-inspired finance

In 2015, world leaders met in Addis Ababa, Ethiopia to agree on the Addis Ababa Action Agenda, a global framework for financing sustainable development supporting the implementation of the 2030 Agenda, including the Sustainable Development Goals. The Agenda recognized the critical mismatch between national development priorities and plans and the financial resources needed to achieve them. To date, the Action Agenda is a tool to align all financing flows and policies with economic, social and environmental priorities (figure 6.6). At the heart of the Agenda are the integrated national financing frameworks that detail how each country intends to pursue its sustainable development strategy. The integrated national financing frameworks are made up of four blocks: (i) assessments and diagnostics; (ii) financing strategy; (iii) monitoring and review; (iv) governance and coordination. Each block contributes to building capacities to strategically plan and manage how to collect and direct financial resources.

124 The Kunming-Montreal Global Biodiversity framework was adopted in December 2022: https://www.cbd.int/gbf/ and the Global Framework on Chemicals in September 2023: https://sdg.iisd.org/news/historic-global-framework-on-chemicals-adopted-following-years-of-talks/

Figure 6.6: Schematic representation of the integrated national financing framework



Note: Dev. Coop. is development cooperation. MTRSs = Medium-Term Revenue Strategies; MTEFs: Medium-Term Expenditure Frameworks[125].

Source: United Nations Inter-Agency Task Force on Financing for Development (2019); United Nations, Department of Economic and Social Affairs (2020).

The 2030 Agenda established an intergovernmental process and an inter-agency task force. The first is the annual Forum on Financing for Development, which has the mandate to review on a regular basis the Agenda and other financing for development outcomes. The second is the Inter-Agency Task Force on Financing for Development, which reports on annual progress and advises on practical matters. The call to mobilize and scale up private and public finance targeted at the Sustainable Development Goals has led to alliances across environmental, social and governance dimensions. The Global Investors for Sustainable Development Alliance is an example of activity coordinated by the United Nations that is aimed at redirecting financial flows towards the Sustainable Development Goals. The Alliance consists of more than 30 heads of major financial institutions and corporations across the globe. In 2020, the Alliance produced a shared definition of "Sustainable Development Investing": "deploying capital in ways that make a positive contribution to sustainable development, using the SDGs [Sustainable Development Goals] as a basis for measurement" (Global Investors for Sustainable Development Alliance 2020). The definition embraces both private and social returns on investments. Moreover, it includes environmental, social and governance investing strategies and impact investing. The implications of this broadened definition are twofold. On the one hand, investments should not have a negative impact (the "do no harm" principle); on the other, investments should generate positive benefits with respect to the objectives of the Sustainable Development

125 Medium-term revenue strategies are government-led fiscal approaches to undertake effective tax systems reform for boosting tax revenues (https://www.imf.org/en/News/Articles/2019/10/28/sp102919-mediumterm-revenue-strategy). Medium-term expenditure frameworks are "linking frameworks" that allow spending to be "driven by policy priorities while being disciplined by budget realities".

Goals (figure 6.7). In addition to the strategies shown, environmental, social and governance investors also engage actively with the companies they invest in, at annual general meetings and investor meetings, to press for more commitment to environmental, social and governance issues.

In the climate context, the United Nations Environment Programme (UNEP) (2022) has suggested a range of actions and instruments for different parts of the financial sector, many of which are relevant to the mining sector (see adapted table 6.1). The suggestions go well beyond the action of United Nations agencies, and involve central and other banks, regulators and different government departments, as well as international financial institutions.


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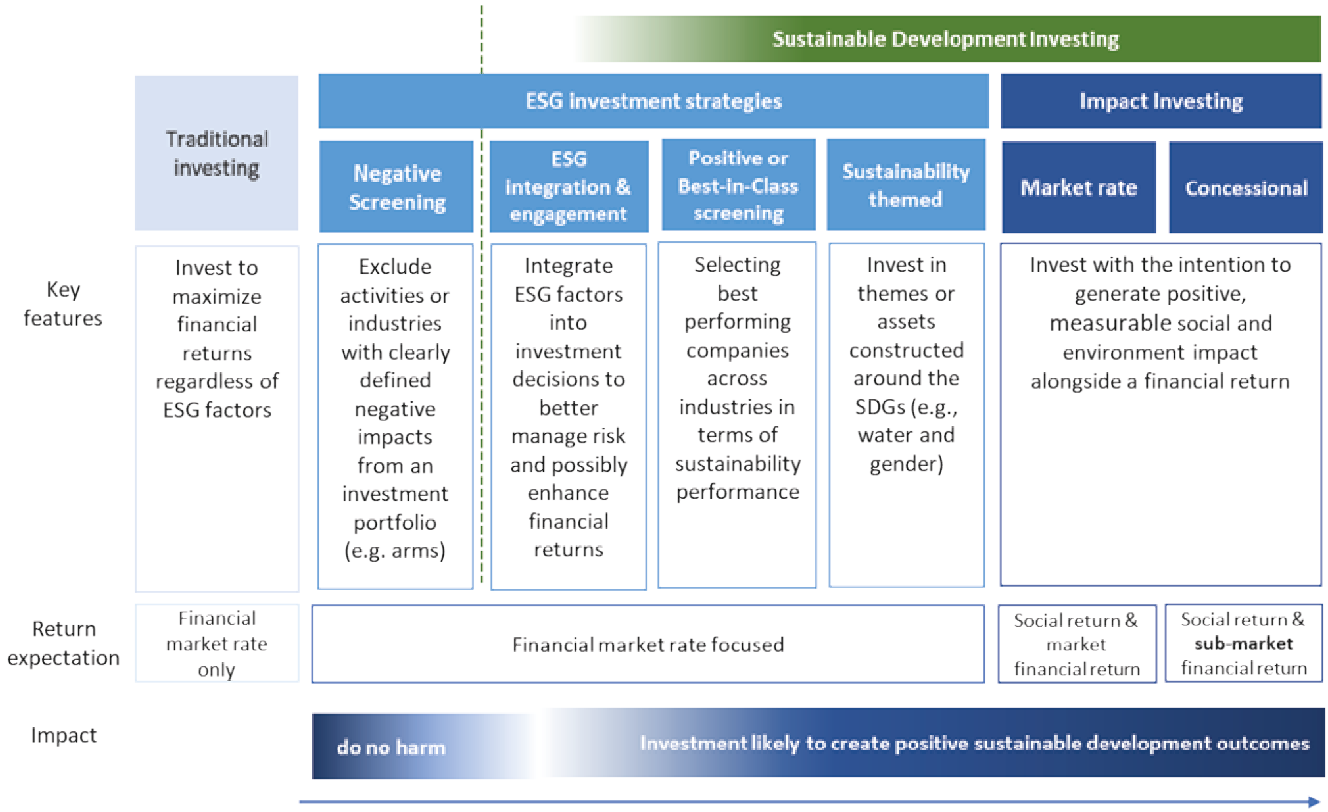
Figure 6.7: The Sustainable Development Investing spectrum



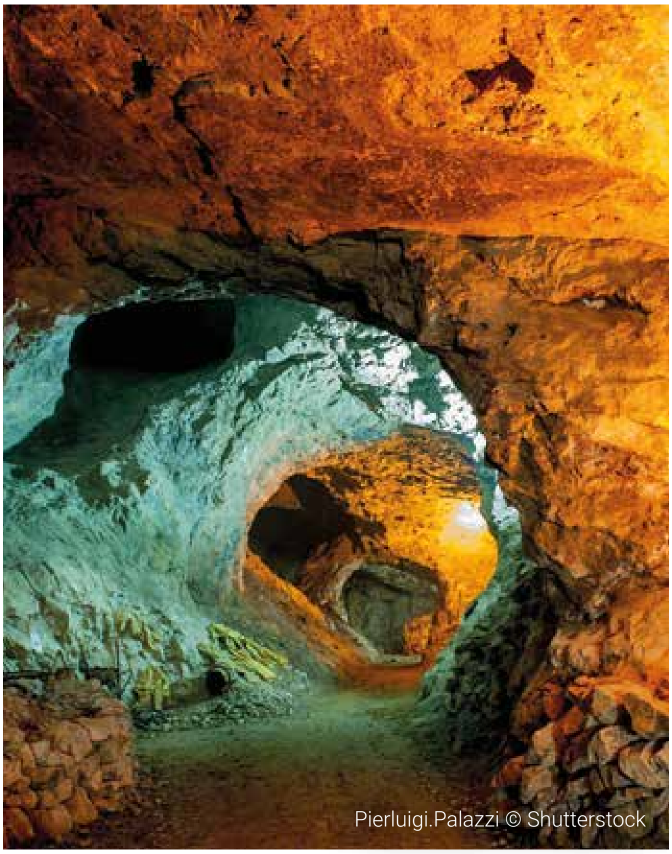
Source: Global Investors for Sustainable Development Alliance (2020).

Table 6.1: Objectives, instruments, institutions and actors for accelerating financial flows for sustainable development

Objective	Instruments	Institutions and actors
Increase the efficiency of financial markets	• Financial transparency rules and protection of investors and consumers • Climate-related financial risk disclosure (voluntary and mandatory) • Taxonomies and classification systems • Financial engineering (structured finance, asset-backed non-recourse debt, venture capital, private equity, etc.) • Definitions and disclosure or recognition of the risk of stranded assets • Green bonds and bond market classifications and standards, including environmental, social and governance standards • Capacity-building	• Financial regulatory institutions • Central banks • Credit rating and related agencies • Banks and institutional investors • Bond market regulators
Introduce carbon pricing	• Carbon taxes • Emissions trading schemes • Fossil fuel subsidy reduction • Carbon credit instruments	• Ministries of finance and treasuries • Financial regulatory agencies • Ministries of power or the environment • International agreements (e.g. United Nations Framework Convention on Climate Change)
Nudge financial behaviour	• Nudges to address herd behaviour and behavioural and system inertia, and to provide benefits from switching to low-carbon alternatives • Divestment movements • Tax benefits to accelerate low-carbon investments • Product taxes, subsidies, regulations, standards, labelling and public infrastructure • Carbon taxes and regulations on greenhouse gas-intensive activities	• Ministries of finance and treasuries • Ministries of environment • Large corporates, supply chains • Multilateral development banks, development finance institutions, export credit agencies
Create markets	• Public bonds and guarantee issuances for domestic, early-stage research and development investment and direct investment support, green banks • Innovation intermediaries and investment • Public-private partnerships • Enabling policy support (feed-in tariffs, reverse auctions, etc.) • Product market regulations and standards • Public procurement contracts and purchase guarantees • Taxes and subsidies	• Ministries of finance and treasuries • National and regional development banks and green banks • Cities and regions • Private equity investors
Mobilize central banks	• Priority sector lending and credit quotas • Prudential lending standards and bank supervision, collateral requirements • Stress testing and financial stability prudential requirements • Enhanced liquidity support to financial system • Creating new asset classes for climate in banking and investment regulation • Quantitative easing and central bank balance sheet activities • Low-carbon climate remediation assets • International Monetary Fund Special Drawing Rights (IMF SDR) issuance funding for climate investment support in low-income contexts	• Central banks • Financial regulators • International Monetary Fund • Banks and institutional investors
Set up climate clubs and international cross-border financial initiatives	• Instruments depend on type of initiative, but include: • Voluntary standards and agreements on fossil fuel subsidy reductions • Agreement on norms for export credit agencies • Just transition initiatives and financial support structures • Multilateral and bilateral climate funds • Multi-sovereign and other guarantee support to de-risk and leverage private investment	• Climate funds • Multilateral development banks, export credit agencies • Multi-sovereign guarantee mechanisms • Credit-rating agencies • Group of Seven/Group of 20 agreements • Larger private institutional actors

Source: Adapted from United Nations Environment Programme (2022, table 7.2, pp. 76-77).

The potential for concerted financing for action inspired by the Sustainable Development Goals came into sharper focus at the end of 2020. The world's public development banks, including a large proportion of national institutions, gathered together at the first Finance in Common Summit. There, they expressed the absolute urgency to mobilize funds towards climate-aligned investments and committed to shift their investment strategies and patterns in support of the Sustainable Development Goals. Furthermore, they agreed to facilitate schemes and practices to enable private investors to come together under the same set of high-level objectives. This important role of multilateral development banks was reiterated at the Summit for a New Global Financing Pact, which took place in Paris in June 2023. While critical materials for the low-carbon energy transition were not explicitly mentioned in the Summit summary,[126] the Summit's statement calling on multilateral development banks "to promote just transitions and foster sustainable development at the global level" (p. 8) provides a solid platform for them to engage with the supply of critical materials for the low-carbon energy transition.



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6.1.3.2 United Nations-led principles

In 1992, a group of 13 financial institutions joined forces under the United Nations guidelines to "change finance and finance change". That was the foundation of the United Nations Environment Programme Finance Initiative (UNEP FI).[127] Since its inception, the sustainable finance landscape has profoundly changed and expanded. At the time of writing, UNEP FI works with more than 500 banks, insurers and investors representing more than US$170 trillion in assets globally.

Since its launch, UNEP FI has helped to establish two co-created frameworks:

- The Principles for Sustainable Insurance in 2012, tailored to the insurance sector with a road map to launch and expand innovative risk management practices and insurance solutions for sustainable development. The Principles are currently applied by insurers representing 25 per cent of world premiums, and seek to build the foundation of sustainable insurance, a strategic approach where the whole insurance value chain is managed responsibly.
- The Principles for Responsible Banking in 2019, to complement the framework of the Principles for Responsible Investment to cover the lending and underwriting activities of banks and ensure that strategies and practices of signatory banks are aligned with the Sustainable Development Goals while being consistent with the Paris Agreement. There are now 325 signatories of the Principles for Responsible Banking, representing half of global banking assets with a value of nearly US$90 trillion.[128] Those signatories engage in a three-step journey to implement six principles that should cut across all business areas: They must: identify the most significant impacts of their products in the sectors they operate in (impact analysis); set targets to achieve measurable and quantifiable progress in areas with the most significant impacts (target setting); and share improvements publicly (reporting).

126 Summary of summit discussions accessible at: https://www.elysee.fr/en/emmanuel-macron/summit-on-a-new-global-financing-pact.
127 United Nations Environment Programme Finance Initiative: https://www.unepfi.org/.
128 https://www.unepfi.org/wordpress/wp-content/uploads/2023/09/PRB-Second-Progress-Report-2023.pdf.

Another influential framework is the Principles for Responsible Investment, which was founded in 2006 and developed "by investors for investors", to align their interests with those of society. By June 2024, the Principles for Responsible Investment had over 3,750 signatories, with assets under management of around $130 trillion. The framework incorporates environmental, social and governance criteria into investment analysis and decision-making and seeks to enhance corporate disclosure and investors' acceptance of sustainability issues.

The sustainable finance landscape is influenced by the actions of networks and coalitions that actively bind their members to principles and actions, some of which are listed in Appendix 6. These networks are global, regional and national and seek to promote one or more of the following objectives: (i) shift financial resources from brown to green assets; (ii) develop shared principles, accounting rules and methods to track greenhouse gas emissions of assets owned; (iii) invest in bankable and clean energy projects and promote a sustainable economy. United Nations-led networks include the Net Zero Asset Owner Alliance, the Net Zero Banking Alliance,[129] the Net Zero Export Credit Agencies Alliance[130] and the Forum for Insurance Transition to Net Zero (the latter replaced the Net Zero Insurance Alliance, which was discontinued in April 2024). Networks normally include banks, asset owners, pension funds, insurance companies, national and international banks, shareholders and companies.

6.1.3.3 Paris-aligned finance

Shifting investments

Many networks target climate-resilient investments aligned with the Paris Agreement. The Glasgow Financial Alliance for Net Zero, presented at the 26th United Nations Climate Change Conference of the Parties (COP26) in Glasgow, is a private sector initiative that, at the time of writing, included over 450 financial companies in 45 countries responsible for over $130 trillion in assets. The Alliance aims to bring together multiple net-zero finance initiatives and accelerate the transition through capital investment. Investors can support net-zero strategies by redirecting capital towards green technologies (divesting from highly polluting sectors and activities) or by supporting carbon capture and storage projects, as well as negative-emission research and development projects.

Improving transparency

When it comes to greenhouse gas emissions, accounting is essential. Networks of investors are strong allies in developing shared frameworks to measure emissions along the value chain. The Platform Carbon Accounting Financials is a global partnership of financial actors that cooperate to develop and implement harmonized approaches to assess and disclose greenhouse gas emissions associated with their lending and investment activities. Founded in 2015, the initiative now includes 206 financial institutions. The Platform guides investors through the accounting process. As such, it contributes to disclosing the real impacts of financial activities. The outcome is the Global GHG Accounting and Reporting Standard for the Financial Industry, which assesses climate-related risks in line with the Task Force on Climate-related Financial Disclosures, sets science-based targets in line with the science-based targets for financial institutions initiative and reports to relevant stakeholders, including the Carbon Disclosure Project.

Coalitions and networks, such as Climate Action 100+, are also active in calling for corporate greenhouse gas reduction strategies and other pro-sustainability actions along the whole value chain. Supported by five pre-existing investor networks from different areas of the world,[131] Climate Action 100+ investors interact with key companies in the capacity of lead, collaborating or individual investor. One of the networks, the Ceres Investor Network on Climate Risk and Sustainability includes more than 200 institutional investors for a total of $47 trillion in assets under management. Ceres members engage and collaborate on environmental, social and governance matters to advance investment practices. The network also pressures stock exchanges and regulators to improve disclosure. The network

129 See progress reports for the Net-Zero Asset Owner Alliance: https://www.unepfi.org/industries/the-second-progress-report-of-the-net-zero-asset-owner-alliance-advancing-delivery-on-decarbonisation-targets/ and the Net-Zero Banking Alliance: https://www.unepfi.org/industries/banking/net-zero-banking-alliance-2022-progress-report/.

130 https://www.unepfi.org/climate-change/net-zero-export-credit-agencies/

131 The five networks are the Asia Investor Group on Climate Change, Ceres, the Investor Group on Climate Change, the Institutional Investor Group on Climate Change and the Principles for Responsible Investment. They provide support, help with facilitating meetings and technical guidance and assistance.

accounts for multiple working groups: the Paris Aligned Investment Working Group, the Ceres Working Group on Land Use and Climate, the Policy Working Group, the Climate Action 100+ North America Working Group, the Shareholder Initiative on Climate and Sustainability, the Investor Water Lab, the Carbon Asset Risk Working Group and the Private Equity Working Group.

The high-level principles inspired by the principles of the Sustainable Development Goals and the Paris Agreement are implemented through frameworks proposed by international institutions, industry alliances or multinational organizations which operate on two complementary levels: data standardization and risk disclosure; and sustainable investments.

6.1.4 Disclosure frameworks for sustainable finance

6.1.4.1 Standardizing environmental, social and governance data

Investors' and lenders' appetite for environmental, social and governance assets is growing. When making investment decisions, financial institutions identify, assess and communicate environmental, social and governance risks to investors as a consequence of increasing negative impacts on the value of investors' assets owing to the multiple risks that may affect the profitability of their investment, and the investor's reputation. Regulation and policy have supported this shift and pushed market factors towards sustainability. As disclosure initiatives proliferate, investors can obtain more comprehensive overviews of the assets in which they have an interest.

The need for punctual, timely and high-quality assured information is key to forecasting and preparing for risks derived from climate change, biodiversity loss and ecosystem collapse. With appropriate data, investors and financial actors can better calibrate models, seize opportunities and price assets accurately. Two landmark initiatives have focused investor attention on the environmental dimension of sustainable development: the Task Force on Climate-related Financial Disclosures, created by the Financial Stability Board to increase and improve reporting of climate-related financial information, and the Task Force on Nature-related Financial Disclosures. The Task Force on Climate-related Financial Disclosures works with companies to improve their knowledge and to support developments in the governance, strategy, risk management and metrics of their businesses. In July 2023, the body behind the International Sustainability Standards Board, the International Financial Reporting Standards Foundation, announced that it will take over this work from the Task Force on Climate-related Financial Disclosures in 2024.[132] Launched in 2021, the Task Force on Nature-related Financial Disclosures released its final recommendations in September 2023.[133] It developed a risk management and disclosure framework for companies, organizations and institutions to report on existing and foreseeable nature-related risks. The identification and disclosure of these type of risks is instrumental to investors' decision-making to move towards nature-positive outcomes.

UNEP-FI supported the adoption of the Task Force on Climate-related Financial Disclosures framework from its launch and gradually introduced indicators aligned with the Task Force into the United Nations Principles for Responsible Investment. First introduced on a voluntary basis, the Principles for Responsible Investment increasingly required its signatories to report on core indicators (starting with the governance and strategy indicators of the Task Force on Climate-related Financial Disclosures framework). From the 2021 reporting cycle, signatories must also accept that the results they report are to be scored and disclosed publicly.

The Global Reporting Initiative is a well-established standards provider in the environmental, social and governance domain. Founded in 2000, it has rapidly become the most widely used framework for sustainability reporting, covering universal and topic-specific standards. The Initiative cooperates with the non-profit Carbon Disclosure Project and with the United Nations Principles for Responsible Investment to work with investors. Science-based targets for financial institutions are tailored to asset owners, asset managers, banks and insurance and has been operational since 2020.

The sister organization of the World Bank, the International Finance Corporation, has played a pivotal role in establishing sustainable finance initiatives and programmes. One of them is the Equator Principles, which rapidly became a reference for the financial industry. The Equator Principles serve as a risk management framework to identify, quantify and

132 https://www.ifrs.org/news-and-events/news/2023/07/foundation-welcomes-tcfd-responsibilities-from-2024/. Accessed 18 July 2023.
133 See detailed recommendations at: https://www.unepfi.org/themes/ecosystems/tnfd-final-recommendations/.

assess environmental and social risks. Published for the first time in 2003, they have now been adopted by 105 major banks. The Equator Principles cover very relevant financial products for mining: project-related financial advisory services; project finance; project-related corporate loans; bridge loans and project-related refinance, as well as project-related acquisition finance. Their rationale lies in ensuring that finance is delivered and developed in a socially responsible fashion to mitigate, reduce or avoid negative impacts of projects.

The International Finance Corporation strategy on sustainable finance also includes the provision of tools for clients and stakeholders. The Environmental and Social Management System Diagnostic Tool of the Corporation helps financial institutions, institutional investors and asset managers to assess their performance against the International Finance Corporation Performance Standard 1 (International Finance Corporation 2022b). The benefits for users are reduced direct and indirect environmental and social risks, including lower credit, market and reputational risks. The focus on environmental and social risks is also supported by the International Finance Corporation Environmental, Social and Governance Toolkit. The toolkit is aimed at helping fund managers and financial institutions to add value through environmental, social and governance management. On the environmental side, mining is explicitly mentioned as critical for resource efficiency and circular economy risks and opportunities. On the social side, mineral extraction activities present modern slavery challenges and should be regulated using human rights protection frameworks and regulations.

Another noteworthy online tool, ENCORE (Exploring Natural Capital Opportunities, Risks and Exposure), was developed by the Natural Capital Finance Alliance[134] in partnership with UNEP to help financial institutions - often dealing with fragmented information – to understand and integrate natural capital risks in their activities and risk management processes; Natural Capital Finance Alliance and UNEP World Conservation Monitoring Centre 2018).

6.1.4.2 Scoring environmental, social and governance performance in mining

One of the most valuable sources of information about environmental, social and governance corporate performance in mining is the Responsible Mining Index, the biennial report of the Responsible Mining Foundation. The foundation supports the view that "extractives value chains should benefit the economies, improve the lives of peoples, and respect the environments of producing countries – while allowing companies to make a fair and viable return".[135] In 2020, the Responsible Mining Index provided an assessment of the policies and practices of 38 of the largest mining companies (accounting for 28 per cent of global mining activities by value of production), as well as 180 individual mine sites. Their latest report scrutinizes 40 companies and 250 mine sites (Responsible Mining Foundation 2022).The assessment is focused on large-scale mining and uses three classes of indicators:

- **Commitment indicators** assess the extent to which companies have produced formalized commitments, endorsed by senior management, and assigned responsibilities and resources to implement these policies.
- **Action indicators** assess the extent to which companies are systematically putting in place measures to improve and maximize the potential economic, environmental, social and governance benefits and avoid, minimize or mitigate the negative environmental, social and governance impacts of their activities.
- **Effectiveness indicators** assess the extent to which companies are tracking, reviewing and acting to improve their performance on managing economic, environmental, social and governance issues.

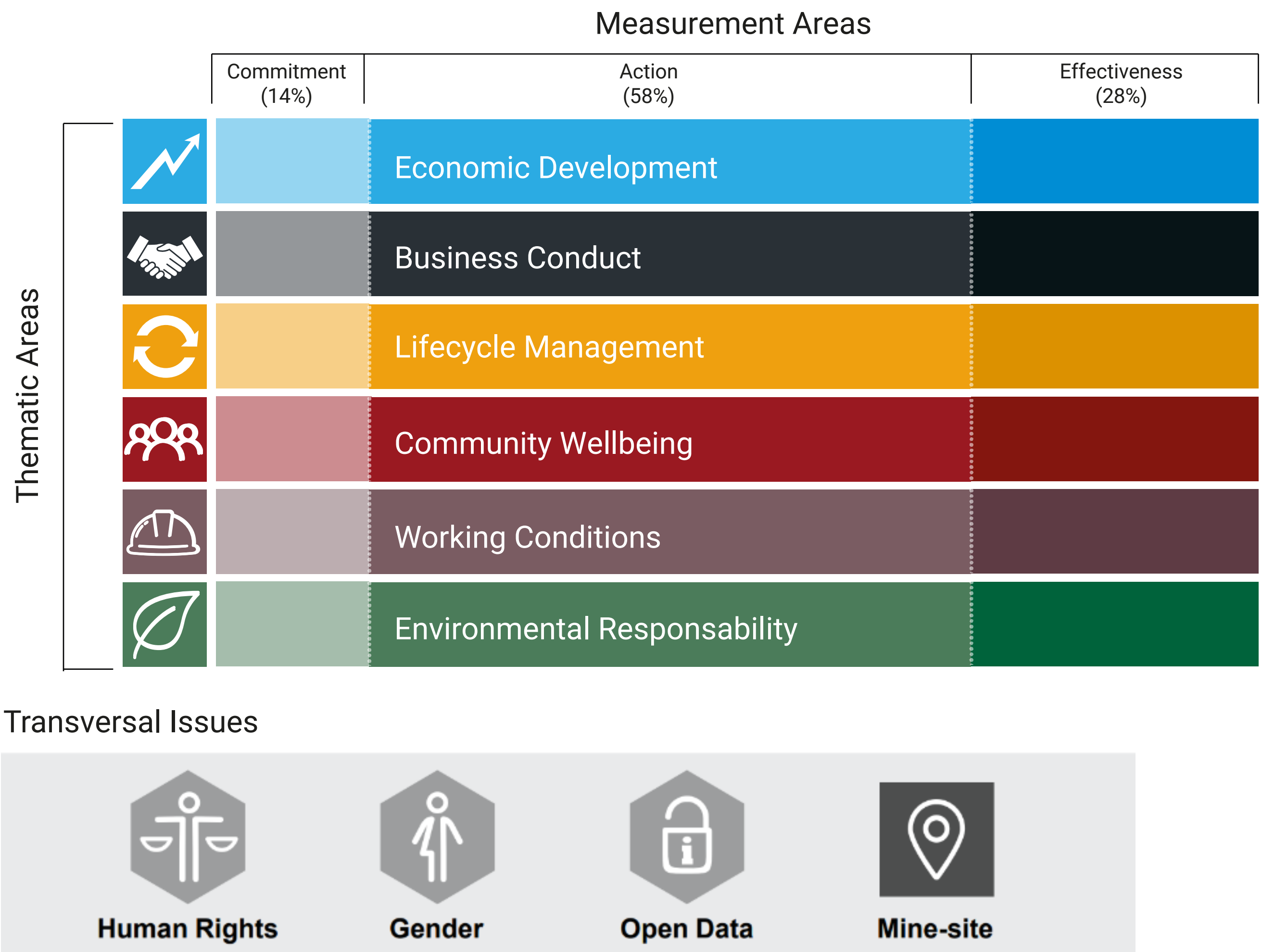
The Responsible Mining Index report offers a unique and detailed overview of environmental, social and governance-related aspects and mining as it provides a mine-site assessment to monitor site-level actions including "local employment, local procurement, post-closure viability of communities, community grievances, worker grievances, air quality, water quality, water quantity, tailings management, and emergency preparedness" (Responsible Mining Foundation 2020).

Figure 6.8 shows the Responsible Mining Index Analytical Framework, and the transversal issues covered in its report. It can be seen that the Commitment, Action and Effectiveness indicators have weights of 14 per cent, 58 per cent and 28 per cent respectively.

134 https://www.encorenature.org/en.

135 See https://www.responsibleminingfoundation.org/.

Figure 6.8: The Responsible Mining Index Analytical Framework and Transversal Issues covered in the 2020 Responsible Mining Index Report



Source: Responsible Mining Foundation (2020)

In the 2022 Responsible Mining Index report, mine-site assessments were particularly concerning, with none scoring over 50 per cent, only 2 scoring over 30 per cent and 16 scoring 0 per cent. The conclusion of the 2022 Responsible Mining Index Report was: "The vast majority of the 250 assessed mine sites across 53 countries cannot demonstrate that they are informing and engaging with host communities and workers on basic risk factors such as environmental impacts, safety issues or grievances. Some 94 per cent of the mine sites score an average of less than 20 per cent on the fifteen basic environmental, social and governance issues assessed. At the same time, a few mine sites show better practices on some of these issues, proving 'it can be done'. It is at mine-site level that these issues matter most - for local stakeholders who risk exposure to harmful impacts, for investors who need to know about asset-level risks, for board members and senior executives to know if risks are being well managed (Hopkins and Kemp 2021). All companies are encouraged to move beyond consolidated reporting and aggregate figures to meet stakeholders' needs for relevant information and meaningful engagement" (Responsible Mining Foundation 2022, p. 6). We echo this recommendation in Chapter 8 of this IRP report.

Across the companies, the 2022 Responsible Mining Index Report showed some improvement in performance compared to the 2020 report, especially among the worst-performing companies. Grouping the companies into three tiers, tier 1 (the best performers) improved their performance on the Responsible Mining Index by 8 per cent, but tiers 2 and 3 improved their performance by 22 per cent and 41 per cent respectively. Progress is also confirmed by the Extractive Commodity Trading Report 2023, produced by the World Resources Forum, together with the Responsible Mining Foundation (World Resources Forum and Responsible Mining Foundation 2023). The Extractive Commodity Trading Report provided an assessment of the environmental, social and governance practices and due diligence mechanisms of 25 companies trading oil, gas, minerals or metals. While they identify progress, they find that overall the sector remains opaque, with no marked shift towards more responsible practices. For instance, very few companies monitor the efficiency of their due diligence procedures. Most of them only set expectations for their suppliers, with a lack of mechanisms for compliance assessment, supplier engagement and fixing potential non-compliance. Overall, due diligence is particularly weak on the mitigation of environmental risks along the supply chain, and only slightly stronger on illicit financial flows. The report finds no evidence from the few companies surveyed that disclosing financial data of public interest (such as taxes, annual turnover and type of purchases from governments) compromises business competitiveness. Most companies still consider this information confidential, creating a lack of accessible data to enhance green financing and the reduction of market development uncertainty.

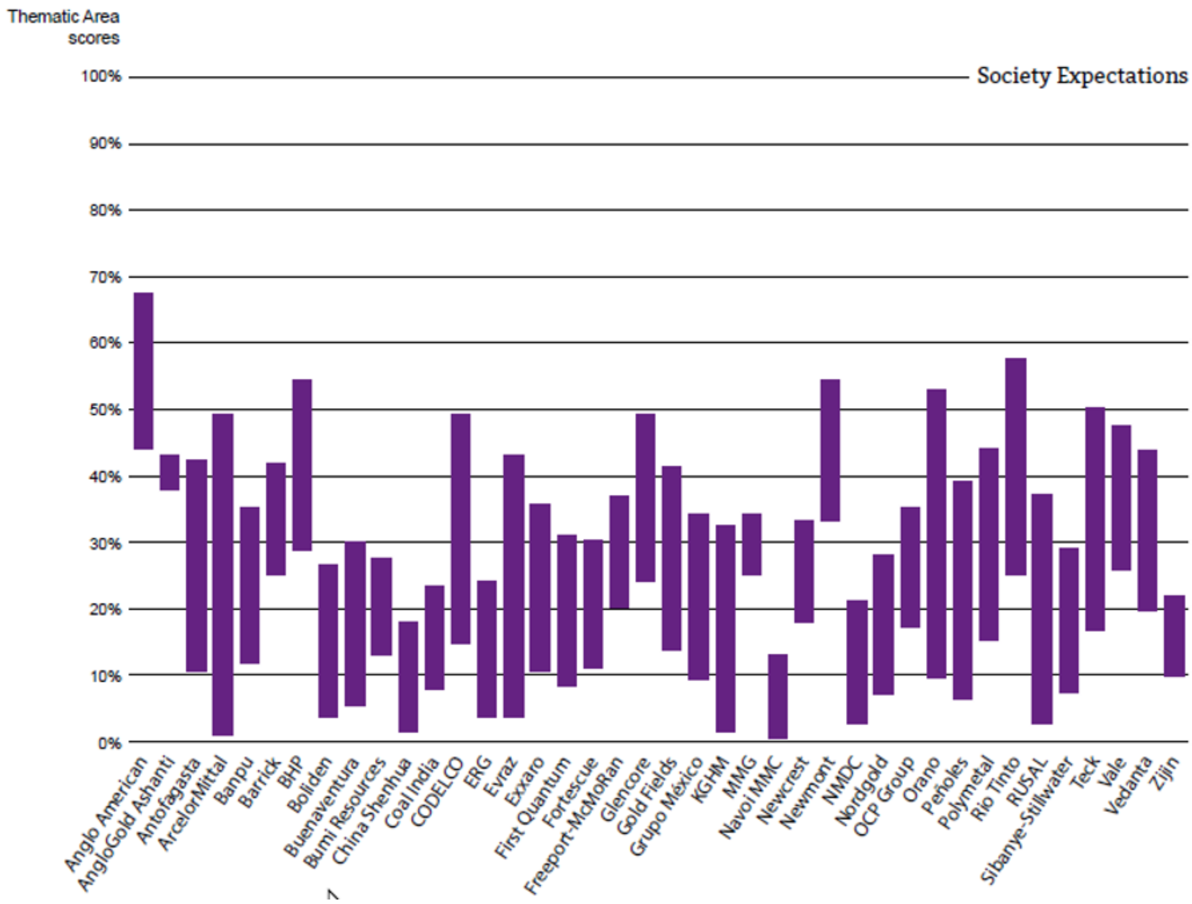
The point that it can be done is borne out by the best practices in the dataset. While the average scores of the six thematic areas in the Responsible Mining Index Report only once exceeds 30 per cent, the collective best score (*"an aggregate measure of the best results seen among all the companies across all the indicators in that area"*) in these areas, is always between 60 per cent and 80 per cent.

The 2022 Responsible Mining Index Report also shows that there is very considerable variation within companies between their scores in different thematic areas. Figure 6.9 shows this variation for the 40 companies in the report, with the bars showing the range of scores, the bottom of the bar showing the lowest score, and the top of the bar the highest. Anglo-American scores the highest in each thematic area and transversal issue except Working Conditions (its lowest score), where it comes second. The full scores for each company can be found in the Report.

For the purposes of this report, 'responsible mining' or 'mining with high-environmental, social and governance standards', a phrase that occurs in Chapter 8 with Recommendations, means a score of 80 per cent in the six thematic areas and four transversal issues of the Responsible Mining Index methodology illustrated in figure 6.8. No company yet achieves this, but the Responsible Mining Index Report indicates that it is certainly achievable. The individual indicators in each thematic area are set out on the website of the Responsible Mining Index. For example, in the thematic area Environmental Responsibility, the individual indicators cover environmental stewardship, tailings management, noise and vibration, biodiversity and ecosystem management, climate change and energy efficiency, and hazardous materials management (Responsible Mining Foundation 2022).

mykhailo pavlenko © Shutterstock

Figure 6.9: The highest and lowest scores for companies across the six thematic areas



Source: Responsible Mining Foundation (2022, p. 13).

6.1.5 Tools and standards for sustainable finance

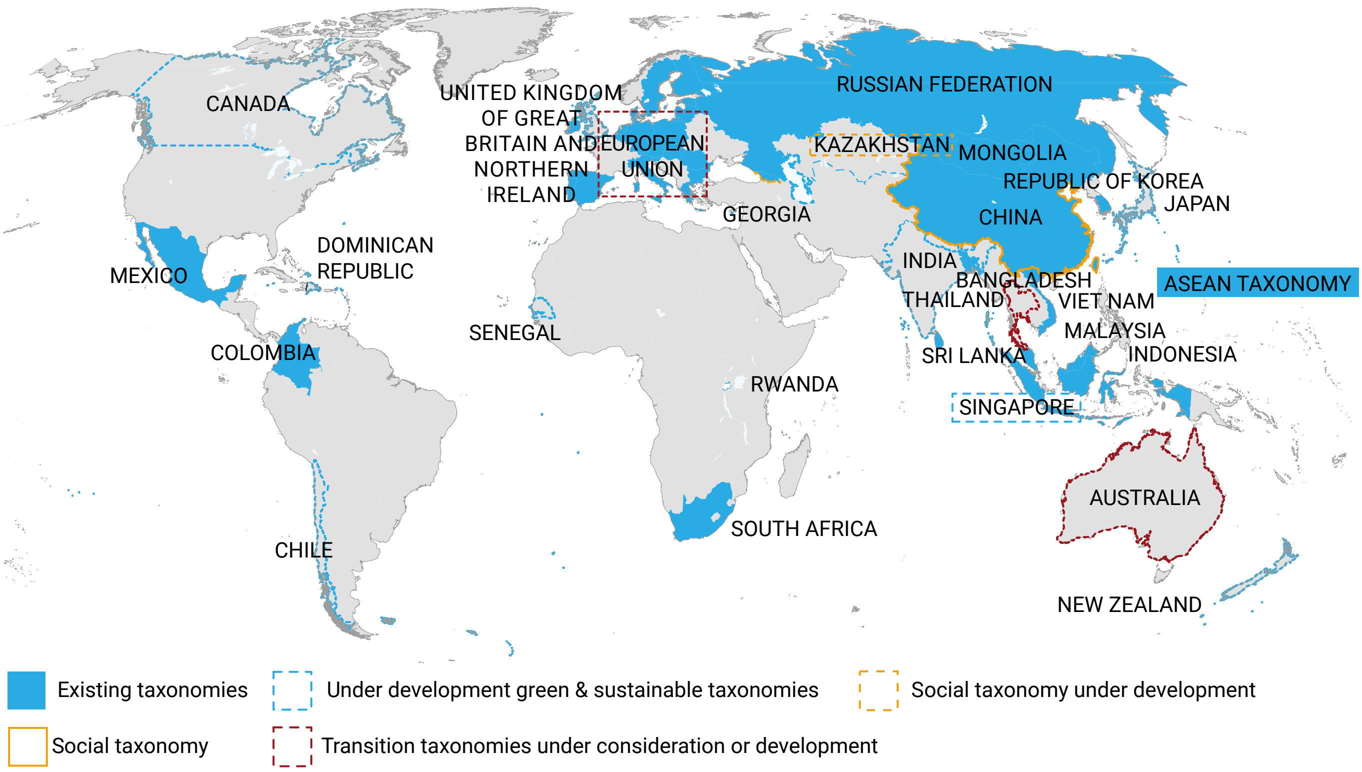
6.1.5.1 Sustainable finance taxonomies

Sustainable finance taxonomies have been developed by countries around the world to help to establish clarity for investors on what is sustainable under environmental, social and governance frameworks (figure 6.10). Mining activities are both highly controversial for their potential environmental impacts, and essential to providing the minerals needed to meet global climate objectives. This ambiguity contributed to making the inclusion of mining in some sustainable taxonomies challenging (see also Section 4.4).

Taxonomies act as classification tools as well as public policy instruments to push for further regulations and norms. In principle, the purpose of every taxonomy is to mitigate the risk of greenwashing when redirecting financial flows towards green activities by setting criteria for different categories. Enacted by governments, the development of taxonomies is obviously a political exercise, but is also intended to reflect scientific realities. At the international level, taxonomies can relate to purely "green" or "transition" activities. While "green" taxonomies are more popular, but static, transition and "brown" ones have higher dynamics and are aimed at including companies and assets that are making progress in reducing their environmental impacts. The European Union defines transition activities as those with no available low-carbon alternative; those that do not hamper the development and deployment of low-carbon alternatives; and those that do not lock-in carbon-intensive assets.[136]

On a practical level, the European Union is evaluating the implementation of a "traffic-light system", with red describing activities with very low potential to become compatible with the target of 2°C degrees and yellow referring to transitioning activities. This new proposal was developed as the binary (green/brown) distinction poses challenges for market operators.

Figure 6.10: The international landscape of taxonomies



Source: NATIXIS (2023).

136 The European Commission Sustainable Finance portal: https://ec.europa.eu/commission/presscorner/detail/it/qanda_19_6804.

The European Union taxonomy

The European Union taxonomy for sustainable activities is the most ambitious and advanced taxonomy to date. Its development started in March 2018, when the European Commission adopted the Action Plan on Financing Sustainable Growth. In June of the same year, the European Commission set up the Technical Expert Group on Sustainable Finance with the aim of working on four fronts: (i) the European Union classification system to determine whether economic activities are environmentally sustainable; (ii) the creation of a European Union green bond standard; (iii) the European Union climate benchmarks; and (iv) the improvements of corporate disclosure of climate-related information.

At the time of writing, the European Union is investigating possible extensions to avoid decreasing investment in the economic activities falling outside of the scope of the current taxonomy, as investors might wrongly perceive the absence of classification as a negative signal. This includes a range of activities needing finance to transition to higher performance levels, ranging from significantly harmful to low-environmental impact activities.[137]

The taxonomy is linked to the broader sustainable finance framework and related disclosure tools. The first tool to be released was the Non-Financial Reporting Directive (Directive 2014/95/EU of the European Parliament and of the Council of 22 October 2014 amending Directive 2013/34/EU as regards disclosure of non-financial and diversity information by certain large undertakings and groups, with supporting implementation guidelines published in 2018) (European Union 2014), the objective of which is to deliver a complete corporate risk assessment with qualitative and quantitative information. The Corporate Sustainability Reporting Directive (Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as regards corporate sustainability reporting), which came into force in January 2023, will effectively replace and extends the requirements of the Non-Financial Reporting Directive from 2024, asking all large companies, whether they are listed or not, to disclose how they manage social and environmental matters.[138] The Sustainable Finance Disclosure Regulation complements the Corporate Sustainability Reporting Directive, and has applied to financial sector companies since March 2021, with Technical Standards having been introduced in October 2022.

Along with the Corporate Sustainability Reporting Directive, the European Union is currently finalizing the Corporate Sustainability Due Diligence Directive (Directive (EU) 2024/1760 of the European Parliament and of the Council of 13 June 2024 on corporate sustainability due diligence and amending Directive (EU) 2019/1937 and Regulation (EU) 2023/2859), a comprehensive legislative framework to enforce corporate reporting and mitigate human rights and environmental impacts across companies' own operations, subsidiaries and the entire value chain. It will also require companies to adopt and communicate on a climate transition plan. Companies may be held liable and face financial penalties if damage occurs because of non-compliance. The directive is expected to provide consistency across different directives, including the outgoing Non-Financial Reporting Directive, the Corporate Sustainability Reporting Directive and the Sustainable Finance Disclosure Regulation, and to harmonize due diligence laws and operations of the European Union as a single market.

The European Union taxonomy covers roughly 40 per cent of listed companies in sectors that contribute to 80 per cent of direct greenhouse gas emissions. The disclosure obligations in the taxonomy apply to financial market participants offering financial products in the European Union. Large financial and non-financial companies that fall within the scope of the Non-Financial Reporting Directive (Corporate Sustainability Reporting Directive from the 2024 financial year, for reports published in 2025) are subject to the legal obligation to disclose whether their activities meet the European Union Taxonomy criteria, and must report according to the newly drafted European sustainability reporting standards (European Financial Reporting Advisory Group 2023). The same obligations are binding on financial market participants, such as asset managers. Furthermore, companies will need to disclose to what extent they plan to expand the financing of taxonomy-aligned activities or how they plan to upgrade activities not yet taxonomy-aligned.

137 The Extended Environmental Taxonomy: Final report on Taxonomy extension options supporting a sustainable transition: https://finance.ec.europa.eu/system/files/2022-03/220329-sustainable-finance-platform-finance-report-environmental-transition-taxonomy_en.pdf.

138 https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en.

Beyond the mandatory clauses, companies can use the European Union taxonomy for multiple voluntary purposes. The taxonomy can help to attract environmentally-conscious investors, improve corporate reputations and promote best practices. It also serves as a strategic instrument to update, revisit and alter plans and strategies. At the policy level, the taxonomy is instrumental for other regulations. Under the Taxonomy Regulation (Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088), the European Union and its member States are obliged to use the taxonomy as the basis for labels of financial products that fall under the Sustainable Finance Disclosure Regulation. This piece of regulation imposes disclosure requirements for "sustainable investment" products and for financial products that claim to be promoting social or environmental features.

In June 2023, the European Commission released new measures and proposals to strengthen the European Union Sustainable Finance Framework, including on the integrity of environmental, social and governance rating activities, to support companies and the finance sector and encourage the private funding of transition projects and technologies (European Commission 2023).

Beyond the European Union taxonomy

The proliferation of taxonomies across the world calls for a wide harmonization effort. Co-chaired by the European Union and China, the International Platform on Sustainable Finance encourages dialogues and when appropriate coordination on the development of shared methodologies and the harmonization of existing taxonomies. The Platform was set up in 2019 by the European Union, Argentina, Canada, Chile, China, India, Kenya and Morocco. Since then, Indonesia, Norway, Switzerland, the United Kingdom of Great Britain and Northern Ireland and New Zealand have also joined the Platform. Moreover, taxonomies are not just developed by sovereign states, but also by the private sector (Canada) (Robinson-Tillett 2019) and academia (Japan) (Milburn 2020), as well as by non-governmental institutions (Climate Bonds Initiative (Climate Bonds Initiative 2021) and the International Organization for Standardization).

Ensuring comparability across multiple taxonomies is urgent. The taxonomy of Singapore is based on the (International Standards Industrial Classification of all Economic Activities, while the European Union taxonomy uses the Nomenclature of Economic Activities. The Chinese, Mongolian, Malaysian, South African and Bangladeshi taxonomies do not have economic activities associated with industrial codes, making comparison harder. Taxonomies also differ depending on the market to which they refer. While some taxonomies use a project-based approach that might be more suitable for investments in interest-earning bonds (debt market) issued by corporations and governments, others have an activity- and entity-based classification that facilitates investment in shares of individual companies (equity markets). The Green Bond Endorsed Project Catalogue of China is a project-based taxonomy exclusively used for bond markets, while the European Union uses economic activities as classification units. Other taxonomies (e.g. the Mongolian taxonomy) are suitable for multiple financial instruments, including loans, bonds, equity investments or insurance. Finally, taxonomies can be used as tools for supervisory activities and to conduct sustainable investments (e.g. the Malaysian or Bangladeshi taxonomies).

The European Union taxonomy is an important step to ensuring the quality of 'sustainable finance' and an increase in flows of such finance. However, so far it has a clear focus on climate emissions and tackling biodiversity concerns, which are equally relevant to reducing climate-induced risks, albeit only to a limited extent.

In the European Union Sustainable Finance Disclosure Regulation, an economic activity is considered to significantly harm the protection and restoration of biodiversity and ecosystems, where that activity is significantly detrimental to the resilience of ecosystems, or detrimental to the conservation status of habitats and species. One of the indicators refers to the share of investments in investee companies with sites or operations locations in or near to biodiversity-sensitive areas where the activities of those investee companies negatively affect those areas. However, the technical screening criteria merely set minimum standards for environmental protection and restoration activities and for accommodation activities. As a result, while biodiversity-related concerns are covered by the taxonomy regime, the respective provisions need to be concretized.

This is also true for the forthcoming Corporate Sustainability Due Diligence Directive, which does not clearly specify what is meant by a company's environmental obligations. In addition, social indicators are not yet well developed in the Sustainable Finance Disclosure Regulation and the respective framework, meaning that companies' obligations are not always clearly specified.

It is therefore clear that the European Union and other countries are at the beginning of the journey towards enhancing and regulating responsible sustainable finance. In parallel to the United Nations Guiding Principles on Business and Human Rights, concrete guiding principles on business and the environment could help to bring about more holistic approaches (International Resource Panel [IRP] 2020). This approach could also be extended to the social obligations of businesses.

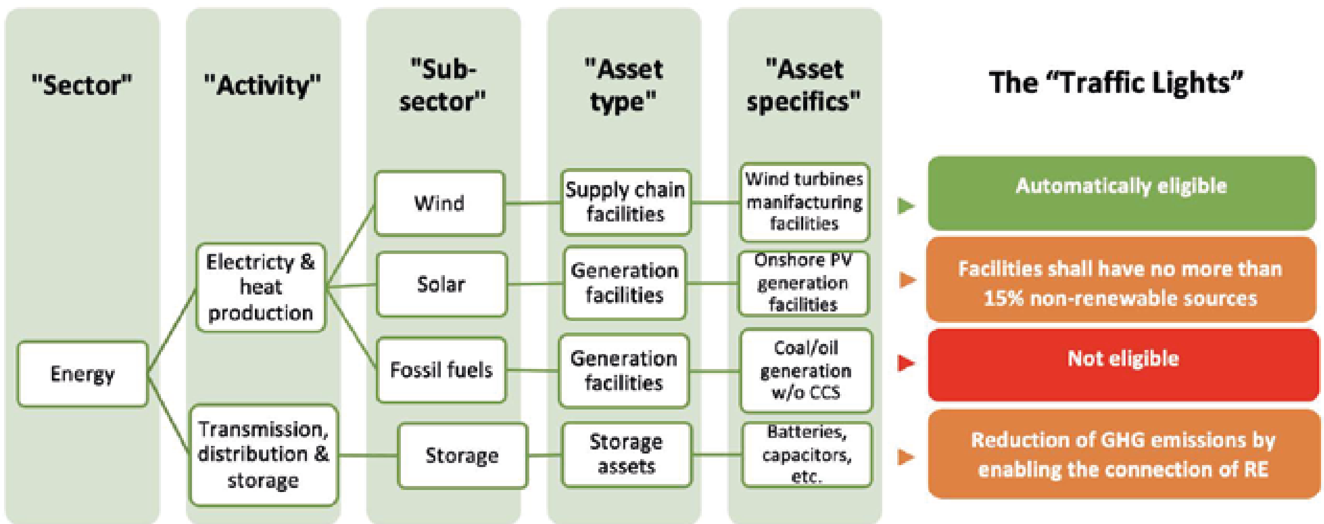
Market-based taxonomies

Market-led taxonomies can also serve as a sustainability financing mechanism. Released for the first time in 2013, the taxonomy of the Climate Bonds Initiative is the most widely and recognized tool providing comprehensive assessments and overview of green investment opportunities. The Climate Bonds Initiative Taxonomy constitutes the bulk of the Certification Scheme for Climate Bonds of the Climate Bonds Initiative, which covers US$150 billion in bond issuance. The Climate Bonds Initiative uses its proprietary classification to determine whether investments are suitable for inclusion in its green bonds list. There are different levels of granularity (figure 6.11) and a traffic-light system allows a more flexible configuration. Assets are attributed "green" if they are automatically eligible, "orange" if they meet some of the screening criteria and "red" when they are deemed ineligible.

The taxonomy is a detailed classification of over 160 assets. Industry-wise, its current scope is energy, transport, water, buildings, land use and marine resources, industry (including cement, steel, iron, aluminium, glass, chemical and fuel production), waste and information and communications technologies (ICT).

Beyond the Climate Bonds Initiative taxonomy, examples of market-led taxonomies include the upcoming Green Taxonomy of the International Organization for Standardization (ISO). As the worldwide federation of national standard bodies, ISO is developing an internationally applicable standard on "Environmental performance evaluation – green debt instruments", which will provide guidance, requirements and verification of green bonds. Strongly inspired by the European Union taxonomy, the ISO version is aimed at being applicable worldwide by recognizing contextual specificities.

Figure 6.11: The Climate Bonds Initiative taxonomy structure



Note: CCS: carbon capture and storage; RE: renewable energy; PV: photovoltaic

Source: Pfaff *et al.* (2021)

6.1.5.2 Sustainable taxonomies and mining

Mining has proved problematic for green taxonomies because the mining sector remains environmentally highly controversial, while at the same time having an essential role in providing minerals that are critical for low-carbon technologies and many other sectors. Mining is absolutely necessary to meet the global climate objective of limiting the temperature increase to well below 2°C, but it needs to do so in a way that has a much lower environmental impact.

These twin imperatives of mining are revealed by the history of their consideration in relation to the European Union taxonomy. In June 2019, the Technical Expert Group on Sustainable Finance set up by the European Commission to provide technical inputs on the screening criteria, published a Taxonomy Technical Report (European Union Technical Expert Group on Sustainable Finance 2019) that stated that "mining is an important sector both in terms of avoiding bottlenecks in the deployment of low-carbon technologies by providing the critical materials needed for low-carbon technologies, as well as the value chain link with energy-intensive manufacturing sectors". The Technical Expert Group recommends that the platform analyses the role played by the sector in terms of enhancing the availability of the critical materials needed for current and future technologies to create a climate neutral, circular and resource-efficient economy, while sourcing raw materials in a sustainable and responsible way, with a view to considering the 'greening' potential of the sector. In addition, minimizing the impacts of the extractive industry could make a significant contribution to climate change mitigation. The Technical Expert Group was not able to complete work for this sector owing to "time constraints and the complexity of the issues", and, possibly, political divergences. In the end, the mining sector was not included as a sustainable activity in the European Union taxonomy. Chile and Canada, in contrast, include mining in their taxonomies as "transitional activities". The potential for digital technology to contribute to the transparency of the sustainability and responsibility of mineral production is well illustrated by the use of blockchain in value chains (see box 6.2).

Box 6.2: New frontiers of financing for the mining and metals industry

Blockchain technology is redrawing the frontier of possibilities for many sectors. Blockchain is a permanent and cryptographically secure archive of records stored in a database consensually shared and synchronized across multiple sites (i.e. distributed ledger). Blockchain facilitates the exchange of critical documents in a secure fashion and improves transparency within an industry and across the whole value chain. The benefits of blockchain include digitalized contracts, faster transactions, compliance with legal standards and potential tracking of sustainability parameters.

In the field of sustainability, blockchain can detect if and to what extent companies are compliant with their pledges and the good practices they have signed. Blockchain can track the whole supply chain by storing and recording all the transactions along it, potentially storing these records as a 'product passport'. Initiatives in blockchain for mining are still few and at the very early stages. At the time of writing, the start-up Minerac is forming a consortium with financial institutions to improve supply chain management and mineral commodities trading and to boost sustainable practices.

kittirat roekburi © Shutterstock

6.1.5.3 Supporting sustainable finance: development banks

Multinational and development banks, as well as international institutions are pioneers in supporting sustainable finance programmes and mobilizing private and public funds. They support the improvement of measurement and valuation tools, data availability and analyses of development risk and opportunities on natural resources. This can help to establish de-risking mechanisms enabling the integration of sustainability considerations into policy, regulatory and corporate decision-making, as well as into financial markets to align financial flows with the sustainable development goals. The World Bank Global Program on Sustainability[139] promotes a data-informed decision-making process for countries capable of including natural capital, ecosystem services and sustainability considerations. The Global Program on Sustainability builds countries' capacity to improve natural capital accounting and measuring. This information is critical to shift investments, build awareness and promote biodiversity protection and economic growth opportunities.

The Sovereign ESG Data Portal[140] is the second of the currently operating initiatives under the flagship sustainable finance work programme of the World Bank. The portal is an investor-oriented data infrastructure that helps to detect and assess risks and opportunities associated with environmental, social and governance dimensions. It incorporates data relevant to all the Sustainable Development Goals, but organizes them by environmental, social and governance themes. To date, data on mineral resources populate the natural capital endowment and management indicator, under the Environment theme. Between 1995 and 2014, the World Bank estimated that out of 28 middle-income nations, 23 were highly dependent on natural (and non-renewable) capital (Lange *et al.* 2018). The Sovereign ESG Data Portal offers a new way of computing the wealth of countries and has the potential to redirect investments towards a new set of nations.

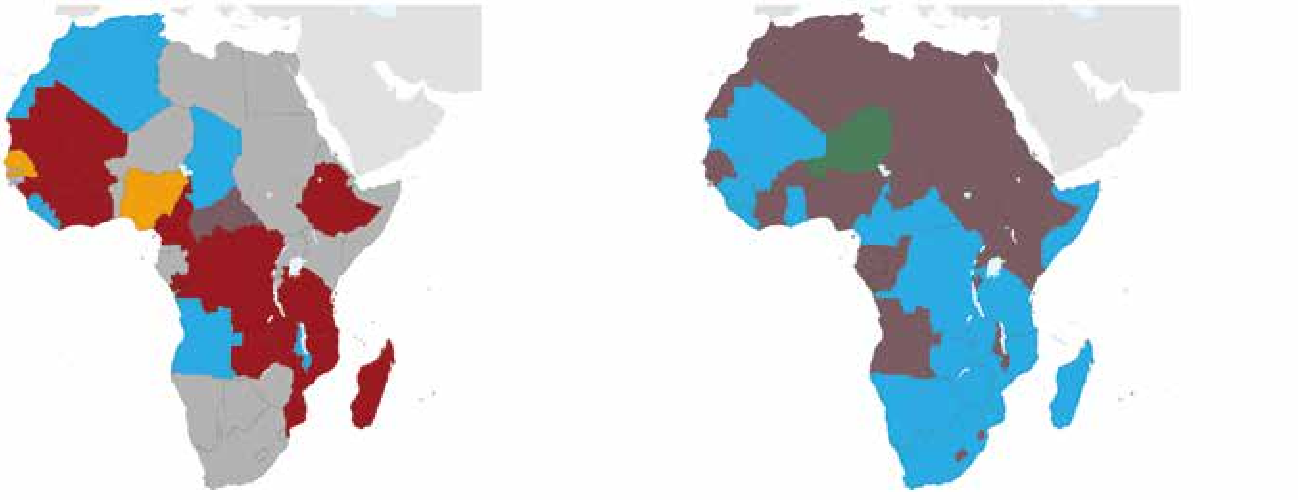
Box 6.3: A global initiative inspired by the Sustainable Development Goals: The Extractives Global Programmatic Support

In relation to mining and the sourcing industry, the World Bank launched the Extractives Global Programmatic Support. This is a multi-donor trust fund facility that helps resource-dependent developing countries to manage their oil, gas and mining resources to support policy goals and sustainable growth. The Extractives Global Programmatic Support works on four components. First, it strengthens transparency and accountability through the Extractive Industries Transparency Initiative. Second, it assists governments in sector reforms and resource governance by co-designing evidence-based decision-making processes with target countries. Here, the Extractives Global Programmatic Support makes use of specific tools, such as the Mining Sector Diagnostic Tool, and feeds a global knowledge open platform (an example in figure 6.12). Third, the Extractives Global Programmatic Support supports the development of resilient local economies by activating regional synergies and by promoting innovation. Finally, the Extractives Global Programmatic Support engages in boosting environmental protection and social inclusion in extractive industries' operations while supporting effective solutions to mitigate the sector's potentially adverse effects. This component targets both artisanal and small-scale mining communities and large-scale mining operations. The outcomes of this work include the creation of the Delve Platform (see Chapter 7), the first global database for artisanal and small-scale mining data, and the launch of two environment-focused initiatives: the Climate Smart Mining and Just Transition initiatives.

139 https://www.worldbank.org/en/programs/global-program-on-sustainability.

140 https://esgdata.worldbank.org/?lang=en

Figure 6.12: An example of outcomes of the Extractives Global Programmatic Support programme



Source: African Mining Legislation Atlas[141].

The Extractives Global Programmatic Support also responded to the coronavirus disease (COVID-19) crisis and identified two action areas: (i) understanding the economic impacts of reduced and halted mining operations for developing economies; and (ii) addressing the impacts of the COVID-19 crisis on local communities dependent on artisanal and small-scale mining.

6.1.5.4 Enabling sustainable finance: sustainability-labelled financial products

As the sources of finance for the Sustainable Development Goals differ from one another, so do financial instruments to raise or invest capital, as shown in figure 6.13. Instruments can normally be divided into cash-in instruments, with values that are directly determined by the markets, and derivative instruments, which are "secondary" investments deriving their value from the speculation of the future value of underlying assets.[142] They can also be divided according to their asset class: debt-based, such as a loan offered by an investor to the asset owner, or equity-based, representing ownership of a share of the asset. The choice of the instrument depends on a variety of factors, including the risk of the project, the risk appetite of investors and capital availability.


Thapana_Studio © Shutterstock

141 https://www.a-mla.org/en

142 See Financial Conduct Authority Handbook of rules and guidance: https://www.handbook.fca.org.uk/.

Figure 6.13: Financial instruments for Sustainable Development Goal finance

Example	Application and description	Special forms of instrument relevant to the SDGs
Loan	Used when a borrower requires a fixed amount of money, mostly from a commercial bank	Green loan, impact-linked loans (where the interest rate depends on the impact performance)
Credit	Used when the borrower requires a more flexible credit e.g. from a commercial bank	Green credit, social credit, impact-linked credit
Bond	Used often when the borrower (issuer of the bond) needs a large amount of money and can go to the bond-market to raise money from many investors. The bond has a fixed return to investors (coupon) and a usually fixed repayment date. The investors can often buy and sell these bonds again on the market without affecting the issuer of the bond	Green bonds, blue bonds, social impact bonds, Islamic bonds, diaspora bonds, transition bonds, impact-linked bonds
Equity	Often used to raise money for a company or project (e.g. through special purpose vehicles or SPVs), where investor(s) take ownership in the company/SPV. Equity usually does not have a fixed return nor a fixed repayment date. Equity can be tradable (e.g. company stock on stock markets), but also non-tradable (e.g. private equity)	Impact finance, crowdfunding
Funds	Used to pool assets (e.g. equity, bonds) to reduce risk of any single asset	Impact funds, crowdfunding, development funds
Crypto-based investment	Using digital currencies and contracts with the possibility to integrate a variety of fund-raising and fund-management functions	Integration of smart contracting (e.g. impact requirement) and covenants for the disbursement of funds and the repayment of investments

Source: Technical Report for Sustainable Development Goal Finance Taxonomy, China (China International Centre for Economic and Technical Exchanges and United Nations Development Programme 2020)

The main difference between instruments linked to the Sustainable Development Goals and their traditional application is the focus on the impact they produce and the type of activity they finance. Taxonomies are therefore useful to pick the most sustainable investments and to apply the most appropriate instrument to them. Beyond traditional markets, decentralized finance ecosystems are maturing and taking advantage of existing shocks on the financial intermediaries' markets (Yan *et al.* 2022).

The next part of the Chapter provides concrete details about financial products and how they can be used to direct sustainable finance towards the mining sector.

Curioso.Photography © Shutterstock

6.2 FINANCING SUSTAINABLE MINING PRACTICES

Large investments are needed to grow the supply of key minerals quickly and sustainably. Owing to the long lead times for large-scale mining and reduced investments in the past decade, gaps in supply are possible, especially for lithium, nickel, graphite, cobalt, neodymium and copper (Energy Transitions Commission 2023), and the resulting price volatility may hamper overall energy transitions. Despite the important environmental and social challenges associated with extractive activities, the production of transition minerals will result in much fewer cumulative life-cycle emissions than the current fossil fuel-based system (15–30 $GtCO_2e$ then fall to zero over time, compared with yearly ~40 $GtCO_2e$ emissions) (Energy Transitions Commission 2023).

Similarly to sustainable finance, sustainable mining does not have a unique, shared and unequivocal definition (Laurence 2011). While some view sustainability as the minimization of harmful impacts from the industry (Gorman and Dzombak 2018), others think that sustainability arises from a more systematic focus on the mining and metals industry in the areas of economy, environment, efficiency, community and safety (Laurence 2011). Environmental stewardship ensures that mining practices are compliant with environmental laws to safeguard water and land resources, control pollution and protect ecological values (Gorman and Dzombak 2018; Schoenberger 2016). The International Resource Panel (IRP) report on mineral governance proposed a protocol for the minimum necessary reporting of mining operations to assess their environmental impact (IRP 2020, p. 311). The social dimension is focused on the need for continuous approval of extractive operations from the local stakeholders that are affected by them. Economic considerations entail the assessment of mining profitability and productivity so as to create value that is shared by shareholders, employees, consumers and communities, as well as the creation of just opportunities for all (Pavan Kumar 2014). The multitude of existing initiatives and proposals for sustainable mining reflect and capture one or more of the sustainability domains to differing degrees. Issues of efficiency (i.e. effective resource management) and human and environmental safety are often given less emphasis in these initiatives (Gorman and Dzombak 2018). Sustainability assessments of different minerals need to take all these factors into account, while common and shared rules about good practices are critically important for the sourcing, processing and smelting processes relating to minerals that feed into multiple economic sectors.

Sustainable finance also needs to go hand in hand with curbing illicit financial flows. Sustainable finance regulations should not only ensure transparency, but also prohibit aggressive tax avoidance schemes (e.g. strategic transfer pricing (Brugger and Engebretsen 2022) and commodity mispricing (Musselli and Bürgi Bonanomi 2022)), enable simplified approaches to taxation in exporting countries, as well as facilitating approaches of unitary taxation across complex company structures, but in a development-friendly way.

6.2.1 Instruments for sustainable finance in mining

Funding to mining companies can be allocated through the financial sector through three general mechanisms.

Equity financing involves selling equity shares of the business through either public or private markets. Seasoned (or secondary) equity offerings offer additional shares in a business if the company is already listed in the public market. In private markets, private placements are the most popular tools used by junior companies to raise capital. Alternative financing options may be more appropriate for high-risk junior companies whose success is not guaranteed. There are two main alternative financing options:

- Royalty deals involve getting up-front lump sum payments in return for a small percentage of revenues or profits generated by future activities.
- Streaming deals involve getting a series of milestone-based payments in return for selling at a fixed price a portion of future production or by-product.

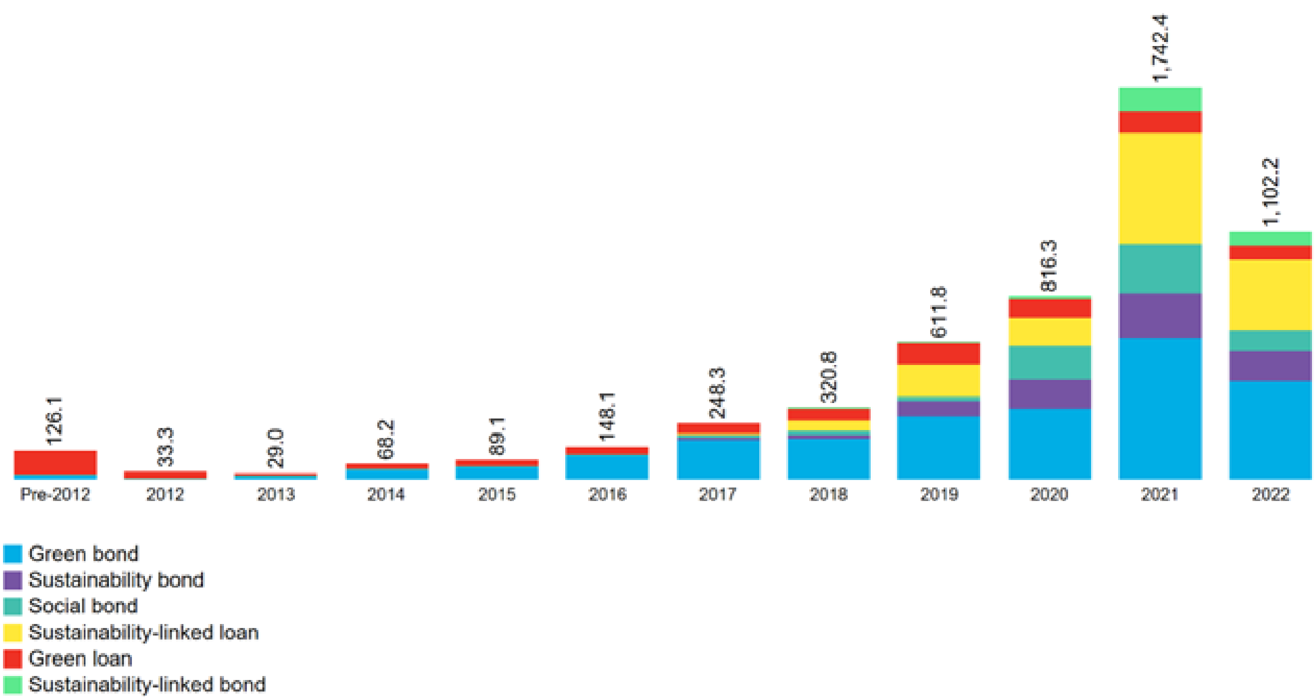
Debt financing is the most common instrument used for mines in production, with the mine usually used as collateral to obtain a loan and lower the risk for the lender. Loans can be of two types: recourse and non-recourse. In the event of a default on a loan, non-recourse loans only entitle the creditor to the collateral that was placed against the loan, while recourse loans allow the creditor to pursue other assets as well, if the collateral does not cover the loan.

Internal funds are financial resources generated by mines operating profitably (after tax) or by property sales.

All these instruments can be deployed under certain conditions to raise capital as sustainable finance. The sustainable debt market is generically defined as a fixed-income instrument with environmental, social and governance purposes. According to Bloomberg New Energy Finance, the 2021 global sustainable debt market reached a size of more than US$1.7 trillion (111 per cent more than in 2020), with green bonds and sustainability-linked loans as the preferred instruments for financing operations (respectively US$631 billion and US$495 billion). Cumulatively, by 2022 the issue of sustainable debt finance was close to US$5 trillion (figure 6.14).

Instruments for sustainable finance can be broadly categorized as activity-based and behaviour-based debt (table 6.2). The former includes green bonds, social bonds, sustainability bonds and green loans. The instrument is used to finance or refinance eligible activities. The latter ties a financial feature of the debt – for example, the coupon – to the achievement of a sustainability target. In contrast to activity-based debt, activities financed by behaviour-based debt are related more to internal environmental, social and governance targets than external sustainability outcomes; the activities performed are not required to be sustainability-focused.

Figure 6.14: The sustainable finance market (US$billion)



Source: Bloomberg New Energy Finance, Sustainable Finance Data, accessed 2022.

Table 6.2 : Different types of sustainable debt and their market shares between 1996 and June 2021

Debt type	Debt style	Purpose	Market size (billion dollars)	Proportion of sustainable debt (per cent)
Green bond	Activity-based	Environmental projects	1.458	45.7
Green loan	Activity-based	Environmental projects	550	17.3
Sustainability-linked loan	Behaviour-based	Institutional environmental, social and governance targets	532	16.7
Social bond	Activity-based	Social projects	343	10.8
Sustainability bond	Activity-based	Environmental and social projects	246	7.7
Sustainability-linked bond	Behaviour-based	Institutional environmental, social and governance targets	60	1.9

Source: Bloomberg New Energy Finance.

Transition bonds are debt instruments tailored for heavy polluters and high-emitting industries to raise alternative sources of sustainable capital. While green bonds are normally aimed at innovation and investment in green technologies by companies in 'green' sectors, transition bonds can provide companies in 'brown' sectors with funding to transition to the new technologies developed. Rather than offering pricing benefits to the issuers, they signal to investors their willingness to engage in a transition pathway and in (mostly) decarbonized operations. Transition bonds are particularly interesting to mining companies as they help companies to shift from high carbon dioxide to lower carbon dioxide activities while not being labelled as "green" or "sustainable". However, the use of transition bonds is highly controversial, as critics see it as a product lacking clarity for investors and potentially misleading them on the green credentials of transitioning companies. The International Capital Market Association published the Climate Transition Finance Handbook (International Capital Market Association 2023), which provides support in communicating to investors the intention to use these instruments. The Climate Bonds Initiatives provides up to date analyses of the green, social and sustainability markets, sustainability-linked bonds and transition bonds in its "Global state of the market" report.[143]

As the risk of greenwashing remains high, the developing regulations, taxonomies and environmental, social and governance standards presented earlier in this Chapter (Section 6.1.4. and 6.1.5.) are required to avoid the misuse of transition bonds to cover highly polluting activities.

6.2.2 Financial markets and environmental, social and governance requirements for large-scale mining

The different environmental, social and governance frameworks presented earlier target the core actors in the financial value chain: companies and investors, including shareholders. Reporting and disclosure bind both companies and investors, while shareholders exert extra power and can learn from climate-related disclosures about their investments' exposure to present and future risks. However, markets are different and so are their needs, requirements, interests and skills. Financial markets relevant to minerals can be categorized in three types: commodity, equity and bond markets. Commodity markets are important for metals and are normally regulated by authorities constituted on an ad hoc basis. Within equity markets, which trade shares of individual companies, investors do not normally invest in a single company per transaction, but rather purchase stocks in multiple companies. Bond markets (debt markets) are populated by the exchange of contracts with repayment schedules and interest rates. In equity and bond markets, investors finance mining companies directly, whereas in commodity markets, which are derivative markets, investors speculate as to the price volatility of a given commodity or products. Investors can be investment companies, hedge funds or producers of metals (the companies themselves). The price of internationally traded commodities set by commodity markets is used to benchmark the contract between mining companies and consumers of metals. The exchanges are not exclusively driven by market fundamentals: prices can change

143 See Sustainable Debt Global State of the Market, Climate Bonds Initiative (2022): www.climatebonds.net/resources/reports/global-state-market-report-2022.

depending on the short-term view of actors on these markets (speculation). As financial operators cannot directly engage with mining companies, but can influence commodity prices, investors do not have the power to influence their practices.

However, in 2019, the London Metal Exchange issued its responsible sourcing requirements in its function as exchange regulator[144]. Disclosures under these requirements are voluntary and they apply to internationally traded metal commodities: aluminium, nickel, cobalt, copper, lead, tin and zinc. The rationale behind the responsible sourcing requirements derives from: (i) the ethical responsibility of the industry; (ii) the commercial imperative to guarantee that the price somehow reflects the value of responsibly sourced metals; and (iii) the request of stakeholders to engage in responsible practices. The London Metal Exchange requirements are structured on the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas and stress the need for transparency along the value chain. The London Metal Exchange requirements do not discriminate between large-scale and artisanal and small-scale mining. On the contrary, they recognize that despite carrying different risks, all are equally important. The requirements are therefore provided for both sourcing approaches.

In the stock markets, investors hold shares of companies they are interested in buying. Environmental, social and governance performance and high environmental, social and governance ratings help mining companies to attract the capital they need for exploration and mine development activities (EY 2022, EY 2024). Companies demonstrating strong financial and non-financial performance will be rewarded in periods of tight capital availability. Non-financial performance can be strongly influenced by the action of shareholders who can provide scrutiny of their investments. The attention of investors to environmental, social and governance issues was enhanced after the Córrego do Feijão tailings dam failure, which occurred at Brumadinho, Brazil in 2019, killing 270 people and devastating the local environment. This catastrophe, involving one of the largest global mining companies, attracted huge international media coverage and had a negative impact on the public perception of the minerals and metals industry, further fuelling distrust and opposition to minerals and metals production projects. Some important constituents of the finance industry also strongly reacted to the event, which triggered The Investor Mining and Tailings Initiative. The Initiative, led by the Church of England Pensions Board and the Swedish Council on Ethics, includes more than 100 investors with US$20 trillion assets under management (Hopkins and Kemp 2021). The Initiative tackles safety matters rather than environmental concerns. The Initiative is an example of the role of finance in driving change: investors requested a tailing information disclosure that eventually reached 726 publicly listed extraction companies, leading to risk-related data disclosure on 1,743 tailings storage sites (Franks *et al.* 2021; Diehl 2021). The results of the disclosure process revealed some important shortcomings in the way tailings dams are built and their exposure to frequent risks. This Initiative led to the launch, in January 2023, of the Global Investor Commission on Mining 2030[145] to broaden the Investor Mining and Tailings Initiative in scope and membership.

Close scrutiny can also take place in the bond market, where there has been significant growth for the mining sector both in numbers and in transaction values (figure 6.15). Metals and mining (included as "Materials" in figure 6.15 (right-hand side)) registered a record number of transactions (33) in 2021 reaching US$14.9 billion in line with the increasing relevance of the sector. As "Materials" acquire new interest for investors, principles and tools help them to discriminate between sustainable and unsustainable practices. There are four sets of principles relevant to mining companies: the first three were developed by the Loan Market Association, while the last one is industry-led and industry-specific.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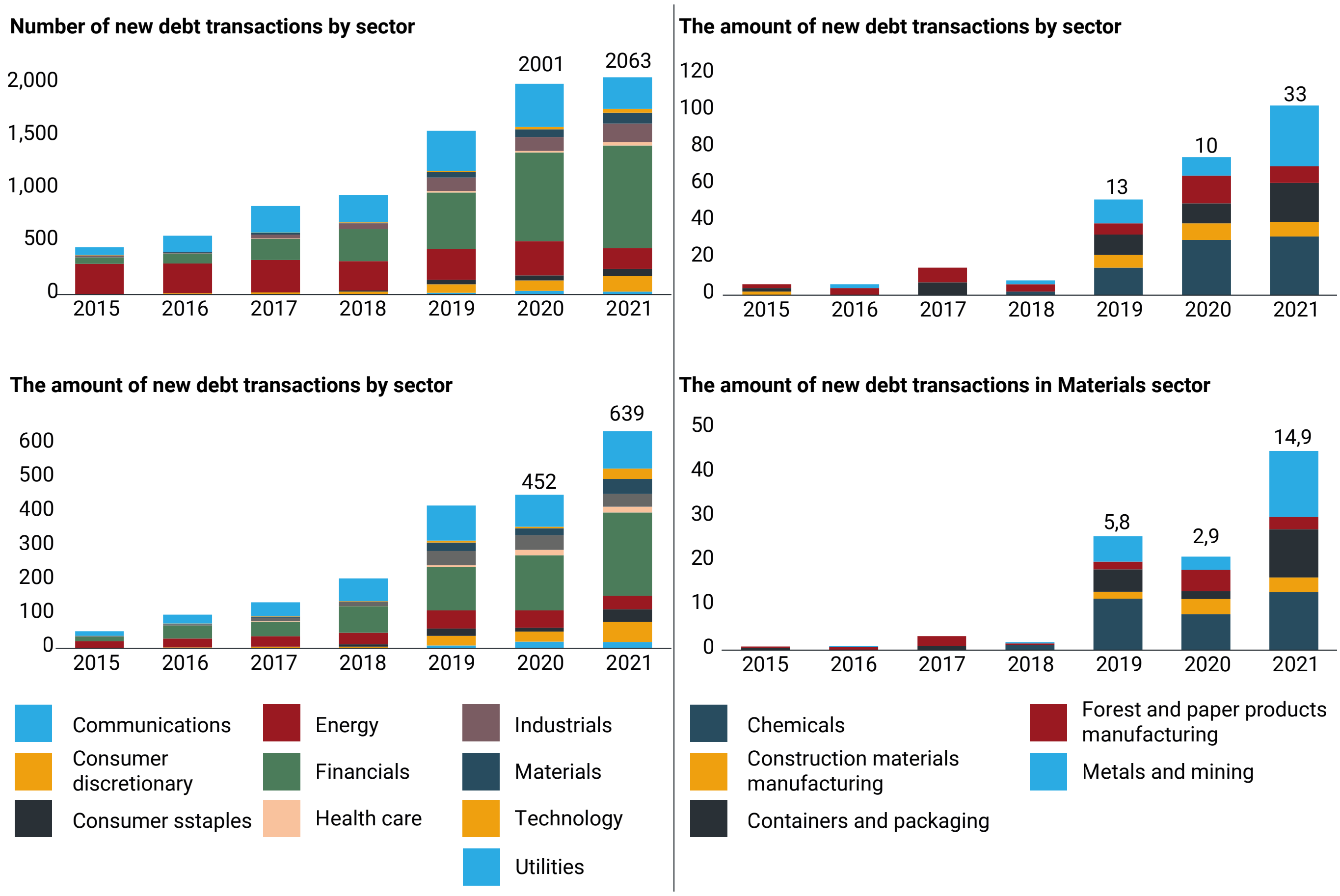
144 https://www.lme.com/en/Sustainability-and-Physical-Markets/Sustainability/Responsible-sourcing
145 https://mining2030.org/.

Figure 6.15: The growth of bond markets for mining



Source: Fedorov (2021), adapted from Bloomberg New Energy Finance data.

6.2.2.1 The Green Loan Principles and Social Loan Principles

The green loan market is aimed at facilitating the development of environmentally sustainable economic activities. The Green Loan Principles were designed to promote the integrity and diffusion of green loan products. They are a set of voluntary recommended guidelines applied by market operators on a deal-by-deal basis depending on transaction-specific characteristics. They clarify how and why loans can be labelled as "green". Four criteria apply:

- **Use of proceeds**: the loans must specifically address green projects that generate environmental benefits.
- **Process for project evaluation**: the borrower is called to clarify to the lender the criteria and the methods used to label the project "green".
- **Management of proceeds**: to guarantee transparency, the proceeds of loans should be credited to a dedicated account.
- **Reporting**: achieved impacts should be noted and recorded. Public disclosure can support effectiveness in outcomes.

The Social Loan Principles mirror the Green Loan Principles and share with them the four criteria. However, the focus is different since the Social Loan Principles target projects that enhance social value or are aimed at specific social issues.

6.2.2.2 Sustainability-Linked Loan Principles

The Sustainability-Linked Loan Principles try to encourage good practices from borrowers by linking the pricing of a loan to the achievement of a particular sustainability target (Sustainability Performance Target). These Targets can be included in the loan agreement. As for the Green Loan Principles, four criteria apply:

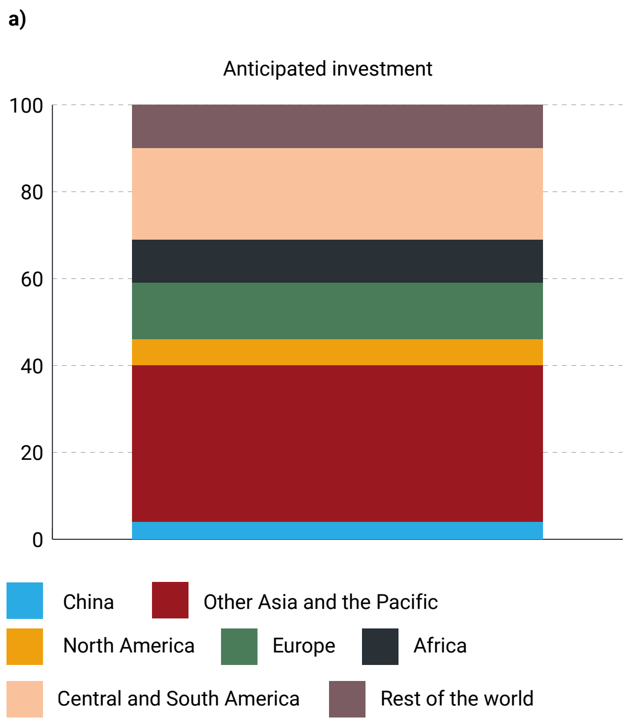
- **Relationship to borrower's overall corporate social responsibility strategy**: the lender should be informed about the sustainability strategy of the borrower.
- **Target setting – measuring sustainability**: the Sustainability Performance Target should be ambitious in relation to the borrower's business and third parties may be consulted for technical opinions.
- **Reporting**: records on the Sustainability Performance Targets should be kept and disclosed to lenders and the public
- **Review**: in the case of publicly traded companies, lenders can rely on the public disclosures of the borrowers. Otherwise, borrowers can be required to seek independent and external review.

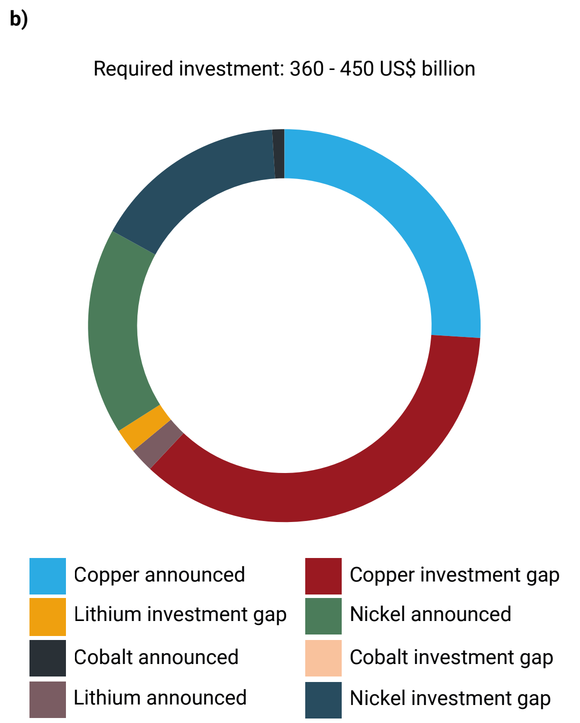
To meet the target of a transition compatible with the Paris Agreement, very large investments are required across all stages of the mineral supply chain: from exploration to mine closure and reclamation. This section explores these issues from the perspective of large-scale mining. Artisanal and small-scale mining is the subject of Chapter 7.

The estimation of required cumulative investments poses challenges owing to uncertainties in forecasting future mineral demand and associated costs. Technology development pathways and policy shape future projections (Morgan Stanley 2021). Mineral-specific factors and country contexts also influence estimates. Market and academic research often use different years of reference, which creates hurdles to comparing and cross-checking forecasts.

Figure 6.16 shows the estimates of the International Energy Agency in its Net Zero Emissions scenario of anticipated against required investment to meet the 1.5°C temperature target. It can be seen that there is a considerable investment gap for some of the most important metals. For copper, lithium and nickel, announced investment will have to be doubled if adequate supplies of these metals are to be available when required for the clean-energy transition.

Figure 6.16: (a) Anticipated investment in mining of energy transition minerals by region or country and (b) required investment over 2022 - 2030 under the Net Zero Emission scenarios of the International Energy Agency





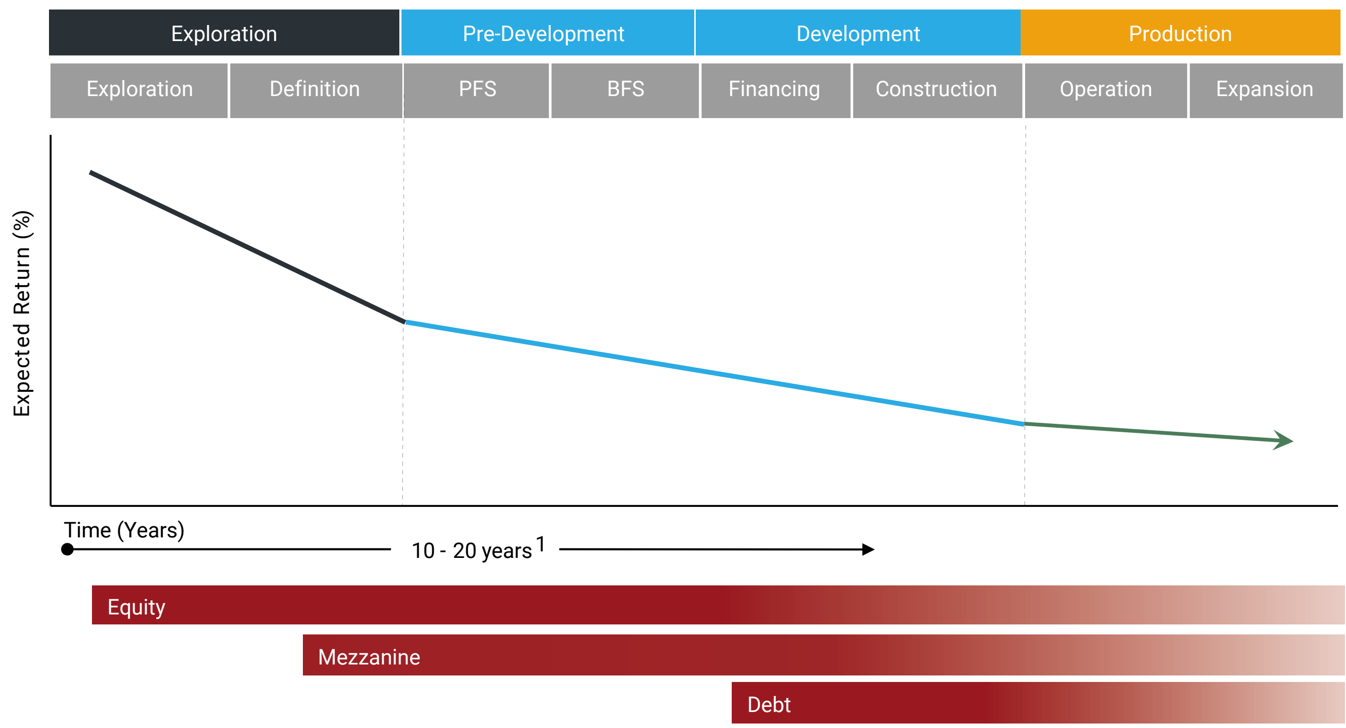
Source: International Energy Agency (2023a).

6.2.3 The need for patient capital

It has been seen that mining, and in particular opening new mines, is a lengthy, as well as costly, process. The International Energy Agency estimates that the time taken from exploration, through discovery, to production is an average 17 years (International Energy Agency 2021) (p. 122). As a result, while investments in greenfield mining projects are necessary and should be financed immediately, they are not sufficient to meet near- and medium-term demand for transition minerals, which will also need to be met through the expansion of existing mines. This will require patient (long-term) capital, and confidence in growing demand, to see through the long waiting times and heavy upfront costs.

Patient capital includes private and public actors, but also international financiers such as the International Finance Corporation. As a lending institution, the International Finance Corporation uses different investment types (figure 6.17): loans (including project and corporate finance or on-lending through intermediaries), equity (up to 20 per cent of a company's equity), syndications (capital mobilization to serve development needs) and risk management services to hedge clients' exposure. The International Finance Corporation combines capital with industry expertise, but also leverages its supranational role to de-risk some investments considered too uncertain for private actors. As an investor, the International Finance Corporation has a long-term equity view (average a 6–8 year holding period) and a longer debt attitude (up to 15-year maturity).

Figure 6.17: The International Finance Corporation investment types span across different stages of the mining supply chain



1 Indicative time range depending on project size, quality, location and sponsor.

Source: International Finance Corporation (2017).

The International Finance Corporation uses a comprehensive risk assessment of projects considered for financing. The due diligence phase includes the assessment of business, environmental, social and economic risks and opportunities. Mining projects are assessed against the Equator Principles and internal sustainability standards, also inspiring the Climate-Smart Mining Initiative (World Bank 2019). Environmental and social project-related information is disclosed to the public and open to comments while the conditions of disbursement, covenants and monitoring requirements are agreed with the client.

As of July 2023, the committed portfolio of the International Finance Corporation in mining was US$835 million, 45 per cent of which is invested in copper. The International Finance Corporation is the largest multilateral source of debt and equity financing for the private sector in emerging and developing countries. In June 2022, Anglo-American received a US$100 million sustainability-linked loan to support rural communities close to mining operations in South Africa (International Finance Corporation 2022a).

Among patient and solid capital providers, governments play a crucial role. Domestic critical minerals strategies typically offer incentives and capital to support the development of the mining sector at home. The Canadian Critical Minerals Strategy provides Can$ 3.8 billion (US$ 2.8 billion) over eight years to invest in adequate infrastructure and exploration tax credits. The United States Inflation Reduction Act, in contrast, contains incentives for electric vehicle manufacturers to source battery metals within the United States of America. In 2021, the Government of Australia established a Critical Minerals Strategy worth $A 2 billion to support projects involved in the extraction and processing of minerals via preferred terms loans. Financing is also a powerful option to secure mineral supply when domestic mineral resources are scarce. For example, the Japan Bank for International Cooperation has separate financing guarantees for mineral resource development projects in the development and production stages. In France, the Government has committed €500 million to foster domestic industry resilience to disruptions along the supply chain. Part of that policy works as a dedicated investment fund that protects French companies from disturbances at the global level (French government, 2022).

6.2.4 Financial instruments along the mine life cycle

The financial mechanisms and instruments outlined in the previous section need to be deployed in different ways at different parts of the value chain.

Geological survey

Geological surveys and geological information can be considered public goods as they inform decision-making processes through the transformation of raw data into knowledge (Bernknopf and Shapiro 2015). Updated geological surveys and improved international data-sharing can alleviate past under-investment and long project development lead times, and help to expand the existing supply (Energy Transitions Commission 2023). The collection, processing and dissemination of data involve costs (both in terms of equipment and specialized personnel): financing these activities is crucial to supporting the mining capacity and economic prosperity of resource-rich countries, as well as the involvement of resource-scarce nations in the procurement of critical material. As noted in Chapter 5, the main source of funds for geological surveys is public finance.

Exploration

Financing options for this stage typically involve the use of equity financing through stock exchanges, which traditionally involve two financing routes:

- Listing of a public company via an initial public offering: the company's owners prepare a prospectus and outline its ambitions. Existing drilling samples (when available) are used to generate demand for the shares. As at this stage of the mining process, most companies do not own any revenue-generating assets; most stock exchanges are uninterested in listing them. The most popular markets and mechanisms are:
    - Toronto Stock Exchange and Venture Exchange, which list 42 per cent of total existing globally listed mining companies. The Toronto Stock Exchange and Venture Exchange listed companies have made over 6,700 financing deals in the previous five years (as of 2023), raising $44 billion. The Toronto Stock Exchange is focused on senior issuers and the Venture Exchange on junior companies in need of growth capital. Its success

with exploration companies is mostly owing to the presence of minimal listing requirements: companies are required to have working capital to meet a minimum 12 months of operating expenses, but no tangible asset is required.

- Alternative Investment Market in London
- Australian Securities Exchange

- Reverse takeover: this is still a public market route, but involves the take-over of an already existing company with no operating assets. The reverse takeover is an agile system that avoids incurring listing costs. A programme to facilitate this process is the Capital Pool Company Program of the Toronto Stock Exchange, which "enables seasoned directors and officers to form a Capital Pool Company with no assets other than cash and no commercial operations, list it on TSX Venture Exchange, and raise a pool of capital" (Toronto Stock Exchange 2022).

Please refer to Chapter 5 for further details on the Toronto Stock Exchange and the Australian Securities Exchange.

Evaluation

Following exploration, any discovery needs to be evaluated in detail, which also requires financing through:

- Royalty agreements: the evaluating company receives money up-front from an investor, who gets a guarantee of a percentage of revenues over the life of the mine.
- Earn-in ventures (quite unique to the mining sector, especially for gold): an agreement between a more cash-rich company and the exploration project. The cash-rich entity has the option to acquire a certain percentage of any mining venture based on funding milestones. The larger the investment of the earn-in partner in the evaluation of the ore body, the larger the percentage of ownership.
- Joint ventures: a business arrangement between companies with complementary strengths and resources. In mining, this is often between junior and senior companies, but joint ventures can also be the association of several junior companies or of State-owned and private companies.
- Streaming transactions: they have similarities with royalty agreements in that mining companies receive a cash up-front payment for future production. Streaming deals are normally focused on specific commodities in a project, such as a metal by-product. The streaming partner will receive a physical share of the future production at a discounted price, rather than a share of the revenue.

Production

Once the mine has been built, the company produces profitably and reaches greater exposure to investors. Mining companies can make use of traditional equity and debt financing options or alternative and hybrid financing options providing better terms. For instance, streaming transactions involve both upfront and follow-up payments and are a cheaper option than equity and a safer one than debt. Debt financing usually involves project facility loans. These are agreements between a lending institution (i.e. a bank) and a mining company set up as non-recourse loans. In addition, internal funds, which include all cash flow generated by the business itself, can be used to expand production, increase efficiency, repay existing debts or diversify portfolios.

Mine closure

Once operations have been completed, the industry has a responsibility to leave a legacy that is socially acceptable and environmentally sound. This stage of mine closure needs to be planned from the very early stages of the project if it is to be implemented efficiently and without controversy. According to the International Council on Mining and Metals, mine closure entails "actions planned for and implemented when a mine ceases operations or a portion of a mine (or mine facility) is permanently removed from use for mining purposes, including rehabilitation or reclamation, remediation, decommissioning, demolition and/or dismantling" (International Council on Mining and Metals 2019).

Mine closure operations must be considered at the beginning of the project using a life-of-asset cost estimate. Such estimates are produced internally by the company and include the total cost of implementing closure. These estimates are usually essential to gain approval from regulators and stakeholders (European Union 2021).

Mine closure operations must be disclosed publicly using the financial liability cost estimate (Peck and Sinding 2009). This represents the net present value estimation of how much a company would pay to settle its obligation (liability). For internal planning purposes, companies also produce sudden closure cost estimates, which evaluate potential business risks to unforeseen changes of circumstances.

To fund mine closure operations, six financial assurance mechanisms can be used (Worden 2020). Financial assurance allows governments to ensure that when a mine is closed, the land is returned to its original state, or with as little damage as possible. Companies can:

- Set aside a cash deposit into a government-managed and controlled account.
- Pay an insurance policy that covers costs over the course of the life of the asset.
- Issue a surety bond, such as a reclamation bond, in which a third party guarantees the respect of an obligation.
- Contribute to a trust fund in case the obligation is not met.
- Merge resources with other companies and issue a bond pool.

As mine closures have multiple socioeconomic and environmental consequences, jurisdictions need to provide clear-cut guidelines and set up mechanisms to enforce compliance and ensure that closure plans are completed even in the case of abandonment or bankruptcy (Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development 2021). A comparison between multiple international mine reclamation bond systems reveals that the United States of America, Canada and Australia have established reclamation bond programmes. China does not have a national system in place, but since 2013, each province has been responsible for its own reclamation bond mechanisms (Cheng and Skousen 2017). While this was true for coal mining, the establishment of effective systems capable of expanding the bond types in use is now more urgent than ever.

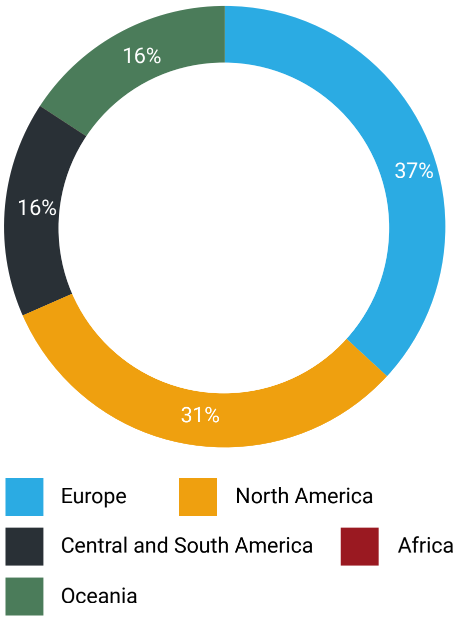
6.2.5 Global survey of large-scale mining companies

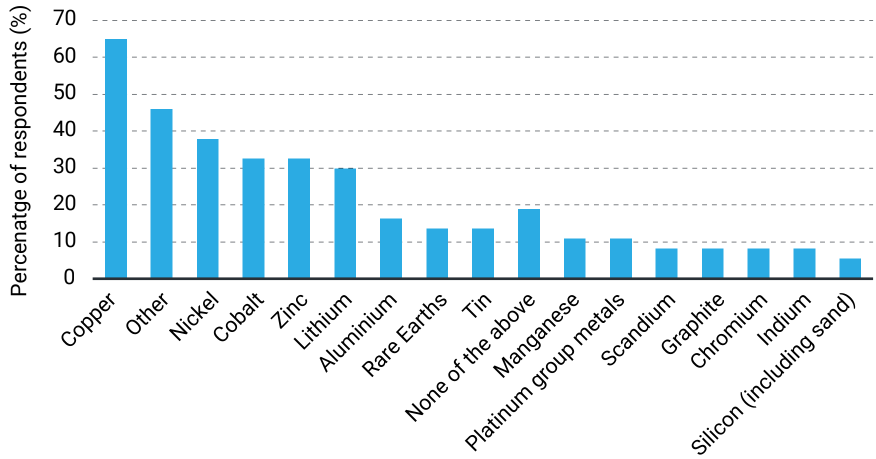
The push towards a more sustainable mining industry is largely driven by investors and international environmental, social and governance regulations. Mining companies are expected to assess their risks and quantify and reduce their socioenvironmental footprints to avoid incurring unexpected losses. Many of them have made a start on addressing these issues. The question then arises as to what the costs of improving environmental, social and governance performance across the mining value chain will be, and whether such performance will command a ‘green premium’ in minerals and metals markets.

A survey was undertaken to collect industry-relevant information on how environmental, social and governance issues affect the relationship between mining companies and their finance providers and learn about the environmental, social and governance risks and opportunities affecting mining companies. The survey was distributed anonymously using a snowball sampling technique and it was left open for 50 days between November and December 2022. Out of 52 responses, more than half (54 per cent) were from producing companies with revenues of more than US$50 million, followed by exploration companies (15 per cent), consulting companies (13 per cent), contractors (10 per cent) and producer companies with revenues of less than US$50 million (8 per cent).

The survey results must be interpreted in light of the fact that a large majority of the respondents are from Europe and North America, with no respondents from China. The survey was designed in English. Figure 6.18 (left panel) shows the geographic distribution of the companies that responded, according to the location of the firms’ headquarters. Europe ranks first (35 per cent, 18), followed by North America (33 per cent, 17), and Australia and Oceania (18 per cent, 9), Central and South America (12 per cent, 6) and Africa (2 per cent, 1). The right panel in figure 6.18 shows the wide range of critical minerals produced by these companies, with copper ranked first (64 per cent of respondents, 32 responses), followed by other metals (mostly gold, iron and coal for 48 per cent, 24), and, among others, nickel (38 per cent, 19), cobalt (34 per cent, 17), lithium (32 per cent, 16) and zinc (32 per cent, 16).

Figure 6.18: Geographical distribution of respondents per firms' headquarters location and the critical minerals they produce





Source: Survey by authors.

Survey respondents identified the environmental, social and governance factors they deemed most critical for their business and ranked them in order of impact. Among the top-cited, the social factors (i.e. local community impact and social licence to operate) were ranked most highly, followed by environmental factors: decarbonization, water management and net-zero strategy being the top three. From a governance perspective, corruption and bribery is cited as the main limiting factor in environmental, social and governance matters twice (8 per cent). Environmental, social and governance issues are recognized by these companies as a key driver of change, but, in line with the Responsible Mining Index Report cited above, they mainly report their environmental, social and governance risks at the corporate level (26 responses) rather than at the operational, site level (20 responses), showing there is wide room for improvement in collecting, storing and processing data at the site level. Reported environmental, social and governance information mostly consists of corporate-level quantitative data (22 responses) and qualitative assessments mostly using benchmarks (14 responses). However, when asked about actual measurements, 20 companies responded that they assess their environmental, social and governance performance at the operational, site level, and then aggregate them to create corporate metrics.

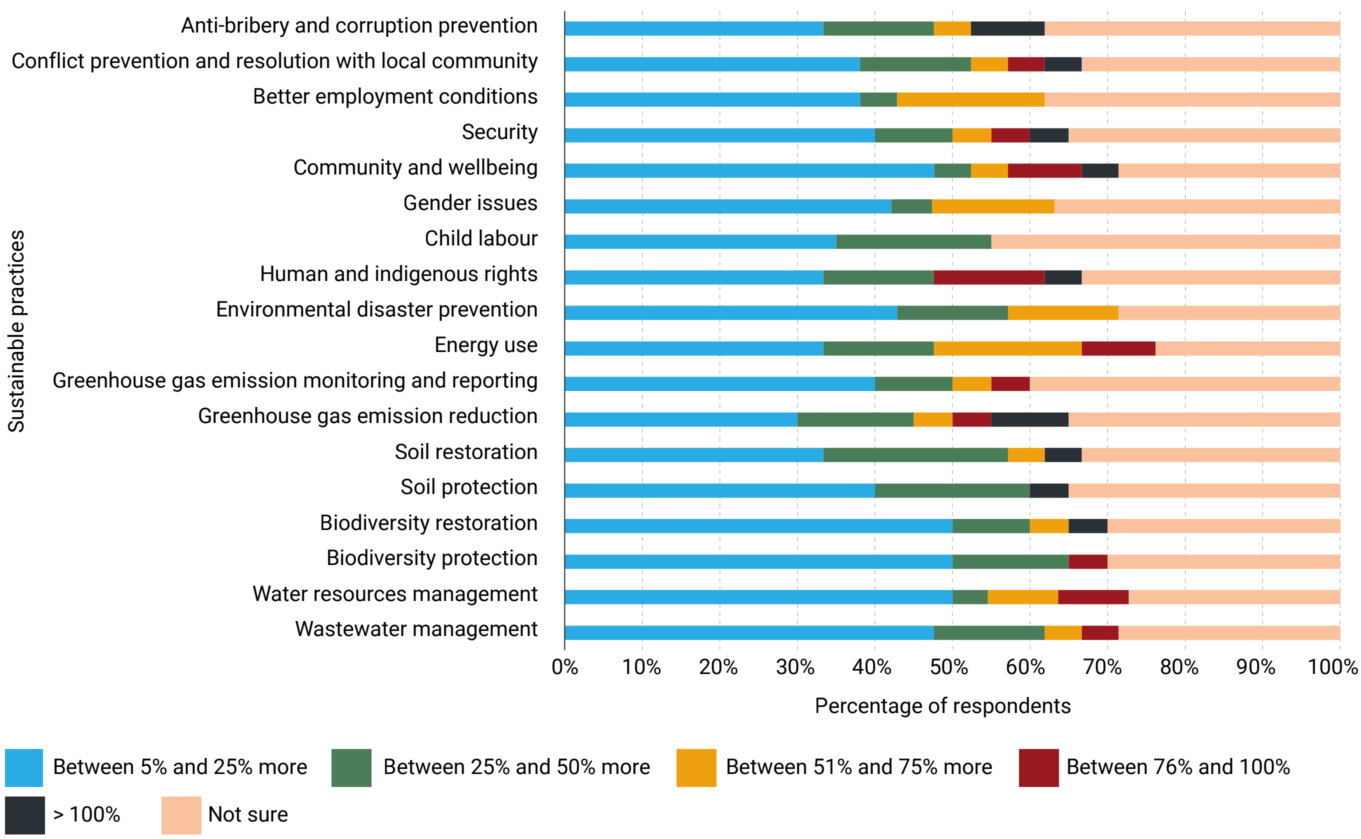
Out of 52 participants, 28 respondents to the global survey for large-scale mining addressed the issue of mine closure operations. Respondents were allowed to select multiple options to detail their practices. Half of respondents (50 per cent, 14) said that they set up a fund at the beginning of the project, while only 10 per cent of the total (3) had signed agreements with debt institutions (i.e. banks). In most cases, respondents reported that mine closure operations are very dependent on countries' jurisdictions. As a general note, respondents prepare and review a cost estimate for decommissioning assets (i.e. pits, dams, industrial facilities) on an annual basis, following the asset retirement obligation methodology, and disclose their financial statements as defined by International Accounting Standard 37.

The companies' appetite for comprehensive environmental, social and governance reporting seems to be motivated by the strong interest of investors: survey respondents consider reporting to be the main issue related to environmental, social and governance risks (18 respondents), followed by civil society (15) and the local population (14). Most respondents believe that environmental, social and governance reporting attracts new investors (55 per cent); 13 respondents do not agree and report that while they are relevant to retaining existing investors, it remains unclear how much financiers weight this information in their decision-making process. Among the universe of interested investors, pension funds, institutional investors and sustainability-linked funds and impact-focused funds are cited as the most critical. This evidence indicates that there may be a potential 'green premium' for companies outperforming on environmental, social and governance issues, in that they may be more appealing to investors than other companies and could more easily access capital from specific financiers.

Critically, it remains unclear whether and by how much such a potential 'green premium' would outweigh the additional costs companies incur when implementing sustainable practices. The global survey reveals crucial details about the extra costs faced by companies in implementing sustainable practices for selected activities (figure 6.19). Environmental issues (water resource management, soil restoration, energy use, environmental disaster prevention, biodiversity protection and restoration and greenhouse gas emission reduction) are perceived to be the most expensive. The costs of responding to social and governance issues are the most uncertain because of the crucial importance of context- and client-specific features.

Clarification of these cost issues seems urgent. Calls for mining to support the Sustainable Development Goals, adopt a sustainable development licence to operate or implement a step change in responsibility and sustainability are unlikely to be perceived as realistic, if financial markets do not reward such practices, and if downstream purchasers either cannot recognize metals and minerals produced to high environmental, social and governance standards, or are unwilling to pay more for them. Governments may need to mandate differentiation of those products produced to high standards, through incentive schemes, favourable fiscal conditions or preferential market access, as well as support and communication for project development. Investors can also use behavioural-linked bonds at preferential rates for companies with good environmental, social and governance practices.

Figure 6.19: Surveyed companies' estimates of the extra costs of improving environmental, social and governance performance



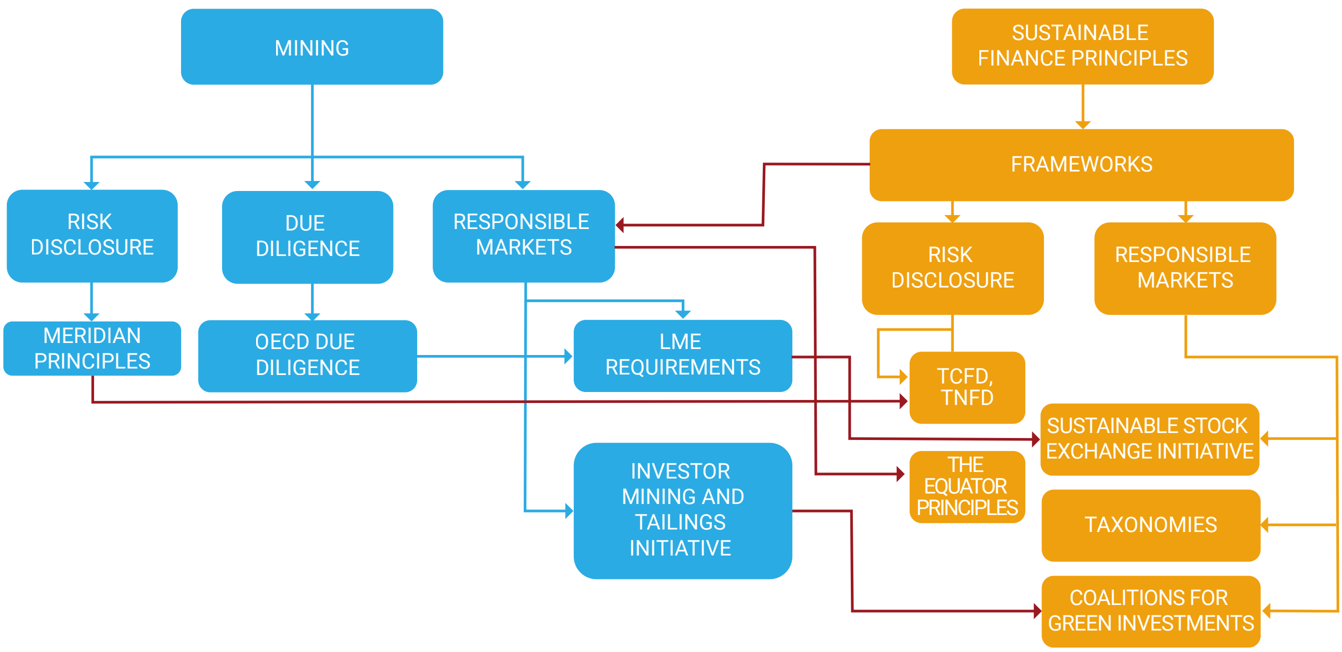
Source: Authors' survey.

6.3 CONCLUSIONS OF THE CHAPTER

The path towards the achievement of a sustainable future will require both sustainable finance and responsible mining, with sustainability in each case defined by strict environmental, social and governance standards. The landscape for each is subject to considerable diversity in terms of their landscapes of principles, frameworks and instruments, some of which are shown in figure 6.20. What is now required is to build a solid integrated framework between the two.

Three lessons emerge from this assessment of sustainable finance policy goals, frameworks and tools. First, a fostered dialogue between finance and mining will help investors to value and promote sustainable practices in the mining sector. This is especially crucial to drafting taxonomies for sustainable investments, which differ greatly in their consideration of the mining sector depending on the jurisdiction. An established cooperation with the financial sector can provide a data-supported scrutiny of existing practices. As the mining industry supports a fast-paced energy transition, this cooperation is urgently needed to manage avoidable harm and avoid unmanageable adverse impacts. Existing networks and coalitions could facilitate this dialogue to identify gaps in adopted standards, address key environmental, social and governance risks and ensure systemic responses to sector-wide issues: recent initiatives such as the Global Investor Commission on Mining 2030 are already working along these lines.

Figure 6.20: The sustainable finance and responsible mining frameworks



Note: LME = London Metal Exchange; TCFD = Task Force on Climate-related Financial Disclosure; TNFD = Task Force on Nature-related Financial Disclosure. The Meridian Principles are a set of principles that have been proposed for artisanal and small-scale mining, as discussed in Chapter 7.

Source: Authors.

Second, the existing focus on environmental and climate concerns, while essential, must not eclipse the need for comprehensive, holistic sustainable development perspectives that integrate environmental, social and governance considerations equally over the whole mining life cycle. Given the current attention to environmental, social and governance-related issues in mining, it is timely to acknowledge that an integrated framework for finance for sustainable mining can only be effective if it combines environmental goals with objectives for a prosperous economy and a fair social landscape.

Third, while reforming the financial system, it is important to address how different instruments and tools can channel capital towards more sustainable practices in the mining industry. Adequately regulated transition bonds can support polluting industries, while behaviour-based debt instruments may lead to long-term impacts on the way companies conduct mine-site-level operations. Investors can drive these transformations by understanding how companies plan to allocate their funds and the way the owner wants to structure the financing framework. By linking finance to measurable, monitorable and quantifiable outcomes, financiers can put environmental, social and governance pressures on companies, which in turn can limit harmful practices while generating positive impacts on both people and the planet.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6.4 APPENDIX

Some sustainable investing networks with their main environmental, social and governance focus

Name	Environmental, social and governance dimension	Region
United Nations Global Compact	Environmental, social and governance	Global
SASB Standards Advisory Group	Environmental, social and governance	Global
Eurosif - The European Sustainable Investment Forum	Environmental, social and governance	European Union
World Benchmarking Alliance (WBA)	Environmental, social and governance	Global
Sustainable Value Creation platform	Environmental, social and governance	Netherlands
Interfaith Center for Corporate Responsibility (ICCR)	Environmental, social and governance	United States of America
Association of Investors for Sustainable Development (VBDO)	Environmental, social and governance	Netherlands
Portfolio Decarbonisation Coalition	Environmental	Global
Transition Pathway Initiative	Environmental	Global
GRESB	Environmental	Global
DNB Sustainable Finance initiative	Environmental	Netherlands
Powering Past Coal Alliance	Environmental	Global
Human Rights Investor Alliance	Social	United States of America
Social & Human Capital Protocol	Social	Global
International Corporate Governance network	Governance	Global
Asian Corporate Governance Association	Governance	Asia
Global Impact Investing Network	Impact	Global
Global Steering Group on Impact Investing (GSG) – Foro Impacto	Impact	Global/ESP
Corporate Sustainability and Responsibility (https://www.csreurope.org/)	Environmental, social and governance	European Union
Mineral Development Network Platform (https://www.mineralplatform.eu/)	Environmental, social and governance	European Union-Latin America
European Union Raw Materials Information Hub (https://rmis.jrc.ec.europa.eu/)		European Union
Principles for Responsible Investment	Environmental, social and governance	Global
Principles for Responsible Banking	Environmental, social and governance	Global

CHAPTER 7

FINANCING ARTISANAL AND SMALL-SCALE MINING

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CONTENTS

7.1 INTRODUCTION

An estimated 44.75 million people are employed in artisanal and small-scale mining and quarrying across the globe (World Bank 2021), providing an important source of household income that often exceeds earnings from agriculture, petty trade and other informal sector jobs. Artisanal and small-scale mining is a highly diverse sector covering numerous commodities, ranging from gold to sand mining, and operations of varying scales. In sub-Saharan Africa specifically, the sector accounts for a significant percentage of a range of export metals and other minerals, including 18 per cent of the region's gold, 15–20 per cent of its diamonds, most of its coloured gemstones (Hilson and Maconachie 2020) and a significant part of its cobalt production (i.e. 25 per cent in the Democratic Republic of the Congo, which itself supplies over 65 per cent of the world's cobalt).[146] Globally, artisanal and small-scale mining is also the main source of locally mined and used development minerals, which have been defined as "minerals and materials that are mined, processed, manufactured and used domestically in industries such as construction, manufacturing, infrastructure and agriculture" (Franks 2020), and which contribute significantly to local economies and are essential for achieving the Sustainable Development Goals (Franks *et al.* 2023).

Artisanal and small-scale mining operations typically have an unskilled workforce that uses simple tools and techniques, with the potential for elevated risks on the environment and on the health and safety of both miners and surrounding communities. In recent years, attention has been given to improving the environmental and social performance of artisanal and small-scale mining, including the development of guidelines and voluntary initiatives focused on reducing supply chain risks for buyers of commodities and improving the lives of miners and their communities.[147] In addition, the artisanal and small-scale mining community has articulated a vision for the future represented by the Mosi-oa-Tunya Declaration on Artisanal and Small-scale Mining, Quarrying and Development, which builds on preceding international declarations (Franks *et al.* 2020).

An urgent issue for artisanal and small-scale mining is the need to improve access to finance for miners, which can provide the necessary up-front costs and the capacity to purchase or hire equipment to enable improved production and incentives to boost operational sustainability. However, the informal status of most operations and the reluctance of financial institutions to lend to what is perceived as a high-risk sector has prevented many operators from accessing formal sources of finance (Eniowo *et al.* 2022a).[148] The formalization of artisanal and small-scale mining is the process by which the sector can be integrated into the formal economy; it should include a tailored adaptation of laws and policies and enable "conditions for accountability within the sector". The legalization of artisanal and small-scale mining practices is only one of many dimensions that must be integrated and addressed simultaneously in the process of formalization (Hilson *et al.* 2018).

This Chapter provides an overview of the artisanal and small-scale mining sector, focusing on how miners access finance, the common challenges faced and the introduction of various schemes. The Chapter also presents the findings of an original survey of financing in the artisanal and small-scale mining sector, implemented through the Delve Exchange knowledge exchange network of artisanal and small-scale miners. The survey findings show how miners in various countries and regions access finance for 'traditional' metals and minerals operations, such as gold, as well as some preliminary information on the financing and location of production of various transition minerals, such as copper, lithium and cobalt. Chapter 8 contains some recommendations, derived from the analysis in this Chapter, to increase miners' access to formal sources of finance as a way of improving the environmental, social and governance performance of their operations and, ultimately, leveraging the contribution of this large and important mining sector to benefit national and global economies, reduce poverty and achieve the Sustainable Development Goals.

146 See *Baseline study of artisanal and small-scale cobalt mining in the Democratic Republic of the Congo*, Responsible Sourcing Network (2021).
147 For example, the CRAFT Code, Fairmined Standard for gold, etc.
148 Pact (2017). Training Handbook for Artisanal and Small-Scale Miners in Zimbabwe. Washington, DC: Pact

7.2 ARTISANAL AND SMALL-SCALE MINING

7.2.1 Overview

In many countries, artisanal and small-scale mining (ASM) contributes significantly to local economies, but the activity is disparate and scattered, making it more difficult to obtain satisfactory and comparable figures. Despite a large contribution to global mineral supply chains, artisanal and small-scale miners are still among the most marginalized workers and little attention is given to the contribution of artisanal and small-scale mining to national and global economies (World Bank 2021). There is often a large discrepancy between the price paid to workers in artisanal and small-scale mining and the price at which their products will eventually be sold on international markets. Mostly informal, artisanal and small-scale mining activities have been the subject of bad press both in industrial supply chains and among the wider public through popular movies. However, these narratives often overlook the rich and diverse stories of artisanal and small-scale mining.

Artisanal and small-scale mining is characterized as labour-intensive mineral extraction and processing activities with low levels of mechanization and material recovery (Hilson *et al.* 2018). It is often carried out by individuals or in small groups, with relatively low levels of capital investment (International Resource Panel [IRP] 2020). Almost 45 million people are directly involved in artisanal and small-scale mining globally across 80 countries, including 20 million in Africa, and between 100 million and 150 million people rely on this income indirectly (World Bank 2021). A much smaller workforce is associated with large-scale mining, in which about 7 million people are involved globally (Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development 2017). Artisanal and small-scale mining is both poverty-driven and has the potential to reduce poverty, as well as being increasingly described as having potential for wealth creation (Fisher *et al.* 2009; Verbrugge 2016).

Artisanal and small-scale mining is increasingly involved in the mining of energy transition minerals and supplies between 18 per cent and 30 per cent of cobalt globally, directly supporting metals and materials for the low-carbon energy transition (Organization for Economic Cooperation and Development [OECD] 2019). Empowering workers in artisanal and small-scale mining with the financial tools to help them to access formal markets can better distribute economic value and benefits. This is exemplified in the Africa Mining Vision of the Economic Commission for Africa to "harness the potential of small-scale mining to improve rural livelihoods and integration into the rural and national economy" (African Union 2009). There is therefore huge potential for better understanding the contribution of artisanal and small-scale mining to national and global economic flows.

7.2.2 Artisanal and small-scale mining and transition minerals

There are currently no databases that provide a comprehensive picture of the production of transition minerals by artisanal and small-scale miners. The data that do exist come from commodity or country-specific studies, such as on cobalt, rare earth elements in Myanmar, tin in Indonesia and tantalum in the Democratic Republic of the Congo and Rwanda (McFarlane and Villalobos 2019; Schutte and Naher 2020). In addition, limited data on artisanal and small-scale mining production associated with some large-scale mining projects have been documented in a recent report of the United States Agency for International Development (USAID), including the production of chromium in Zimbabwe and South Africa, and lead and zinc in China (United States Agency for International Development [USAID] 2021).

A recent survey of representatives artisanal and small-scale mining cooperatives and associations in the Delve Exchange knowledge network, provides a further picture of artisanal and small-scale mining production. While only a limited number of countries are represented in the survey, the findings revealed that artisanal and small-scale miners in the Delve Exchange produce at least seven key transition minerals, including copper, lithium, zinc, manganese, nickel, bauxite and chromium. Miners also produce a large volume of sand, crushed stone and gravel (aggregates) and limestone needed for the infrastructure to support renewable energy (table 7.1).

Table 7.1: Confirmed transition minerals produced by Delve Exchange members

Region and countries responding to the survey	Mineral
Anglophone Africa (Nigeria, United Republic of Tanzania, Zambia, Zimbabwe)	Copper, lithium, manganese, chromium
Francophone Africa (Burkina Faso, Democratic Republic of the Congo, Madagascar)	Copper, zinc, manganese, bauxite
South America (Peru, Bolivia [Plurinational State of])	Copper, zinc, sand
South-East Asia and the Pacific (Indonesia, Philippines)	Sand, manganese, nickel

Source: Authors' elaboration from survey conducted through the Delve Exchange knowledge network

7.2.3 Gender, human rights and "levelling up" opportunities

There is a large number of women participating in artisanal and small-scale mining supply chains and their proportion in this sector is much higher than in private and large-scale operations. Studies have mostly been focused on male labour and digging practices, making the contribution of women more opaque. Artisanal mining has low entry barriers and provides work opportunities for women that may not exist otherwise, supporting them in their efforts to ensure food security for their household (Lahiri-Dutt 2012) and use the income in strategic ways (e.g. school fees, small land acquisition, funerals). Many women perform processing activities while working on domestic chores (Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development 2018), and the proportion of women is more dominant in lower-value mineral sectors.

Some economic empowerment can be created for women in artisanal and small-scale mining, including when assuming roles such as mineral trading, but a lack of mobility and finance can put a break on the progress of female traders. Women entrepreneurs generally experience the impact of institutional barriers to successful participation in the markets. These can be both formal, such as a lack of education and resources that make it difficult for them to obtain mining and commercial permits, and collateral for finance, and informal, such as cultural and religious constraints. There is a clear intersection between gender and poverty, which compounds to constrain the futures of female traders and their daughters (Djoudi *et al.* 2016; Kabeer 2015). Hinton points out that such poorer women and their daughters are held back by a lack of negotiating skills, knowledge of how to value minerals and a time deficit caused by the need to juggle domestic duties and work (Hinton 2016). These barriers reflect a significant and long-lasting impact of the lack of opportunities for education, as well as the persistence of gender norms, which disadvantage women at many levels.

Even though artisanal and small-scale mining can represent a ladder of opportunity, female miners are particularly disadvantaged, with institutional, normative and structural factors combining to disempower women and creating gender asymmetries in the opportunities offered to female small-scale miners. Female miners, like other rural women, have low levels of financial inclusion and few have bank accounts or the capacity to take out loans. This is the result of structural inequality, such as a lack of education, steady income, collateral, access and control over lands, productive resources, licences, funds and geological data. It is also the result of normative constraints of law and tradition, where men are considered to be the head of the household and are responsible for all decision-making, including financial decisions (United Nations, Committee on the Elimination of Discrimination against Women 2015). This increases their vulnerability and unequal access to the ability to fulfil formalization requirements.

More than one million children have been estimated to be working in artisanal and small-scale mining (International Labour Organization [ILO] 2019), a number that is growing steadily (Schipper *et al.* 2015), although reductions have been observed in formal small-scale mining in countries such as Brazil.[149] There is high potential for harsh and exploitative conditions where the physical and psychological integrity of children is at risk. However, many women also work with their children; while some donors consider child labour in mining to

149 See "Socioeconomic and Environmental Diagnostic of Small-Scale mining in Brazil". www.delvedatabase.org.

be the worst from of child labour, others argue that these activities sometimes enable children to go to school and stay with their families, and that simply outlawing it may drive poor families into further poverty and children into greater risk (O'Driscoll 2017; Faber *et al.* 2017). Appropriate and context-specific supporting mechanisms for families must ensure a successful and sustainable transition out of mine work for children over time.

In Ghana, a small group of successful women who have artisanal and small-scale mining licences are themselves supporters, providing finance for other operations, and some are brokers trading and dealing in gold and diamonds (McQuilken *et al.* 2017). Support from male relatives can be crucial in helping women to become traders in minerals in both Ghana and Sierra Leone. Women with support from male relatives and opportunities to take a second job have human capital that many more vulnerable female traders could only dream about.

Combining better access to schools with training for women and members of the community, notably in science, geology and global value chains, is a practical lever of empowerment. This can contribute to turning artisanal workers into players able to trade professionally and ensure that benefits go to their communities (as with practical workshops held in impoverished areas of Madagascar).

7.2.4 Transfers of livelihoods

Times of crisis, inflation, unemployment and poverty drive an increase in artisanal and small-scale mining. The exact contribution of artisanal and small-scale mining to a family's income can be hard to quantify, as several livelihoods are often interconnected, notably with farming (Hilson 2016).

There is an observed transfer from agriculture livelihoods to the informal extraction of mineral resources, owing to several complex reasons, including economic reforms benefiting foreign direct investment, rising commodity prices and large corporations being favoured by policies equating large operations to development (IRP 2020). Climate change is also already affecting the dynamics of artisanal and small-scale mining, especially in relation to internal migration and the interaction of this and climate change itself with rural areas. For instance, in Madagascar, more women move from the southern areas of the country in search of mining opportunities, sometimes with their whole families, because droughts have led to sterile soils and a lack of crops to harvest. In effect, this makes them climate refugees.

7.2.5 Development minerals

Research, policy and investments in mineral value chains are often channelled towards so called high-value metals. However, their added value in terms of local development opportunities is contestable, as they are primarily minerals for foreign export. In contrast, huge volumes of minerals in artisanal and small-scale mining are mined, processed and used domestically in construction, manufacturing industries and agriculture, directly contributing to local economies and domestic supply chains. Perhaps the most significant of these is sand, an often overlooked, yet essential mineral for development. The total historic production of gold amounts to around 212,582 metric tons (World Gold Council 2024) the equivalent of around four Olympic-sized swimming pools) whereas production of sand, gravel and crushed stone is estimated at 50 billion metric tons per year[150] (Franks 2020). Development minerals are still often called or considered "minor" or "low-value" minerals and materials, despite their immense economic value and importance to local development and the achievement of the Sustainable Development Goals.

7.2.6 Governance

Around 80 per cent of the world's gemstones and 10 per cent to 30 per cent of the global supply of gold are currently provided by artisanal and small-scale mining activities. Informal artisanal and small-scale mining for gold is a particular source of concern owing to the use of mercury and its substantial environmental health impacts (IRP 2020; Seccatore *et al.* 2014). Entrenched habits are hard to change as the use of mercury is cheaper and faster than more environmentally friendly alternatives.

Artisanal and small-scale mining is considered and addressed differently in many countries. Often, legislation is not appropriately synchronized with the reality in the field, owing to the diversity, complexity and fast evolution

150 See data from https://www.gold.org/goldhub/data/how-much-gold and https://www.unep.org/resources/report/sand-and-sustainability-10-strategic-recommendations-avert-crisis.

of local contexts. Many governments do not hold reliable figures on workers and production levels in artisanal and small-scale mining, which impede the development of dedicated policies and programmes (Collins and Lawson 2014). Governance of artisanal and small-scale mining requires the enforcement of regulatory responses along with adequate financial, technical and training support (including geological mapping, land use and resource-use planning), and bottom-up structures would increase the protection of communities and the environment. In Brazil, mineral cooperatives were induced by regulatory requirement to increase formalization and solve governance issues in artisanal and small-scale mining. However, so far, such cooperatives have struggled to follow successful cooperative models because of a lack of accompanying public policy structure to support organization and action at all levels (da Silva *et al.* 2023).

There are many land-use management tensions linked to artisanal and small-scale mining activities. Conflicts can happen between local authorities and the government, owing to complex relationships with land tenure arrangements. Policymaking is often focused on land rights and licensing procedures, overlooking informal and customary property systems (Dube *et al.* 2016). A lack of secure land tenure provides little incentive to formalize activities or adopt environmentally responsible practices. Appropriate governance would contribute to the beneficial coexistence of farmlands, artisanal and small-scale mining and large-scale mining, and ensure that artisanal and small-scale mining can become a tool for poverty reduction in the communities of resource-rich countries. The Sustainable Artisanal Mining Project in Mongolia was recognized as a source of best practices in artisanal and small-scale mining governance (Swiss Agency for Development and Cooperation 2017). It aimed to make artisanal and small-scale mining a sustainable driver of rural development and improved the public and political perception of artisanal and small-scale mining in the country.

A number of ethical schemes have focused on security and conflict minerals to ensure commodities are not linked to armed groups, as operations financed by organized crime pose particularly important security, governance, social and environment concerns (World Bank 2021). However, some interventions have been denounced as top-down structures, ignoring local social and cultural dynamics or working only with miners with local power, leaving marginalized community members unable to access formal markets. Some research finds that an excessive focus on conflict-free supply chains mostly protects corporate public image interests and may not provide actual benefits to local populations and economies (Radley and Vogel 2015; Hilson *et al.* 2016; Spiegel 2015a).

For more detail and references on minerals categories and a deeper dive into artisanal and small-scale mining governance, please refer to the International Resource Panel report on mineral governance (IRP 2020).


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7.3 REFORMING THE SECTOR

7.3.1 Existing efforts

The World Bank contributed US$1.4 billion towards reforms in the mining sector between 1988 and 2012, including support loans focused on legislative, fiscal and institutional reforms (Hilson *et al.* 2016). While several countries, notably in sub-Saharan Africa, revised their mining codes, this largely resulted in increasing investments in large-scale mining and large areas of land being granted to foreign multinationals, leaving little viable land left for legal artisanal and small-scale mining activities. This has encouraged informal artisanal and small-scale mining further, creating links between a liberalization of the economy benefiting a few individuals and the expansion of informal activities, a pattern also observed elsewhere (e.g. Mongolia). Formalizing the sector would create economic opportunities for other parties, including suppliers of equipment and finance, and push technological and financial innovations, increasing the number of licensed operators using supplies from international markets (World Bank 2021).

Intergovernmental organizations and multilateral lending agencies established interventions focused on reducing mercury in artisanal and small-scale mining (Collins and Lawson 2014; Sippl and Selin 2012). In addition, although the Minamata Convention on Mercury promotes environmental, social and governance issues and public health, many cultural, geological and socioeconomic barriers to implementation remain, which can be mitigated by increasing institutional and State expertise.

For large private companies, artisanal and small-scale mining represents an important environmental, social and governance risk linked to financial liabilities, public reputation, environmental health and safety and human rights issues, including child labour. For instance, consumers' and investors' scrutiny of environmental, social and governance performance is intended to ensure that products do not use "conflict minerals". Foreign investment and exploration can be discouraged by national governments' lack of control of artisanal and small-scale mining (Dondeyne and Ndunguru 2014). A number of international schemes have been established to strengthen due diligence, certification and transparency.

In the past, international development programmes incentivizing capacity-building and improved environmental heath in artisanal and small-scale mining have failed or been misused owing to a lack of ongoing commitment and of comprehensive consideration of the local context. Issues such as the unsuitability of equipment, a lack of training programmes or long-term affordability have arisen. However, several multilateral and multi-stakeholder initiatives have also led to encouraging outcomes, including the Yaoundé Declaration in 2002 (United Nations Economic Commission for Africa [UNECA] 2002, as reported in Franks *et al.* 2020), the investment of US$45 million in the Global Opportunities for Long-term Development in Artisanal and Small Scale Mining Programme (GEF GOLD), focusing on formalization, educating investors and consumers, access to finance and global markets for artisanal and small-scale mining communities, reduction of mercury use and knowledge exchange, the Development Minerals Programme of the African, Caribbean Pacific Group of States and the European Union, or the Mosi-oa-Tunya Declaration (Franks *et al.* 2020; Hilson and McQuilken 2014).

Other initiatives have been proposed to help artisanal and small-scale mining to contribute to achieving the Sustainable Development Goals, notably through financing mechanisms. Some are focused on innovative financing models (such as hiring and pay-back schemes for equipment and technologies), bottom-up approaches to engage miners and enhance context-specific implementations (Salo *et al.* 2016; Verbrugge and Besmanos 2016) and formalization for effective management and regulation (Smith *et al.* 2017). Other recent programmes were developed to support buyers' due diligence while creating an opportunity for artisanal and small-scale miners to enter formal markets (e.g. the CRAFT Code). As will be discussed later in this Chapter, artisanal and small-scale mining is generally not directly attractive to traditional finance owing to numerous factors, such as unpredictable returns on investments and a lack of collateral. Much like in large-scale mining, artisanal and small-scale mining activities are directly affected by the booms and busts of global commodity prices. For instance, the economic growth of China is linked to an increase in artisanal and small-scale gold mining in Ghana (African Center for Economic Transformation 2017).

7.3.2 Artisanal and small-scale mining, large-scale mining and building trust

Because of the lack of appropriate data to represent the specificities of artisanal and small-scale mining and illustrate their impact on downstream markets and community development, unfair comparisons are often made with large-scale mining, which affects economies and societies differently.

Artisanal and small-scale mining can be permanent, seasonal or part of an influx of internal migration. Artisanal and small-scale mining also often occurs on land leased to large-scale operations (Hilson *et al.* 2020), triggered by an influx of miners looking to benefit from the mine by working on its outskirts or even in heavily polluted tailings. Conversely, the presence of artisanal and small-scale mining can also be an indicator of interest in large-scale exploration (International Council on Mining and Metals 2010). Migration related to artisanal and small-scale mining can lead to the quick growth of urban settlements without essential facilities, and in some cases lead to conflicts and confrontations with local populations (Nyame and Grant 2014). Many experts emphasize trust as an essential driver of collaboration and conflict resolution (Fulmer and Gelfand 2012). Trust can be impeded by "extractive" relations established at the outset of large mining projects (e.g. a lack of due diligence and appropriate community engagement), which fail to build trust and create negative relationship legacies. Early engagement and planning with artisanal and small-scale miners can help to establish agreements for the entire life cycle of the mine and leverage the potential for private companies to contribute to capacity-building that will benefit artisanal and small-scale mining communities (Verbrugge 2016).


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7.3.3 Formalization

Providing artisanal and small-scale miners with the financial tools to access formal markets can distribute economic value and benefits to local communities in resource-rich countries. The formalization of the sector must be well defined to improve environmental, social and governance standards and bring added value to work opportunities and education without putting additional constraints on the most vulnerable workers. Disproportionate barriers exist for women in accessing finance and technical training. For example, in Ethiopia, limited financial flexibility and insufficient microfinance schemes lead to a lack of skilled labour and training opportunities even for licensed miners. A lack of strategies for incubation or promotions for small and medium-sized enterprises (SMEs) can also hamper the scale-up of small operations (Getachew 2018). Formalization processes should be built in steps to prevent the de facto exclusion of people who do not have the necessary initial capacity (e.g. literacy, access to finance). As many miners want to get into formal supply chains and sell their products on global markets, intermediaries such as skilled local people that can develop the conversation around the specificities of the local context are needed, and initiatives must be enacted with room for flexibility to suit the diversity of local contexts.

Barriers to formalization include compliance fees, land tenure, limited institutional knowledge, complex registration processes, and a lack of crucial finance and support services to access markets (Dube *et al.* 2016). Obstacles can be reduced by a simplification and decentralization of licensing procedures, capacity-building, training and knowledge exchange, tax incentives providing market access (e.g. governments paying a higher price than informal markets, or access to higher end markets), access to funding and technical support, increasing understanding of local contexts, increasing local participation, longer licence periods and access to geological mapping and geospatial data. National institutions must also be strengthened to implement initiatives efficiently. Formalization policies that are not designed appropriately can sometimes strengthen existing imbalances in power rather than distributing benefits and opportunities more fairly (Spiegel 2015b).

7.3.4 The importance of transparency and better data

Improving the quality of data on artisanal and small-scale mining requires improving information technologies in the field offices of mining ministries to consult real-time data on artisanal and small-scale mining permits, production levels and the number of workers, and to pilot methods to capture the development impacts of artisanal and small-scale mining on local communities. Using reliable data to understand the sector's access to finance and the types of financing needs is essential to inform the effective formalization of programmes, promote gender equality and sensitize financial institutions to the sector's dynamics (World Bank 2021).

Gathering more data on the economic contribution of artisanal and small-scale mining to national and global economies will also reveal how finance contributes to the sector's production and evolution. More disaggregated and accurate data are required to detail the contribution of artisanal and small-scale mining to gross domestic product (GDP) and the value of exports, rather than relying only on absolute export figures and declared production and sales, which put the focus on large-scale mining investments.

The supply chains of artisanal and small-scale mining can include local traders, financiers, civil servants, politicians, the army or even criminal networks. Capturing these financial flows can help to understand power relations within existing policy systems and balance the interests of diverse economic actors and affected communities.

There is much value and capacity in national and regional artisanal and small-scale mining associations and networks. Some are proactively engaged in advocacy to reform the sector's policies and funding pilot projects for mine-site improvement (e.g. case studies in Ghana and the United Republic of Tanzania by the International Institute for Environment and Development (Flores Zavala 2017); work of the Association of Women in Mining in Africa (2024)).

7.4 THE ECONOMICS AND FINANCING OF ARTISANAL AND SMALL-SCALE MINING

Much of what is known about the financing of artisanal and small-scale mining comes from the gold sector, which is not surprising given the large number of artisanal and small-scale miners involved in gold mining globally, around 15 million people,[151] and the high value of the commodity on local and international markets. Artisanal and small-scale gold mining also presents significant environmental and human health risks, largely owing to the use of cyanide and mercury in gold processing, with governments and the international community encouraging investment in and the adoption of mercury-free processing technologies.[152] Less is known about financing arrangements for other commodities, including transition minerals.

This section examines the various financing arrangements, initiatives and challenges in the artisanal and small-scale mining sector. In addition to a review of the literature, the discussion draws on the findings of a recent survey of artisanal and small-scale miners who are members of the Delve Exchange knowledge network (ASM Survey). Launched in 2021, the Delve Exchange is an online network to facilitate knowledge-sharing and support among artisanal and small-scale mining associations and communities and quarry workers across the globe, initiated during the coronavirus disease (COVID-19) pandemic.[153] It now has over 1,000 registered members in 71 countries across 6 regions, including Anglophone and Francophone Africa, Central and South

151 See planetGOLD (2020a). *Access to Finance: Options for Artisanal and Small-Scale Mining; planetGOLD (2020b). Improving Access to Formal Finance in Artisanal and Small-scale Gold Mining; planetGOLD (2020c). Unlocking Finance for Artisanal and Small-Scale Gold Mining: A Frontier Investment Sector.*

152 The United Nations Environment Programme Global Mercury Partnership supports implementation of the Minamata Convention on Mercury, the goal of which is to reduce and eliminate mercury use in gold mining globally: https://www.unep.org/globalmercurypartnership/.

153 The Delve Exchange is a knowledge exchange network run for, and by, artisanal and small-scale miners and quarry workers operating across Africa, the Asia-Pacific, and Latin America and the Caribbean. It was established with the support of the University of Queensland's Sustainable Minerals Institute, the Association of Women in Mining Africa, OECD and the Development Minerals Programme of the African, Caribbean Pacific Group of States and the European Union implemented by the United Nations Development Programme, with funding from the Extractives Global Programmatic Support Fund of the World Bank. https://delvedatabase.org/delve-exchange-en.

Asia, Latin America, the Caribbean and South-East Asia and the Pacific.

The survey included questions such as where miners obtain their finance, the challenges and barriers faced in accessing finance and how finance is used in operations. Links to the survey were sent to 54 representatives of artisanal and small-scale mining cooperatives and associations in the 6 regions, representing more than 250,000 miners, who were asked to report back on their members' common experiences in accessing finance. Responses were received from representatives of cooperatives and associations in four of the six regions.[154]

7.4.1 What is finance used for?

Despite the relatively simple technology and techniques used in much of the sector, artisanal and small-scale mining is highly dependent on access to finance to be profitable and sustainable. Miners typically do not independently have the financial resources to support their operations, which usually includes the purchase of equipment and the payment of operational costs. These are particularly high in the artisanal and small-scale gold mining sector where miners must pay for mills, centrifuges, drills, repairs and maintenance, training and other inputs, such as the mercury used to process gold. The adoption of clean processing technology in the gold sector, such as gravity concentration equipment that eliminates the need to use mercury (e.g. spiral concentrators and shaking tables), imposes particularly high costs on miners that, outside of donor or grant funding programmes, many are unable to afford.

The ASM Survey revealed that the most common finance needs reported by representatives of the associations and cooperatives in the Delve Exchange are for purchasing equipment and machinery. This includes things like compressors, excavators, start-up mining equipment and tools. Finance may also be needed for exploration purposes to cover the costs of reconnaissance, permits, licences, feasibility studies and mine site preparation. In addition, there are operational costs that, depending on the size of the operation, include salaries for workers, food supplies, utilities and fuel or diesel. Other financing needs include payments for children's education and the purchase of personal protective equipment, although the use of this is virtually non-existent in some contexts.

Given the great diversity of artisanal and small-scale mining operations globally, it is not possible to provide definitive figures on financing needs. However, drawing on data from the Impact Facility, planetGOLD reports that the typical investment costs for artisanal and small-scale gold mining in a mercury-free gold mining operation can be as high as US$89,730, not including transport costs, repairs and maintenance, and operational costs (table 7.2). For cost estimates in other contexts, such as Guyana see Laing *et al.* (2023).

Clearly, operations of this scale require significant investment and in such cases it is not uncommon for an intermediary between miner and investor to cluster several small mines together to meet investment needs including, in the case of gold, the purchase of, inter alia, mineral-processing equipment (planetGOLD 2020b; planetGOLD 2020a).

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154 No responses were received from countries in the Caribbean or South and Central Asia by the survey cut-off date.

Table 7.2: Typical investment costs for an artisanal and small-scale gold mining operation

Investment needs	Cost US$	Local or import	Explanation
Compressor	15,000	Local	Improves productivity by drilling using compressed air to more easily blast and disintegrate the rocks to access high grade ore zones.
Mud water pump	3,530	Local	A water pump has benefits for both safety and productivity by reducing the water level in shafts or adits to enable safer working conditions. It can then enable continued work during rains or at depths which would be otherwise inaccessible or dangerous.
Handheld rock drill	7,500	Import	Improves productivity through enhanced ability to explore and target high grade zones underground.
Generator	11,300	Local	Improves productivity though a reliable power source.
Ball mill	8,000	Local	A ball mill crusher will effectively grind the gold bearing rocks to powder and alternative to hand crushing which is slow and less precise.
Gold kacha	3,000	Import	Centrifugal concentration equipment, such as the Gold Kacha replace sluice boxes in the concentration process and promote mercury elimination. Not only does this process take significantly less time than traditional sluicing, it can also increase recovery to up to 95% when used by trained personnel.
Shaker table	13,000	Import	The shaking table works in synergy with concentration equipment to separate out gold particles from gold concentrate, enabling mercury elimination through subsequent smelting of the final concentrate.
Winch	15,000	Local	A winch is helpful to hoist waste rocks and ore from underground to the top of the pit enabling pit development and safety improvement.
Equipment clearance and transport costs	TBD	n/a	Budget for clearance and transport costs must be allocated.
Installation and training costs	13,000	n/a	Installation of equipment and training in its use is required to ensure any purchases are used safely and effectively. Training on repayment schedules, monthly mine and ESG data are also important considerations to measure the positive impact activities and the provision of equipment has on the mines.
Repairs and maintenance	TBD	n/a	A contingency budget may need to be set aside for repairs and maintenance beyond warranties.
Sub-Total	**89,730**		

Source: The Impact Facility, cited in planetGOLD (2020c).

** Gold kachas are simple centrifugal gravity concentrator processing systems*

7.4.2 Mechanisms for financing artisanal and small-scale mining

In contrast to large-scale mining projects where finance is provided by large private financial institutions and national development banks, artisanal and small-scale mining operations have limited access to formal sources of finance, i.e. from lenders who operate within legal frameworks governing commercial transactions (planetGOLD 2020c). Miners instead rely on a variety of informal lenders, such as family members, cooperatives and mineral traders and buyers who may take an inequitable cut of production or charge usurious interest rates.

With limited access to formal sources of finance, artisanal and small-scale miners are often unable or unwilling to invest in the necessary upfront costs that would lead to better mining practices. Where miners do have access to formal finance it typically includes debt finance arrangements such as microfinance, local savings and credit schemes, (rarely) commercial banks, cooperative banks and national development banks, as well as equity-financing arrangements.

Responses to the artisanal and small-scale mining survey show that 45 of the 51 (88 per cent) cooperative and association representatives reported that, most often, their members obtained finance from informal sources. The most common sources of informal finance were mineral buyers (around 53 per cent of all respondents), cooperatives (21.5 per cent), family members (4 per cent) and investors or other informal lenders (6 per cent). Some 6 per cent of all respondents said that the most common source of finance in their cooperative or association was self-financing. There was little variation between the regions in terms of the incidence of informal financing, which, as would be expected, was high across the board. Only 8 of the 51 representatives (around 15 per cent) stated that formal financing from banks was the most common arrangement in their cooperative or association.[155] In some cases, respondents reported that more than one source of finance, including both formal (banks) and informal sources, were common among members of their cooperatives or associations.

The sections below describe the various informal and formal mechanisms for financing artisanal and small-scale mining, before discussing the barriers and challenges preventing most miners from accessing finance from banks and other formal sources.

7.4.3 Informal arrangements

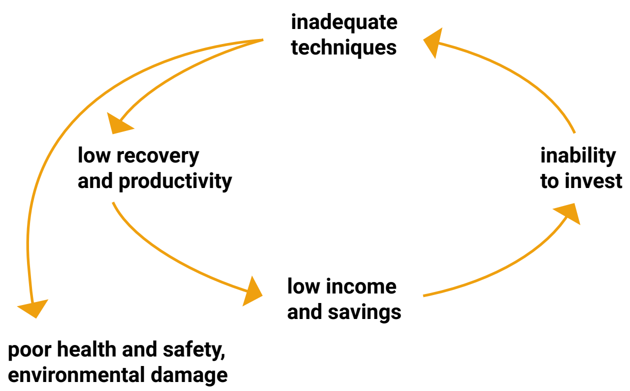
One of the most common arrangements for accessing finance in the artisanal and small-scale mining sector is for miners to receive funds from external, often local, investors. Such investors typically have an interest in the mineral to be mined and provide investment capital in exchange for an agreement that miners will sell their product to them, usually far below market prices (Eniowo *et al.* 2022a). While some have argued that such arrangements in places such as the Philippines have been beneficial (Verbrugge 2014), the consensus across sub-Saharan Africa and other developing countries is that informal financing arrangements are not usually positive for miners or the environment (Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development 2018; Perks 2016). Miners do all the work, often in dangerous conditions and, in some cases, they are barely able to survive, as was shown in Nigeria (Mallo 2012). In Ghana, sponsors (who are also buyers) will provide loans to purchase more expensive equipment, such as crushers and generators, but require very high interest rates (Hilson and Ackah-Baidoo 2011). In such circumstances, miners have little ability to plan or invest for the future, including in more environmentally-friendly mining techniques and technologies. High interest rates are also evident from the artisanal and small-scale mining survey. For example, some mineral buyers engaged with miners in one cooperative in Malawi levied a 60 per cent interest rate per year.[156]

Eniowo *et al.* (2022b) describe how a lack of access to formal sources of credit commonly perpetuates a cycle of poverty and poor environmental and social performance, where poor mining techniques lead to inefficient mineral recovery from ore, low incomes and the inability to invest in a mine and improve mining practices. The consequences of this are poverty, negative impacts on workers' health and safety – potentially of the surrounding community – and environmental damage. This situation is summed up by Noetstaller in figure 7.1.

155 Interestingly, six of these representatives also reported that both informal sources, such as mineral buyers, and formal sources, such as banks, were common arrangements.

156 In Indonesia, amounts borrowed ranged from US$100 to US$2,500, with the loan to be repaid within a year. Monthly repayment amounts vary between US$25 for smaller loans to US$170 for larger loans.

Figure 7.1: Implications of A lack of access to finance in artisanal and small-scale mining



Source: Noetstaller (1995).

Another problem raised in the artisanal and small-scale mining survey was the occurrence of abusive and exploitative lending practices by informal lenders. Almost 47 per cent of the survey respondents reported that such practices were experienced by some of the members of their cooperatives or associations. The occurrence of these practices is not unique to any particular country or region and they are as likely to be found in Africa as they are in South America and Asia. Examples given include exorbitant interest rates as high as 50–60 per cent, the seizure of tools and other property as collateral, and even threats of violence against borrowers. Furthermore, Perks (2016) has shown how lenders' vested interests have caused them to try to undermine the formalization programmes of the World Bank in the United Republic of Tanzania because it would potentially improve miners' access to finance and reduce their reliance on them.

7.4.4 Formal sources of finance

Donor-funded schemes

Probably the most common source of formal finance for the artisanal and small-scale mining sector has been international and national donor-funding, typically in the form of grants where there is no requirement for repayment. The World Bank has taken a lead role in this regard under its extractives programme area. It has funded several major initiatives supporting the artisanal and small-scale mining sector since the mid-1980s.[157] Of note is the small grants programme provided through its Sustainable Management of Mineral Resources Projects. A number of these Projects were established in recent decades in sub-Saharan Africa, providing small grants to support various artisanal and small-scale mining activities. In Uganda, for example, a Sustainable Management of Mineral Resources Project operating between 2009 and 2014 provided grants to support the adoption of more efficient and safer artisanal and small-scale mining practices. To be eligible, miners had to form a group and undergo training in financial literacy procurement. This scheme was reportedly successful and even motivated some artisanal and small-scale mining associations to form village savings and loan schemes to provide small loans to members in times of need, such as for family emergencies and school fees.

Government loans

Some take a more critical view of donor-funded grants on the grounds that they do not instil financial responsibility for repayment in miners and are therefore unsustainable. Siegel and Veiga (2009) suggest that a better strategy is for donors to support government loan facilities that better distribute the risk and thus the financial responsibility. They cite two successful examples in Namibia and Mozambique. In Namibia, through the Minerals Development Fund, the Government provided US$92 million in loans to miners, with a focus on building shafts, exploration and mine expansion. The loans had low interest rates and long repayment periods, which, according to the authors, is the reason there has been a 92 per cent repayment rate at the time of writing (Siegel and Veiga 2009). In Mozambique, a similar fund provided loans on the condition that miners

157 These include the Communities and Small-Scale Mining initiative, Delve, the Pollution Management and Environmental Health programme in Africa, the ASM Sahel Associated Trust Fund and, most recently the emergency response window for artisanal and small-scale mining during the coronavirus disease (COVID-19) pandemic, which supports the Delve Exchange and other projects.

could show collateral, create a loan repayment plan and other requirements. The Government of Zimbabwe has also established loan schemes for the sector, including a loan for mine establishment that covers six months of operating costs (Hinton 2005). A number of other government loan facilities have been used in the sector in other countries in sub-Saharan Africa and regions over the past few decades.

Microfinance

Another source of formal finance is microfinance. Made popular by the Grameen Bank in the 1970s, microfinance became popular in the artisanal and small-scale mining sector in the 1980s. It provides financial services, including insurance, deposits and small loans to small and micro-enterprises, often groups of miners or cooperatives, who may be deemed too risky to lend to by banks and other lenders (planetGOLD 2020b). Microfinance schemes for artisanal and small-scale mining have been established in sub-Saharan Africa, Latin America and Asia.

The literature paints a mixed picture of success with microfinance. Hilson and Ackah-Baidoo (2011) describe how in sub-Saharan Africa, lenders are unwilling to lend to unlicensed miners who are operating outside of the law. They also describe how there have been high rates of loan default owing to lenders tending to be "cavalier" when what was needed was a proper understanding of an appropriate rate of interest, the geological content of the concession and thus the lifespan of the mine, as well as how to collateralise commitments to repayment.

Hilson and Ackah-Baidoo nevertheless believe that with the right governance processes, microfinance remains a good potential source of finance for the sector. planetGOLD (2020a) describes success in a microfinance initiative in Ghana that supported an equipment-lending project in gold operations based on a group-sharing arrangement. The authors argue that the success of this initiative was that participants in groups of 5–10 people were ranked in terms of their financial strength, which determined the priority in distribution of loans.

Commercial banks

There are relatively few examples of artisanal and small-scale miners accessing finance through commercial banks and, where these have occurred, there have usually been significant challenges (Eniowo *et al.* 2022a). For instance, in Zambia, emerald miners could access credit from the European Investment Bank if they provided "bankable documents" and "technical documents" with their credit applications. Their low levels of education meant that miners struggled with their applications. Furthermore, the technical assistance unit of the European Investment Bank, which was meant to assist miners with their applications, required a fee of 30 per cent to cover the cost of preparing their documents. This was beyond the means of miners, with the end result being that the project was unable to fund any artisanal and small-scale mining operations (Siwale and Siwale 2017).

Other sources of formal finance

The literature documents a number of other potential sources of formal finance that are potentially available for the artisanal and small-scale mining sector, of which few have succeeded. Hinton (2005), drawing on research undertaken by the United Nations Economic Commission for Africa (2002–2012), describes the following arrangements. The first is equity-based finance schemes where risks are shared by joint ventures, investment banks, trusts and other entities. Other mechanisms include hire-purchase schemes where miners rent or rent-to-own equipment, and cooperation between the large and small-scale mining sectors. In this case, loans and, in some cases, technical support and equipment are provided to artisanal and small-scale miners.

As will be discussed in the next section, most of the above-mentioned formal financing arrangements are off-limits to miners for numerous reasons.

7.4.5 Barriers to accessing formal finance

Research in the artisanal and small-scale gold mining sector by planetGOLD (2020a) and others (Reichel 2020) has identified a number of barriers preventing miners from accessing formal finance:

Formal status

Perhaps the most important barrier is the informal or illegal status of artisanal and small-scale mining operations. This is often because the regulatory and mineral tenure systems are not designed to include artisanal and small-scale mining. Formal financial institutions are typically unwilling to enter into financing agreements with miners whose operations are not legally sanctioned. This lack of formal status is one of the main reasons there has been a concerted push by the World Bank and others to support formalization of the artisanal and small-scale mining sector. However, formalization itself does not guarantee access to formal finance. For instance, research in Zambia by Siwale suggests that formalization "may increase access to credit, but not from formal lending institutions nor in a manner that has led to positive outcomes for operators" (Siwale 2018). She describes how the Ministry of Mines and Mineral Development of Zambia disbursed loans of US$5,000, but this "paltry amount" was much below the actual funding needed.

Traceability

The sector is regularly perceived as associated with local conflicts, child labour, criminal activities or money-laundering, all presenting major risks for financial institutions to finance artisanal and small-scale mining. Consumers and intergovernmental organizations have called for transparency and greater traceability on the origins of products and their source of funding. Improved transparency alleviates risks, but some requirements can be difficult for artisanal and small-scale miners to meet. Countries with internal systems of gold buying at the source, such as Ghana, Guyana, the Philippines and Mozambique, can help to sustain engagement and provide more visibility to formal and informal artisanal and small-scale mining operators (planetGOLD 2020a).

Lack of geological information

For those who do have their own mine, few have evidence of the prospectivity of their lease since there is no mapping or geological report that they can take to the bank to support their application and business case. This geological information on mineral reserves is needed so that potential lenders can understand the production potential and lifespan of the mine, and without this, they are often reluctant to provide loans. To strengthen the appetite to provide loans for artisanal and small-scale miners or cooperatives, geological investigations sponsored by governments and development partners could delineate economically viable areas for artisanal and small-scale mining activities.

Small operations and lack of experience with financiers

A third barrier is that many artisanal and small-scale mining operations are too small and the transaction costs too high to attract investment from financial institutions. Although miners in some contexts might have access through microfinance schemes and other sources mentioned above, the amounts available are often insufficient to enable investments in operations that would substantively improve mining practices, including management of environmental and social issues. Other barriers include miners' lack of experience in dealing with formal financial matters; and a reluctance to enter into the formal economy and its obligations, including paying taxes.

Inability to meet due diligence requirements

With limited finance, miners are also unable to meet the due diligence requirements of lenders, which often require assessment and management of environmental, social and governance risks, as well as the potential benefits of projects, including future profitability.

Current due diligence schemes are too often not grounded in the reality of the challenging artisanal and small-scale mining environment and miners, who despite their best efforts, may repeatedly fail the audit of the certification bodies.

Lack of financial products appropriate for artisanal and small-scale mining that meet the sector's specific needs

A fourth barrier is the lack of financial products that meet the specific needs of artisanal and small-scale mining. Financiers themselves face a number of barriers to financing the sector. These include, as discussed earlier, environmental, social and governance risks that may pose a threat to their reputation, high transaction costs and a lack of experience of lending to the artisanal and small-scale mining sector. Even if financial institutions are willing to provide finance, they will typically require collateral, and have interest rates that are prohibitive for miners and strict terms and conditions.

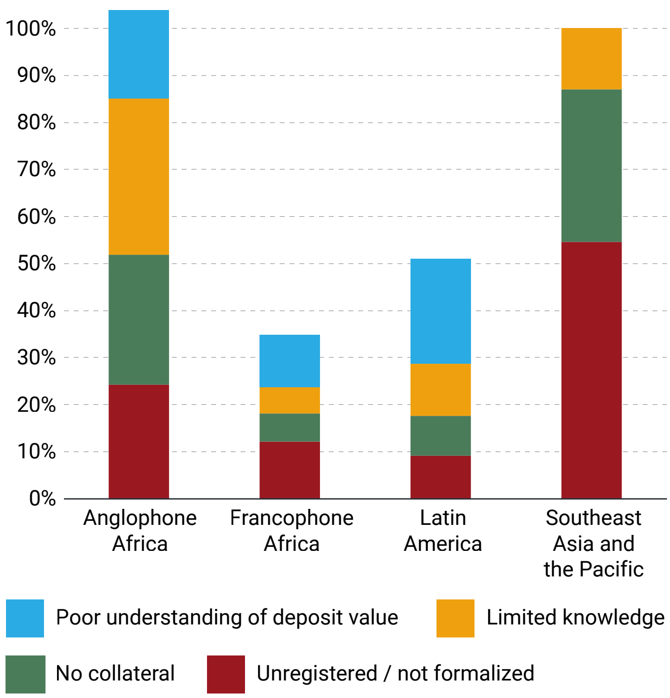
Cultural barriers for women

Finally, women miners in artisanal and small-scale mining are particularly disadvantaged in accessing finance, with cultural and institutional norms restricting their access to collateral and title deeds that, in some cases requires the permission of male family members. This highlights the fact that financing initiatives must take into account structural inequalities and local and institutional specificities in order to enhance access to funding for the most disadvantaged. As Spiegel points out in the case of microfinancing schemes, finance initiatives can be captured by elites and may be limited if they do not address such structural inequalities (Spiegel 2012).

Barriers highlighted by the survey

The artisanal and small-scale mining survey confirms that many of these barriers apply to miners of the Delve Exchange. Respondents report four main barriers to accessing finance from formal sources. Lack of concession registration and informalization were the most common reasons cited, with representatives of cooperatives and associations in each region reporting this. In South-East Asia and the Pacific, this accounted for more than half of responses. The second most common reason was poor understanding of the value of miners' deposits, followed by a lack of collateral and lastly, miners' poor understanding of how to access finance from banks and other formal sources (figure 7.2).

Figure 7.2: Barriers to accessing finance from formal sources for Delve Exchange members



Source: Author's elaboration from survey data

7.5 INITIATIVES TO IMPROVE ACCESS TO FINANCE IN THE ARTISANAL AND SMALL-SCALE MINING SECTOR

It is evident from the literature that there is no one-size-fits-all solution to artisanal miners' inability to access formal sources of finance. As discussed earlier, even formalization does not guarantee access to bank loans or credit from formal sources. Rather, solutions must be tailored to specific contexts and address common barriers. This was one of the recommendations of the Mosi-oa-Tunya Declaration on Artisanal and Small-scale Mining, Quarrying and Development, which, inter alia, urges "all stakeholders to improve access to affordable and tailored financial products for ASM [artisanal and small-scale mining], for example, by sensitizing financial institutions about the development and business potential of ASM, by facilitating the provision of credit guarantee facilities in partnership with private and public financial institutions, and by fostering knowledge sharing" (box 7.1).

Box 7.1: Recent international policy instruments recognising the importance of inclusive finance in artisanal and small-scale mining

Mosi-oa-Tunya Declaration on Artisanal and Small-scale Mining, Quarrying and Development

"Emphasise that lack of access to affordable and tailored financial products is a key constraint often cited by ASM [artisanal and small-scale mining], that leads to stagnation and eventual abandonment of ASM business ventures. Urge all stakeholders to improve access to affordable and tailored financial products for ASM, for example, by sensitizing financial institutions about the development and business potential of ASM, by facilitating the provision of credit guarantee facilities in partnership with private and public financial institutions, and by fostering knowledge sharing. Acknowledge the need for governments to grant mining rights to ASM with appropriate duration, size and production among others, to allow their use for collateral for access to credit."

United Nations Environment Assembly Resolution on Mineral Resource Governance

"To address the challenges and opportunities related to Artisanal and Small-scale Mining, the following actions should be considered by relevant actors:

a. *Encourage relevant state and non-state actors to action and adapt to the local context the Mosi-oa-Tunya Declaration on Artisanal and Small-scale Mining, Quarrying and Development;*

b. *Encourage states and other stakeholders to conduct research and share knowledge regarding the scale and geographic extent of the artisanal and small-scale mining sector through country-wide censuses;*

c. *The international community should investigate the development of a standard similar to the Equator Principles to support the financing of artisanal and small-scale mining for transformation, and to investigate options for strengthening artisanal and small-scale mining associations at the international level."*

Source: United Nations Environment Programme (2022). Mineral Resource Governance and the Global Goals: An agenda for international collaboration. Report of activities to implement United Nations Environment Assembly resolution on mineral resource governance (UNEP/EA.4/Res.19). Nairobi, Kenya: United Nations Environment Programme and the University of Queensland.

Box 7.2: Inclusive finance for small and medium-sized enterprises in Development Minerals: Partnership agreement between the African Guarantee Fund and the Development Minerals Programme of the African, Caribbean Pacific Group of States and the European Union

An example of a successful initiative to address the financial needs of artisanal and small-scale miners is the partnership agreement between the African Guarantee Fund for Small and Medium Sized Enterprises (AGF) and the Development Minerals Programme of the African, Caribbean Pacific Group of States and the European Union (implemented by UNDP), which was signed in 2017. This US$12 million memorandum of understanding provides credit guarantees to private financial institutions for loans to small and medium-sized enterprises (SMEs) operating in the development minerals sector. The agreement provided support to the development minerals sector through three main mechanisms:

1. **Capacity-building of financial institutions to understand the needs of the sector**
   A need for the provision of financial solutions for the SMEs in this sector was identified by a series of baseline studies undertaken by the Development Minerals Programme. Financial institutions were unaware of opportunities in the sector. The partnership addressed the above needs by allocating US$100,000 to capacity-building in financial institutions in the private sector. Senior managers from 50 different financial institutions in 5 countries, Zambia, Uganda, Cameroon, Guinea (Conakry) and Nigeria, were trained in inclusive finance, credit and risk assessment in the artisanal and small-scale mining sector and were sensitized to the sector through field trips to reassess their perceived high risk of lending to the sector.

2. **Capacity-building of SMEs to develop business plans, understand and apply for finance**
   The Development Minerals Programme provided for training and capacity-building of the small-scale private sector in each of the focus countries in market analysis, enterprise skills, entrepreneurship and investment promotion. Training alumni then prepared business plans to assist them to access the loans provided by the financial institutions.

3. **Provision of Credit Guarantee Facilities to financial institutions.**
   Through the agreement between the African Guarantee Fund and the African, Caribbean Pacific Group of States and the European Union, up to US$12 million in credit guarantee facilities was made available to financial institutions for the financing of SMEs in the Development Mineral Sector in the five pilot countries.

This highly targeted programme addressed specific gaps in knowledge, skills, collateral and risk that exist in both financial institutions and SMEs in this sector by providing:

- access to financing and business development services for SMEs operating in the sector;
- increased awareness within financial institutions of the entrepreneurial potential of the sector;
- technical support on financial product development by the technical staff in financial institutions in charge of business and product development;
- support for the provision of credit guarantee facilities by financial institutions through sector-specific training; and
- support to develop action plans for the financial institutions in introducing or enhancing their lending in the Development Mineral portfolio.

This case provides a unique example of a public-private partnership in the area of finance to create business success in a field that has previously been neglected.

What is evident from these and other initiatives is that there are important measures that can be applied in specific contexts which address gaps in knowledge, skills, collateral and risk that exist in both financial institutions and at the supply and miner side. One example of such an approach is the partnership between the African Guarantee Fund and the Development Minerals Programme of the African, Caribbean Pacific Group of States and the European Union, implemented by the United Nations Development Programme (UNDP). As shown in box 7.2 this initiative provided capacity-building for financial institutions to understand the needs of the sector, capacity-building for SMEs to develop business plans and understand and apply for finance, and the provision of credit guarantee facilities to financial institutions. The initiative produced various successes, including the establishment of a very successful stonecraft business in Uganda.

Apart from such tailored initiatives, the artisanal and small-scale mining sector would greatly benefit from the establishment of an international framework that directly addresses financial challenges in artisanal and small-scale mining, as suggested by the report on the implementation of the United Nations Environment Assembly Resolution on Mineral Resource Governance (box 7.1). The Resolution called on the international community to "investigate the development of a standard similar to the Equator Principles to support the financing of artisanal and small-scale mining for transformation, and to investigate options for strengthening artisanal and small-scale mining associations at the international level" (Franks *et al.* 2022).

To this end, Professor Daniel Franks and Dr Paul Rogers from the Sustainable Minerals Institute of the University of Queensland have proposed what they have termed the "Meridian Principles". The proposed Meridian Principles framework has been inspired by the widespread adoption and successes of the Equator Principles. Established in 2003, the Equator Principles is a voluntary set of guidelines for financial institutions to follow when assessing and managing environmental and social risks in large infrastructure and industrial projects they are considering financing. Under the Equator Principles, financial institutions (Equator Principles Financial Institutions) commit not to provide project finance or project-related corporate loans to clients who do not, or are unable to, meet core standards of social and environmental performance, as outlined in the Performance Standards of the International Finance Corporation.

Today, 137 financial institutions in 37 countries representing all segments of the financial sector have adopted the Equator Principles.[158] While the Equator Principles have received their share of criticism over the years, primarily related to the funding of controversial projects,[159] they have nevertheless been responsible for improving environmental practices, labour standards, human rights and engagement with local communities in the context of large-scale project development (Le Houérou 2018).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158 https://equator-principles.com/about/.

159 https://www.banktrack.org/page/tracking_the_equator_principles.

7.6 THE MERIDIAN PRINCIPLES

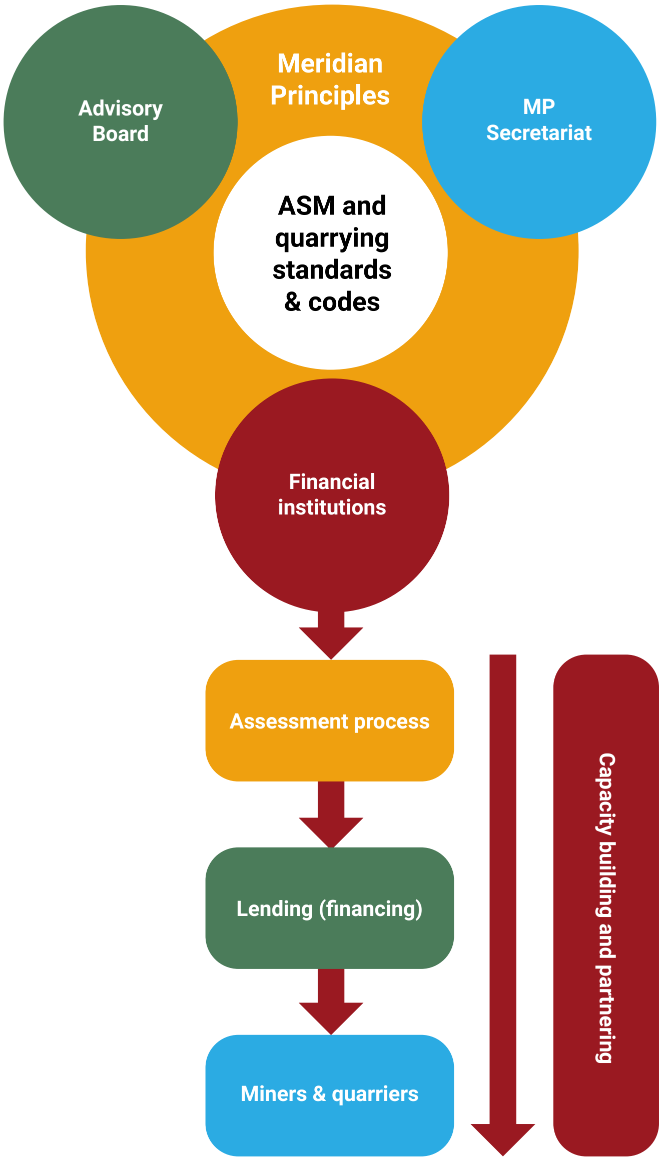
7.6.1 Objectives

Like the Equator Principles, the proposed Meridian Principles could comprise a set of specific due diligence principles that financial institutions commit to apply when they are considering financing artisanal and small-scale mining and quarry operations (figure 7.3). The primary aims of the principles are to:

- Ensure that the provision of any finance for artisanal and small-scale mining operations is contingent on borrowers complying with one of the recognized international codes of good artisanal and small-scale mining practice (e.g. the CRAFT Code[160] and the Fairmined Standard (Alliance for Responsible Mining 2019)), thereby improving the environmental, social and governance performance of operations. It is hoped that the Meridian Principles would inspire and consolidate other commodity-specific international codes of good artisanal and small-scale mining and quarrying practice.
- Ensure that careful due diligence is undertaken by financial institutions in the selection of borrowers (e.g. commitment to formalization, respect for environmental, social and governance and human rights standards).
- Build the capacities of both financial institutions and miners in financial literacy and understanding the sector.
- Enable gender equity as an integral and cross-cutting requirement.
- Contribute to the goals of the Mosi-oa-Tunya Declaration on Artisanal and Small-scale Mining, Quarrying and Development, including enhancing livelihoods and employment generation, particularly youth employment, poverty reduction and sustainable development.
- Manage environmental, social and governance and other risks for financiers, therefore improving miners' access to finance.

A potential structure for the proposed Meridian Principles is shown in figure 7.3.

Figure 7.3: Proposed structure of the Meridian Principles



Source: Authors

160 The overall aim of the CRAFT Code is "to promote the sustainable social, environmental, and economic development of the ASM [artisanal and small-scale mining] sector, by leveraging demonstrable conformance with due diligence requirements as an instrument for generating a positive development impact for ASM producers" (CRAFT 2.0, p. 8).

Key stakeholders involved in the initiative will include:

- A Meridian Principles secretariat to oversee management and administration of the principles. The secretariat could comprise representatives of multilateral and bilateral institutions, academic institutions and key financial institutions. The financial institutions represented in the secretariat would work closely with all financial institutions that have adopted or intend to adopt the principles. In addition, the secretariat could include representatives of artisanal and small-scale mining associations.
- Financial institutions that intend to become Meridian Principles financial institutions, such as microcredit agencies operating at the regional, national or international level.
- An expert advisory board comprised of representatives of international donors (e.g. World Bank), non-governmental organizations (NGOs) (e.g. Alliance for Responsible Mining[161]) and representatives of international artisanal and small-scale mining standards (e.g. the CRAFT Code). Representatives of artisanal and small-scale mining associations should also be part of the advisory board to guide the initiative, provide an important grounding in the realities of the sector, and ensure that miners are involved substantively in decision-making.

With guidance from the secretariat, Meridian Principles financial institutions will undertake an assessment to determine mineral producers' compliance with the principles, including one of the recognized artisanal and small-scale mining standards and codes. Once this assessment is complete, the financial institution will then approve finance for the artisanal and small-scale mining operation.

7.6.2 Key challenges

There are a number of significant challenges that will have to be addressed if a framework for managing environmental and social risks linked to finance for artisanal and small-scale mining is to be developed and widely adopted by both miners and potential financiers. These challenges are described in the following sections.

Informal nature of the sector

As discussed above, the informal nature of the artisanal and small-scale mining sector is a major barrier to accessing finance and will have to be addressed if the principles are to be feasible. It is estimated that, in many countries, 70–80 per cent of artisanal and small-scale mining operations are informal, meaning they operate outside of formal legal, regulatory and policy frameworks (Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development 2017). For this and other reasons, there have long been calls to formalize artisanal and small-scale mining operations in various countries so that their operations have the legally required licences and permits (World Bank 2021).

Formalization nevertheless presents significant challenges, particularly when most of the prospective land is under lease to others (for example large-scale miners) and the processes for applying for formal licences are complex and too expensive for many in artisanal and small-scale mining.

Another approach, advocated in the Mosi-oa-Tunya Declaration, is to support miners in regularizing their operations. Regularization is the first step to formalization involving activities such as establishing bank accounts and developing business partnerships, or even a bridging permit enabling a level of hybridity and flexibility (Lawson 2020).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161 https://www.pactworld.org/our-expertise/mining. Accessed 22 July 2023.

Different levels of financial literacy

Artisanal and small-scale mining is conducted by a broad cross section of people; some are educated businesspeople, but a large proportion have low levels of education, literacy and financial literacy. A staged approach to formalization and regularization provides opportunities for capacity-building and understanding existing systems of traditional finance (such as women's savings clubs).

Different levels of understanding of the prospectivity of their mine and market demand for their product

There is an opportunity for miners to engage in small-scale approaches to understanding the geology and value of their product, its supply chain and the opportunities for growth.

Gender inequality in accessing finance

Two groups of systemic and institutional constraints face women in artisanal and small-scale mining and also control the work they do. These are: lack of ownership, control and access to finance and more valuable assets; and the high burden of unpaid and poorly paid work that women undertake, which limits their economic opportunities. Gendered structural inequality often means that women in poorer areas have had less access to education. Women who cannot read are disadvantaged in all administrative and legal procedures for land permitting and licensing. Accessing finance for business development in artisanal and small-scale mining is difficult enough for women, but becomes almost impossible without literacy and numeracy. While banks may lend to agricultural projects, they are often unwilling to lend to 'risky' artisanal and small-scale mining projects and rarely consider mines as collateral (Spiegel, 2012). Banks will consider property as collateral, but this is less likely to be held by women. Women may also be required to have a male relative's signature on official documents.

Capacity to undertake environmental, social and governance assessments

It will be important to involve a range of stakeholders in environmental, social and governance assessments, notably the miners themselves through self-assessment and in cooperation with local authorities and non-governmental organizations with sympathetic and constructive oversight. Involving miners themselves and building a team of assessors will contribute to creating an enabling culture in the industry.

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7.7 CONCLUSIONS OF THE CHAPTER

The artisanal and small-scale mining sector is a labour-intensive activity sustaining millions of people and contributing significantly to national economies and global mineral supply chains. It is also the main source of development minerals, which are used domestically in construction, manufacturing and agriculture. Operations are mostly informal and artisanal and small-scale miners are among the most marginalized workers globally. Initiatives such as the Mosi-oa-Tunya Declaration and the United Nations Environment Assembly Resolution on Mineral Resource Governance (UNEP/EA.4/Res.19) seek to reduce supply chain risks for buyers of commodities and improve the lives of communities. Barriers to formalization include compliance fees, land tenure, complex registrations and lack of finance. These obstacles can be reduced with locally tailored and decentralized licensing procedures, as well as capacity-building, tax incentives, access to funding and technical support, more local participation and access to geological and geospatial data. Often perceived as high risk by financiers, the sector is not directly suitable for traditional finance owing to unpredictable returns on investments and a lack of collateral. Potential formal sources of finance include debt finance arrangements, such as microfinance, local savings and credit schemes, commercial banks, donor-funded schemes, cooperative banks, government loans and national development banks, as well as equity financing arrangements. An original survey of artisanal and small-scale mining miners in the Delve Exchange knowledge network of the World Bank highlighted common finance needs for equipment and machinery, exploration, mapping, permits, licences, feasibility studies and mine-site preparation. Further costs include salaries for workers, food supplies, utilities and fuel, as well as education. The survey also highlighted the prevalence of abusive and exploitative lending practices by informal lenders.

As suggested by previous international policy instruments, the sector would greatly benefit from the establishment of an international framework that directly addresses financial challenges. To this end, the Chapter introduces the concept of the Meridian Principles, inspired by the Equator Principles. These should be designed in such a way as to not only benefit miners and their communities, for example through improved health and safety standards, but also through mitigation of environmental, social and governance risks in artisanal and small-scale mining operations, to make previously high-risk investments more attractive to financiers. Processes for carefully selecting borrowers (e.g. prioritizing groups that can demonstrate accountability for their loans), capacity-building on both the supply and demand sides, and the provision of credit guarantee facilities will also increase the interest of financiers.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS FOR FINANCIAL AND OTHER REFORMS TO ACHIEVE THE RESPONSIBLE PRODUCTION OF METALS AND MINERALS

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CONTENTS

8.1 CONCLUSIONS

This report has shown the need for internationally coordinated action by multiple stakeholders – the financial sector, including the banking sector, insurers and financial institutions more generally, bilateral agencies, public authorities, investors, academia and research institutions, and non-governmental organizations (NGOs) – to close the gap between mineral and metal production and sustainable development. There is widespread support for mining in many of the communities in which it operates because of the benefits it generates. There are also many examples of social and environmental good practice in the mining industry, but there is also evidence that impacts related to minerals and metals production are still considered economic externalities by a large part of the industry and left for local communities, governments and future generations to cope with. In consequence, social and environmental impacts on these communities, which have a disproportionate impact on women and Indigenous peoples, continue to generate widespread hostility to mining. Individual initiatives alone will not solve these problems and the adoption of good practice would be accelerated by some supervision by a global yet streamlined public-private structure that combines the most ambitious approaches of the many fragmented governance initiatives.

There has been considerable development in the form of some widely used reporting standards for exploration projects, as well as real progress over the last 20 years in the availability, accessibility and quality of site-level data and information on exploration projects. Despite this, there are still many gaps to be filled to provide the comprehensive, site-level, detailed data and information needed to inform all stakeholders of the full sustainable development-related impacts of minerals and metals production projects and productive operations, including those of artisanal and small-scale mining. These data and information are necessary to properly inform and guide the actions of investors and financial institutions and all other stakeholders. As regards the facilitation of decision-making, the availability of such data and information would help to develop trust among stakeholders, speed up projects and, ultimately, reduce costs, including those related to economic, environmental and social externalities. Financial and other policy instruments need to be assessed in tandem.

The development in Australia and Canada of mandatory reporting on mineral exploration projects carried out by companies listed on their respective stock markets, while not perfect from a sustainability perspective, and the Global Tailings Management Initiative show that progress is achievable and that it is not only not a deterrent to, but may be a requirement for, the development of the minerals and metals industry. In South America, the Regional Agreement on Access to Information, Public Participation and Justice in Environmental Matters in Latin America and the Caribbean (Escazú Agreement), which came into force in 2021, may lead to greater information provision from and community engagement in, mining projects.

At the same time, a possible future framework on international reporting and disclosure will need to be adapted to the constraints of small and medium-sized companies, both domestic and international, and to the local complexities of artisanal and small-scale mining operators, who lack the resources to report on their activities in detail. The almost total opacity of the agreements for long-term contracts, which some original equipment manufacturers and supply-chain enterprises have entered into with mining companies, will also need to be addressed.

It will be very important for transparency and reporting requirements to extend to supply chains too. The approach of the guidance of the Organization for Economic Cooperation and Development (OECD)[162] means that all companies throughout the supply chain have to share the task of collecting information, carrying out risk assessments and implementing mitigation measures. The European Union has been building its environmental, social and governance expectations around this system, in particular through the Batteries Regulation (Regulation (EU) 2023/1542), but also the Conflict Minerals Regulation (Regulation (EU) 2017/821), the Directive on corporate sustainability reporting (Directive (EU) 2022/2464) and the Directive on corporate sustainability due diligence (Directive (EU) 2024/1760). The approach requires independent third-party verification at specific points in the supply chain. With the cooperation of the London Metal Exchange, all metals producers now have to comply with the requirements of the OECD guidance, which allows companies further downstream in the supply chain to have some sense of

162 https://www.oecd.org/daf/inv/mne/mining.html.

assurance.

Processing and refining capacities are also an important part of the supply picture; they may present some of the biggest bottlenecks and challenges around securing capital expenditure for investment in new processing and refining capabilities. This is also the stage where some of the minor metals that are very important for the low-carbon energy transition, and that are produced in very small or relatively small quantities, leave the mining value chain. An important task of the proposed international minerals and metals agency (see below) would be to determine how to secure greater recovery of these minor (or companion) metals where this seems desirable.

Looking at the sector in the round, there will be no low-carbon energy transition away from fossil fuels without action leading to the restoration of trust among all parties involved and to the production of the needed minerals and metals in accordance with traceability and verifiability standards, the Sustainable Development Goals and ethical principles. Many projects essential to delivering the minerals and metals needed to enable this transition could be delayed for years and even decades as a result of the lack of trust among stakeholders. They need to come together to provide each new project with its sustainable development licence to operate, which, among other benefits, could strengthen sector governance and reduce the risks to investors of roadblocks to project delivery.

The responsibility for action cannot be left solely to some members of the global minerals and metals or finance industries. Policymakers have a major role to play in synthesizing the many regulatory and institutional standards to create an international framework and address the sustainability issues of the minerals and metals industry. The State also needs to invest in responsible mining, while reducing subsidies and tax holidays for non-responsible mining. Governments need to take risks, but also benefit from returns. In addition, investors and financial institutions, industry end-users and consumers have an important role in making this happen by imposing their fundamental right to full information on economic, environmental, governance and social production conditions. Moreover, companies, irrespective of their business model, must be required to disclose data on their projects and operations that have sizeable environmental, social and governance impacts, such as water usage, energy consumption or carbon dioxide emissions, with minimum exemptions on the grounds of necessary commercial confidentiality. A sensitive balance needs to be struck, as will hopefully be the case with the forthcoming implementation of the Directive on corporate sustainability reporting, between the agility and flexibility of the market and the need for some regulation and bureaucracy to ensure that high environmental, social and governance standards, as defined and discussed in Chapter 6, are met, and non-market public goods are delivered.

Of the transition metals in use today, the capacity of recycling to meet the demand in the next decade is estimated to be low. Higher recovery rates are possible, and in the European Union, for example, they could be mandated through the Regulation on critical raw materials (Regulation (EU) 2024/1252). However, too often high levels of recovery are not economical from a private stakeholder perspective. In those cases where higher recovery rates are possible with current technologies at a reasonable cost, placing a tax on wasted metal could increase recovery rates. The revenues could help to develop new technologies and their market uptake. Alternatively, mining permits could be issued that are conditional on the proportion of the resource extracted. This is not currently a metric tracked by regulatory agencies, but it should be. However, higher recovery rates of metals, and the expansion of circularity approaches to increase the length of time they stay in the economy and recycling to produce secondary materials, may not be enough to permit a sufficient supply of some of these metals to meet the higher projected demands. In such cases, measures will need to be taken to act directly on such demand, to ensure that transition minerals are put to their highest value use to fulfil the basic functions (e.g. renewable energy generation) for which they are required.

A sustained internationally coordinated effort is needed to support the reinforcement of institutional capacities in lower-income, mineral-rich countries and to assist with the development of their geoscientific databases, as well as with the acquisition and dissemination of environmental and social baseline data so as to, inter alia, reveal and harness the contribution of artisanal and small-scale mining. Geological settings across the world make trade essential to supplying minerals and metals to countries without favourable geological conditions. To ensure that this trade fosters the sustainable development of all parties, a partial minerals and metals decommodification is necessary. This would involve a willingness on the part of the manufacturing industry, which depends on minerals and metals downstream, and their consumers to pay a premium price for minerals and metals verifiably produced according to the responsible mining practices outlined in this report as part of a commitment to responsible consumption. There is some evidence of such willingness in the green steel contracts that are being entered into by some vehicle manufacturers. All of this calls for well-coordinated international actions to address the sustainability issues related to the minerals and metals industry, and involves a fundamental reconfiguration of trade in metals and minerals and the exchanges through which the market operates. In the absence of internationally well-coordinated actions, geopolitical conflicts for control over strategic natural resources, including minerals and metals, seem likely.

Investment considerations

The provision of minerals for the low-carbon energy transition at the projected levels of demand requires huge investment. If these minerals are produced by fossil fuels, their provision will cause impacts contrary to the objectives of the global transition towards zero-carbon emissions. Even with a significant expansion of secondary sources, hundreds of billions of dollars in investment will be required up to 2050 to explore for and put into production, alongside low-carbon energy, the mineral deposits needed to meet the projected demand. The scale of investment required makes it even more important that high environmental, social and governance standards are observed; the expansion of mining could cause otherwise enormous social and environmental damage.

A huge research and innovation effort will be needed to develop and implement pro-sustainability technologies throughout the minerals and metals life cycle, with priority to be given to resource savings and efficiency, followed by the high-quality recycling of minimized production wastes and end-of-life products. The development and deployment of these technologies must not be allowed to be impeded by overly restrictive bureaucratic requirements, including where in relation to intellectual property.

The market problem with the supply of green metals is that higher prices are needed for the needed quantity of supply to be explored for, developed, mined, and delivered to the market over the next 30 years. Miners are not willing to act now at the necessary scale to bring deposits on line in 15 years in view of the lack of surety over returns. Demanders are similarly unwilling to undertake research and development to develop green energy alternatives on the scale needed without some surety of green metals supply at a reasonable price. Forward markets, where suppliers sell and demanders buy at some future specified date, as is offered for some metals by the London Metal Exchange,[163] need to be further developed for transition minerals.

Public investment in minerals provision is likely to be mainly focused on education, research and innovation and the strengthening of scientific institutional capacities, including in geological surveys, which will then enable mining companies to undertake the more detailed exploration activities needed to determine whether there is an economically viable resource. Attracting more students into the study of mining disciplines is also of major importance. At present there are falling numbers of student recruitment in every discipline related to mining, even geology, which is at least partially because mining may be perceived as a 'dirty' industry. It is important to raise the profile of mining as a field that can lead to rewarding careers not just in mining, but also in environmental, social and governance-related fields in the industry. Mining needs to be perceived and recognized as a business requiring many different skills that is fundamentally important to achieving the Sustainable Development Goals and delivering sustainable development.

While public finance is also proving important in some jurisdictions for exploration, as well as geological surveys, private funds will also need to be leveraged (for example, through public-private partnerships, blended finance solutions and concessional finance) in exploration and mining activities further downstream. Many governments need to strengthen their actions to design and implement the national regulatory frameworks required to foster a pro-sustainability minerals and metals industry. There also needs to be international coordination of these frameworks to develop a global regulatory playing field that is pro-sustainability. Such actions are of the utmost importance to building transparency and trust among the many stakeholders in the global minerals and metals industry.

163 See the Guide to cash-settled futures of the London Metal Exchange (July 2020) at https://www.lme.com/en/education/online-resources/lme-insight/introduction-to-cash-settled-futures.

The drivers of pro-sustainability improvements in mining will need to be: effectively enforced legal frameworks; effectively enforced transparency (site-level disclosure) and accountability (quadruple bottom-line reporting at the site level), with short-term (next year), medium-term (2–5 years) and long-term (5–10 years) quantified improvement objectives; civil society engagement, with free and prior informed consent; informed and transparent economic, environmental, social and governance objectives for investors; and an end to tax havens and tax evasion schemes, in line with the standards of the Global Forum on Transparency and Exchange of Information for Tax Purposes.[164] The Responsible Mining Index[165] has also played a very useful role in highlighting progress, or the lack thereof, on issues of social and environmental responsibility in the mining industry. Such issues are also now being picked up by policy developments in the European Union (the Directive on corporate sustainability reporting and the Directive on corporate sustainability due diligence). In the United States of America, there have been some developments (e.g. Climate Disclosure Rules of the Securities and Exchange Commission) in the same direction.[166]

For private finance to flow at scale into the mining sector, the risk/return ratio will need to be sufficiently attractive. The risk side of the ratio is adversely affected by a number of circumstances that are not exclusive to, but are particularly relevant to, the mining sector: geopolitical risk; governance and policy risk; environmental, social and governance-related risk; local social factors; and the risk of asset-stranding from technological innovation (see the Appendix to Chapter 5).

Policy risk comes about through uncertainties related to national and international policy. The former arises over uncertainty as to whether national governments will permit mining companies, once investments have been made, to extract the minerals over the long term so that the companies can recoup and make a normal return on their investment. The latter may arise when the governments of richer countries engage in subsidy competition to attract investment away from countries that would be better suited to supplying mineral demands. Countries and regions with a strong regulatory framework may need to review it to enable permits to be obtained more quickly. Stable and proportionate policies are essential to allowing the kind of innovation that will be required to meet the coming global demand for minerals and metals in a sustainable manner. This calls for internationally coordinated action.

Environmental, social and governance-related risk for investors arises when the mining companies that receive their investment do not pay adequate attention to environmental, social and governance factors and thus attract negative publicity and, perhaps, hostile campaigning activity. At the least, this can lead to reputational damage, but if sufficiently intense it can have an effect on the actual mining operations of the company and to the global supply of minerals and metals. To reduce this risk, the alignment of investors' financial portfolios with climate and biodiversity goals should be assessed and monitored, with the definition and disclosure of viable pathways to allow companies to align with such goals. The effective traceability of environmental, social and governance-compliant minerals throughout the whole mineral life cycle (including recycling) is also key to reducing these risks. On the basis of these factors, financial institutions can determine specific exclusion criteria and an engagement strategy that supports companies' transition pathways.

The risk arising from local social factors is a specific kind of environmental, social and governance risk, in that it derives from the company failing to win a social licence to operate, either because it damages some aspect of the community or environment in which it is operating, or because it fails to meet the economic expectations (e.g. in respect of wages, employment, working conditions or community infrastructure) of its host community. Transparency in respect of mining operations is essential to winning the trust of local communities, including in terms of their impacts, particularly on women and Indigenous people. It may be that the social licence to operate, which is currently informal, should be tied in some way to regulatory processes.

164 https://www.oecd.org/tax/transparency/.

165 https://2022.responsibleminingindex.org/en.

166 United States of America, Securities and Exchange Commission, see: https://www.sec.gov/news/press-release/2022-46; https://www.sec.gov/files/rules/final/2024/33-11275.pdf.

The return side of the risk/return ratio is obviously affected by the uncertainties surrounding both the cost at which the mineral can be produced and the price at which it can be sold. Mining companies are used to handling these uncertainties, but they are likely to be particularly acute in respect of the minerals required for the low-carbon energy transition, for at least five reasons, which are discussed in detail in earlier chapters.

First, the scale at which it seems likely that some of the minerals will be demanded (e.g. copper and perhaps nickel), which requires very large investments.

Second, innovation and technological change, which means that minerals currently thought crucial to the low-carbon energy transition (e.g. lithium and graphite) may be substituted by other minerals or displaced by completely new technologies serving the same function.

Third, the fact that many of the relevant minerals are currently produced as by-products of the production of other metals, so that the profitability of producing them is inextricably linked to that of the primary metal being produced.

Fourth, some of the minerals are needed in very small quantities (e.g. rare earth elements), meaning that they are expensive to process and may not be attractive for mining companies, despite selling for a high price (as they would require a lot of investment for a very small market). Moreover, the competitiveness of new production plants may be undermined by predatory pricing from other jurisdictions.

Fifth, the production of minerals to high environmental, social and governance standards may incur costs that are not faced by production elsewhere that are subject to lower standards, making minerals subject to high environmental, social and governance standards uncompetitive in price-driven commodity markets.

Addressing these issues requires major changes to price and procurement policies so as to allow investors and mining companies to invest and produce in the knowledge that they will sell their product at a price that will take into account the observance of high environmental, social and governance standards. Policy instruments for these purposes need to be developed and implemented internationally. Suggestions for such instruments have been made throughout this report and are summarized in the recommendations to follow.

Each of these risk/return issues has its own dynamics and will require a risk strategy, involving the relevant set of actors. Such issues need to be addressed so that private financial institutions feel sufficiently confident to provide the scale of finance that is required. This involves agreements founded on a mutually beneficial three-way partnership between the host community, the producing country and the importing country, which includes the major relevant stakeholders (companies, investors, trade unions) from each side. North-South partnerships must put the sustainable development objectives (including strengthening local content) of mining countries at their heart and back this up with the capital and guarantees needed for responsible mining compliant with environmental, social and governance standards.

The terms of the partnership must be sufficiently attractive to the local community for it to actively welcome the mine, following extensive engagement with the mining company at the exploration stage and thereafter. For the national government, the terms must offer the prospect of wider economic linkages and development. For the importing country, the partnership needs to ensure the security of the mineral supply within an agreed price window.

The partnership agreement would need to be expressed in a long-term binding contract that sets out the details of the terms along these lines, such that each of the major stakeholders feels that it is deriving a fair share of the benefits of the mining enterprise. The alternative seems likely to be an intensification of the current arrangements of supply contracts, offtake agreements and other means (as discussed in Chapter 5), which could lead to an unseemly scramble for transition minerals, price volatility, speculation and potential hoarding by original equipment manufacturers, driven by expectations of future mineral shortages.

The negotiations over these terms would doubtless be intense and protracted. Given the levels of mistrust currently common between local communities, host countries and mining companies, this is to be expected. It is only through the successful conclusion and operation of such partnership agreements that greater trust can evolve so that mines can be built and operated without conflict.

This is important for small, local companies as well as for large-scale mining operations. These companies can be supported by collaborative organizations, i.e. clusters, associations and networks that can discuss, negotiate and develop more sustainable mining. An example of a good practice is the Iberian Sustainable Mining Cluster, which is aimed at promoting sustainable mining, consolidating the strengths of the mining sector and its associated services and boosting sustained economic growth, giving priority and special attention to small and medium-sized enterprises (SMEs). There is also the Towards Sustainable Mining standard,[167] developed by the Mining Association of Canada, which is now being used by some Scandinavian countries. However, in less advanced developing countries, support may be necessary for local communities and businesses that lack the structured business activities and skill levels to allow them to negotiate effectively with mining companies.

The rest of this Chapter sets out recommendations for the conditions that would have to exist for such stakeholder partnership arrangements to be viable.

8.2 RECOMMENDATIONS

i. Improve transparency, reporting and local engagement

Transparent reporting is essential and a pre-condition for mining companies to be held accountable to stakeholders for their impacts. These companies should therefore have a mandatory requirement to disclose information about their environmental and social impacts, on a site-by-site basis, and ensure that this information is publicly available to inform decision-making processes.

This is especially important because, with an expansion of mining activities, more and more projects will enter into the lands claimed by Indigenous people, and many land claims are not yet settled by nation States. The financial sector needs to recognize this and promote implementation principles based on free prior and informed consent, recognizing Indigenous people's rights according to United Nations rights to land (for example, as articulated in the Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security of the Food and Agriculture Organization of the United Nations[168] (see Chapter 3)), rights to national resources and the requirement to seek meaningful consultation and consent. This will require an engagement with customary systems that are not often recognized by States and companies. There should be more support for Indigenous communities, as environmental, social and governance issues cannot be adequately considered without considering Indigenous rights. The reporting should also include the issues of climate mitigation, climate adaptation, impact on biodiversity, social impacts and pollution (including toxicity and the use of chemicals), and take into account the interconnection between agendas and how they can interact positively or negatively.

The reporting should be done to an international standard with a harmonized minimum core set of data points to help benchmarking, inform decision-making on investment and lending, and rely as much as possible on existing or emerging reporting and disclosure requirements (e.g. the Task Force on Climate-related Financial Disclosures and the Task Force on Nature-related Financial Disclosures). This information should be externally audited to assess its veracity. The concept of a competent or qualified person, developed by stock market supervisory authorities, essentially in Canada and Australia for reporting on exploration activities, at the time of the completed feasibility study, could possibly be extended to implement this auditing requirement. It is to be hoped that many of these issues will be effectively addressed by the forthcoming implementation of the Directive on corporate sustainability reporting and the Directive on corporate sustainability due diligence, as discussed in Chapter 6 and mentioned above.

167 https://mining.ca/towards-sustainable-mining/.
168 https://www.fao.org/tenure/voluntary-guidelines/en/

The current sustainability reports of many companies mainly provide company-wide aggregate information only, often across sites in many different countries. This is not adequate to provide transparency on company operations in particular places and countries. It is easy to gloss over poor practices and outcomes in a general sustainability report. The variety of reporting standards also fails to serve transparency because they enable companies to choose indicators that show them off to best advantage, while allowing them not to report on issues where their performance has been substandard. It is to be hoped that the work of the International Sustainability Standards Board, which seeks to integrate some of the most used reporting protocols and is taking over the monitoring and responsibilities of the Task Force on Climate-related Financial Disclosures from 2024, will provide a reporting framework that becomes universally adopted in the near future. So far, the Standard for Responsible Mining developed by the Initiative for Responsible Mining Assurance is the most comprehensive existing reporting framework available for reporting on the environmental, social and governance performance of active production sites.

From the very beginning of mineral exploration, companies performing exploration activities, investors in these activities and public authorities promoting and regulating these activities should all support the acquisition of baseline data by environmental and social scientists, distinguishing between men and women, and with the active, verifiable engagement of the local community, including women and Indigenous people. Working jointly, developing transparency and public reporting on these topics is an efficient way of identifying risks and developing risk reduction and mitigation strategies at an early stage, reducing the risk of later conflicts and other issues that otherwise can delay a project for years, or even block it. These risks can also be reduced by using these engagement activities to identify local economic opportunities and improve social conditions. Risk reduction of this kind will make projects more attractive to investors and financial institutions.

In addition to more transparent reporting and systematic engagement, work should be accelerated on enabling a digital product passport for all mineral commodities and their value chains, so that the output of each mine and its subsequent processing can be identified according to its environmental, social and governance credentials on the basis of a standard reporting protocol. Trading exchanges could require such environmental, social and governance information for the metals which they handle.

In the first instance, the passport could only be applied in respect of the mine output, although in due course it could be applied downstream to metallurgical processes for particular issues, such as greenhouse gas emissions. The process could start with some of the metals that have the most problematic environmental, social and governance impacts and could be implemented by companies with the necessary skills and resources to do so. By specifying the contents and location of key metals in a given product, it is to be hoped that the end-of-life reclamation of these metals would be greatly facilitated, and investors, financial institutions and the downstream supply chain would be reassured about the responsible nature of production. Special arrangements may need to be made for minerals from artisanal and small-scale mining. The Global Battery Alliance has already developed a proof-of-concept in the form of a digital twin of a battery passport, which specifies the information requirements for such a passport in some detail.

Recommendations:

- Mining companies should report their financial, environmental, social and governance outcomes on a site-by-site, gendered and 'shared value' basis that also takes Indigenous rights into account, according to an agreed industry-wide protocol.
- Site-by-site reporting should contain at a minimum the information covered by the International Resource Panel (IRP) Protocol for the planning and monitoring of mining operations (IRP 2020, p. 311).
- Current corporate processes that engage with and involve local communities in data acquisition and reporting should be developed and become more widely adopted.
- A digital product passport for all mineral commodities and their value chains, including environmental, social and governance information, should be developed on the basis of a standard reporting protocol, and be required by metal trading exchanges.

ii. Incentivise higher mineral recovery and recycling rates as part of the circular economy

There is a lack of incentives in policies and practices in many countries for the recovery of a high proportion of the main metal resource, let alone for minor by-products and accompanying elements. The residual metal therefore ends up in tailings, which are often not properly recovered during the mineral processing and metallurgical treatment of ores, so the metal residues end up diluted in containments or in slags, or are wasted. Most of the minor metals are concentrated in smelters and refineries and often do not count in mining operations (in the absence of integrated processes). Even though there are many possible innovative approaches to recovery, there is a high risk associated with complicated processes and a lack of standards and good practices to support circular economy initiatives, such as industrial symbiosis. Incentives should be given to mining companies to extract a high proportion of the available resource. The presence of minor elements in exported ores should also be identified so that consideration can be given to the benefit the exporting country should derive from them.

In principle, recycling should be considered a final-stage circularity option after the implementation of all other possible pro-circularity actions needed to reduce the demand for primary minerals and metals and to promote the use of more abundant minerals and metals. Pro-circularity actions include a wide range of actions, such as the eco-design of products and the fight against planned obsolescence, as well as the reuse, refurbishment, repairability and remanufacturing of goods, and lifetime extension options. Any targets for material recovery and recycling through extended producer responsibility requirements should be set without compromising these other circularity approaches.

At the same time, the finance of pro-circularity projects should promote the best available technologies and practices so that products may be put to alternative use (e.g. batteries can have multiple lives), and new, more efficient technologies can supersede outdated ones. The social costs of all available circularity options, including material, energy and labour inputs, environmental impacts and geographical conditions, should be taken into account, as well as their potential benefits, such as energy efficiency in the (remaining) lifetime of products and job creation.

The volume of transparent and updated information about, inter alia, resources, investment procedures, taxes and local requirements in mining countries has been increasing,[169] as have global industry standards on tailings management. However, more transparent data, regulations and good practices are also needed for the recovery of metals from tailings and elsewhere, e.g. through biomining.

The safety and regulation of informal recycling systems need to be improved through effective monitoring measures and the funding of appropriate technology. Public-private partnerships can be used to set up formal recycling systems, particularly in emerging economies. Eco-design financing can help to address the challenge of product design, which is critical to ensuring that products can be easily disassembled and recycled. Green bonds can be used to fund the development of new recycling facilities and infrastructure able to handle the increasing complexity of modern products. Impact investment can be used to fund companies that are developing new recycling technologies able to handle different processing streams, including urban mining, and working on new ways to recover metals from products that are difficult to recycle. Governments can finance awareness-raising campaigns for household recycling with a particular focus on population groups with lower rates of recycling. Governments can enable finance for investments in the recycling infrastructure to lower the cost of recycling and make it more economically viable. Without the reliable and realistic measurement of past and current recycling efforts, it becomes extremely difficult for stakeholders to make decisions on recycling policies and finance.

The long lifetime of products, while generally desirable from a circularity perspective, presents a challenge for recycling, because economically viable recycling requires substantial quantities of end-of-life materials to become available, and because technologies can evolve quite quickly, creating uncertainty about the demand for the recycled materials once they eventually become available. Financial support for recycling may be required in advance of these materials becoming available for recycling. In addition, projections of future metal prices are crucial to making decisions about investments in recycling infrastructure. Internalizing the social and environmental costs of primary metals in their price will make it more economically viable to recycle these metals, but financial incentives for integrated metal production may also be required to reduce the vulnerabilities of recycling firms to the high volatility of metal prices. A

169 E.g. https://www.mineralplatform.eu/.

better understanding of the comparative environmental and social costs of mining and recycling required to produce transition minerals is necessary to make better-informed investment decisions for sustainable resource management. The environmental and social cost of metal recycling can be assessed using methods such as the impact pathway approach. The development of assessment methods for environment, health and safety in the mining and recycling industries could also help policymakers to choose more eco-friendly support measures.

Recommendations:

- Incentives should encourage mining companies to extract high proportions of the metals in their ores.
- More information about tailings and other residues should be made available to open up possibilities for re-mining in the future.
- Exporting countries should benefit from the extraction of by-product metals recovered in the smelting and processing stages in other countries.
- The recycling of minerals and metals should be considered the final stage in circular materials management, following the application of other circularity approaches before products reach the end of their life.
- Policymakers should improve the economic viability of circular economy approaches to materials and product management by internalizing the social and environmental costs of primary materials production, implementing circular policies through the transition minerals value chains, validating novel financial instruments (e.g. green bonds) to increase investment in circularity, and supporting innovative remanufacturing and recycling technologies.
- In addition to the maximum use of circularity policies and approaches, material demand management is likely to be necessary to ensure that the material supply is sufficient for the essential uses in the low-carbon energy transition.

iii. Improve the management of mineral markets and build stronger national institutions

Current metal markets discriminate against metal production with high environmental, social and governance standards because of the lack of a recognition system for such products, which would allow them to command higher prices and attract customers aware of environmental, social and governance concerns. While the ultimate objective should be for all traded metals to be produced according to high social and environmental standards, there are a number of possible ways that global metal production could be pushed in this direction, including by developing mandatory product passports and giving greater weight to environmental, social and governance performance by the financial sector, as discussed earlier.

Companies that seek to produce to high environmental, social and governance standards and internalize environmental and social costs run the risk of becoming less competitive than companies that do not. A solution that has often been proposed in such contexts is a border adjustment that seeks to level the playing field between products and processes that have internalized environmental and social costs and those that have not. A possible mechanism to achieve this would be a raw material border adjustment mechanism. Its purpose would be to ensure that products produced to high environmental, social and governance standards, and the factories and other facilities that produce them, are not undercut in price by commodities with low environmental, social and governance standards The border adjustment mechanism is not meant to be a protectionist tool but rather aimed at leveling the playing field in terms of sustainability indicators in global trade. Including development indicators and benefit sharing impacts in the adjustment mechanism may favor the Global South as well.

The implementation of this recommendation would require the availability of the information resulting from earlier recommendations. The instrument should be designed in such a way as to encourage all jurisdictions to adopt high standards so as to obviate the need for border adjustment for imports. The instrument should also be robustly designed to ensure it is not discriminatory, except as regards high and lower environmental, social and governance standards, and it should be flexible enough to recognize efforts to improve environmental, social and governance performance from low starting points, as well as high environmental, social and governance standards.

A mining club for sustainable development might help to increase environmental, social and governance standards, perhaps building on an initiative like the Minerals Security Partnership, a coalition of 14 countries and the European Commission set up "to accelerate the development of diverse and sustainable critical energy minerals supply chains" and "strive to elevate environmental, social, and governance (ESG) standards across the global minerals sector".[170] However, the Partnership currently only has developed countries as members, with the exception of India, and has no representation from either Latin America or Africa. It will need to become more diverse if it is to achieve its objectives and provide a solid basis for responsible minerals production and trade.

Through international development cooperation and other means, many resource-rich countries require support for regulatory capacity-building and reform in order to ensure that they can monitor and enforce the production of their resources to high environmental, social and governance standards. A possible mechanism would be the inclusion in free trade agreements of a requirement for trade in raw materials to meet high environmental, social and governance standards in areas such as capacity-building, economic diversification of the exporting country, access to finance, corporate social responsibility and responsible business practices.

Three sets of institutions are needed for governments to ensure the expansion of responsible mining: a geological survey to identify the most promising sites for future mining; a mining directorate to develop and enforce appropriate legislation, negotiate with companies to obtain appropriate value-sharing, and ensure that local communities are properly represented and able to participate actively in decision-making about mining in their localities; and an environmental agency to ensure that the mining operates in an environmentally sustainable manner and, jointly with the geological survey, acquire baseline data and identify any subsurface related issues, such as the availability of sufficient groundwater to feed future projects, the selection of the best possible waste storage sites and the assessment of natural hazards that may have an impact on future production or waste storage. While many countries already have these institutions, there are also many gaps, and some of the existing institutions are under-resourced. The institutions need to be robust enough to counter efforts at bribery and corruption, which still affect a number of countries, and to operate a legal system that is effective at dispensing justice. In countries with effective minerals governance, there may be a role for State-owned companies, as shown by the experiences of Finland, Sweden and Chile.

Support is also needed, especially for small-scale mining companies, to minimize permitting risk and ensure the achievement of responsible mining standards. In some mining countries, each step of mining operations (from exploration through to mine closure and reclamation) is well regulated, but care should be taken to avoid conflicting regulations at different levels of government. Mining associations or clusters to support SMEs in permitting and ongoing operations, as well as to help them to cooperate with different agencies and bodies, are also needed.

The Democratic Republic of the Congo would be a prime candidate for such support. It has some of the largest and highest-grade copper and cobalt deposits in the world. High-grade deposits may mean that the mining has a lower environmental impact, thanks to a lower amount of energy needed and a smaller amount of waste produced per metric ton of metal extracted. However, the Democratic Republic of the Congo is one of the riskiest countries in which mining companies can invest. In such circumstances, there is a temptation for companies to extract only the most accessible resources and get their money back quickly, leaving much of the metal in the ground and likely sterilized. Reducing risk in the Democratic Republic of the Congo to enable consideration of longer-term investment is a high priority.

Recommendations:

- Mineral-rich developing countries should be supported as necessary, through international development cooperation and other means, to legislate for and build the necessary institutions to regulate responsible mining effectively and justly, so that the whole society can benefit from the coming mining boom.
- Jurisdictions that wish to actively stimulate mining to high environmental, social and governance standards and to import products from such mining should join together in a mining club for sustainable development and consider establishing a raw material border adjustment mechanism. The border adjustment mechanism is not meant to be a protectionist tool but rather aimed at leveling the playing field in terms of sustainability indicators in global trade. Including development indicators and benefit sharing impacts in the adjustment mechanism may favor the Global South as well.

170 https://www.state.gov/minerals-security-partnership/.

iv. Reform the financial system: Financial taxonomies, architecture and instruments

Expanding mining will need improved access to finance.

At present, mining generally does not appear in sustainable finance taxonomies, and is often excluded from sustainable finance portfolios. This must change, because there will be no low-carbon energy transition, and therefore no large-scale climate mitigation, without the minerals discussed in this report. It is therefore logical that finance for mining to high environmental, social and governance standards should qualify as sustainable finance and perhaps be included as a special form of climate finance, to be administered by the institutions responsible for delivering such finance, as well as through normal financial markets. To make a difference to investment levels, this would require both sustainable and climate finance to be dramatically increased.

More broadly, sustainable finance taxonomies are expected to be a powerful way to reorient financial flows towards pro-sustainability activities. Rather than including mining as a sector, it may be desirable to limit inclusion in the taxonomy to only those minerals and ores that are the most critical for the transition. This could help to reorient financial flows, e.g. from minerals such as gold, which are of limited industrial application, towards transition minerals. Inclusion in a taxonomy would require the reporting by mining companies on the environmental, social and governance conditions of production, including in respect of shared value between the community, mining company and country of operation. Sustainable finance should also be made available to improve the conditions and situations of those not performing to such a high standard, including in artisanal and small-scale mining production, provided that they have clear and monitored plans for such improvement that the finance could enable them to implement. Sustainable finance regulations also have an important role to play in curbing illicit financial flows, including those associated with aggressive transfer pricing and commodity mispricing.

All sources of funding, including sovereign wealth funds and the sustainability coalitions of private financial institutions (e.g. Glasgow Financial Alliance for Net Zero/Net Zero Banking Alliance for Climate) should set mandatory standards to finance only those mining projects that are consistent with major global agreements (e.g. the Paris Agreement and the Kunming-Montreal Global Biodiversity Framework), that have won the consent of local communities and host countries and that have a low environmental impact.

Along with the standards there would need to be recognition that minerals that meet such standards might need premium prices to enable any associated costs to be recovered. While the standards would need to be set and their achievement monitored at the national level, special efforts should be made to involve key insurance actors, re-insurers and agencies, such as the Multilateral Investment Guarantee Agency of the World Bank Group, to help to develop a globally responsible mining concept based on the design and implementation of a sustainable development licence to operate, in order to clarify and reduce the risks they are exposed to when covering specific mining projects.

Instruments promoting sustainable activities or behaviours support the proliferation of good practices and provide market signals to investors and financial institutions. Companies should have a credible (and ideally verified) transition plan that meets minimum requirements. Transition bonds, tailored to enable heavy polluters and high-emitting industries to improve their environmental, social and governance performance, are currently perceived as having a high risk of greenwashing, which is one of the reasons why the market for transition bonds has not yet been greatly developed. To address this perception, there is a need to agree on common minimum requirements to qualify for transition bonds. The same applies to sustainability-related bonds. If robustly validated and subject to stringent monitoring, reporting and verification requirements, transition bonds could be a valuable alternative means of raising capital for companies willing to shift from high- to low-carbon activities without being labelled as "green" or "sustainable", while still signaling their transition ambition to investors and financial institutions.

Public finance for mining could be provided, for example, through concessional finance or the reduced cost of capital provided by multilateral development banks, preferably through a coordinated initiative supported by all such banks. It could also use export credit agencies to foster higher environmental, social and governance standards. Such public finance should be allied to governance reforms to leverage private capital into mining at scale, by reducing investment risks.

Financial institutions should be required to assess and manage environmental and social risks in their lending and investment activities when targeting mining assets, and to promote responsible finance and investment by incorporating environmental, social and governance-related considerations into their decisions. Many equity firms and other investors (for example, the Investor Mining and Tailings Safety Initiative of the Church of England Pensions Board and the Swedish Council on Ethics) already hold mining companies accountable for their environmental, social and governance performance. This should be generalized across the finance sector, including through new financial arrangements such as those involving original equipment manufacturers and supply chain actors. Aligning with existing legal and permit requirements, and building on the emerging recommendations of the International Sustainability Standards Board and the Task Force on Climate-related Financial Disclosures and the Task Force on Nature-related Financial Disclosures, social and environmental standards should be ambitious. The assessment of performance against these standards would require the harmonization of metrics and the development of and access to relevant data and tools.

Increased investment in responsible mining could also be encouraged by other public policies. For example, fiscal instruments could include policies that affect prices (taxation and subsidies), spending and investment, and public guarantees. Efforts to improve the transparency of climate risks in financial markets and regulatory prudential frameworks (e.g. capital requirements, the "green supporting factor" and the "brown penalizing factor") could support the development of markets for green financial securities (e.g. green bonds markets). Possible monetary policies include adapting the collateral frameworks of central banks and using environmental, social and governance criteria in their support for mining investments. Such mechanisms should pay special attention to strengthening the investment environment (e.g. in terms of good governance and policy stability).

Substantial finance will be required to build institutional capacities in many resource-rich countries to enable them to promote and regulate responsible mining in their territories. A 0.1 per cent ad valorem tax on metal production would yield about US$1 billion per annum.[171] This would act as a small additional royalty payment on mined metals, as discussed in Readhead *et al.* (2023). If well thought through, it could have the double effect of incentivizing best practices (e.g. if its percentage is reduced if certain environmental, social and governance criteria are met) and providing funding, and both its design and level could be set according to these intended effects. The effect of such a tax on the prices of finished products would be very small, but it would provide the resources to fund or provide more resources for: a functional international minerals and metals agency (see below); a global tailings database (see below); specific support on geoscientific and environmental baseline data acquisition, especially in developing countries; training and capacity-building activities (in support of both public institutions and private sector development); legal assistance for developing countries to help them to better negotiate with foreign investors; and research and innovation projects and technology transfer.

Both the agreement to and implementation of this would be difficult, as has been shown by discussions about international funds in the climate arena, but it is hard to see how else to finance the many public goods that are required for mining to contribute more consistently to sustainable development. In the interim, before consensus on such a tax has been reached, funds to enhance collective environmental, social and governance efforts could be collected on a voluntary basis through a mining industry trade group, such as the International Council on Mining and Metals. The World Gold Council collects such a levy from its members (in the order of US$2/oz produced), which could be a model.

171 Calculated from World Mining Data, 2022 edition (2020 data).

Recommendations:

- Mining that meets high environmental, social and governance standards should be included in the list of sectors in finance taxonomies (e.g. that of the European Union) that qualify for sustainable finance and should also qualify as a special form of climate finance. Concrete guiding principles on business and the environment – similar to the very effective United Nations Guiding Principles on Business and Human Rights – could enable responsible mining to be identified for this purpose.
- Reforms should be made to the financial system (e.g. taxonomies), governance (e.g. taxation regimes) and regulation (e.g. in terms of formalization or artisanal and small-scale mining) to ensure more capital flows to mineral exploration and to mining for the clean energy transition, while ensuring the implementation of risk management and environmental, social and governance-related investment criteria.
- Mining investments and financing should be tied to mandatory climate and nature-positive requirements, subject to stringent audit requirements. In particular, mining should not take place in protected areas.
- Investors' financial portfolios with climate and biodiversity goals should be assessed and monitored for their alignment with defined and disclosed pathways to companies' alignment with climate and biodiversity goals. Financial institutions can use this to determine specific exclusion criteria and an engagement strategy that supports companies' transition pathways.
- Companies with transition plans that have robust validation should be able to receive sustainable and climate finance in order to signal their intentions to investors and financial institutions.
- Financial institutions should enhance their capacity to assess and manage the environmental and social risks and impacts associated with mining in order to be able to recognize and finance mining to high environmental, social and governance standards.
- Fiscal, financial and monetary policies should be used to support finance for and investment in responsible mining and infrastructure and for the more circular use of metals in society.
- The mining industry should implement a global 0.1 per cent ad valorem levy on all companies as a contribution to a mining sustainable development fund. In due course this could become an internationally-administered global sustainability tax, levied on all produced non-energy minerals and metals.

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v. Consider establishing international institutions

The International Energy Agency has already started publishing information about non-energy resources that are important for the low-carbon energy transition, but this is only a subset of the minerals and metals that are crucial for humanity's future. Given the importance of the low-carbon energy transition, and the vital role of metals and minerals in that transition, there is a clear case for considering the establishment of an international minerals and metals agency. This would be independent of industry, although it would need to work closely with it and relevant NGOs, and would be tasked with providing science-based statistical data and evidence-driven analysis on non-energy mineral markets, technologies and scenarios, and on how to increase the recovery of companion metals. To be effective, such an agency should have experienced staff, adequate resources and be flexible and agile in its goals and organization. In the short and medium term, before an agency can be established, existing international institutional structures should be strengthened to fulfil these tasks. The development of an international minerals and metals agency could be taken forward by the Minerals Security Partnership. The Climate, Energy and Environment Ministers Communiqué from the 2023 meeting in Japan of the Group of Seven provides an admirable starting point for setting out what an international minerals and metals agency might seek to achieve in its promotion of responsible mining and supply chains that "follow the highest possible environmental, social and governance standards with full respect of human rights".[172] An international minerals and metals agency could also form part of an international resources agency that went beyond minerals and metals, were such a body to be established.

Such an agency could also serve the function of a global commodity price observatory that monitors and analyses price behaviour, promotes price transparency and establishes an early warning capacity on commodity prices that captures changes to market fundamentals. Commodity price surges can lead to inflation, supply chain disruptions, cost-of-living crises and political instability. Commodity price uncertainties also have an impact on the viability of sustainability transition policies. This suggests that there is a case for globally coordinated, short-term macroeconomic policies and long-term sustainability policies to consider and manage commodity price risks through bespoke financial stress testing. An institution that could undertake this immediately is the network of central banks organized as the Network for Greening the Financial System, but in due course it could work on this with global commodity price observatory of an international minerals and metals agency, as and when it is established.

Another task for an international minerals and metals agency could be to facilitate the development and adoption of a framework of principles for investment in artisanal and small-scale mining. A draft framework, drawing on lessons learned from the Equator Principles, and known as the meridian principles, already exists. These comprise a set of specific due diligence principles that financial institutions commit to apply when they are considering financing artisanal and small-scale mining and quarry operations. The principles would ensure that the provision of any finance is contingent on borrowers complying with one of the recognized international codes of good practice in artisanal and small-scale mining (e.g. the Code of Risk-mitigation for artisanal and small-scale mining engaging in Formal Trade (CRAFT Code)), thereby improving the environmental, social and governance performance of operations and reducing the environmental and social risks that have historically deterred formal lending to the sector. In doing so, the framework would be likely to open up new funding opportunities for the artisanal and small-scale mining sector.

Before the establishment of an international minerals and metals agency, the development of the meridian principles should entail establishing a secretariat comprising the World Bank, financial institutions from different regions and representatives of artisanal and small-scale mining associations, including those involved in the World Bank Delve Exchange knowledge exchange platform for the artisanal and small-scale mining sector. The initiative could commence with pilot programmes targeting artisanal and small-scale miners engaged in the production of energy transition minerals. By encouraging responsible mining, this could also open up new sources of minerals for industry and new export avenues for artisanal and small-scale miners.

172 https://www.env.go.jp/content/000127828.pdf (para. 8).

Another task that would eventually be taken on by an international minerals and metals agency, but one which should be started immediately by a collaboration between governments, mining companies and NGOs, is the creation of a global database of tailings from former and operational ore-processing facilities, which is a necessary step towards achieving a more sustainable mining industry. The organization and finance of a such a global database would need to be carefully planned and executed to ensure its success, through a collaborative and innovative approach, balancing the needs and interests of various stakeholders while ensuring the long-term viability of the project. A central governing body should oversee the collection, analysis and dissemination of data within the database, which would be coordinated by an international minerals and metals agency once one has been established.

The rationale for such an effort is centred on the fact that, while there is currently considerable data available on tailings facilities, it is focused primarily on understanding their potential environmental impacts of those facilities rather than the minerals, including companion metals, that could potentially be recovered from them. A comprehensive database that includes data on the mineralogical and geochemical composition of the waste, with its three-dimensional variations over time, data on the geotechnical and hydrogeological characteristics of the waste disposal site and of any waste confinement structures (such as tailing dams), and data and information on the potential impacts of any existing natural hazards (seismic events, landslide, climate change and extreme climate events) would be invaluable to developing new sustainable methods for extracting transition minerals from these tailings. Mining the tailings dams, while paying special attention to safety issues, could also help to reduce their environmental impact through the treatment of potentially toxic materials.

The creation of such a database should build on existing databases, such as the Global Tailings Portal, by employing a combination of data scraping and qualitative research to collect historical data on tailings dams, including potential gains from tailings. In addition, research and development on how to extract minerals from tailings would be a crucial complement to the database, identifying which minerals can be extracted from which mine tailings and using which methods.

In terms of finance, in the absence of the above-mentioned recommended bespoke levy, funding for the creation and maintenance of the database could come from a variety of sources, such as government grants, private sector investment, the mining industry and philanthropic organizations. While it would be highly desirable for the database to be open access, it may also be possible to generate revenue from the sale of data or the licensing of technologies developed through research, development and innovation efforts.

Finally, the critical importance of all resources to sustainable human development argues for the eventual consideration of creating a United Nations convention on sustainable resources to encourage the sustainable production and consumption of resources, including resource efficiency and moves towards a circular economy. While respecting the sovereignty of countries over the resources in their territories, such a convention would be aimed at standardizing across countries high environmental, social and governance standards for the production of resources, the incorporation of production externalities in their prices and the promotion of measures to ensure their efficient and circular use in the countries of consumption.

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Recommendations:

- Consider establishing an international minerals and metals agency to provide oversight and information about the state of and outlook for the world's non-energy mineral resources and markets. It should also provide support for capacity-building and institutional strengthening, especially in developing countries, as well as support for research and innovation activities and for the development of global minerals and metals exploration and production-related standards.
- Encourage the Network for Greening the Financial System to undertake systematic monitoring of macroeconomic risks to the financial sector emanating from commodity markets, through a global commodity price observatory, eventually in collaboration with an international minerals and metals agency when one is created.
- Establish an international framework for managing environmental and social risks and improving access to formal sources of finance in the artisanal and small-scale mining sector.
- Governments, mining companies and NGOs should collaborate to establish a global database for mine tailings facilities and the potential availability of minor (or companion) metals, eventually to be managed by an international minerals and metals agency.
- In due course, consider establishing a United Nations convention on sustainable resources to encourage the sustainable production and consumption of resources, including resource efficiency and moves towards a circular economy.

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