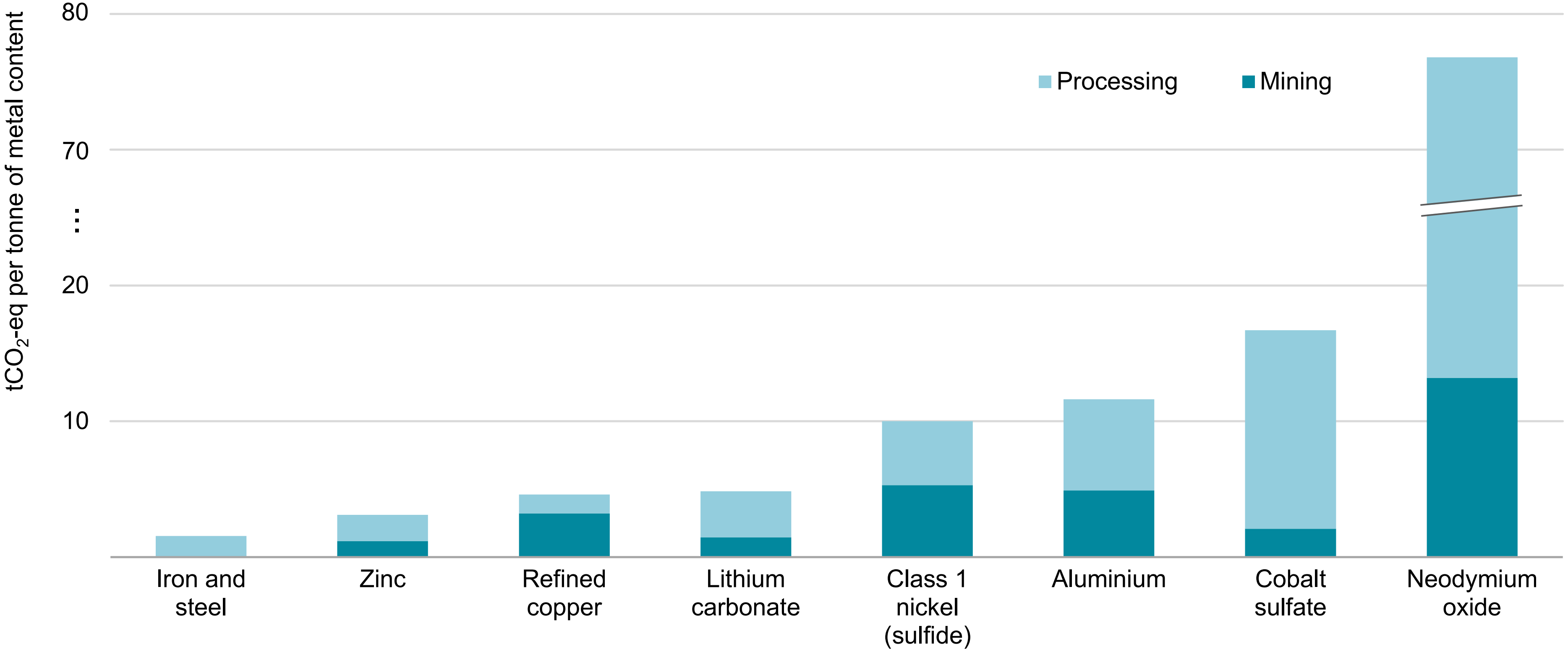
However, there is a growing imperative to tackle emissions from mineral development as energy transition minerals involve higher GHG emission intensities

Average GHG emissions intensity for production of selected commodities

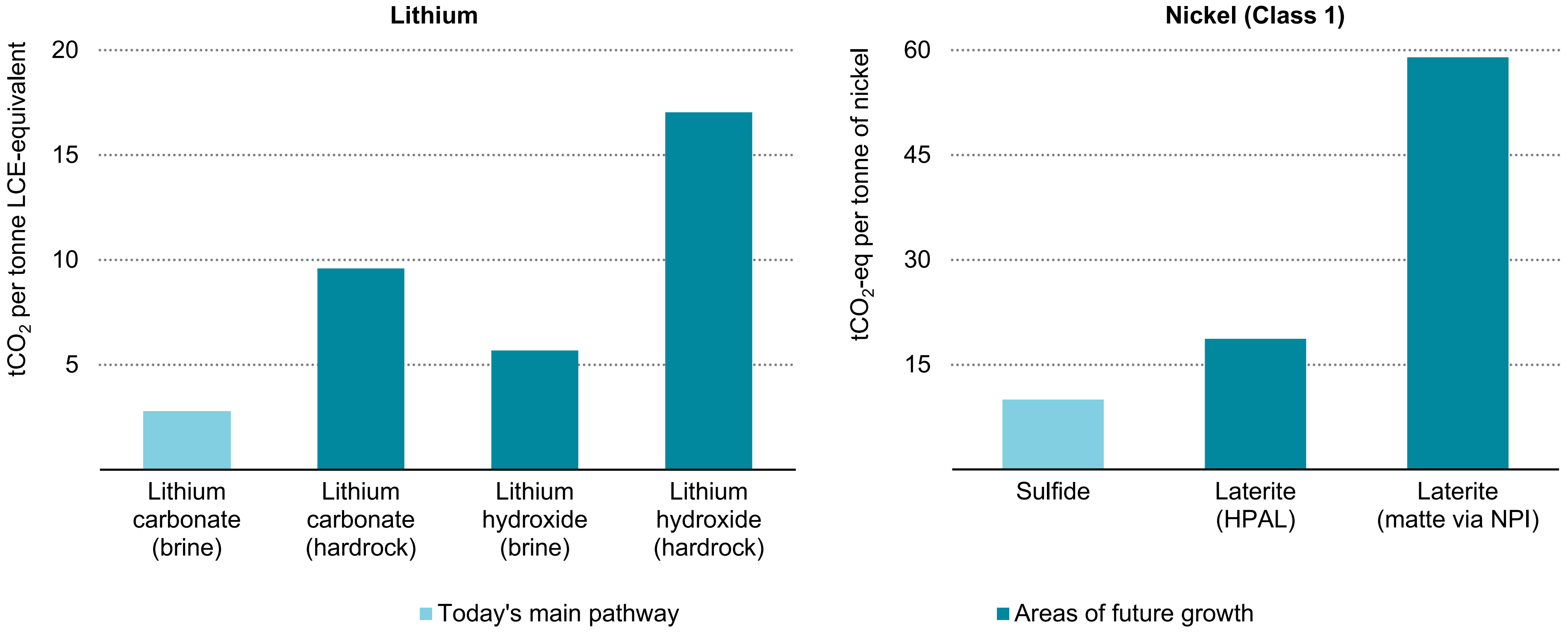


Notes: Includes both Scope 1 and 2 emissions of all GHGs (the majority of which are CO_2) from primary production. The values for lithium carbonate refer only to CO_2 emissions based on the weight average of brine and hard-rock production (denoted on a lithium carbonate-equivalent basis).

Sources: IEA (2020b) and Rio Tinto (2020) (steel); Nuss and Eckelman (2014) (zinc); data received from Skarn Associates (copper and nickel); Roskill (2020) and S&P Global (2021) (lithium); IEA (2020b) and Tost et al. (2018) (aluminium); Argonne National Laboratory (2019) (cobalt); Marx et al. (2018) (neodymium).

Changing patterns of demand and types of resource targeted for development are set to exert upward pressure on emissions

GHG emissions intensity for lithium and nickel by resource type and processing route



Notes: LCE = lithium carbonate-equivalent; HPAL = high pressure acid leaching; NPI = nickel pig iron. Includes both Scope 1 and 2 emissions from mining and processing (primary production). For lithium hydroxide, the value of brine is based on Chilean operations and the value for hardrock is based on a product that is mined in Australia and refined in the People’s Republic of China (“China”).

Source: IEA analysis based on Roskill (2020), S&P Global (2021) and Vulcan Energy (2020) (lithium); data received from Skarn Associates (nickel sulfide and laterite HPAL) and Trytten Consulting Services (nickel matter via NPI).

Stronger action will be required to counter upward pressure on emissions from mineral production

The process of producing various commodities, such as fossil fuels and steel, is a significant contributor to global emissions. For the moment, emissions from producing minerals vital for clean energy technologies are relatively small, due to their low production volumes. However, these minerals require much more energy to produce per unit of product, which results in higher emissions intensity than other commodities. For example, emissions from producing the average tonne of lithium carbonate and Class 1 nickel are three and ten times higher, respectively, than those from producing a tonne of steel.

The higher emissions relate to the fact that most energy transition minerals have a lower metallic concentration in ore. While the metal content in iron ore is typically 50-70% (IEA, 2020c), the average ore grade for nickel is less than 2% and under 1% for copper. Lower grade ores require more energy to extract the valuable fraction, and to move and treat the waste fraction (the “gangue”).

The effects are aggravated by deteriorating ore quality. The average ore grade for copper in Chile declined from 1.25% in 2001 to 0.65% in 2017. As a result, fuel and electricity consumption per unit of mined copper increased by 130% and 32% respectively over the same period (Azadi et al., 2020). Given their large electricity consumption, refining and smelting operations are also a major contributor to emissions, especially when relying on coal-based electricity.

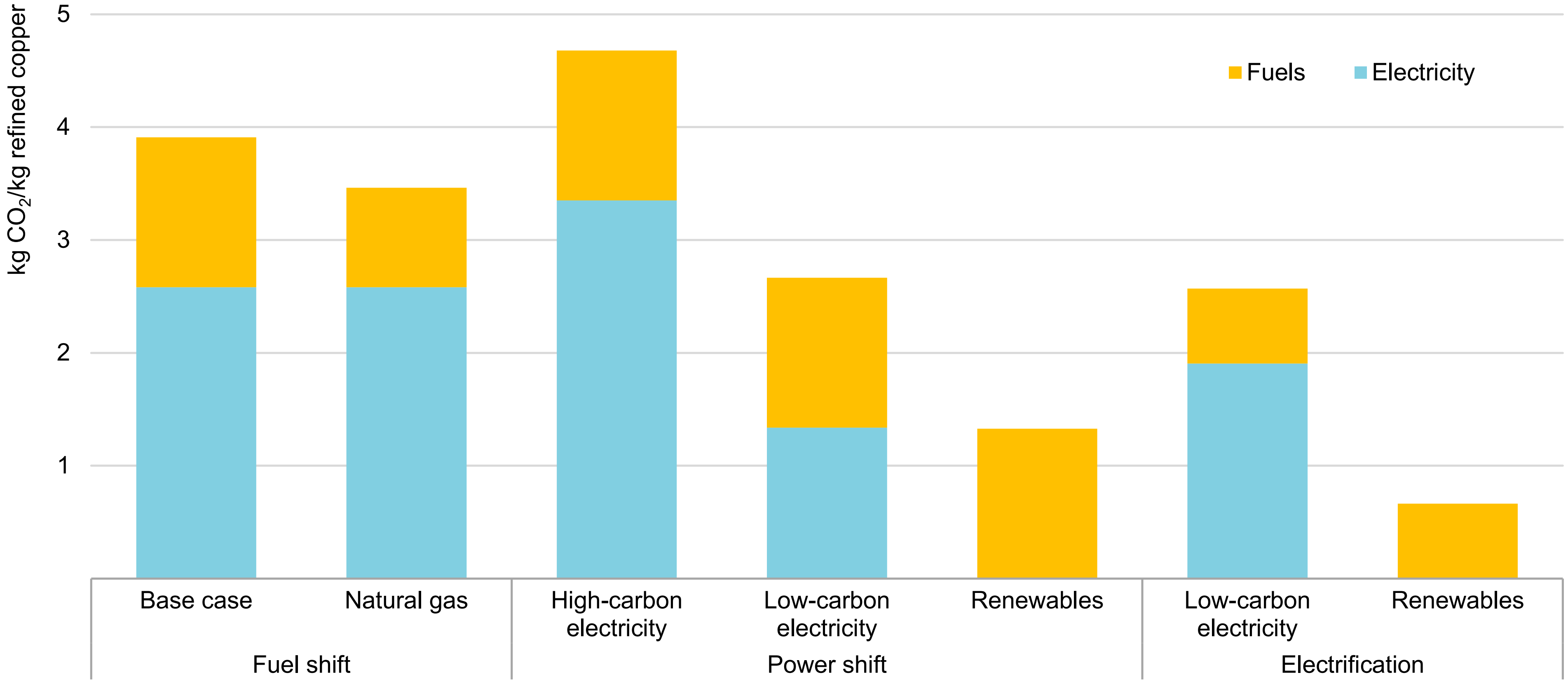
Future production is likely to gravitate towards more energy-intensive pathways. Lithium production has been moving from brine-based recovery (mostly in Chile) to mineral concentrate production from hardrock (mostly in Australia). The emissions intensity of hardrock-based lithium carbonate production is three times higher than that of brine production. This is due in part to higher energy requirements in mining and also in refining, the latter being mainly carried out in China where coal plays a dominant role in the power mix. In this context, several companies in Australia are looking to integrate projects within the country to lower these emissions.

There is also additional pressure from changing demand patterns for lithium. Demand is moving from lithium carbonate towards lithium hydroxide, as the latter is more suitable for batteries with higher nickel cathode chemistries. However, lithium hydroxide involves more emissions as it requires an additional processing step to convert lithium carbonate to lithium hydroxide (when produced from brine resources).

Battery-grade nickel faces a similar situation. While sulfide resources played a major role in the past, future growth is increasingly coming from laterite resources, which require more energy to produce. These underlying pressures highlight the need for companies to take stronger action to address emissions across their value chains.

The emissions intensity of production can vary considerably across companies and regions…

Energy-related CO_2 emissions intensity for an indicative refined copper production project under different energy consumption scenarios

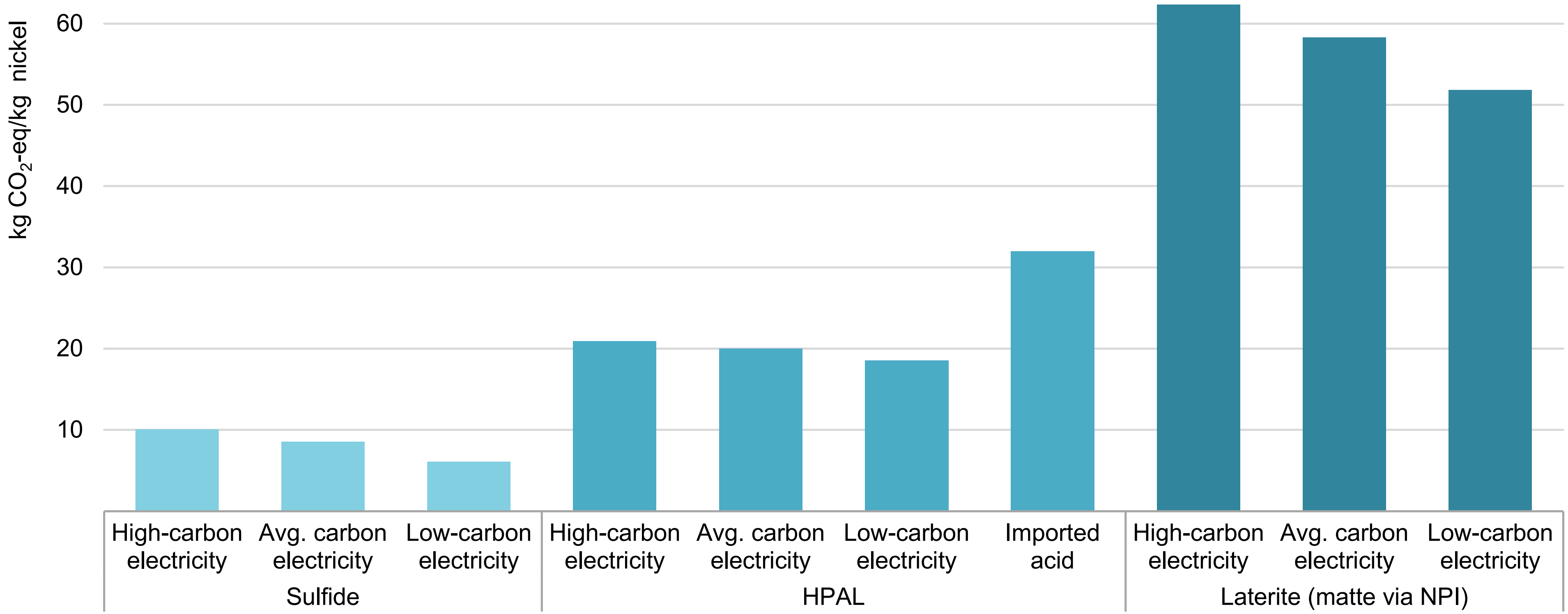


Notes: The base case assumes a fuel mix of 33% coal, 33% diesel and 33% natural gas with a global average emissions intensity for electricity (463 g CO_2/kWh). The high-carbon and low-carbon electricity cases assume 600 g CO_2/kWh and 240 g CO_2/kWh, respectively, and renewables are assumed to be carbon neutral. The electrification case assumes 50% of the energy demand from fuel consumption becomes electrified.

Source: IEA analysis based on Cochilco (2020).

...depending on operational practices, power sources and production pathways

GHG emissions intensity for an indicative nickel production project under different grid scenarios and production pathways



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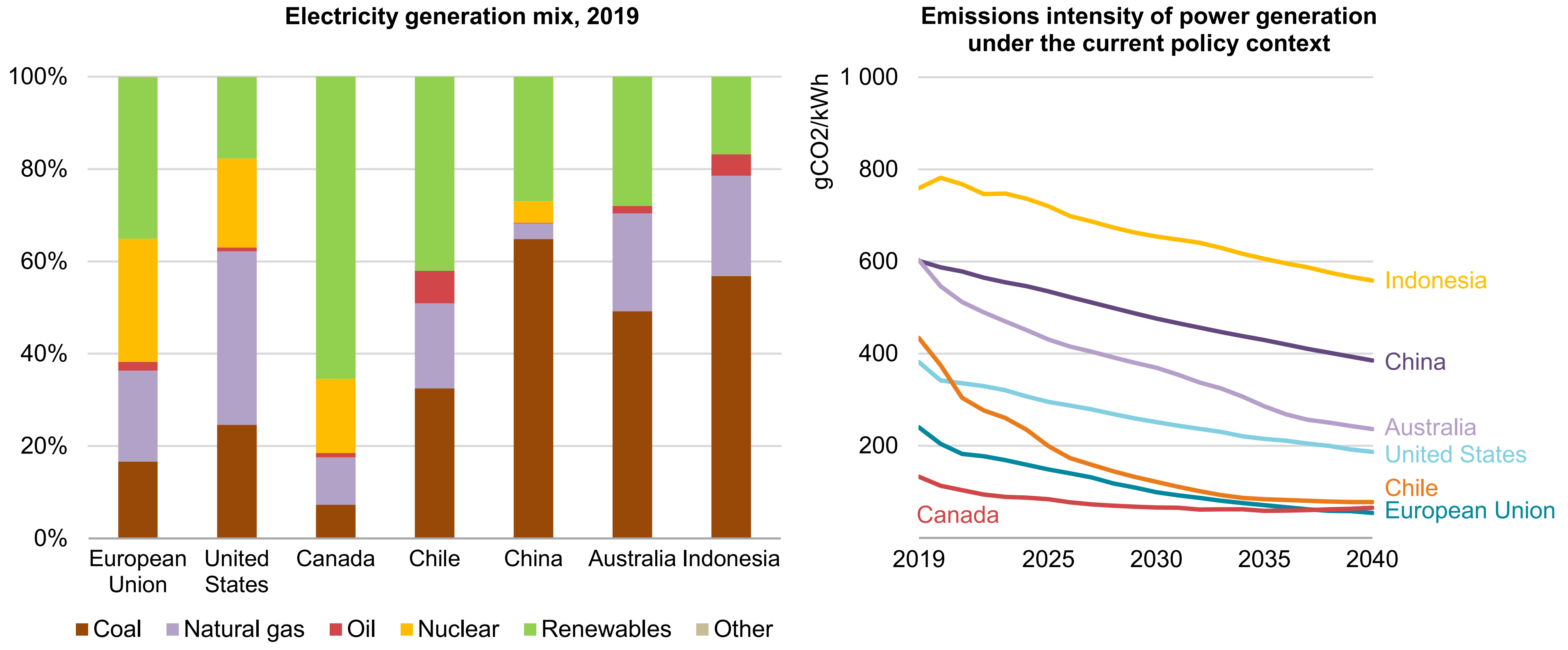
Notes: Avg. carbon electricity = global average emissions intensity for electricity (464 g/kWh). The high-carbon and low-carbon electricity cases assume 600 g CO_2/kWh and 240 g CO_2/kWh, respectively. Includes both Scope 1 and 2 emissions from mining and processing. Imported acid HPAL assumes average electricity carbon intensity.

Source: IEA analysis based on data received from Trytten Consulting Services.

The carbon footprint of the electricity mix and the pace of future decarbonisation have significant impacts on the emissions profile of mineral production

Electricity mix and emissions intensity of power generation in selected regions



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Notes: The emissions intensity under the current policy context is based on the projections in the Stated Policies Scenario. The values for Australia also cover New Zealand as the two countries are modelled together in the World Energy Model.

Source: IEA (2020b).

Minerals are needed for clean energy transitions, and sustainable mineral development needs clean energy

Many aspects of mineral production contribute to climate change, and foremost among these are direct and indirect sources of GHG emissions. Direct emissions, also called Scope 1 emissions, include vented CO_2 from waste rocks, emissions from fuel used in mining and refining operations and GHGs from acid neutralisation, mineral beneficiation (e.g. flotation), extraction and waste streams (e.g. tailings). Indirect emissions are either associated with the generation of purchased energy (e.g. electricity, steam and heat) (Scope 2) or any other emissions that occur in the products' value chain (Scope 3). Overall, Scope 3 emissions are the largest source of GHG emissions from the mining sector, representing well over two-thirds of the total (McKinsey, 2020), which is why many companies are taking steps to curb these emissions by partnering with end users, such as the steel industry.

Even within similar production routes, GHG emission intensities vary greatly between operators, depending on the technologies employed and mine characteristics. For instance, a time-series life-cycle assessment study, which looked at copper mining and smelting in Australia from 1940 to 2008, indicated that the carbon footprint of copper produced at all sites over the time period ranged from 2.5 to 8.5 kg CO_2-eq/kg copper (Memary et al., 2012).

In the context of Scope 1 and 2 sources, emissions from mineral production are largely driven by electricity consumption and fuel use. Electricity serves multiple purposes throughout mineral development, but refining activities are particularly electricity-intensive, representing a large share of emissions that are linked to the grid's carbon footprint. Comminution, the process of crushing and grinding solid materials, is estimated to consume up to 3% of all the electricity generated in the world (NRCan, 2016). Meanwhile, fuels are mostly used by vehicles (e.g. diesel consumption by trucks in ore hauling and loading operations) and to generate heat for processing steps.

Emissions from mineral development can be significantly reduced by a shift in fuel sources and by using low-carbon electricity. A simulation of an indicative refined copper production project under different energy consumption profiles reveals a wide variation in emissions intensity depending on the type of fuel used and the intensity of electricity supplied by the grid. Shifting all fuels to natural gas would bring emissions down by 10%, while using renewable-based electricity reduces CO_2 intensity by about two-thirds. Further reductions could be achieved through the electrification of fuel use. When combined, electrification and renewable-based electricity have the potential to reduce emissions intensity by almost 80%. Similar trends are also visible in nickel production.

Fuel switching, low-carbon electricity and investment in energy efficiency can significantly reduce the emissions footprint of mineral production in the near term

Near-term strategies to reduce energy-related emissions include increasing the share of low-carbon electricity, acting on energy efficiency and switching to cleaner fuels.

Emissions from electricity use can be lowered by using low-carbon electricity via corporate power purchase agreements (PPAs) or on-site renewable generation. Glencore, for example, built a 3 megawatt wind turbine at its Raglan Mine in Canada to replace diesel power generation. The project received funding from the Canadian government to couple leading-edge storage technologies with an Arctic-grade wind turbine and demonstrate that such a system can operate reliably (NRCan, 2021). Meanwhile, BHP stepped out of nearly 800 million dollars in contracts for coal-fired power in Chile and established 6 terawatt hour renewables power purchase contracts (Reuters, 2019a). Of note, PPAs need to go hand-in-hand with efforts to lower the grid's carbon intensity to be more effective. For better results, low-carbon electricity can be coupled with higher power demand resulting from increased electrification of equipment and the incorporation of batteries to safeguard flexibility in operations.

Additional emission reductions can be achieved through investment in energy efficiency, for example through digitalisation, automated process management and technological improvements (e.g. using high-efficiency burners in furnaces). Glencore's Nikkelverk refinery in Norway, for example, implemented a portfolio of energy management technologies to save over 30 gigawatt hours annually (Eurometaux, 2019). The plant reduced its energy consumption by installing new tanks, electrical contacts and energy-efficient anodes. Moreover, waste heat from its sulfuric acid plant replaced previously electrically generated steam.

In the medium term, reducing or displacing diesel use in trucks is an important element of many companies' efforts. Options include optimising material handling practices, using other transport means (e.g. conveyors) or switching to electric trucks. Some companies are also exploring the possibility of using hydrogen. For example, Anglo American is partnering with ENGIE to develop a hydrogen-powered mine haul truck (Anglo American, 2019).

Companies are also increasingly reviewing options to tackle Scope 3 emissions, by shifting their business portfolio away from polluting fuels (such as coal), using low-carbon fuels for shipping and working with customers to co-invest in emission reduction measures. Another option to reduce emissions is to scale up secondary production. An assessment of current copper production routes in China shows that producing copper from scrap has the potential to reduce GHG emissions intensity to about a quarter of conventional routes (Dong et al., 2020).

An increasing number of mining companies are committing to reduce emissions...

Net CO_2 emission reduction pledges for top 20 mining companies

Company	Scope 1 and 2		Scope 3	
	2021-2030	Long term	2021-2030	Long term
Vale	33%	100%	-	15%
BHP	30%	100%	30-40% [i]	-
Rio Tinto	30%	100%	15%	-
Glencore	40%	100%	40%	100%
Freeport-McMoRan	15%	-	-	-
Codelco (Corporación Nacional del Cobre)	70%	-	-	-
Fortescue Metals Group	26%	100%	-	-
Norilsk Nickel	25% [i]	-	-	-
Barrick Gold	10%	-	-	-
Southern Copper	-	-	-	-
Newmont	30%	100%	15%	100%
Hancock Prospecting	-	-	-	-
KGHM Polska Miedź	-	-	-	-
Teck Resources	33%	100%	-	-
AngloGold Ashanti	-	-	-	-
First Quantum Minerals	-	-	-	-
Zijin Mining Group	-	-	-	-
Anglo American	30%	100%	-	-
Sibanye-Stillwater	27%	-	-	-
Mitsui	50%	100%	50%	100%

Notes: Reductions can account for CO_2 removal (e.g. through afforestation or direct air capture) and emission credits (generated by emission reductions in other sectors). Long-term targets include pledges to be fulfilled in 2035, 2040 or 2050. i = intensity target.

Source: IEA analysis based on company filings or websites.

... but a wider range of companies needs to come on board if overall emission levels are to follow a sustainable development path

With mounting pressure from investors, governments and other stakeholders, the industry is increasingly aware of its environmental footprint. The Responsible Mining Index reports that the vast majority of companies track their performance on Scope 1 and 2 GHG emissions, with over half disclosing comprehensive tracking data against publicly stated targets. However, fewer companies review the effectiveness of measures taken to manage emissions, and fewer still take actions to respond to such reviews.

Announced emission reduction targets have proliferated in recent years among major mining companies. Two-thirds of the top 20 mining companies have established Scope 1 and 2 emissions reduction targets for 2030. A further one-third have extended targets to include long-term and Scope 3 reductions, with Glencore, Mitsui & Co. Ltd, and Newmont Corp. setting full net-zero targets.

While encouraging, companies with emission pledges account for only a small proportion of global mining output – 25% for cobalt, and less than 20% for copper and nickel. Greater pressure from governments, investors and end-use customers is needed to expand emission reduction initiatives across sectors and regions, to include junior miners, refiners and Chinese players. Major companies, via their influence in non-operated ventures, can also influence the performance of the sector as a whole.

Mineral development can also contribute to clean energy transitions in other sectors. It can act as an anchor consumer for renewable power, support demand response and export residual energy to nearby users. In Chile, copper mines consume substantial amounts of electricity in an area with one of the world's highest levels of solar irradiation. This, coupled with the declining cost of renewables, has led to an increase in renewable power capacity, which contributed to reducing the carbon footprint of the grid (OECD, 2019a). Moreover, in the refining sector, many electricity-intensive facilities provide services to the power grid (e.g. grid stabilisation and peak attenuation) by allowing for temporary interruption of power supply or demand reduction in instances of lower supply. Automated process management helped these services become competitive in many countries, such as France and Germany, particularly for aluminium, zinc and copper production (Eurometaux, 2019).

To achieve net-zero targets, mining companies will have to address all GHG sources in their value chain, including those hard-to-abate sources. In this context, carbon offsets may complement direct emission reduction measures. However, for offsets to be effective, mining companies must verify that they result in permanent, additional, real and verified emission reductions.

Industry and market-driven disclosures are starting to improve transparency on sourcing and sustainability…

Industry sustainability initiatives have pushed companies towards voluntary environmental impact disclosures, bridging the gap between consumer and investor expectations and regulatory processes. For example, the Mining Association of Canada's Towards Sustainable Mining (TSM) initiative has developed an assessment tool, the TSM Energy and Greenhouse Gas Emissions Management Protocol, which calls for companies to develop a comprehensive GHG emissions management system, track and report GHG emissions metrics and set reduction targets. The Initiative for Responsible Mining Assurance's GHG emissions requirements in their Standard for Responsible Mining similarly encourage companies to quantify and report emissions and to develop specific emission reduction strategies.

Market mechanisms

Trading platforms and metal purchasers can also play an important role in encouraging companies to adopt voluntary approaches to reduce emissions. The London Metal Exchange (LME) trading platform is aiming to provide consumers with greater transparency of the carbon footprint of traded metals, building on recent efforts to incorporate responsible sourcing standards into its brand listing requirements. The new voluntary disclosures will be introduced in 2021 starting with aluminium, in the form of an "LME passport" and a spot-trading platform so that producers can substantiate their carbon emission claims. This digital passport will then be phased in for all LME's physically settled metals requiring certificates of analysis, including cobalt and nickel from 2023 (LME, 2020). Public disclosure of sustainability metrics can incentivise producers to measure emissions in a credible manner, and ultimately lower their carbon footprint to meet consumer demands. This in turn may eventually support a price premium for low-emission metals. It can also act as an indicator to policy makers to assess industry and consumer buy-in (IGF, 2018a).

These industry initiatives actively support greater disclosure of emissions data, but it will take time for them to mature enough to provide consistent data and indicators. Moreover, further effort is needed to develop standardised accounting frameworks to ensure emissions data is comparable across companies. So far, industry sustainability standards remain voluntary, and thus their impact is limited to companies that choose to implement them. Although governments can encourage companies to adopt these standards – as Canada does for TSM – policy support will be needed to provide incentives for further uptake of transparency norms.

…while regulatory approaches to reduce mining emissions are often incomplete

Once an industry standard is broadly accepted, governments can play a key role in turning voluntary commitments into legal requirements. For example, the EU Batteries Regulation will mandate disclosure of key sustainability metrics already reported on a voluntary basis under industry standards (see Box 3.5). Voluntary climate-related financial disclosures, such as the Task Force on Climate-related Financial Disclosures, are also being progressively incorporated into law, for instance in the United Kingdom and New Zealand (Davies et al., 2020).

Inconsistent reporting frameworks

Governments also have a role to play in driving standardisation among emissions accounting frameworks. Although companies are increasingly expected to disclose GHG emissions, including any indirect emissions in the value chain (Scope 3), the lack of consistency in reporting makes it challenging to compare data. Even under the Greenhouse Gas Protocol, which is designed explicitly to create a corporate standard allowing comparable reporting, companies are free to choose which values to report, emission category boundaries and relevant categories. Empirical research on the copper supply chain demonstrated that GHG accounting protocols were often lacking and differed dramatically between companies (Lee et al, 2020). As such, policy support to standardise accounting principles is necessary to bolster emission disclosures.

A suite of policy options for mining emissions

Government policies can drive companies to adopt emission reduction strategies across their operations, including fuel switching and investing in low-carbon electricity and energy efficiency. These can be addressed through a suite of policies such as renewable portfolio standards, energy efficiency mandates, emission regulations and carbon pricing. In particular, allowing independent power producers to enter the market could facilitate less emission-intensive power generation. For instance, in 2015 Chile mandated power distribution companies to conduct tender processes to provide energy to regulated customers, thus facilitating the successful development of renewable-powered mines (CCSI, 2018).

R&D and innovation support is also key to lowering emissions in mining. For instance, in the context of the European Battery Alliance, the European Union financially supports a “Zero Carbon Lithium” project in Germany to find less water- and carbon-intensive ways to extract the mineral (Energy Storage News, 2020). The Australian Renewable Energy Agency and other government entities also provided financial support for solar-powered energy generation at the DeGrussa copper mine in Western Australia, which has the potential to meet up to 90% of the mine’s daytime demand (CCSI, 2018). Clean fuel standards can also impact mining operations given their use of liquid fossil fuels and freight services (Government of Canada, 2020).

Carbon pricing can complement other policies by providing incentives to reduce emissions

Carbon pricing holds potential to become an important component of climate governance, at both national and international levels. Carbon taxation and emissions trading schemes can be an effective tool for driving reductions in emissions in line with the "polluter pays" principle while encouraging innovation. However, so far the impact of carbon pricing mechanisms on the minerals sector has been limited to only a handful of contexts.

In many cases, the impact of carbon pricing mechanisms on minerals has been limited to the indirect effects of carbon pricing applied to electricity or fuel use. This indirect effect is small as long as carbon prices remain low. The carbon tax in Chile is a good example of these limits. The tax applies to power generation, which may ultimately be passed on to mineral producers in electricity contracts. The actual impact is minimal due to the low level of the price: USD 5 per tonne CO_2-eq (ICAP, 2021). Further, the mining sector has sometimes been exempted or received free allocation of allowances due to carbon leakage and competitiveness concerns.

However, there are encouraging efforts to apply carbon pricing directly to mining and mineral processing operations. Canada's output-based pricing system, which applies to provinces and territories that do not have their own carbon pricing systems with comparable stringency and coverage, targets large industrial emitters. Among the sectors covered, the system puts a price on emissions occurring from mining and refining base metals such as nickel, copper, zinc, lead and cobalt, in addition to a charge on fossil fuels (Government of Canada, 2019). By combining direct and indirect carbon pricing, such schemes can provide further incentives to lower emissions.

For carbon pricing to have a more widespread impact on the mining sector's emissions, rigorous implementation will be needed and governments should send clear policy signals to this effect. For instance, the Canadian government has proposed increasing the federal carbon price by CAD15 per year from 2023, reaching CAD170 per tonne CO_2-eq in 2030 (Government of Canada, 2021a). Such policies can incentivise investment in emissions reduction measures in project planning. However, uncertainty over carbon pricing in different jurisdictions complicates the picture for companies.

Some companies have established an internal carbon price within corporate account systems. For instance, BHP has established a "shadow" carbon price ranging from USD 10 to USD 110/t CO_2-eq. It uses the price in scenario modelling to determine the competitiveness of fuels across sectors, to inform investment decisions and asset valuations (BHP, 2020). The use of shadow prices within company decision-making is a positive step to track and reduce emissions, but clear signals from governments on carbon pricing remain crucial.

Sustainable minerals development

A holistic approach can help integrate sustainable practices in mineral development

Mineral development affects the local and regional environment in different ways. Related interactions must be managed carefully to mitigate negative impacts and reduce associated risks. In this section, we focus on three chief challenges that are present throughout the mining value chain:

- Land use change – This is the main source of direct and immediate impacts on people, biodiversity and ecosystems. It can result in the displacement of communities and the loss of habitats that are home to endangered species.
- Water use – Mining generally requires large volumes of water for its operations. It can also be a source of water contamination, be it through acid mine drainage, wastewater discharge or the disposal of tailings.
- Waste generation – Mineral development results in massive amounts of residues, both during extraction and after utilisation, some of which are hazardous to human health.

Mineral development also entails other environmental aspects and impacts, including air pollution from particulate matter (e.g. mine dust) and gaseous emissions (e.g. sulfur and nitrogen oxides), and noise pollution due to blasting and transporting activities.

Experience suggests that it is possible to manage these impacts effectively via a combination of policy measures, robust project management and technological solutions. In particular, integrating environmental concerns at the early stages of project planning can go a long way to ensuring sustainable practices do not come at a high cost.

In this context, employing a holistic approach enables an integrated assessment of the drawbacks and benefits of different project alternatives. Often there are trade-offs between different environmental objectives. Open-pit mining, for example, has lower energy requirements than underground mining, generally leading to lower emissions, but results in more land use change. However, there are also cases where an alternative presents synergistic outcomes. The recovery of minerals from waste streams (e.g. reclaimed copper production) illustrates this, as it can reduce the amount of waste that needs to be disposed of, lessen the ecotoxicity of effluents and lead to lower GHG emissions (Hong et al., 2018).

Furthermore, taking an integrated approach to sustainability can enable better resource use and systemic innovation, often resulting in lower overall energy needs (Lèbre and Corder, 2015). For example, extracting multiple minerals from the same ore or reworking tailings to maximise recovery rates are ways to increase production, reduce pollution and often minimise other risks in parallel.

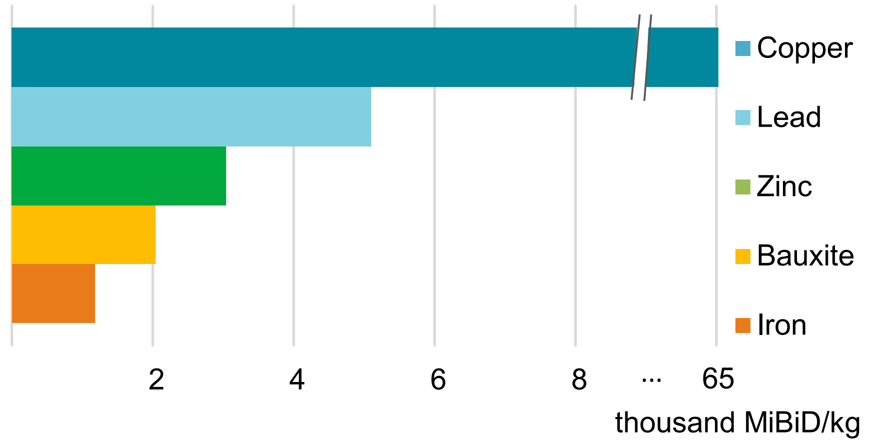
Land use: Mining can displace communities and threaten natural habitats

Mining brings major changes in land cover. Open-pit mines, in particular, can spread across several kilometres and usher in dramatic changes to the surrounding environment. Underground mines have a lower surface impact, but still generally require areas for processing, waste management and transport systems that have a sizeable aboveground footprint. Furthermore, mining activities can have spillover effects in nearby regions, such as increased urbanisation or the conversion of land to plantation forestry, which is used in the supply chain of related industries (Sonter et al., 2014). Global estimates for the area disturbed by mining activities lie between 0.3% and 1% of total terrestrial land surface (Tost et al., 2018).

The amount of land needed for mining varies significantly according to the technologies employed, the minerals produced and project characteristics. A recent study used satellite image analysis to assess land use change at three copper mines, showing results ranging from below 5 to about 20 hectares of built-up land needed per thousand tonnes of copper ore extracted (Murakami et al., 2020). The highest values were tied to an open-pit mine in a mountainous and forested location in Indonesia, which aggravated spatial requirements and related impacts, whereas the lowest values came from an underground mine in a Chilean desert. Other influencing factors included mine productivity, ore grade and afforestation initiatives.

Impacts from land use change have a cumulative nature and can cause far-ranging repercussions. In sensitive areas, such as habitats of endemic species or traditional indigenous territories, engaging in new mining developments might present a lower societal value than maintaining healthy ecosystems.

Intensity of mining pressure on biodiversity for selected minerals



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Note: MiBiD is a non-dimensional index based on data regarding land cover, protected areas and mining operations.
Source: Kobayashi, Watando and Kakimoto, 2014.

Land use: The effects of mining projects on people and biodiversity

Activities, impacts and risks of mineral development related to land use change

Segment	Activities	Impacts	Risks
Production	• The installation of a mine involves the clearing of an area for exploration, initial processing and logistics • Open-pit mines expand as production progresses, while underground mines remain mostly with the same superficial area throughout their development • Tailings (waste materials left over after target minerals are extracted from the ore) are often stored in large dams	• Noise pollution from operating machines and the transport of materials • Habitat reduction and fragmentation, resulting in the loss of fauna, flora and ecosystem services • Potential displacement of communities in the area of the project • Landscape change and labour migration with impacts on local social settings and lifestyles	• Biodiversity loss, sometimes increasing endemic species' vulnerability to extinction • Loss of cultural heritage sites • Soil erosion can lead to changes in topography, soil quality and water pollution • Failure of underground mine excavations can lead to surface subsidence
Processing	• Refining involves large facilities and substantial material flows	• Landscape change • Noise pollution from trucks and machines	• Spills of hazardous materials or the deposition of toxic dust can lead to soil contamination
Distribution and use	• Railways and waterways are the main means of transporting minerals	• Habitat fragmentation • Noise pollution (both in land and aquatic environments)	• Accidents during transport can harm people and fauna

Land use: Appraisal and management systems can ensure projects follow a sustainable profile

Mitigating the damage from land use change requires the potential land use issues to be considered before a project is approved. Integrated management of environmental and social impacts can help ensure projects conform to regulatory requirements.

Environmental and social impact assessments (ESIAs), which evaluate project alternatives with regard to their environmental impacts, can support decision making by providing an understanding of present environmental conditions and future consequences of proposed actions. Thus, ESIAs may identify areas that should remain untouched or options to reduce environmental impacts. For example, the Carajás S11D iron-ore project in Brazil is a case where the ESIA and project appraisal process led to reduced impacts on a national reserve, the use of technologies that do not require tailings dams and a transportation system without trucks (IBAMA, 2016).

ESIAs are now mandatory for most mining developments; however, their implementation still faces major challenges related to poor integration in project planning, monitoring and community engagement (IGF, 2019). The Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development has released a guidance document for governments on improving ESIA-related legal frameworks. Project appraisal can also provide an avenue for public participation and enable conflict resolution at an early stage of the development process. To support citizen engagement, the Environmental Law Alliance Worldwide published a guidebook for evaluating mining project ESIAs.

A major component of ESIAs is a set of measures addressing both the mitigation of impacts and their eventual compensation, such as the provision of alternative settlements for displaced populations. These are consolidated in environmental management plans (EMPs), which integrate regulatory requirements and company mitigation efforts, such as pollution control, environmental monitoring, compensation projects and risk management. EMPs commonly take a continuous improvement approach to ensure that problems are identified, corrected and procedures improved to prevent similar occurrences in the future. These plans should be present in all project phases. For example, before the start of an activity, they may provide for wildlife relocation. During operations, EMPs can address issues such as fugitive dust emissions control and the management of hazardous materials. Lastly, a major concern for mining undertakings is closure and relinquishment. There are hundreds of thousands of abandoned mines across the world, posing multiple hazards – from collapsing tunnels to soil and water contamination – with entities in charge of site clean-up often either foregoing remediation or restricting actions to highly affected areas (Gutierrez, 2020). Closure plans are a part of EMPs that help mitigate these risks by outlining costs, strategies and activities related to decommissioning.

Box 4.2. Mine closure: Australia's Leading Practice Sustainable Development Program

Australia is a major mineral resources holder, with over 300 mining projects in operation and the world's second-largest reserves of cobalt, copper, nickel and lithium (Australia Minerals, 2021). It is also home to biodiversity hotspots and reference environmental management initiatives. One of these is the Leading Practice Sustainable Development Program for the Mining Industry, a series of handbooks developed by experts, industry, government and non-governmental representatives to serve as a reference both to mine operators and regulators.

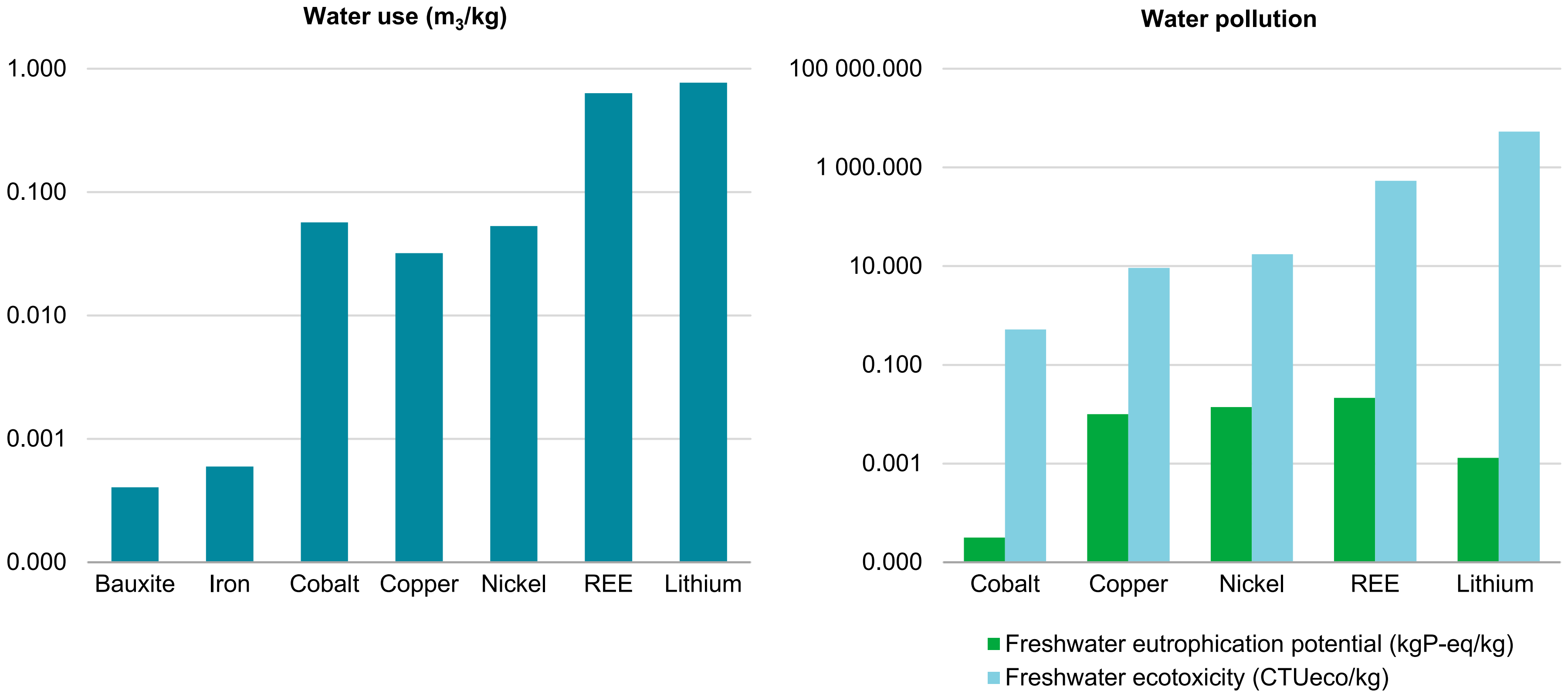
Australia has about 60 000 abandoned mines and often it falls to the authorities to address these sites, such as in 2015, when the Western Australian government took on responsibility for a recently abandoned nickel mine (Campbell et al., 2017). The mine closure handbook sets out approaches on how to prevent or minimise adverse long-term impacts from mining. It states that most Australian jurisdictions require mine closure planning as part of the approval process for mining activities. Moreover, regulators usually have significant enforcement powers over company commitments, often linked to financial securities. Post-mining land use planning is thus incorporated in project design, including measures to minimise disturbance, establish stable non-contaminated landforms, ensure progressive rehabilitation and enable subsequent use.

Closure plans should reflect local circumstances and build on local strengths, which are often a key factor for a successful transition after relinquishment. Future uses may comprise agricultural activity, industrial development, ecosystem conservation or community use. In this sense, planning for mine closure and rehabilitation requires a holistic approach and stakeholder engagement. Furthermore, it is an essential part of the various phases of a mining development's life cycle, from feasibility studies to project design throughout operations and decommissioning. This involves: continuous planning efforts; progressive allocation of financial resources, asset review and divestment evaluations; and implementation of closure, including remediation and monitoring, until agreed-upon completion criteria are met.

Even after infrastructure removal and site rehabilitation, there is still a need for ongoing management and monitoring until final relinquishment is approved and new users take ownership and responsibility for the land. Poorly closed and derelict mines provide a negative legacy for governments, communities and companies, while also leaving lasting environmental impacts. Best practice recognises that the mining sector is a temporary user of land and that sites should be returned to a state that enables the sustainable development of present and future generations.

Water management: Energy transition minerals have high water requirements and pose contamination risks

Indicators for water use and water pollution for selected minerals



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Notes: REE = rare earth element; CTUeco = comparative toxic unit for ecosystems; kgP-eq/kg = kilogramme of phosphorous-equivalent per kilogramme; m^3/kg = cubic metres per kilogramme. Lithium data is for brine-based resources. REE refers to neodymium iron boron (NdFeB) magnet.

Source: IEA analysis based on Farjana, Huda and Mahmud (2019) (cobalt, copper, nickel); Jiang et al. (2020) (lithium); Marx et al. (2018) (REE); Tost et al. (2018) (bauxite and iron).

Water management: Mining is a major water user and can cause long-lasting water pollution

Mining is a water intensive activity. Copper facilities alone withdrew over 1.3 billion cubic metres of water in 2006 (Gunson et al., 2012). Water is used along the production value chain, from exploration to processing (e.g. flotation uses water to concentrate mineral ores) and transport. It is a major input of many standard operations, such as cleaning, cooling, dust control and pumping. Energy transition minerals often have higher water needs than other commodities, although this varies according to the production process. Water consumption levels for nickel and copper production, for example, are more than double in hydrometallurgy compared with the more common pyrometallurgical method (Northey et al., 2014).

However, the most long-lasting impacts from mining do not come from water consumption. Acid mine drainage, resulting from water flows coming into contact with sulfide-rich materials, can persist long after a mine has been closed. Moreover, tailings ponds pose a risk of contamination to downstream water bodies, including extensive damage resulting from potential dam failure. Meanwhile, mines that employ dewatering operations (when groundwater inflows are pumped out to maintain access to the site) can cause a decrease in the surrounding water table or contaminate communicating aquifers.

Water pollution is particularly worrisome in the processing stage, where grinding, milling and concentration methods generate toxic effluents loaded with heavy metals and chemicals.

The associated contamination potential varies significantly among different resources, processing routes and means of disposal. Lithium production involves the highest eco-toxicity risks, mostly due to its leaching process. Moreover, the shift from traditional brine-based production to rock-based lithium leads to an almost tenfold increase in eco-toxicity values (Jiang et al., 2020). Water pollution is especially problematic in China, where REE production was conducted illegally or in unregulated small-scale activities until recently. There are numerous wastewater ponds, formerly used for leaching activities, abandoned near mining sites. China is taking steps to change this picture by remediating polluted areas and enacting stricter regulations to prevent new sources of contamination.

Mineral development can also affect the marine environment. Seabed mining can lead to significant water pollution through the release of dewatering waste or side cast sediment with fine particles and heavy metals (Miller et al., 2018). Deep-sea tailings placement, which involves the dumping of tailings in the ocean, also poses high contamination risks. Indonesia is one of the few remaining countries with mining activities that still use this disposal method. Legislation from 2001 outlawed marine tailings disposal, but two copper developments that already used deep-sea disposal before this remain in operation and a new nickel project is applying for a permit despite the existing regulatory framework (BloombergNEF, 2020).

Water management: The effects of mining projects on water resources

Activities, impacts and risks of mineral development related to water

Segment	Activities	Impacts	Risks
Production	• Water is required for exploration (e.g. drilling), extraction, initial processing (e.g. ore crushing) and related operations • Mining frequently encounters water resources, such as aquifers, creating the need for mine dewatering • Mining often encompasses a large area subject to rainfall and related drainage • Tailings with high water content are typically stored in artificial ponds	• Reduced availability for other uses due to increased overall demand or lower quality of sources • Pollution of water bodies by discharged effluents, including leachate, process water and other effluents • Acid mine drainage and sediment build-up in nearby waterbodies	• Increased water stress in the area and depletion of groundwater resources • Contamination of aquifers or downstream water by acids, sulfates and metals • Reduced surface water storage capacity
Processing	• Water is used to separate and concentrate minerals as well as for operational needs such as dust control	• Processing operations reduce water availability and generate effluents rich in chemicals and metals	• Increased water stress in the area • Contamination of freshwater bodies
Distribution and use	• Water is used in pumping and to transport minerals through pipelines	• Pollution of water bodies	• Spills can occur during the transport of minerals by ship, rail or pipeline

Water management: An integrated approach can help to address water needs sustainably

Water availability and demand depend on geographical conditions, the number of users and their different needs. That is the reason why water management increasingly requires an integrated catchment approach, addressing water systems at a basin level to better co-ordinate water uses and flows. This generally involves engaging stakeholders to address two major topics in a participatory manner.

Fulfilling water needs

There are several policy options to regulate surface and groundwater use, including the control of withdrawal through permits, economic instruments – such as pricing and setting a market for water rights – and defining standards for efficiency of use. These regulations often rely on monitoring systems that cover related flows and reservoir levels, to both verify compliance and ensure the sustainability of water sources.

Mining can improve its water footprint by reducing its water needs or by using alternative sources. Efficiency can be gained by reducing losses (e.g. minimising wet areas, filtrating tailings, monitoring pipelines), using dry processing technologies and by replacing evaporative cooling with less water-intensive methods. Furthermore, mining operations can often use water that has lower quality, such as water from mine dewatering and surface runoff, as well as recycled process water, treated wastewater or desalinated seawater. The Mining Association of Canada's TSM initiative has a Water Stewardship Protocol and Framework that sets benchmarks for company water management programmes.

Ensuring water quality

Effluents from the mining industry contain toxic substances, such as residual metals and chemicals used for extraction and processing. Comprehensive standards for the discharge of wastewater are a way of guaranteeing that polluting substances remain within acceptable limits, with acidity and metal toxicity being two key parameters to address (Opitz and Timms, 2016). These can be complemented by quality norms for water bodies, which align uses with required conditions and support the monitoring of affected ecosystems.

To reduce the load of pollutants discharged and meet established standards, mining facilities can reduce the volume of water that is contaminated (e.g. by managing runoff or covering waste rock and ore piles) and prevent it reaching waterbodies (e.g. implementing a drainage system or designing the project to avoid contact with groundwater). Furthermore, multiple treatment technologies allow the industry to remove the different contaminants present in its effluents. These include both simple measures (e.g. pH correction and the use of coagulants to precipitate metals) and advanced technologies, such as membrane filtration or photochemical oxidation.

Box 4.3. Managing groundwater: Lessons from Chile, where copper mines stand next to earth's driest non-polar desert

Chile is the world's largest copper producer, responsible for about 28% of global supply in 2019. It is also the most water-stressed country in the Americas, ranking 18th globally in terms of baseline water stress (WRI, 2021). Moreover, most of its copper mines are located in the Andean mountain range in the dry northern part of the country, with approximately 54% of copper production occurring in the Antofagasta province (Lutter and Giljum, 2019), which lies next to the Atacama desert.

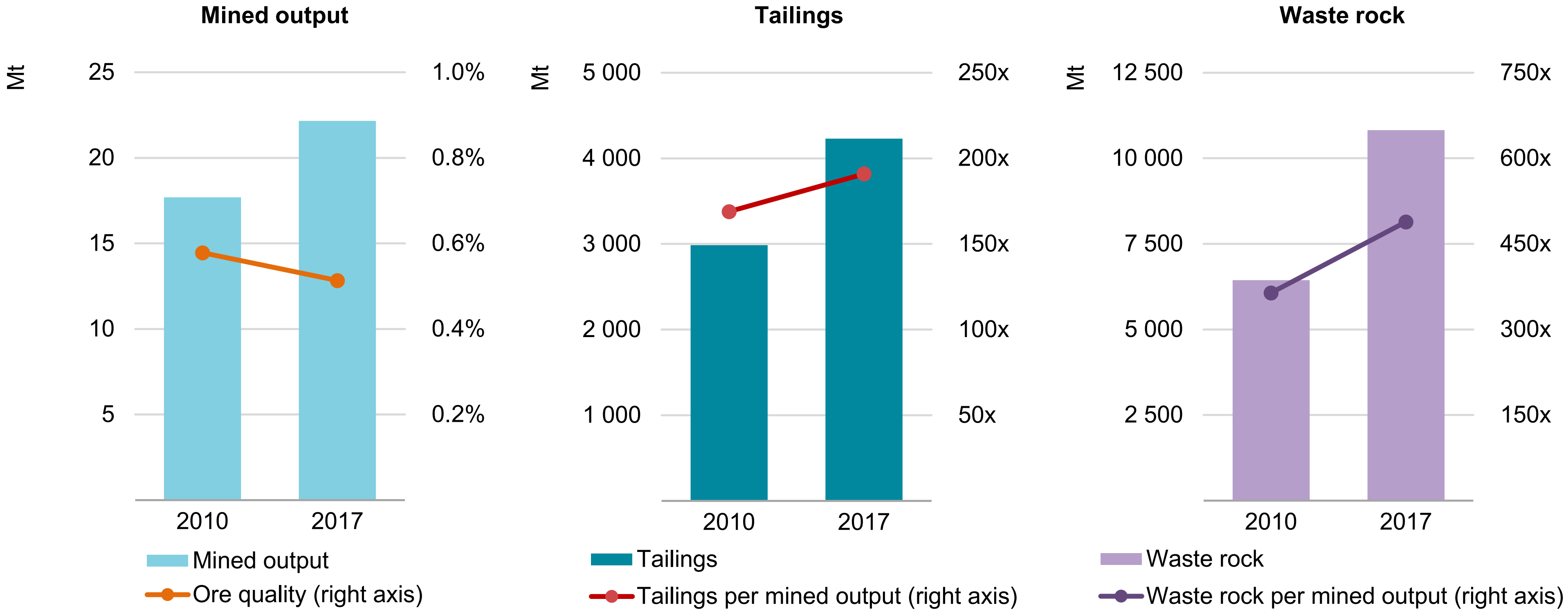
In this region, groundwater faces competing interests from agricultural, domestic and industrial activities, including mining. The development of copper, in particular, not only demands water for dust control and the extraction, separation and transport of ore, but can also potentially contaminate the scarce water resources due to acid mine drainage, dewatering and the disposal of tailings.

However, until the mid-2000s Chile did not have a specific legal framework to regulate groundwater use. The Water Code of 1981, which implemented a water permit trading scheme, was designed to address surface water use. In 2005 this legislation was amended to include procedures related to groundwater management (Donoso, Lictevout and Rinaudo, 2020). These included defining and allocating groundwater property rights, regulating its use, establishing user associations and enabling the reallocation of rights through market mechanisms. Restrictions on use apply when there is a decline in reservoir levels, exploitation generates a risk of contamination, and to safeguard water flows for sensitive ecosystems. The industry has been looking to keep pace with these developments. Anglo American, for example, took measures to allow its Los Bronces mine to recycle over 78% of the water it uses, upgrading a water transport system and using an automated circuit for recirculation (Copper Alliance, 2021).

Chile has put in place new legal instruments to address water stress. However, it could still benefit from a more integrated approach to water management, as it is not able to manage resources at river basin level or involve multiple stakeholders in co-ordination efforts (Donoso, 2018). Moreover, it faces a number of implementation challenges, such as inadequate monitoring and enforcement, often leading to the over-allocation of use rights (Donoso, Lictevout and Rinaudo, 2020). This is aggravated by the fact that many reservoirs were already overexploited before the relevant legislation came into place, highlighting the importance of regulating groundwater at the early stages of its use.

Waste: Growing production volumes and declining ore quality are leading to a substantial increase in waste volumes from mining operations

Waste generation from copper and nickel mining



Source: IEA analysis based on data updated and expanded from Mudd and Jowitt (2016).

Waste: Mineral development generates vast volumes of residues that have, on more than one occasion, led to large-scale environmental disasters

Mining is generating increasing volumes of waste. This includes overburden (materials covering mineral resources), waste rock (uneconomic materials removed in ore extraction), and tailings (fine-grained materials left after separating the valuable fraction of the ore). The total amount of residues generated during mining can vary depending on the extracted commodity, methods employed and resource conditions (e.g. ore grade), but is usually quite significant. In 2018 the mining and quarrying sector accounted for over a quarter of the total waste generated in Europe (Eurostat, 2021).

Typically, the volume of waste rocks is governed by the stripping ratio, which refers to the amount of material removed to extract one unit of ore. This ratio spans from 2:1 to 8:1 in surface extraction and is much lower in underground mining (EC JRC, 2018). Waste rocks are often stored close to the mine, in piles or heaps. Meanwhile, the amount of tailings is related to the ore grade (i.e. the share of valuable minerals in the ore). For copper and nickel, of which ore grades are low, the waste rock and tailings generated to produce one tonne of product amounted to almost 700 tonnes in 2017, 30% more than in 2010 due to deteriorating ore quality and the predominance of surface mining. Tailings are usually transported through pipes to a tailings storage facility. The number of these facilities are estimated at around 32 000 globally – among active, inactive and abandoned facilities – containing around 223 billion tonnes of tailings (World Mine Tailings Failures, 2020). The most common type is an embankment dam that is designed to retain tailings and the associated water.

These facilities pose contamination risks for nearby soil and water bodies and the hazard of dam failure. The locally called Rare Earth Lake, for example, covers over 10 square kilometres of Bayan Obo, a mining town in China, and the soil surrounding it is highly enriched with heavy metals (Pan and Li, 2016). In 2019 the collapse of the tailings storage facility at Vale's mine in Brumadinho, Brazil, led to mining waste surging across the surrounding areas and the death of over 270 people (see Box 4.6). In 2015 Brazil had already seen the collapse of the Fundão dam, which released 43 million cubic metres of iron ore tailings, polluting 668 km of watercourses from the Doce River to the Atlantic Ocean (Carmo et al., 2017).

Mining and mineral processing also generates hazardous waste, an output related not only to the metals and chemicals handled in these activities, but also to the presence of naturally occurring radioactive material (NORM) in some ores. NORM can be further concentrated during mineral processing and end up in waste, with the highest activity concentrations having been found in scales from wet chemical processes and in precipitator dust from high-temperature processes (IAEA, 2005).

Waste: The impact of mining operations on residues

Activities, impacts and risks of mineral development related to waste

Segment	Activities	Impacts	Risks
Production	• Excavation removes overburden, while initial processing generates waste rock and tailings • Seabed mining might discharge plumes of contaminated waste sediments and slurry in the seafloor	• Formation of waste piles, often with the potential to result in acid drainage • Generation of hazardous waste, including heavy metals and, in some cases, radioactive material (NORM)	• Soil contamination due to the leaching of waste piles • Pollution of downstream water bodies, including adjacent aquifers
Processing	• The beneficiation of minerals frequently requires the use of chemicals and the comminution of ores (e.g. grinding) • Processing equipment can concentrate NORM, resulting in technically enhanced substances (TENORM)	• These processes generate waste streams with fine metal particles and, in many cases, high toxicity • Waste with higher radioactivity (TENORM) generally must be disposed of through permanent storage in specialised facilities	• Hazardous waste poses health threats to workers as well as environmental contamination potential
Distribution and use	• Products that reach their end of life are discarded by users	• Generation of hazardous waste, often with mixed substances, such as a combination of plastics and metals	• Improperly managed waste can end up being handled in unsafe environments or contaminating ecosystems

Note: TENORM = technologically enhanced naturally occurring radioactive material.

Waste: A robust waste management framework can ensure that companies take steps to reduce waste generation and handle waste safely

Sustainable waste management can ensure that instead of causing environmental harm, mining residues are used as resources and support economic development. This usually follows a "reduce, reuse and recycle" hierarchy, with disposal as a last resort.

Policies and plans to manage waste

Effective waste management policies ensure that companies take action to reduce the risks to the environment and public health from waste streams, take steps to reduce waste generation and undertake proper disposal or recovery. The European Union's Directive on Management of Waste from Extractive Industries, 2006/21/EC, for example, requires the use of best available techniques, including techniques to reduce the volume of extractive waste and use of residues for backfilling or construction purposes. In addition, the EU directive requires operators to develop waste management plans that cover all aspects of waste management, including waste reduction, storage, transport, monitoring and reporting, for each phase of production.

Waste management plans typically involve establishing procedures for each type of residue. The International Finance Corporation indicates measures for management of key mining waste categories in their Environmental, Health and Safety Guidelines for Mining.

Dewatering tailings to reduce waste volumes and risks

Tailings dewatering techniques offer several benefits, including less land use, lower risk of dam failure and reduced scope for acid drainage. Thickened or dried tailings can be disposed of as a paste or through dry-stacking, both of which create more stable disposal structures and allow water recovery. Many methods exist to dewater tailings, including pressure filtering and thickening agents, but until recently, these methods had been used primarily at high-grade, low-throughput operations due to technical limitations and high capital costs. However, a recent pilot project in the Escondida copper mine in Chile demonstrated their feasibility at higher-throughput projects, indicating that the economics of these technologies are improving. Furthermore, increasing water scarcity and safety requirements created in the wake of the Brumadinho disaster may provide the push needed to scale up tailings dewatering (Leonida, 2020).

Thickened tailings can also facilitate tailings reprocessing and support a more recovery-focused management strategy. This enables waste reduction while also increasing mineral supply. Most types of waste generated by mining can be used by other sectors, for example, in cement production. Moreover, metals contained in products that reach their end of life can generally be recycled, even if this potential is still widely underexplored (see Chapter 3).