UK Parliament POST

Research Briefing

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Annex to mining and the sustainability of metals

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For further information on this subject, please contact the co-author, Dr Jonathan Wentworth.

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Contents

Summary

This Annex provides additional material to the POSTBrief on the sustainability of mining.

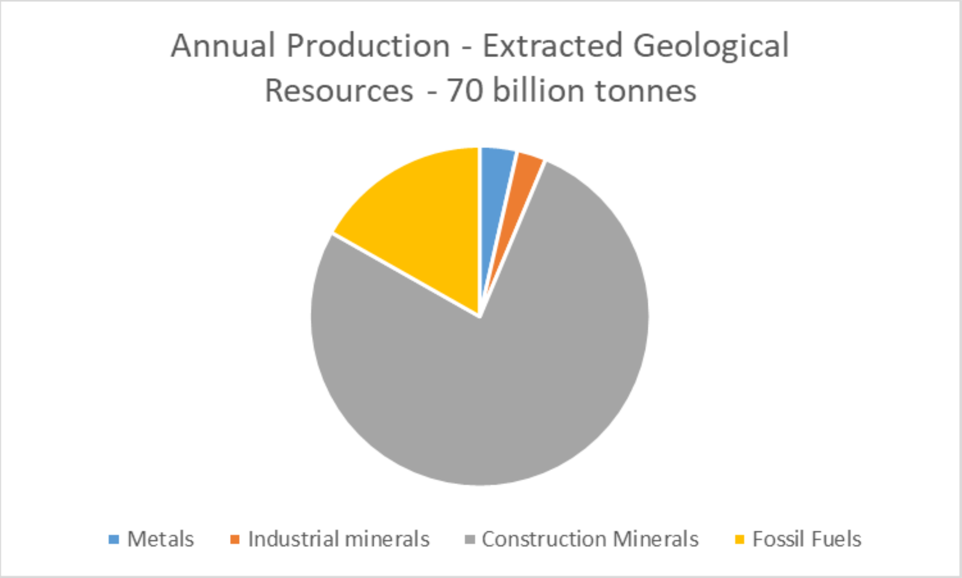
- Section 1 is an introduction to the modern mining industry and the production and supply of metals. It is intended as a primer for readers who are unfamiliar with mining and mineral processing, with some explanation of technical concepts and basic statistics.
- Section 2 provides additional details on specific regulations that apply to environmental and social impacts in the mining industry. These regulations include transnational laws and conventions. Local legislation is often quite variable and inconsistent between jurisdictions; there are some examples provided of the differing regulations.
- Section 3 includes some additional content related to sustainability reporting and certification schemes relevant to the mining sector. This section provides some greater detail of specific schemes, and in some cases, academic criticism of the success of certification and reporting mechanisms.

1 The mining industry in the 21st century

1.1 Mineral resources and metal production

Mining is necessary to produce a number of resources (Figure 1). Materials for construction include sand, gravel and crushed rock (approximately 50 billion tonnes extracted per year),[1] and minerals for cements (4 billion tonnes per year).[2] Fossil fuels are the next largest category of mineral resources, with over 11 billion tonnes of coal and oil and over 3 million cubic metres of gas extracted per year.[3] Approximately 2.5 billion tonnes of metals and 1.9 billion tonnes of non-metallic 'industrial minerals' are produced each year.

Figure 1: Annual total production from geological resources (excludes natural gas). Quantities shown refer to finished product, and exclude associated waste



Source: Data from [1–3]

Mineral resources extracted and processed for their metal content are referred to as *ores*. They are commonly divided by the major metals in the ore, and are often considered in groups defined by markets and traders: ferrous ores, used for iron and eventually steel production; aluminium; base metals including copper, lead, zinc, nickel, tin, tungsten; precious metals including gold, silver, platinum, palladium and the other platinum-group elements (PGE); minor metals that are more recent additions to terminal markets such as the London Metal Exchange, including cobalt and lithium; and speciality metals that are rarely traded on terminal markets, and are

The exploration for new mineral deposits can be slow – it may be decades between discovery and production.

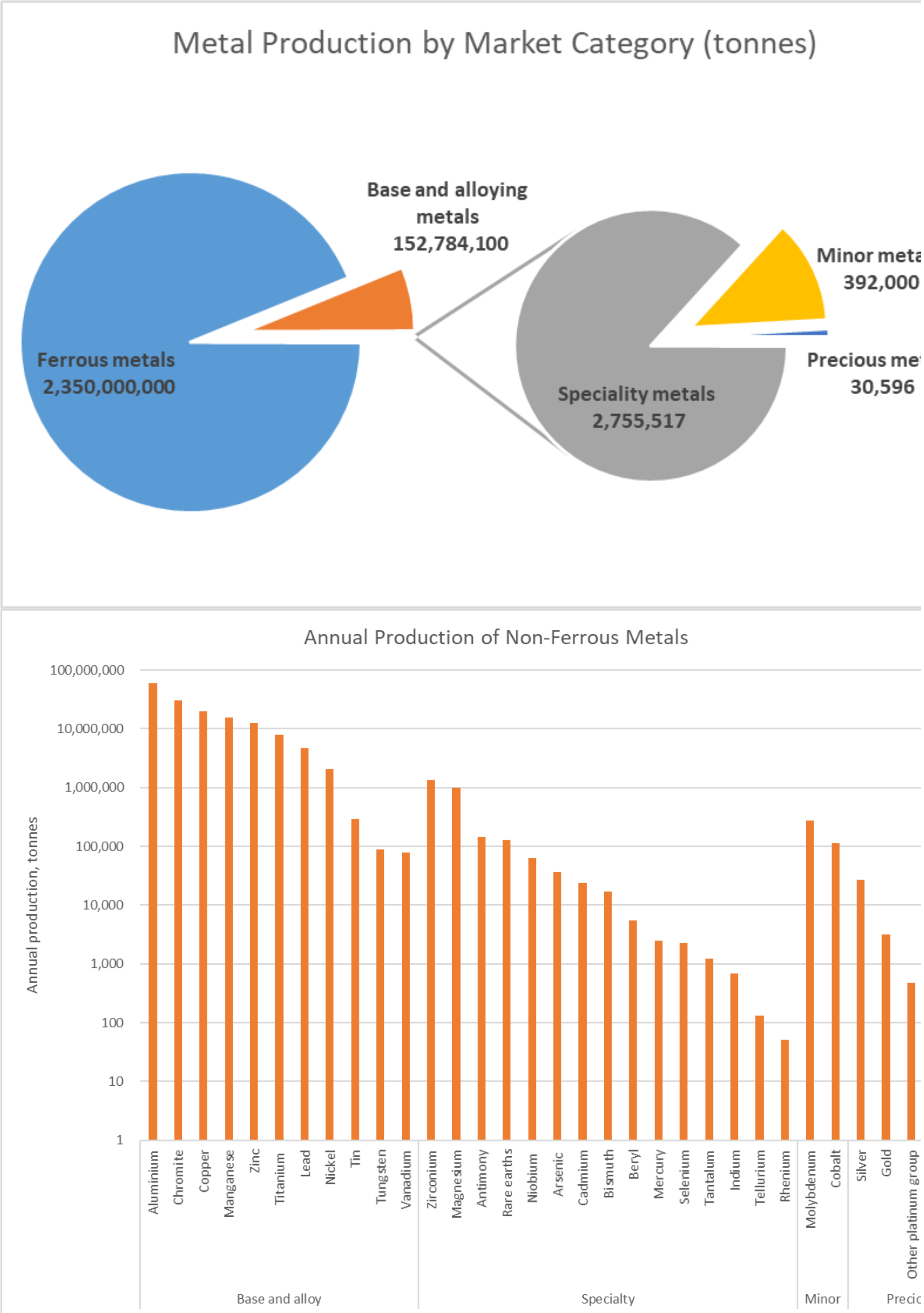
commonly extracted as by-products from other ores, and include the rare earth elements (REE), tantalum, and tellurium (Figure 2).

Mining and exploration companies, investors and markets use one of a family of resource codes to define the ore deposit into different categories. Although there are various codes (e.g. JORC, SAMREC, CRIRSCO, NI 43-101) dictated by the country of company listing, mining jurisdiction, market regulations, or by company choice, they have a broadly common set of definitions. *Mineral resources* are potentially valuable, and for which reasonable prospects exist for eventual economic extraction, whereas *mineral reserves* are valuable and legally, economically, and technically feasible to extract. Ore deposits that have yet to meet these thresholds are often referred to as *prospects*. A viable reserve will typically have a high concentration (in mining terms - *grade*) of one or more target metals, concentrated into minerals that can be feasibly and favourably processed. There needs to be a sufficient volume of rock containing that mineral (often referred to as the *tonnage* of the deposit), within a defined space that can be mined cost-effectively. The exploration of an ore deposit requires significant data to be collected on the geology and mineralogy; in most mining jurisdictions these data need to be signed off by a third party 'competent person'. Combined with analysis of the economics, mineral processing and metallurgy, legal rights, environmental impact assessment and post closure plans, exploration companies develop data-poor prospects into data-rich resources; the distinction between resource and reserve may be market conditions, final permits and approvals.

The mining life cycle

Parcels of land including known prospects will be permitted for further exploration as "licence" or "tenement" areas, administered and regulated by local and national governments. Licence areas are then subject to further exploration, which will typically include higher resolution, mapping, surveying and sampling. Drilling and digging of small pits or trenches are used to extract samples from the subsurface, and build the dataset needed to advance the prospect.

Figure 2: A) Global metal production for 2016. Based on contained metal – excludes waste from mines. Data from 2. B) Breakdown of non-ferrous categories from A, showing production by metal. Titanium, zirconium, niobium and tantalum by mineral concentrate, not contained metal. Chromite and beryl by gross (mineral) weight. Arsenic as arsenic trioxide. 'Other platinum group' include iridium, ruthenium, osmium and rhodium.



Source: Data from [2]

The social licence to operate is not a formal permit; it describes whether a company has public approval to continue operations.

The exploration company must assess the feasibility of mining the resource legally, technically and economically. This involves metallurgical testing; design of the mine, processing facilities and supporting infrastructure; economic analysis of costs and predicted income; and environmental impact assessment. For public companies, these data and analyses are typically consolidated into a 'feasibility study' for disclosure to shareholders, and to raise finance for the proposed mining project. The feasibility study incorporates significant analysis of risk – geological, technical, financial and environmental.

Environmental and social impacts of mining projects are subject to additional criteria beyond the legal obligations of the host jurisdiction. Due diligence in the assessment of environmental and social impacts is a key step for access to finance, with the Equator Principles being a notable example of a framework in use by financial institutions. A company's past performance with respect to environmental and social impact may also be tracked through markets – the Dow Jones Sustainability Indices are one such example of long term, cross-project review of impact.

Mining projects often need to obtain a 'social licence to operate'. At all stages of the mining cycle – from prospecting through to post-closure, companies often need the acceptance of local communities. This may be enshrined in governance and regulation and enforced by legal tools; where it is not enforced, the social licence to operate will be reflected by access to finance, labour, and other permissions. The loss of a social licence to operate constitutes a major risk for a mining project. Missteps in the exploration stages of a project can jeopardise the social licence to operate, even in situations where the exploration company do not intend to take the project through to mining themselves. The delineation of a mineral reserve and permission to mine (including finance) may take years or even decades from initial prospecting. Junior exploration companies may seek to sell on projects prior to the development to reserve status because of the time and finance requirements of seeing a project through to mining.

Once a project is given permission to mine, and has sufficient finance in place, on-site infrastructure needs to be developed, and preliminary groundwork on the mine site itself needs to be carried out. This may take two or more years, culminating in the mine commencing production. The ultimate life of mine will depend on the reserve and resource base and rate of production; the resources and reserves will vary over the lifetime of the mine, with additions from continued exploration, reductions from production, and modifications based on metal price and costs. Some of the world's largest operating mines have been in production for decades (e.g. Bingham Canyon, Utah, USA: 1863 to present; Cripple Creek, Colorado, USA: 1890 to present). The mine may change ownership through its lifetime. Sale of mines typically includes sale of the environmental liabilities including waste facilities.

Eventually a mine will be closed; typically, this will be a consequence of unfavourable economics rather than exhaustion of the mineral resource. The closure of a site will require remediation of the land used for the mine and for waste piles. Tailings and other waste may be used to backfill the mine void.

The type of mine can affect what impacts it has on the environment.

Remaining waste piles will be profiled, landscaped and vegetated for stability. Mine workings – particularly open pits – may be left unfilled, and instead allowed to flood. Post-closure remediation is essential, as the abandoned mine can represent an environmental liability for decades or longer.

Mining operations

The design and operation of a mine is subject to some fixed, site-specific factors – shape and depth of ore body, rock engineering properties, etc. – as well as decisions about costs, and nature of impacts at the surface. Thus, an ore body may be mined out in in open cut pit, or underground via various methods. Mining projects may extract shallow portions of an ore body by open cut mining, then proceed underground to extract deeper reserves. Different mining methods have different impacts upon the environment during and after mining, and those impacts may drive the choice of method.

Open cut mines are typically developed in near-surface orebodies. Some ores such as nickel "laterites" and (aluminium) bauxite deposits form in broad horizons near or at the surface and are mined by stripping off these layers. Other ores are found tens to hundreds of metres deep. Open cut mining is favoured for large tonnage, low grade ores. Open pits can range in scale from a few cubic metres in volume in artisanal workings, to a few cubic kilometres: the Bingham Canyon copper-molybdenum-gold mine in Utah, USA, is approximately 4 km wide and 1.2 km deep.

Some surface mines are operating in sands and gravels in or near rivers and beaches. These mines are working *placer deposits*, in which specific minerals (e.g. gold, tin ore, rare earth minerals) have been transported by river and deposited in sand banks, gravel beds and estuarine sands. Placer deposits are typically worked by dredging, then processing in sluices to separate the economic minerals from the sand and gravel.

Where ore reserves are deeper underground, or mining permits prohibit significant surface impacts, then mining will be by one or more underground methods. Underground mining may result in less obvious impacts at the surface than open cut methods, and where backfilling is used, surface waste piles may be significantly less too. Ore deposits with spatially restricted mineralisation (e.g. confined to specific veins or layers) may be particularly amenable to underground mining, as it allows for highly selective, low waste, mining. Typically, this is only economic for high value ore minerals / metals, such as gold and other precious metals. The underground method of "block caving" may be cost-effective for low grade, high tonnage deposits with a moderate value (such as copper). Underground mining is typically more costly and energy intensive than open cut methods due to haulage, ventilation and pumping needs. Particularly deep mines (e.g. Mponeng gold mine, South Africa, reaches 3.9 km below the surface) need cooling too.

Most mineral require processing to produce pure metals.

In both underground and surface mining, extraction of ore is performed by blasting to fragment the rock, which is subsequently hauled to processing facilities. The ore minerals are accompanied by waste:

- overburden (volumes of uneconomic rock between the ore and the point of access);
- dilution (uneconomic material that is deliberately extracted for engineering or access purposes);
- and gangue (non-target materials and minerals that are intimately associated with the target ore minerals).

Ore processing typically crushes and mills the rocks (a process known as *comminution*), and separates waste from ore minerals (*beneficiation*) to produce a mineral *concentrate* which is then metallurgical processed or sold and shipped. Waste produced by comminution and beneficiation is often a fine-grained, wet slurry of material called *tailings*.

Metallurgical processing

Concentrates are further processed to produce a final saleable metal or a crude intermediary. Many mine sites sell the concentrates, potentially overseas, for further processing. *Pyrometallurgical* processing of concentrates uses smelting to liberate crude metals or *mattes* at high temperatures. Smelting is typically a fossil-fuel intensive process. As well as fossil fuels, smelting requires the addition of fluxes to help separate the metals from the impurities. The final products include the crude metal and a waste product known as *slag*. Additional waste products include ashes and dusts from the filtration of particles from emissions.

Concentrates can also be processed through *hydrometallurgy*, where a crude or pure metal is extracted by the use of a wet solvent (e.g. cyanide, sulphuric acid). Concentrates may need to be roasted or oxidised using micro-organisms prior the metallurgical extraction. Metals are extracted from solution by reaction with solids (e.g. activated carbon for gold in cyanide; further processed by smelting) or by electrolysis. Hydrometallurgy produces effluents – water contaminated with metals and reagents.

After a concentrate is treated by hydro- or pyro-metallurgy, there may be further steps needed to purify it and convert it into the standard form traded on terminal markets (or, for specialty metals not traded on such markets, converted to the purchaser's specification). Unfinished metal products are transferred or sold to refineries, with additional metallurgical processing for purification.

By-products

Many critical metals are recovered as by-products from the mining of other metals.

Wastes from the metallurgical processing (smelters and refineries) may be treated to recover additional *by-product* metals. A number of industrially-important metals are recovered exclusively as by-products, and based on their geological scarcity are unlikely to be recovered as the primary target of mining operations. Where ores and concentrates are processed for multiple metals at all stages, the secondary metals are referred to as *co-products*; these are typically an important part of the mining operation's finances, and as such are characterised during exploration. Common examples of co-products are gold and molybdenum from copper deposits, and silver from gold deposits. In contrast, by-products are not important contributors to the overall value of an ore, and may not be well characterised during exploration of processing. Mining companies may see no value from their eventual recovery at all – third-party companies may process waste to recover the metals and their value.

Figure 3. A number of metals are dependent on production as by-products or 'companions' of more abundant metals (such as iron, aluminium and copper). This figure shows what percentage of a metal's production is as a by-product.

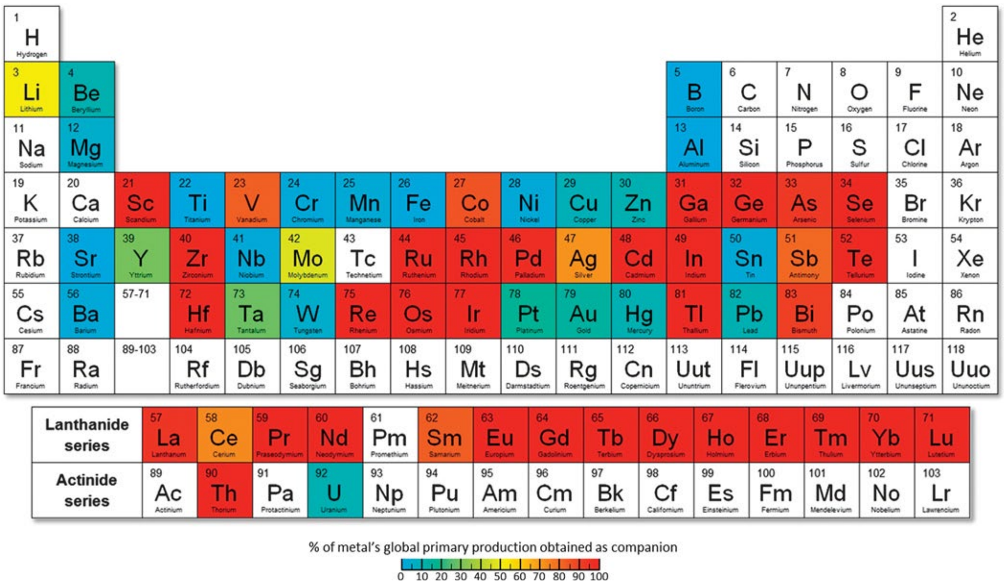


Figure from [4]

Many of the metals that are considered 'critical' (Figure 4) are those recovered as by-products. Their criticality reflects geological scarcity and is compounded by the complex supply chains that bring them to markets. As they are rarely fully characterised during exploration, and none of the mining, beneficiation or metallurgical steps are designed or optimised for their recovery, the by-product supply may not be strongly linked to changes in demand. There are potential by-products that are lost to waste streams with no current recovery.

Figure 4. : A significant number of critical metals (e.g. as per the EU 2017 list).5 Colour code as per Figure 3.

EU Critical Metals 2017 - % obtained as by-product					
Antimony	Cobalt	Hafnium	LREEs	PGMs	Tantalum
Beryllium	Gallium	HREEs	Magnesium	Scandium	Tungsten
Bismuth	Germanium	Indium	Niobium	Silicon metal	Vanadium

1.2 The structure of the mining industry

State organisations: State geological surveys often carry out the earliest prospecting stages of the mining life cycle, including regional mapping and data. Later stages of exploration, mining and mineral processing may be carried out by state-owned companies (such as CODELCO, Chile; Ma'aden, Saudi Arabia), either as sole operators, or as joint ventures with private sector companies.

Private companies: Commercial companies with public ownership act at all stages of the mining lifecycle, from prospecting through to metal refining, and include companies that reprocess waste for by-products. Several of the largest mining companies – often referred to as the *majors* - have a project portfolio covering several metals, and are sometimes described as *diversified miners*. Other majors focus on one metal, e.g. gold or iron. The majors are vertically integrated, with in-house capabilities in exploration, mining, smelting and refining. The majors have the capital and expertise to afford the considerable infrastructure costs and commitments that come with the world's largest mining projects, such as the construction of deep water ports, railways and road networks,[6] and desalination plants.[7]

Companies with a smaller market capitalisation (sometimes referred to as 'mid cap miners') tend towards more focussed portfolios of metals. They may operate mines and associated facilities as *joint ventures* with other companies (including the majors) to access capital and finance. As mid-caps tend not to be vertically integrated, they sell intermediate products from their mines (concentrates or crude metals) on to smelting and refining companies, or to the majors with processing facilities.

Junior companies are most active at exploration stages, from prospecting through to permitting. Although some may see a project through to mining, Supply chains are global, and will pass through multiple countries between mine and sale of final product.

many junior companies will sell projects and exploration data onwards, and the epithet is usually applied to companies that do not produce metal. Junior companies involved in prospecting may have no intention or ambition of mining a project after discovery, as the capital costs of doing so are high – instead they return value to shareholders by upgrading a tenement (by data collection) and selling the project. Junior companies are typically listed on smaller or sub-markets, such as London's Alternative Investment Market (AIM). Markets in countries with an active mining sector often host juniors (e.g. Australian Securities Exchange, Toronto Stock Exchange).

Artisanal and small-scale mining: ASM is most frequently associated with the extraction of high value minerals and metals, including precious metals, and exotic metals used in modern technologies (e.g. tantalum). ASM covers a broad spectrum of mining activities: from legal and fully permitted activities carried out by small businesses and landowners; illicit or unpermitted subsistence working (particularly in developing countries), and illegal mining activities on unlicensed land (or land registered to other miners). ASM activities are a source of income for non-government and criminal groups, and the ASM sector has particular vulnerabilities to human rights abuses, social impacts, and environmental mismanagement. However, a significant proportion of employment in mining is through ASM, rather than industrial: 40.5 million people engaged in ASM in 2017 (compared to 7 million employed by the formal industry in 2013).[8]

Artisanal mining operates both parallel to and within the industrial mining structure: whilst some artisan-mined material will be processed and sold as value-added goods through fellow 'cottage industries', a proportion of artisan-mined material will be incorporated into the industrial supply chains, both legitimately and illicitly. Consumer concerns over the environmental and social impacts of ASM are a key driver in the development of mining company and supply chain certification schemes.

Metal supply chains

The supply chains from ore to saleable metal are complex, and vary between different metals, and different companies. The largest mining companies have the capital and capacity to run *vertically integrated* mining projects, with mines, smelters and refineries. This infrastructure may be global however, with intermediate products such as concentrates shipped internationally. Some ores and mining methods are amenable to vertical integration – projects that use copper heap leach with solvent extraction and electro-winning produce cathode copper (the LME-traded commodity) on site.

For smaller mining companies and mining projects, vertical integration is too costly. Instead, concentrates are shipped, often internationally, to smelters, and in turn, crude metals are shipped to refineries. The supply chains for metals, and particularly the by-products, are multinational and complex, with a number of companies involved (Figure 5).

The complexity of metal supply chains, spanning multiple companies and countries, pose challenges for linking finished products back to their raw materials sources and stakeholders in that supply chain. The conversion of mineral concentrates into metal commodities through the supply chain means that there are opportunities to mix responsibly mined concentrates with those mined without due regard to social and environmental impacts.

Certain mineral resources are mined from very few geographical locations; smelting and refining capacity is also concentrated into certain countries and regions. This geographical concentration of aspects of metal supply chains contributes to geopolitical risk in security of supply; this is particularly acute for the critical metals (see also 0), where production is from unique ore deposits, or highly specialised metallurgical facilities.

Figure 5. solar panel needs two by-product metals - cadmium and tellurium - derived from waste products of zinc and copper refining respectively. The production of useable Cd and Te involves multiple mines, smelters and refineries, possibly distributed around the world.

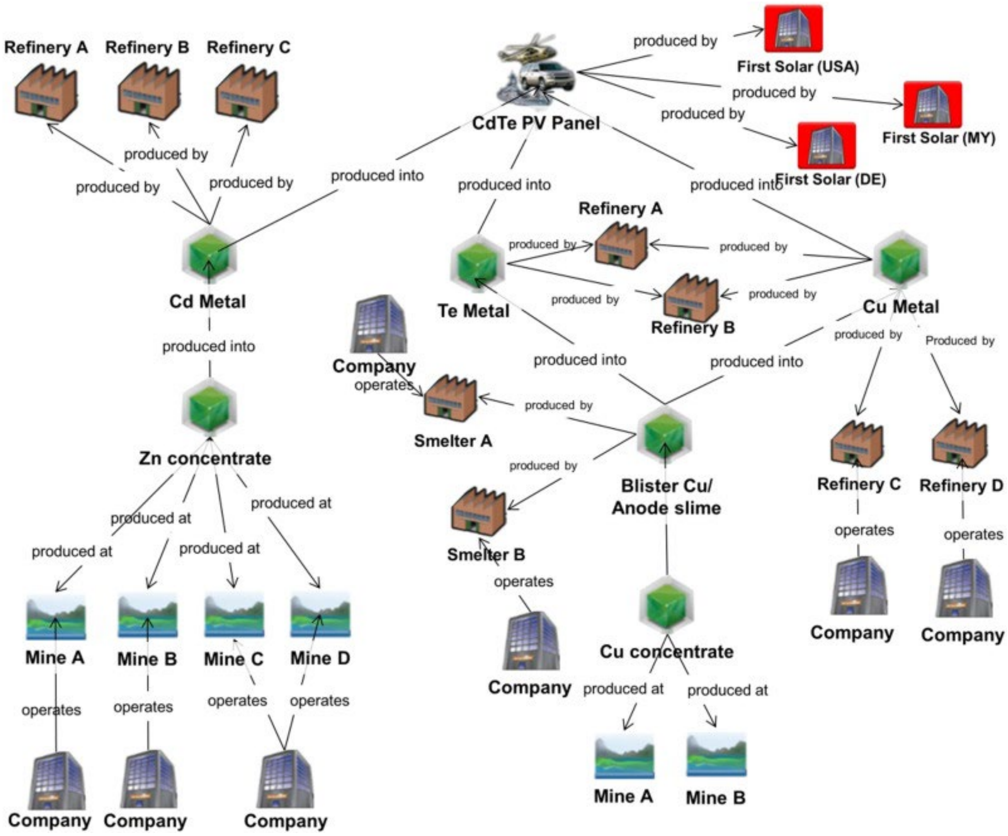


Image sourced from [9]

Trade and Markets

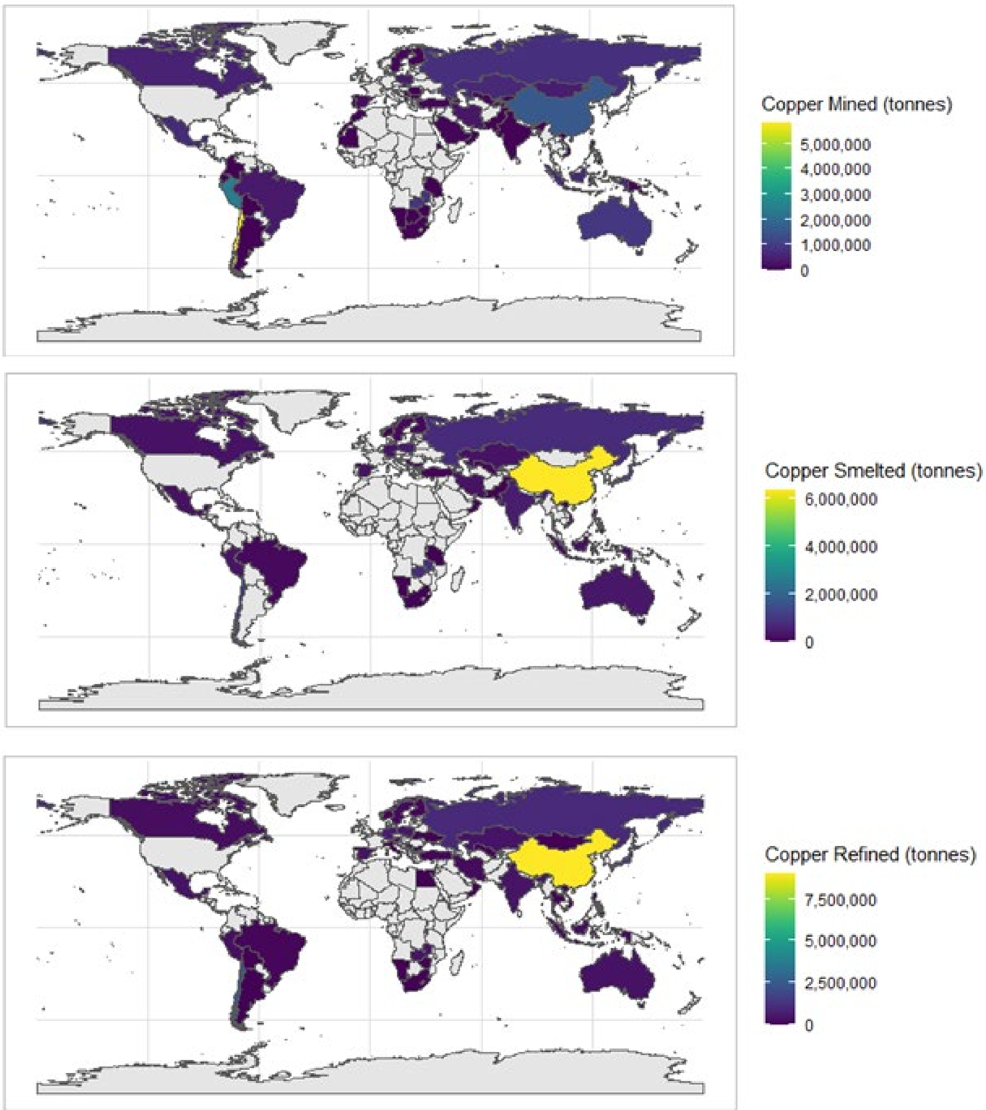
The UK is an important hub for global metal trade.

Some metals are traded as commodities on terminal markets such as the London Metal Exchange. These include aluminium, cobalt, copper, lead, molybdenum nickel, tin, various forms of steel, zinc, gold, silver, platinum and palladium. As commodities, these metals are traded internationally in a standardised form and market-set price; as a consequence, producers have little influence over the pricing of the metals. The terminal markets provide trading mechanisms such as futures and options, giving rise to speculative activity around metal prices; through associated warehousing facilities they also act as a market of last resort, and balance metal supplies between periods of over- and under-supply.[10]

The other metals – the specialty metals – are more typically traded through distributors or by direct contracts between producers and consumers. These mechanisms allow for a greater diversity of pricing, and producers can market 'value-added' metals and alloys at non-standard specifications.

Consumer drive for sustainable and ethical products is leading to trade of metals – particularly precious metals – outside of the traditional supply chains and terminal markets. The added costs of certification for schemes such as Fairmined are recovered through establishing separate markets and trading partnerships that sell metals at a premium over the market prices.[10]

Figure 6: Global production of copper from mines, smelters and refineries, based on contained metal in outputs. Chinese mines contribute approximately 7% of global copper supply, but its smelters and refineries handle approximately 38% of the global supply. Conversely, Chile mines close to 30% of annual copper production, but refines only 10% .

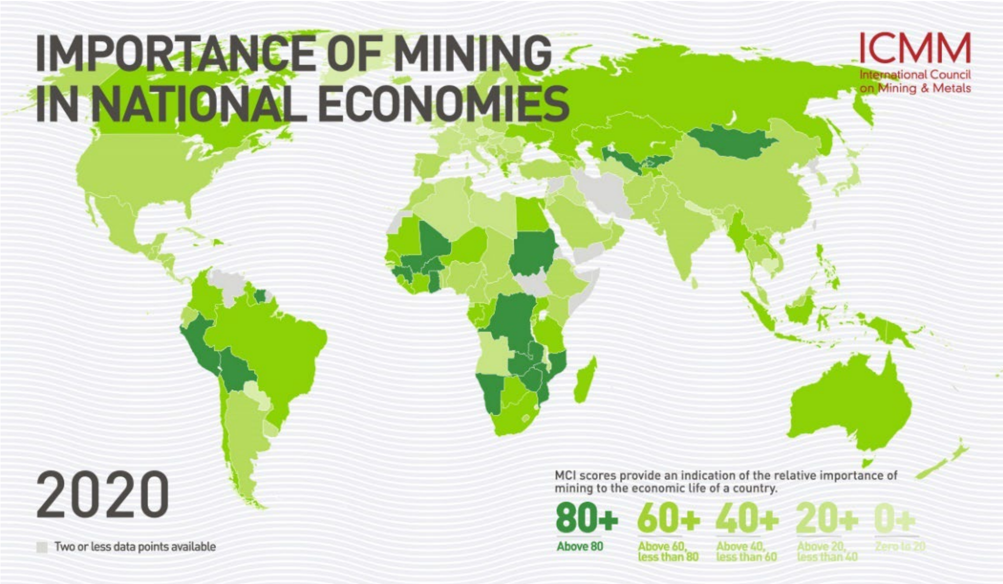


Data from [3].

Economics and employment

As well as the raw materials that mining provides, the sector is important for wealth generation. The ICMM calculate a Mining Contribution Index for the world's nations, based on mineral export contributions, mineral rents, and mineral production value as a proportion of GDP.[11] A number of countries are economically dependent on mining; these are typically non-OECD nations in Africa, South America and central Asia (Figure 7). Several OECD nations do have important mining sectors — China, Australia and USA notably.

Figure 7: ICMM map of Mining Contribution Index. A higher value indicates a greater proportion of a nation's economy is associated with mining and mineral production



As well as export of mineral products and rent derived from mining activities, the mining sector provides economic contributions through supporting other industry. Significant parts of the value (23%) of the mining sector stems from the provision of services to the sector; these service providers are often based in OECD countries (USA, China, Germany, UK, Japan, France and the Netherlands).[12]

The world's mining companies have multibillion dollar market capitalisations, with listings on both major and minor investment markets. This represents a conversion of global mineral resources into revenues for multinational companies, investors and governments in host countries. These beneficiaries are often in OECD countries.

The commercial mining industry employs around 7 million people worldwide, in roles that range from unskilled labour through to high level technical expertise demanding graduate-level qualifications and minimum professional experience. Western mining companies tend to operate sites with a mix of a local labour force, and migrant or expatriate workers in managerial, skilled and technical roles. Migrant workers may be highly temporary — often travelling to mining and exploration sites for a few weeks at a time. Such 'fly in, fly out' rotations may be international in scope. Unskilled and semi-skilled labour may use more migrants (international and national) during the most labour intensive parts of a mine's life (e.g. construction).[13] Chinese companies tend to use a higher proportion of migrant (Chinese) workers in skilled and unskilled roles throughout a mine's life.[13,14]

The commercial mining sector is male dominated, with women representing 15% of the workforce (up from ~10% in 2013).[15] Around 10% of board positions in the top 500 mining companies are women.[16] The major mining companies have committed to increasing local employment, including skills gaps that expatriate workers fill, and to improve the gender balance of the workforce.[15,17,18]

The International Labour Organisation report that the mining sector constitutes 1% of the global workforce but is responsible for 8% of fatal accidents.[13] These figures are inclusive of ASM and the figures for the commercial mining sector will be much lower; nevertheless, mining is a hazardous occupation. A study of mines in the USA in 2015 reported a fatality rate of 11.4 per 100,000 versus an all-sector rate of 3.4 per 100,000, and lost-time injury rate of 1.7 per 100 full time-equivalent employees, compared to 0.9 for all sectors.[19,20] There has been a consistent and collaborative effort in the mining industry to move towards zero fatalities / zero harm,[21,22] and an improvement in the industry's safety record over time.[19]

2 Regulations in the mining industry

The mining industry is subject to a complex system of regulations. For the most part, it is the laws and permitting requirements of the host countries that dominate the regulatory frameworks. There are a few key areas where international agreements and transnational regulations produce a consistent, global, set of regulations. This section describes some key discrepancies and commonalities in significant areas of environmental and social impact for mining regulations.

Water use

Water is allocated to mining and mineral operations by authorities (typically national or state-level government), and is usually requested as part of the mine permitting procedure and potential impacts covered by the environmental impact assessment.[23] The volume of water an operation is permitted to use can vary considerably as a function of the legal framework of the host country — for example, in the USA, landowners can use as much of the surface water on their property as they have historically acquired, whereas in Chile, the landowner has no entitlement to surface water at all.[23] Permitting and allocating procedures for water allowances are increasingly considering the impacts of water demand on the environment and other users.[23] Community participation in decision making on water allocations varies between jurisdictions, but is typically in the form of a time-limited call for consultation and objection. South Africa has no time limit on public objections, and Peru has initiated more advanced public consultation requirements into the permitting process; China has no requirement for public consultation.[23] A mining operation may include significant investment in water infrastructure, and coupled with their financial value, the operating company may have disproportionate bargaining power with authorities, in planning and water-allocating systems that are opaque and overly technical to civil society.[24]

Water quality

Water quality and the management of discharges from mine sites are reviewed during permitting procedures for mines. Water quality in rivers and streams close to mine sites may be monitored and reported by the mine operators, national or local environmental agencies, NGOs, and local communities. In any one mining jurisdiction, there may be a number of guidelines governing water quality, with reference to drinking water [25] or impacts on aquatic life.[26] Limits on water quality discharged by a mine site might be set during permitting, or be required to remain within pre-set standards. Determining baselines for both ecological flow, existing industrial and community use, and quality (in terms of chemistry and biodiversity) are a common early step.[27]

Most jurisdictions demand detailed post-closure plans for water management, with particular emphasis on water quality and AMD mitigation. Some authorities (e.g. South Africa, China) require a bond, to be repaid after the site has implemented the closure plans.[23] In the USA, validation of the post-closure plan may need a minimum period of monitoring (e.g. 12 years in New Mexico), but outside the USA there is often no obligation for monitoring once the implementation of a post-closure plan has been certified.[23] Mining companies remain liable for water quality issues on their legacy sites in some countries (e.g. Australia, USA) but in some cases for only a defined period (e.g. 5 years in Chile), and this liability may end if the legal entity that operated the mine is dissolved or declared bankrupt. [23] The mining sector often uses mine-specific legal entities and subsidiary companies to operate a site in order to accommodate joint ventures, public-private partnerships with state-controlled resource companies to satisfy local regulations (e.g. tax systems), and to thwart them (e.g. corporate tax avoidance).[28] As a result, many mining companies are indeed wound-down once a mine closes.

Energy and greenhouse gas emissions

The monitoring and disclosure of energy use and associated emissions are covered by a number of legal instruments and reporting frameworks. Target setting for emissions reductions or maximum caps is governed by international agreements (e.g. UNFCCC 2015 Paris Agreement) and national laws, such as the UK's commitment to net zero carbon by 2050.[29] Within these schemes, corporate contributions to national CO_2 budgets may be governed by emissions trading schemes or by compulsory reporting and disclosure of energy use and greenhouse gas emissions.

Air quality and atmospheric emissions

The continental-spanning impacts of industrial air pollution and acid rain led to international co-operation on emissions control. The United Nations' Economic Commission for Europe (UNECE) introduced the Convention on Long-range Transboundary Air Pollution in 1979 (CLRTAP),[30] with signatories from Europe, Canada and Russia committing to reducing SO_2 emissions. Further protocols in 1985 and 1994 have committed signatories to further reducing SO_2 fluxes, as well as ground level ozone, NO_x, heavy metals and more.[31] Control is largely at source, with flue gas desulphurisation and other flue-scrubbing technologies deployed at smelters. Control of SO_2 and acid rain has been a success story in Europe, North America, Japan, and Australia, but emissions remain high in other industrial nations such as China and India.[32,33]

Waste

Mining and mineral processing waste is governed by a complex mixture of local (host country) laws, and international standards. Regulatory frameworks typically focus on one or both of the major threats from waste — contamination (of land or water) risk, and physical risk (i.e. failure of tailings facilities). Waste management on any given site will be subject to local authority approvals and laws which may specify acceptable levels of contaminants (including reagent effluents and metals) in wastes, volumes of wastes, design specifications for waste impoundments, permits to transport waste offsite for processing (e.g. for by-product metal recovery) or higher specification impoundment (for radioactive or high toxicity wastes).

The thresholds for defining contaminated land and problematic waste vary by country; contaminants of concern, and acceptable means of measuring them or defining actionable limits (e.g. soil guideline values, biological assay-based techniques) may differ by jurisdiction. Many mine wastes are relatively low in the contents of hazardous substances — some are environmentally inert — and as such are often excluded from other directives, laws and standards related to pollution, waste and contamination (e.g. mine waste is excluded from the EU Seveso directive),[34] and may be governed as a distinct class of wastes (e.g. EU Directive 2006/21/EC;[35] and the Mine Waste Directive[36]). Specified pollutants within wastes may have statutory requirements to report quantities released / disposed of into the environment. The UK maintains a Pollutant Release and Transfer Register as part of its commitment to the 2003 Kiev Protocol,[37,38] and in line with the United Nations Economic Commission for Europe (UN-ECE) Protocol on Pollutant Release and Transfer Registers. The UK PRTR includes mining and mineral processing, for arsenic, cadmium, chromium, copper, mercury, nickel, lead, zinc and their compounds.

Social impacts

The interaction between mining companies and their host communities is governed by local laws and agreements typically set during the exploration stages of the mining lifecycle, as part of the authorisation process. The involvement of local communities or their representatives in planning and permitting varies between countries; this heterogeneity has led to the development of transnational best practice guidance, and various reporting frameworks for disclosures that seek to level requirements between jurisdictions. Community or Impact Benefit Agreements (CBAs / IBAs) are a growing part of the authorisation process; they are a legal requirement in more than 30 mining countries [39,40] and are more widely seen as an essential part of corporate social responsibility and obtaining the social licence to operate.[41] CBAs are perhaps the most significant system by which local communities extract benefits from a mining operation, and have some input as to minimising negative impacts. They remain problematic though, with no standardisation across jurisdictions; uneven bargaining power between communities, governments and mining companies; and poor or uneven observation, metrics and assurance systems.[41]

The United States' Dodd–Frank Wall Street Reform and Consumer Protection Act of 2010 included a provision regarding the use of possible conflict minerals (tin, tungsten, tantalum, gold, the 3TGs) and an assessment of whether they were sourced from the Democratic Republic of Congo or surrounding states. Dodd–Frank brought in a legal requirement for due-diligence and audit of supply chains. The OECD introduced "Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas", with no restriction in geographical scope to the DRC.[42] This Guidance formed the basis of EU-wide regulations on the import of raw and processed 3TGs[43] that came into force in 2021. Some studies suggest that these laws have unintended consequences, such as negative economic impacts in the DRC (as large parts of the ASM sector cannot meet the legal requirements) and greater violence as a consequence.[44,45]

3 Reporting and certification

Reporting and certification schemes help to level differences in laws between countries, and allow investors to scrutinise the performance of mining companies.

To produce a more consistent system of environmental, social and governance performance, a number of sustainability reporting and certification schemes have been developed. These often act with, or in addition to, both local and international laws. The varied schemes have different approaches in how they handle key impact areas within mining, and indeed, some certification schemes are specifically focused on just one thematic area (e.g. tailings). This section provides some details on how key impact areas are incorporated into selected certification and reporting schemes.

Water use

Reporting of water use is covered by a number of certification schemes, as well as legal obligations to the host country and regulatory agencies, although these commonly rely on self-reported data rather than independent assessment. [23] Publicly-traded mining companies self-report water management data to investors, typically as part of their wider reporting of sustainability metrics. Companies using the GRI Standards [46] report data on volumes, quality and sources of water extracted, and volumes and receivers of water discharged, and identify data that are from water-scarce environments. However, sustainability reporting is typically a corporate rather than site-level activity, and water data may be aggregated, with a loss of context.[47]

Flexibility in reporting standards mean that companies might aggregate waters of different qualities together to report on water consumption, and there are inconsistencies in units used.[48] Quantifying volumes of water used by mining operations is further complicated by whether the operator considers all water it extracts (including in dewatering), or just water that it actively uses;[24] and the recycling and reuse of water may be presented as percentages of either total water use or of the original freshwater input.[47] Such inconsistencies are often despite guidance tailored specifically towards mining operations, such as the ICMM's guidance on Water Reporting.[49,50] The variability in corporate water reporting mean that while they have some application in evaluating year-on-year performance of a company, they are less useful in benchmarking companies against each other.[51] Aggregated and variable water reporting means that calculating the 'embodied water' or 'intensity of water' used for a specific product on the market remain difficult.[52,53] ICMM recommend calculation of water intensity (consumed) per unit material produced as an internal metric,[49] pointing out that reducing complex, context-sensitive data to a single number can limit the meaningfulness of intensity metrics, and that a single company might reasonably have multiple intensity benchmarks representing different products (metals and level of beneficiation).[50]

Water quality

Water quality is a component within the GRI and UN System of Environmental-Economic Assessment for Water (UN SEEAW) standards, but they have differing definitions. GRI requires reporting of usage data on freshwater (total dissolved solids < 1000 mg/l) and other waters, and disclosure of:

> "*Priority substances of concern for which discharges are treated, including:*
>
> 1. *how priority substances of concern were defined, and any international standard, authoritative list, or criteria used;*
> 2. *the approach for setting discharge limits for priority substances of concern;*
> 3. *number of incidents of non-compliance with discharge limits*",

with priority substances of concern defined as those which cause "irreversible damage to the waterbody, ecosystem, or human health".[46] UN SEEAW does not require distinct reporting of (or define) freshwater, and the standard does not define pollutants itself, instead suggests that a "list of pollutants is based on the country's environmental concerns as well as its national legislation on water and, where applicable, international agreements".[54] The lack of agreed definitions on water quality between nations and between the two major reporting standards means there are inconsistencies in water quality reporting.[55]

Energy and greenhouse gas emissions

Mining and mineral processing companies operating within the UK, listed on the London Stock Exchange, or admitted to or dealing on the New York Stock Exchange or NASDAQ, must disclose according to the Streamlined Energy and Carbon Reporting (SECR) regulations.[56] The SECR guidance requires disclosure on:

- Annual global emissions from activities for which that company is responsible including the combustion of fuel and the operation of any facility; together with the annual emissions from the purchase of electricity, heat, steam or cooling by the company for its own use. (Global GHG Protocol Scope 1 and Scope 2 emissions);[57]
- At least one 'intensity ratio' - at least a metric which expresses the business' annual emissions in relation to a quantifiable factor, most appropriate to their business activity;
- Previous year's figures for energy use and GHG emissions (except in the first year);
- Methodologies used in calculation of disclosures;
- Underlying global energy use that is used to calculate GHG emissions, including previous year's figure; and,

- Information about energy efficiency action taken in the organisation’s financial year.

There is broad alignment between the UK SECR and widely-used international reporting mechanisms such as the Global Reporting Initiative Sustainability Reporting Guidelines (GRI) and the GHG Reporting Protocol.

The Task Force on Climate-Related Financial Disclosures (TCFD) recommend that companies report on the risks of climate change to their operations and ability to do business. Rather than reporting GHG emissions, companies instead disclose the risks and opportunities associated with climate change and a transition to a lower carbon economy, ideally with “forward-looking statements on financial impacts”.[58] This takes the form of companies reporting their dependencies under different climate change scenarios (as opposed to other emissions reporting frameworks, which focus on the impact the companies have had on the environment).[59]

Whilst climate change poses material risks to mining companies and their operational sites, the transition to a lower carbon economy is also an opportunity for mining companies, as the technologies that underpin renewable energy generation, storage, transport etc. are typically metal-intensive. [60,61] Improved outlooks for metals (Ni, Al, Cu) in such scenarios mean that TCFD-aligned reports in the mining sector may have an overall positive outlook [62–64] with the portfolios of diversified miners being “naturally hedged”.[65] Likewise, gold producers may see more positive outlooks based on gold having a “robust… risk-return profile”[66] despite its trivial role in environmental technologies. There are increased costs of de-risking operations for climate-related threats, and costs associated with low carbon energy supply — but in the case of energy supply, increasing oil and gas prices in ‘business as usual’ scenarios also lead to increased costs.[64,67]

TCFD-compliant disclosures may lead to better uptake of efficiency measures and carbon-abating processes, as within this framework they are translated into material and financial terms and released to investors, and mining company disclosures already suggests that energy consumption (whether from low carbon sources or not) are a significant source of costs and financial risk.[66,67] The ICMM considers the TCFD to have “provided the impetus for many organisations to progress climate risk and opportunity assessment and management”.[68]

In October 2021, the ICMM and its members made a commitment to Net Zero Scope 1 and 2 emissions by 2050.[69] Commitments include reporting progress on Scopes 1, 2 and 3 annually, obtaining external verification of performance, and report in alignment with the recommendations of the Task Force on Climate-related Financial Disclosures.

Air quality and atmospheric emissions

GRI reporting standards, widely used within the mining sector, require disclosure of various emissions, including those covered within CLRTAP.[46] The GRI standard is limited to reporting emissions, rather than having requirements to limit or reduce the release of air pollutants. The Initiative for Responsible Mining Alliance's standard (IRMA) for the mining sector aligns with the EU Air Quality Standards,[70] or with local regulations if they are more stringent.[71]

Waste

GRI reporting of waste [46] includes volumes of waste, waste avoided, disclosure of any hazardous waste, and a summary of the disposal of the waste. It does not require any disclosure of specific pollutants, and does not align with the Kiev Protocol. The reporting of tailings and other rock wastes within older GRI reporting standards has been variable, with not all mining companies using the additional sector-specific guidance,[72] and some aggregating different solid wastes into single categories.[73] 2020 updates to GRI[46] recommend specific reporting of tailings, and the 2018 Sustainability Accounting Standards Board (SASB) Metals & Mining Standard[74] has specific reporting requirements for tailings.

In the aftermath of the Mount Polley and Germano tailings disasters, the ICMM reviewed tailings management guidelines and issued recommendations in 2016,[75] largely focused on the integrity of the dam structures (building on the 2001 review by the International Commission on Large Dams, ICOLD).[76] Shortly afterwards, ICMM issued a new Position Statement that set out a tailings governance framework.[77] The United Nations Environment Programme formed a Rapid Response Assessment and made various recommendations on improving tailings management.[78] However, the Brumadinho disaster in 2019 prompted greater investor focus on tailings, with the Church of England Pensions Board, and Swedish Council of Ethics of the AP Funds, and other investors totalling $13 trillion of mining sector assets initiating the creation of the Investor Mining and Tailings Safety Initiative. This group issued a request for data in April 2019, which was made publicly available through a Global Tailings Data Portal.[79] In March of 2019, ICMM, UNEP and PRI jointly announced their intention to convene a Global Tailings Review,[80] and subsequently published the Global Industry Standard on Tailings Management (GISTM),[81] which built upon the previous ICOLD, ICMM and UNEP recommendations.

The Global Tailings Review and GISTM should lead to much greater disclosure of tailings management at mine sites, including legacy sites, and has switched the emphasis from reviews of failures to more comprehensive disclosures around design, management, risk reduction and impact assessment. Separate revisions to GRI reporting are contributing to improved detail in waste and tailings reporting.[82]

Social impacts

Details of community benefit / development agreements (CBAs and CDAs), community relations and wider social impacts will be communicated in sustainability reporting. Reporting standards such as GRI and SASB request disclosures on the management of community relations — details of stakeholder engagement plans, impact assessments, formal grievance processes etc. — and realised impacts. The emphasis is on the prediction and management of impacts from the mining project onto the community. However, SASB guidance also suggests companies quantify the material and financial risk posed to operations and project value as a result of community risks.[74] The completeness of disclosures in sustainability reports has been low (~50%) and selective over what is reported, but steadily improving.[83]

The relationships between mining projects and indigenous people are governed by local laws, and subject to disclosure via annual sustainability reporting. Sustainability reporting and certification is a key tool in 'levelling' between countries, as indigenous communities may have variable recognition, representation and protection in local legislation. Local laws and reporting standards typically align with the UN Declaration on the Rights of Indigenous People (UNDRIP 2017).[84] Within UNDRIP, indigenous people have the right to self-determination, and autonomy and self-government in regard to local and financial affairs, and thus are important stakeholders in the permitting of mining projects. UNDRIP's Article 10 states that "Indigenous peoples shall not be forcibly removed from their lands or territories. No relocation shall take place without the free, prior and informed consent (FPIC) of the indigenous peoples concerned"; as mining often has a significant land-use footprint, Article 10 plays an important role in mine permitting and decision making. Although FPIC has been widely adopted by sustainability standards and the mining industry in general, it remains challenging to apply: there is no clarity on how reaching 'consent' is determined; implementing FPIC in regimes that do not recognise indigenous people (i.e. as a 'beyond compliance' activity) may be impossible; appropriate representation of indigenous groups may be difficult, and contradict other measures of sustainable governance (e.g. gender-inclusive representation).[85]

Mining companies publish their governance and management structures in sustainability and investor reports, but they are only one half of the governance equation. The countries in which miners operate are also under scrutiny for their governance structures. The Fraser Institute's Annual Survey of Mining Companies [86] collates responses from mining professionals to rank different jurisdictions (countries and individual states in federal systems) on the basis of governance, policy and investment potential.

Governance data from host countries may be published and released in accordance with the Extractive Industries Transparency Initiative (EITI),[87] founded in 2003 with 55 participating countries including the UK. EITI nations form multi-stakeholder groups (government, mining industry, civil society) to establish local process, and collate and publicly release data on the governance of the extractives sector (including financial streams between government agencies and companies). The EITI is considered to have been a success in improving institutional transparency, but it is less clear that has led to improved governance structures, less corruption or more inclusive forms of development.[88–90]

The governance of artisanal mining is challenged by its nature as an informal, and often illicit or illegal activity. Schemes such as Fairmined and Fairtrade

Gold provide certification for ASM miners, and hence assurances on their labour conditions and the environmental and legal rights of the mining activities. These schemes remain under-subscribed, however. Some schemes aimed at commercial miners include provisions for engaging with and formalising relationships with artisanal miners in close proximity to projects (e.g. IRMA).[71]

The combination of the EU regulation, Dodd–Frank and OECD Guidance has led to the concept of 'responsible sourcing' in the supply chains of the 3TGs. There have been concerns raised over the supply of other metals too, most notably cobalt. Alignment with the Dodd–Frank Act, EU Regulation or various standards that put the OECD practice into guidance (e.g. IRMA)[71] is a condition of access to some markets, including the London Metal Exchange.[91,92] The concept of 'chain of custody' to promote sustainable development is in use for metals beyond the 3TGs — the Aluminium Stewardship Initiative have a voluntary chain of custody standard[93] that works in concert with their Performance Standard[94] (compulsory for ASI members).

References

1. UNEP Sand and sustainability: Finding new solutions for environmental governance of global sand resources. United Nations Environment Programme.
2. USGS (2020). Minerals Yearbook 2016 (Tables release only).
3. Brown, T. J. *et al.* (2019). World Mineral Production 2014-2018. British Geological Survey.
4. Nassar, N. T. *et al.* (2015). By-product metals are technologically essential but have problematic supply. *Science Advances*, Vol 1, e1400180. American Association for the Advancement of Science.
5. Commission, E. U. (2017). Study on the review of the list of critical raw materials. *European Commission: Brussels, Belgium*,
6. Rio Tinto Rio Tinto - Pilbara operations.
7. (2020). BHP to supply water for Escondida mine from desalination plant only. *MINING.COM*.
8. Fritz, M. M. C. *et al.* (2017). Global Trends in Artisanal and Small-Scale Mining (ASM): A review of key numbers and issues. *Working Papers*. HAL.
9. Nuss, P. *et al.* (2016). Mapping supply chain risk by network analysis of product platforms. *Sustainable Materials and Technologies*, Vol 10, 14–22.
10. Cook, G. (2018). As good as (ethical) gold.
11. ICMM (2020). Role of Mining in National Economies: Mining Contribution Index. ICMM.
12. Korinek, J. (2020). The mining global value chain. OECD.
13. (2016). International Migrant Workers in the Mining Sector.
14. Smith, G. (2013). Nupela Masta? Local and Expatriate Labour in a Chinese-Run Nickel Mine in Papua New Guinea. *Asian Studies Review*, Vol 37, 178–195. Routledge.
15. ICMM (2021). Diversity and inclusion.
16. PwC *et al.* (2015). *Mining for talent 2015: A review of women on boards in the mining industry 2012 – 2014*.
17. ICMM (2021). Future of Jobs in Mining Regions. ICMM.
18. Bureau of Labor Statistics (2016). Employer-Reported Workplace Injuries and Illnesses - 2015. 28.
19. Nowrouzi-Kia, B. *et al.* (2017). Systematic review: Lost-time injuries in the US mining industry. *Occupational medicine*, Vol 67, 442–447. Oxford University Press UK.
20. US Bureau of Labor Statistics (2016). Fatal occupational injuries in 2015.
21. ICMM (2020). Mining Principles. ICMM.
22. ICMM (2019). Fatality Prevention: Eight lessons learned. ICMM.
23. Thomashausen, S. *et al.* (2018). A comparative overview of legal frameworks governing water use and waste water discharge in the mining sector. *Resources Policy*, Vol 55, 143–151.
24. Sosa, M. *et al.* (2012). Exploring the Politics of Water Grabbing: The Case of Large Mining Operations in the Peruvian Andes. Vol 5, 16.
25. World Health Organisation (2018). WHO | Developing drinking-water quality regulations and standards. WHO.

26. Barton, C. *et al.* (2021). Water quality.
27. ICMM (2015). A Practical Guide to Catchment-based Water Management for the Mining and Metals Industry. ICMM.
28. Finér, L. *et al.* (2017). Tax-driven wealth chains: A multiple case study of tax avoidance in the finnish mining sector. *Critical Perspectives on Accounting*, Vol 48, 53–81.
29. The Climate Change Act 2008 (2050 Target Amendment) Order 2019. Queen's Printer of Acts of Parliament.
30. UNECE (1979). 1979 Convention on Long-range Transboundary Air Pollution. UNECE.
31. Menz, F. C. *et al.* (2004). Acid rain in Europe and the United States: an update. *Environmental Science & Policy*, Vol 7, 253–265.
32. Grennfelt, P. *et al.* (2020). Acid rain and air pollution: 50 years of progress in environmental science and policy. *Ambio*, Vol 49, 849–864.
33. Maas, R. *et al.* (2016). Towards Cleaner Air-CLRTAP Scientific Assessment Report 2016. in *EMEP-Steering body and Working Group on Effects-Convention on Long-Range Transboundary Air Pollution*. Vol 1,
34. (2012). Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC. *197*. Vol OJ L,
35. European Commission (2006). Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC.
36. DEFRA (2010). Environmental permitting guidance: The mining waste directive. DEFRA.
37. UNECE A simplified guide to the Protocol on Pollutant Release and Transfer Registers.
38. Regulation (EC) No 166/2006 of the European Parliament and of the Council of 18 January 2006 concerning the establishment of a European Pollutant Release and Transfer Register and amending Council Directives 91/689/EEC and 96/61/EC (Text with EEA relevance). Queen's Printer of Acts of Parliament.
39. Dupuy, K. E. (2014). Community development requirements in mining laws. *The Extractive Industries and Society*, Vol 1, 200–215.
40. Columbia Center on Sustainable Investment (2021). Community Development Requirements: Laws, Best Practices, and Community Development Agreements Database.
41. Hira, A. *et al.* (2021). Improving mining community benefits through better monitoring and evaluation. *Resources Policy*, Vol 73, 102138.
42. OECD (2016). OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas (Third Edition). OECD.
43. EU (2017). Regulation (EU) 2017/821 of the European Parliament and of the Council of 17 May 2017 laying down supply chain due diligence obligations for Union importers of tin, tantalum and tungsten, their ores, and gold originating from conflict-affected and high-risk areas. *(EU) 2017/821*.

44. Stoop, N. *et al.* (2018). More legislation, more violence? The impact of Dodd-Frank in the DRC. *PLOS ONE*, Vol 13, e0201783. Public Library of Science.
45. Parker, D. P. *et al.* (2017). Resource cursed or policy cursed? US regulation of conflict minerals and violence in the Congo. *Journal of the Association of Environmental and Resource Economists*, Vol 4, 1–49. University of Chicago Press Chicago, IL.
46. GRI (2020). Consolidated Set of GRI Sustainability Reporting Standards. GRI.
47. Northey, S. A. *et al.* (2019). Sustainable water management and improved corporate reporting in mining. *Water Resources and Industry*, Vol 21, 100104.
48. Boiral, O. *et al.* (2017). Is Sustainability Performance Comparable? A Study of GRI Reports of Mining Organizations. *Business & Society*, Vol 56, 283–317. SAGE Publications Inc.
49. ICMM (2017). Water Reporting. ICMM.
50. ICMM (2021). Water Reporting: Good practice guide (2nd Edition). ICMM.
51. Lee, J. *et al.* (2020). Responsible or reckless? A critical review of the environmental and climate assessments of mineral supply chains. *Environ. Res. Lett.*, Vol 15, 103009. IOP Publishing.
52. Northey, S. *et al.* (2013). Using sustainability reporting to assess the environmental footprint of copper mining. *Journal of Cleaner Production*, Vol 40, 118–128.
53. Northey, S. A. *et al.* (2016). Water footprinting and mining: Where are the limitations and opportunities? *Journal of Cleaner Production*, Vol 135, 1098–1116.
54. (2012). *System of environmental-economic accounting for water: Seea-water.* United Nations.
55. Cote, C. M. *et al.* (2009). Developing a water accounting framework for the Australian minerals industry. *Mining Technology*, Vol 118, 162–176. Taylor & Francis.
56. (2019). Environmental reporting guidelines: including Streamlined Energy and Carbon Reporting requirements. HM Government.
57. World Resources Institute *et al.* (2004). Corporate Standard | Greenhouse Gas Protocol.
58. Task Force on Climate-related Financial Disclosures (2017). *Recommendations of the Task Force on Climate-related Financial Disclosures.* 74. Task Force on Climate-related Financial Disclosures.
59. O'Dwyer, B. *et al.* (2020). Shifting the focus of sustainability accounting from impacts to risks and dependencies: researching the transformative potential of TCFD reporting. *Accounting, Auditing & Accountability Journal*, Vol 33, 1113–1141. Emerald Publishing Limited.
60. Arrobas, D. L. P. *et al.* (2017). *The growing role of minerals and metals for a low carbon future.* The World Bank.
61. Hund, K. *et al.* (2020). *Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition.* Climate-Smart Mining Facility, World Bank Group.
62. Anglo American (2020). Sustainability Report 2020.

63. Anglo American (2019). Climate Change: Our Plans, Policies and Progress.
64. Newcrest (2020). *Newcrest 2020 Sustainability Report*. 84.
65. Rio Tinto (2018). Our approach to climate change.
66. World Gold Council (2019). *Gold and climate change: Current and future impacts*.
67. Barrick (2020). The Gold Standard in Sustainability: the Barrick Sustainability Report 2020.
68. ICMM (2019). Adapting to a changing climate. ICMM.
69. ICMM (2021). ICMM · Our commitment to a goal of net zero by 2050 or sooner.
70. Standards - Air Quality - Environment - European Commission.
71. Initiative for Responsible Mining Assurance (2018). IRMA Standard for Responsible Mining IRMA-STD-001. IRMA.
72. ICMM (2010). GRI Mining and Metals Sector Supplement, version 3.0. ICMM.
73. Mudd, G. M. (2007). Sustainability and mine waste management—A snapshot of mining waste issues. in *Waste Management & Infrastructure Conference, Melbourne*.
74. Sustainability Accounting Standards Board (2018). *Metals & Mining Sustainability Accounting Standard*.
75. ICMM (2016). Review of Tailings Management Guidelines and Recommendations for Improvement. ICMM.
76. International Commission on Large Dams (2001). *Tailings dams: risk of dangerous occurrences : lessons learnt from practical experiences.* Commission Internationale des Grand Barrages.
77. ICMM ICMM · Tailings Governance Framework: Position Statement. ICMM.
78. Roche, C. *et al.* (2017). Mine Tailings Storage: Safety Is No Accident. United Nations Environment Programme and GRID-Arendal.
79. Global Tailings Portal.
80. Global Tailings Review.
81. ICMM *et al.* (2020). Global Industry Standard on Tailings Management.
82. Franks, D. M. *et al.* (2021). Tailings facility disclosures reveal stability risks. *Scientific Reports*, Vol 11, 5353. Nature Publishing Group.
83. Arthur, C. L. *et al.* (2017). Investigating performance indicators disclosure in sustainability reports of large mining companies in Ghana. *CG*, Vol 17, 643–660.
84. UNDRIP (2017). United Nations Declaration on the Rights of Indigenous Peoples | United Nations For Indigenous Peoples.
85. Owen, J. R. *et al.* (2014). 'Free prior and informed consent', social complexity and the mining industry: Establishing a knowledge base. *Resources Policy*, Vol 41, 91–100.
86. Yunis, J. *et al.* (2020). *Fraser Institute Annual Survey of Mining Companies 2020*. 82. Fraser Institute.
87. Extractive Industries Transparency Initiative. *Extractive Industries Transparency Initiative*.

88. Rustad, S. A. *et al.* (2017). Has the Extractive Industries Transparency Initiative been a success? Identifying and evaluating EITI goals. *Resources Policy*, Vol 51, 151–162.
89. Sovacool, B. K. *et al.* (2015). Does transparency matter? Evaluating the governance impacts of the Extractive Industries Transparency Initiative (EITI) in Azerbaijan and Liberia. *Resources Policy*, Vol 45, 183–192.
90. Kasekende, E. *et al.* (2016). Extractive industries and corruption: Investigating the effectiveness of EITI as a scrutiny mechanism. *Resources Policy*, Vol 48, 117–128.
91. London Metal Exchange (2018). *Responsible Sourcing: An LME Position Paper*.
92. London Metal Exchange (2019). *Overview of LME responsible sourcing*. London Metal Exchange.
93. ASI (2017). ASI Chain of Custody (CoC) Standard v1. Aluminium Stewardship Initiative.
94. ASI (2017). ASI Performance Standard v2. Aluminium Stewardship Initiative.

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