OECD Green Growth Studies

Mining and Green Growth in the EECCA Region

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Foreword and Acknowledgements

For most countries in the Eastern Europe, Caucasus and Central Asia (EECCA) region, mining is an important economic sector that contributes to employment and public revenue. It is also a major historic source of environmental damage, and continues to have the potential for immediate and long-term negative environmental effects. Governments in the region have a vital role to support better environmental performance in the mining sector and ensuring the industry can be a progressive part of a greener economy.

This report provides a foundation upon which to develop country-specific strategies for reconciling green growth and the mining sector. To that end, the report examines the environmental impacts of the mining sector in the EECCA. It assesses what has worked and not worked in OECD member countries to improve environmental performance. And it studies specific examples of successful sustainable mining operations.

Furthermore, it reviews environmental impacts and trends in the mining sector. It complements international knowledge and efforts in providing new evidence and best practices from leading mining jurisdictions. In so doing, it provides policy makers with guidance to reconcile environmental and competitiveness objectives in the mining sector.

This report would not have been possible without the generous support of the governments of Norway and Switzerland, and both the author and the OECD express their gratitude. The author is also grateful for the invaluable comments he received from his colleagues at the OECD, including Krzysztof Michalak, Jean-François Lengellé, Nelly Petkova, Taka Kato, Enrico Botta, and Chris McDonald, as well as from Claudia Kamke at UNECE.

This report:

- reviews principal examples of the environmental damage caused by different forms of mining
- presents emerging technology trends that are either directly or indirectly impacting environmental performance in mining
- identifies linkage opportunities between the mining sector and the green economy
- recommends areas of policy response for governments to improve environmental performance in the mining sector.

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Executive summary

The shift to a greener global economy will continue to demand significant quantities of natural resources, including copper, lithium and cobalt. However, the mining sector is a major potential source of immediate and long-term environmental damage. In the Eastern Europe, Caucasus and Central Asia (EECCA) region, the extraction of mineral resources remains an important contributor to export earnings, employment and public revenue at the national and sub-national level.[1] Governments have a vital role to play in supporting better environmental performance in the mining sector. They can ensure that industry is a progressive partner in promoting green economic growth and achieving the Sustainable Development Goals.

Beyond reducing the impact of mining on the environment and local communities, sustainability is increasingly an asset for competitiveness. Good environmental performance lowers costs by improving efficiency and helping ensure that mining companies earn a social licence from stakeholders.

The mining sector has substantial backward and forward linkages to other parts of the economy. Shifting mining to a more sustainable path can potentially improve environmental performance in existing linkages, as well as develop new ones. This includes acting as a conduit for new technologies, such as automation and digitalisation. It also means becoming a driver for environmental service providers, renewable energy and green infrastructure.

Mining has significant environmental impacts that stretch beyond the life of a mine

Surface and underground mining – the most common mining techniques – often generate significant adverse environmental impacts. Such impacts can go beyond the immediate operational area to cross watersheds and borders. At the same time, surface and underground mining can contribute to climate change. Environmental impacts in the immediate area can include ecosystem destruction; negative effects on biodiversity; release of heavy metals, toxic substances and particulate matter through both mining and the beneficiation processes; and significant use of water resources.

OECD mining jurisdictions generally have legal requirements for site rehabilitation. However, waste rock and tailings management facilities (TMFs) can remain potentially dangerous sites of environmental contamination for decades – and even centuries – after mining ceases. Because closed mines are monitored less than operational ones, environmental impacts can be particularly damaging. These impacts can range from acute damage caused by an accident at a TMF to longer-term effects.

These issues are particularly pertinent in the EECCA region. The legacy of Soviet-era mining has left significant numbers of poorly maintained non-operational mine sites and legacy pollution, without clear paths for rehabilitation.

Technology trends on sustainability in the mining sector

Automation and remote control in mining is largely driven by productivity and safety concerns. However, it has additional positive environmental effects. For instance, automated mining trucks can reduce emissions, use inputs more efficiently and prolong machine life.

Electrification, including electric vehicles and renewable energy deployment, has potential benefits for input efficiency, reliability and emission reduction. For off-grid mines, integrating renewables can reduce emissions and costs, while improving reliability. For underground mines, electrification means more safety and efficiency.

Advances in data **digitalisation and remote sensing** have drastically changed the quality and quantity of data available to mining companies. Exploration companies can now use a range of remote sensing technologies to avoid more invasive approaches.

Developing the connections between the green economy and the mining sector

Improving the environmental performance of the mining sector can have tangible socio-economic benefits for the companies involved and spill-over effects into other parts of the economy. Public policy can play an important role to facilitate the transfer of skills and technology that can generate these benefits. First, it can offer incentives to encourage deployment of technology. Second, it can mandate technology transfer and training as components of mining licences. Third, it can encourage mining companies to maximise local procurement and help local companies meet internationally recognised standards. Fourth, it can develop human capacity.

Deployment of new technology: The mining sector can act as a conduit for the deployment of new green technology, including automation, which can be transferable to other sectors.

Environmental services: This shift can also generate new markets for environmental services companies that help mining companies go green.

Green shared infrastructure: Transport, water and power infrastructure can be constructed to green standards and with capacity to benefit the broader community.

The circular economy: The circular economy, a conceptual re-envisioning of economies from linear patterns of material use to one without waste, could affect the mining sector across a number of areas, including mining waste reprocessing.

Key recommendations

Successful OECD jurisdictions demonstrate a confluence of policies that together incentivise, support and regulate mining companies to reduce their environmental impact. Key recommendations to governments in the EECCA region include the following:

- Develop a whole of government approach to improving mining environmental performance, using international conventions for standards and information.
- Implement clear, stable and consistently enforced environmental regulation that stimulates operators to implement efficient and green techniques and technology.
- Facilitate broader stakeholder participation in support of good environmental performance, including local communities in monitoring environmental impacts.

- Support innovation in the mining sector through promoting sustainable and innovative infrastructure and the funding of sector-specific and applied research.
- Build human capacity in technical and environmental skills and knowledge through education, training and work experience.
- Develop policies to address abandoned and orphaned mine sites, including holding responsible parties liable and incentivising investment in reprocessing waste.
- Support the development of a market for third-party green service providers in the mining sector, including accreditation processes

Notes

[1]. The International Council of Mines and Metals' 2016 Mining Contribution Index measures the significance of the mining sector's contribution to national economies. Three EECCA countries (Uzbekistan, Kyrgyzstan and Tajikistan) rank among the top ten globally. Two others (Ukraine and Armenia) are in the top 20. In 2015, in the Kyrgyz Republic, Uzbekistan and Armenia mineral rents constituted 7.5%, 4.6% and 3.2% of gross domestic product respectively. In the same year, ores and metal exports contributed 44.4%, 15.6% and 12% of total merchandise exports in Armenia, Georgia and Kazakhstan.

1. Mining, sustainability and the EECCA region

This chapter discusses the environmental impacts of mining operations at different stages of the mine lifecycle, including impacts on water, soil, biodiversity and climate change. It also provides context on sustainability trends and drivers in the mining sector. Mining across the countries of Eastern Europe, the Caucasus and Central Asia (EECCA) is explored, with a focus on its economic importance and the need to improve environmental performance. Finally, this report is put in context with ongoing OECD work related to the region and to the mining sector, as well as projects and conventions at the international level that can help shape sustainability and the mining sector in the EECCA region.

1.1. Introduction

Mining remains an important economic sector for many countries in the Eastern Europe, Caucasus and Central Asia (EECCA) region. At the same time, EECCA countries are adopting strategies to promote green growth. They aim simultaneously to improve livelihoods, while decoupling economic growth from destructive environmental practices. Determining the role of government policies in rationalising green growth strategies with the extractive sector, and improving the environmental performance of mining operations, are critical challenges.

The immediate impact of mining on ecosystems and human health, as well as long-term concerns about climate change and global ecosystem sustainability, is sharpening focus on the environmental footprint of the mining sector. Whether underground or open pit, mines have the potential to affect their environment, both locally and over broader geographic areas, including across borders.

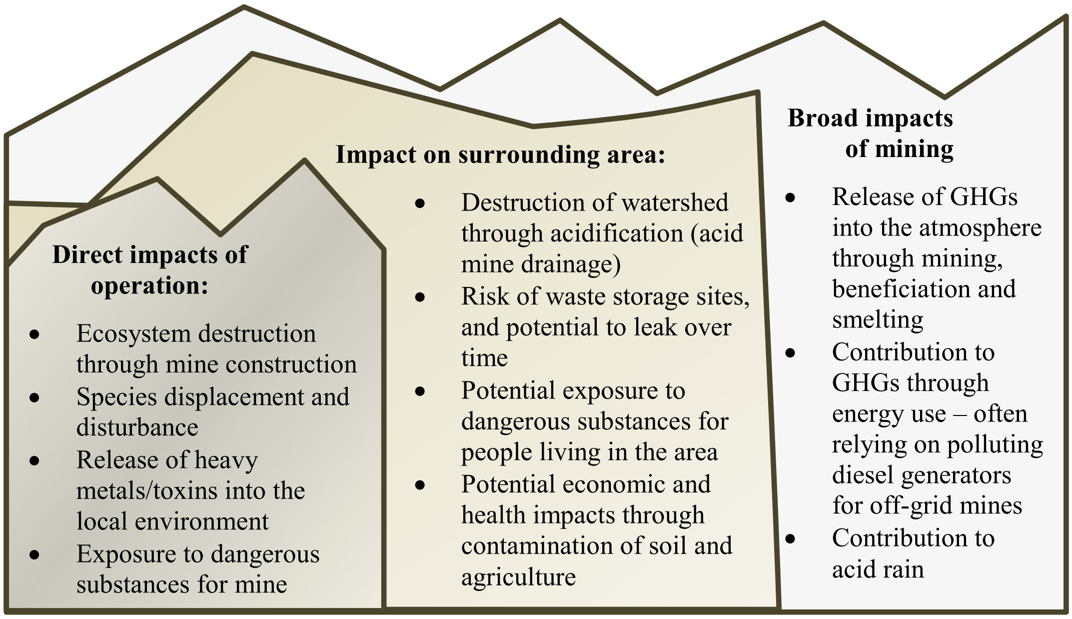
Despite the potentially negative environmental impact of mining, the transition to a greener economy will continue to require new sources of minerals and metals. Even the most optimistic circular economy projections anticipate a continued need for new primary sources of metals and minerals. In this context, governments play a vital role in ensuring better environmental performance in the mining sector and ensuring that industry can be a progressive part of greening the economy. Although there is an inherent contradiction in the term "green mining", the mining sector can improve its environmental performance and reduce impacts.

1.2. Environmental impacts of the mining sector

As its name suggests, the extractive sector involves the permanent removal of natural resources from the ground. This takes a variety of forms, including surface mining (most commonly open-pit), underground, in-situ and heap leaching, as well as small scale and artisanal mining. Each of these carries its own environmental challenges. Beyond that, the geographic characteristics and location of the mine form the underlying environmental risks and challenges for both ecosystems and surrounding communities.

The potential environmental impacts of mining can be seen as a series of nested circles. They begin with the immediate impact of the mine – the hole that is dug, the tunnels that are built, the soil and water that are displaced. They continue with impacts on the wider ecosystem – how water is used or contaminated, how habitats are disturbed or destroyed, and how biodiversity suffers. This is not just limited to the mine site itself, but also encapsulates the transportation and energy infrastructure needed for most projects. Going larger still, airborne emissions from mining can contribute to both local air pollution and greenhouse gases.

Figure 1.1. Environmental impacts of mining



Note: GHGs = greenhouse gas emissions.
Source: Author's graphic; MIT 2012. "Environmental risks of mining," Massachusetts Institute of Technology.

Related to these environmental impacts, but potentially distinct in terms of the policy responses, is the impact of mining on people. Most directly, noise and air pollution affects the health of workers involved in mine operations. These impacts affect people in nearby communities as well, who in addition suffer from habitat destruction. The productivity of those who earn their livelihood from the land, including from food production and agriculture, is affected by contaminated water and soil. Contaminated air, water and soil can also have major health impacts.

1.2.1. Impacts on water, air and soil

The degree and type of environmental impact depend on the mining method, on the geography and ecology, and on the geology and the specific metals and minerals mined. Beyond the extractive process itself, most mined materials need to be processed to separate the economically valuable metals and minerals from the waste rock. This process normally occurs on site to reduce transportation costs, and is itself a major component of both energy and water use, as well as potential emissions.

The mining of a wide number of base metals, including gold, copper and nickel, can result in mine waste that acidifies water. It causes significant ecological damage, impacting biodiversity in both land and water. In addition to being highly acidic, the water also dissolves heavy metals and other toxic elements into it. Damage can occur from tailings and mining waste, as well as from the active mining site itself. Acidification can occur through a variety of chemical processes, but most often with iron sulphide associated rocks (Akcil and Koldas, 2006[1]).

Acid mine drainage can form during any stage of the mining process, including both surface and underground mining. During the operational phase, the danger is normally not as significant. In a properly regulated mine, water is pumped and treated, and prevented from mixing into the groundwater. However, after a mine has closed, monitoring is generally reduced, if it occurs at all. In both underground and open pit mines, mining often occurs below the water table. With the pumps shut, returning water dissolves minerals and rock, and becomes acidic. In waste dumps and tailings storage areas, this same process can have even more devastating results as the base material is more concentrated. Even where tailings are managed, unexpectedly high rainfall or other weather conditions can cause dams and earthworks to fail. This, in turn, can lead to destructive discharges of highly acidic water into the water table (Johnson and Hallberg, 2005[2]).

The effects of such accidents, especially if transboundary rivers are polluted, can affect neighbouring countries. The 2000 Baia Mare accident in Romania, for example, triggered by heavy rainfall, released 100 000 m^3 of cyanide into the Somes River. It had severe effects outside the country, threatening the drinking water supply of more than 2.5 million Hungarians. It also killed 1 200 tonnes of fish, causing 15 000 people in Hungary's fishing industry to lose their livelihoods. Other than high rainfall, severe weather events such as earthquakes, floods and extreme heat can also cause tailings failures. Technological accidents trigged by natural hazards can, in turn, trigger domino/cascade events (OECD, 2015[3]).

Box 1.1. Environmental impact by mine type

Surface mining, including open pit, strip and mountain top removal, is the most common form of mining. Material is excavated and processed, with different techniques depending on the metals or minerals being sought. Because the economically viable minerals or metals are generally not on the surface, substantial quantities of overburden and "waste rock" must be removed and relocated. This has direct environmental impacts – the destruction of habitats for flora and fauna, and the exposure of ore that can contain radioactive elements and asbestos.

The pits often go below the level of the water table. To facilitate deeper mining, water is progressively pumped out. In addition to the risks of water contamination during the mining process, the pumping also leads to issues when the mine is shut down and the water table rises again. Mining by-products left behind can contaminate the water and drastically change its pH level, leading to broader damage to surface and underground water.

Underground mining also involves the removal of substantial amounts of waste rock and the disturbance of flora and fauna. It can contribute to changes in the landscape when tunnels collapse, land subsides and sinkholes develop. Water contamination is a common issue, as water is pumped out of mines that are below the water table. As with open pit mining, pumped water can contaminate surface and groundwater if not properly monitored and controlled. The same issues exist with tailings ponds.

In-situ leaching (ISL) causes minimal surface disturbance. Holes are drilled from the surface; once the mineral deposit is reached, a leaching solution is pumped into the holes to dissolve the minerals. The solution containing the minerals is then pumped to the surface, where the desired minerals are processed out of the solution.

ISL does not cause dust or airborne radiation pollution or disturb flora and fauna on the surface. However, it does require treatment of substantial quantities of wastewater. Because the dissolving solution is highly acidic, it can also dissolve toxic and radioactive elements. The solution needs to be thoroughly treated before being released again to avoid contamination of the water table. Otherwise, it must be stored in tailings ponds.

Similar to ISL, **heap leaching** involves dissolving (leaching) valuable minerals from waste rock. However, the ore is first mined and piled on to a large area with a sealant underneath to prevent leakage. Heap leaching avoids releasing dust from pulverising the rock, and thus avoids the risk of leaking directly into the water table associated with ISL. However, the solution still needs to be properly treated and disposed of. In addition, the heap leaching area itself must be properly sealed, with waste stored in tailings ponds or treated.

Different mineral **concentrating and beneficiation** processes, including smelting, electrowinning and floatation usually take place at or nearby the mine site. They have significant environmental impacts. Ore is pulverised and mixed with water into a thick solution to separate the targeted material from the waste rock. Separating minerals and metals can introduce other environmentally harmful substances, such as arsenic. Once separated, the mixed waste rock and water is left in tailings ponds, which can be toxic and radioactive. If not properly stored, tailings can leak into the water table and surrounding environment.

A tailings failure may also result in uncontrolled spills of tailings, dangerous flow-slides and release of hazardous substances. This, in turn, can lead to major environmental catastrophes within and across borders. Pulverising the ore creates dust, which leads to air pollution and can further release the aforementioned elements. In addition, tailings can dry out and the dust can be spread over tens of square kilometres due to strong winds. This can affect human health and the environment in the surrounding areas.

Source: MIT (2012), "Environmental risks of mining." Mission 2016: The future of strategic minerals.

The impact of the mining sector on air, water and soil is evident across the EECCA region. In Armenia, there are at least 15 active tailings ponds covering 700 hectares. There is little oversight of these ponds. They are vulnerable to weather events and have significant potential to impact human health (World Bank, 2014[4]). Pure Earth, a non-governmental organisation, organised a Toxic Site Identification Program in conjunction with the World Bank and other development partners. It found these sites were contaminating soil, groundwater and surface water with toxic metals such as cadmium, lead and arsenic. Toxins were found to be entering into ecosystems. When contaminated water was used for irrigation or the tailings were used for local building materials, the toxins were affecting human health (World Bank, 2014[4]).

Bioaccumulation is a major issue with many heavy minerals. Through this process, toxins concentrate as they move up the food chain from water, to soil, to the plants that grow in soil, to the people that eat the plants or use them for livestock feed.

In Armenia, a study found that mercury from mining operations had polluted soil and water fed into crops and cows' milk. It found mercury in the hair of children living in impacted areas (Sahakyan, 2015[5]).

In Ukraine, the metallurgy industry is a leading source of wastewater discharges, while mining and quarrying were responsible for 37% of industrial air pollution in 2004. Waste rock and mining tailings from ferrous metal mining operations have contributed significantly to acidification of local water. They have also led to leaching of heavy metals such as cadmium, arsenic and lead. The mining sector generates about 120 million tonnes of waste annually (UNECE, 2007[6]). The past tailings accidents in Kalush (2005) and

Nikolaiev (2011) demonstrate the urgent need for action to deactivate some of these "ticking time bombs".

In Kazakhstan, the mining and metallurgical sector (excluding hydrocarbons) is one of the biggest polluters in the country, with varying impacts depending on the metals mined and the associated geography. For example, one study estimated that by 2006, 21 billion tonnes of solid waste had accumulated from the mining sector, with an additional 1 billion tonnes added every year. Tailings ponds from polymetallic mining operations continue to leak into groundwater, while gold mining operations often still use cyanide in their processing (UNECE, 2008[7]). The negative environmental impact that an uncontrolled spill of hazardous substances from tailings facilities could create, have been demonstrated, not least, by the mining waste spill in Ridder in 2016 (The Siberian Times, 2016[8]).

1.2.2. Impacts on biodiversity and ecosystem integrity

Mining impacts biodiversity in a variety of ways. It destroys habitats in the immediate area of mining activity. It breaks up wildlife corridors through the construction of transportation infrastructure. It contaminates air, water and soil with toxins. And it changes the pH balance of water and soil, thus affecting flora and fauna in those habitats. Depending on the size and type of mine, as well as the controls taken to reduce impact, the loss of biodiversity may be local without broader impact.

The type of mining can influence its effect on biodiversity. Open-pit mining tends to have a greater impact on biodiversity, destroying or significantly disturbing habitat in the immediate impact of the mine. Underground mining, heap and in-situ leach mining do not necessarily cause as much surface damage. However, they can still have major negative effects on biodiversity through water, soil and air quality damage.

Impact on biodiversity can be difficult to predict. Pools created by closed underground mines can form valuable habitats for certain species (Dolný and Harabiš, 2012[9]). The same can be true of open pit mines, but it depends significantly on the underlying geology and the potential for acidification.

Compared to agriculture, mining can actually have a relatively controlled effect on biodiversity. Even open pit mines tend to use less land than agriculture. However, this does not account for other indirect and direct means through which mining can impact ecosystem integrity and biodiversity (Rolfe, 2001[10]). The local effect on biodiversity in the immediate area around a mine can become more significant and widespread if numerous mine sites are operating in the same area.

Releases of mining waste into water, unplanned or planned, can massively expand the geographic impact on biodiversity. This is relevant for the countries in EECCA. There are numerous mines developed under older mining regimes with more lax regulatory setups. Similarly, many mines continue to operate for socio-economic reasons despite violating environmental regulation.

Box 1.2. Industry solutions to biodiversity concerns in mining

Major mining companies have shown a strong interest in trying to address threats from mining to biodiversity. They are responding both to regulatory pressures and the need for "social licence to operate. The International Council of Mining and Metals collaborated with the International Union for Conservation of Nature to develop the *Good Practice*

Guidance for Mining and Biodiversity ((ICMM, 2006[11])). Approaches to addressing risks to biodiversity from mining projects emphasise:

- having a deep understanding of the ecosystem and the biodiversity that exists through baseline studies
- the importance of addressing the situation before the mining process starts, and including specific considerations for biodiversity at the exploration, operations, and closure and rehabilitation stages
- avoiding decisions that would damage the ecosystem and, if the ecosystem will necessarily be impacted, then minimising the damage as much as possible
- taking steps to repair damage to specific ecosystem features
- offsetting damage by investing in improving or protecting other areas if damage around a mine site cannot be avoided or restored.

Source: ICMM 2017, "Good Practice Guidance for Mining and Biodiversity", International Council of Mining and Metals (ICMM).

1.2.3. Mining, climate change and GHG emissions

Mining operations contribute to climate change through energy use in day-to-day operations, through the release greenhouse gases (GHGs) in smelting and other beneficiation processes, and through the destruction of carbon sinks, mainly in the form of forests. Many mining companies are reducing their carbon footprint through more efficient use of fuel and other energy inputs, electrification of vehicles and use of renewable energy. However, they will also need to adapt to climate change itself (Odell, Bebbington and Frey, 2018[12]). With its remote locations, reliance on water sources and exposure to severe weather, the mining sector could be significantly impacted by climate change.

In filings with the Carbon Disclosure Project from 2009, more than three-quarters of responding mining companies identified climate change as a concern. Areas of concern included disturbance to mine infrastructure and projects, changing access to supply chains and distribution routes, worker health and safety conditions, environmental management and mitigation, community relations, and exploration and future growth (Nelson and Schuchard, 2010[13]).

Major weather events, warmer or colder than normal temperatures, and droughts or floods are becoming more common, although it is difficult to attribute particular events or shifts to climate change. Weather events can have a major impact on mining operations. Although mining companies acknowledge these risks, many are reluctant to act because there are other more immediate costs (David Suzuki Foundation, 2009[14]). Companies would do well to plan for a storm that occurs once in 500 years; if it occurs, the breach of a tailings dam could have disastrous environmental impacts. However, climate change is a long-term threat for many operators, and heir priority is complying with regular environmental restrictions to their operations.

Box 1.3. Impact of climate conditions on mining operations

Climate change presents risks to the mining sector, both for those operating in remote areas and for mines that are grid-connected and closer to population centres.

- **Increased frequency of extreme weather events:** mines generally need to be prepared for an extreme weather event that will occur once in 50 years or once in 100 years. The risk of these events is manifold – high-water levels can cause tailing dams to breach with catastrophic results. Storms considered to occur once every 100 years now arrive with much more regularity.
- **Transportation challenges related to extreme weather:** mines in remote areas in cold climates often rely on ice roads. A warming climate is already making those roads less reliable and shortening the season of their operation. Other remote mines rely on air resupply, which faces a different set of challenges: more frequent extreme weather makes flying much more difficult.
- **Impact of rising temperatures on air quality:** rising temperatures and humidity levels contribute to reduced air quality through retention of particulate matter. This is an issue in areas where mines are operating close to population centres. It can force mines to shut operations on a daily basis to avoid exceeding pollution limits.

Source: (David Suzuki Foundation, 2009[14]).

1.3. Sustainability trends in the mining sector

One of the oldest industries known to humans, mining has constantly evolved with new developments in technology. However, it has adapted to environmental concerns more slowly. Mining most often occurs in remote or sparsely inhabited areas. Consequently, access to information on environmental impact has historically been low except in cases of environmental catastrophe. This is no longer the case. Today, sustainability reports are *de rigueur* for leading mining companies, and environmental concerns are increasingly at the forefront of discussions (Jenkins and Yakovleva, 2006[15]).

While environmental impact is intrinsic to mining, new driving factors have begun to shift the industry towards better environmental performance. These drivers, which include technology development, economic trends and societal expectations, are highlighted below:

- better awareness and understanding among the public about environmental issues related to mining, including the danger from tailings dam disasters, as well as better information dissemination concerning environmentally impacts when they occur (Jenkins and Yakovleva, 2006[15])
- global concern about climate change and GHG emissions, influencing both mining operations, as well as mineral fuels being mined (coal and bitumen) (Odell, Bebbington and Frey, 2018[12])

- increasingly stringent environmental regulation in jurisdictions like Canada, Australia and the United Kingdom that are home to globally active mining giants
- international initiatives that force better standards across entire value chains, thereby providing a strong incentive for large publicly listed multinational mining companies to ensure that suppliers and sub-contractors abide by the same environmental performance standards as the parent company espouses to its shareholders
- technology advancements that ensure better environmental performance, both through pollution management and control, as well as from optimising operations to use fewer inputs and the shift to renewable energy
- increasing interest in circular economy considerations and waste reduction (OECD, 2019[16]).

Responding to these drivers, governments from resource-producing countries are attempting to improve the environmental performance of the mining sector through a range of different policy and regulation.

This is a vitally important topic for the EECCA region, a vast geographic area with a diverse range of countries within it. Although mining varies in economic importance in the different countries, the sector plays a role in almost all of them. Exports are only one measure of economic value. They do not reflect associated employment and taxes, or related industries, such as equipment production. Belarus, while lacking the resource-oriented economy of Kazakhstan, is a key manufacturer of mining equipment. How the region addresses sustainability in the mining sector will be an important factor for both supporting economic development and improving environmental performance.

1.4. Mining in the EECCA region: Centrality, challenges and opportunities

The mining sector plays an important role in most EECCA countries, contributing to export earnings, employment and economic growth. This is evident across a range of indicators. The International Council of Mines and Metals[1] measures the significance of the mining sector's contribution to national economies through the 2016 Mining Contribution Index.[2] The index showed three EECCA countries (Uzbekistan, Kyrgyzstan and Tajikistan) ranked among the top ten globally. Two others (Ukraine and Armenia) were in the top 20. In 2015, in the Kyrgyz Republic, Uzbekistan, and Armenia mineral rents constituted 7.5%, 4.6% and 3.2% of gross domestic product (GDP), respectively. In the same year, ores and metal exports contributed 44.4%, 15.6% and 12% of total merchandise exports in Armenia, Georgia and Kazakhstan.

The following rankings illustrate the importance of mining to the region. Kazakhstan is the largest producer of uranium, the second largest producer of chromium and a significant producer of many other metals. Belarus is the third largest exporter of potash. Armenia was the sixth largest world exporter of molybdenum in 2015. Tajikistan is the second largest producer of antimony and the third largest producer of mercury. Uzbekistan is a globally significant producer in many mining products, including gold, rhenium, titanium, kaolin and others. Ukraine is a top producer of gallium, rutile, titanium and iron ore, among other minerals. Even Azerbaijan, whose exports are dominated by crude oil and natural gas, produces a range of minerals and metals. These include aluminium, iron ore, steel, bromine and iodine. Finally, Turkmenistan is a leading producer of bromine and iodine (United States Geological Survey 2016).

Many EECCA countries also produce coal, both from open pit and underground mines. Kazakhstan is a coal exporter, while other countries such as Georgia produce it for domestic consumption. All EECCA countries also quarry building materials, which have some environmental impacts, though relatively smaller than most metals extraction.

Countries in the EECCA region are often divided into two groupings. On the one side are the resource-rich countries (Azerbaijan, Kazakhstan, Turkmenistan, Ukraine and Uzbekistan). On the other are those with lesser natural endowments (Armenia, Belarus, Georgia, Kyrgyz Republic, Moldova and Tajikistan). However, as Table 1.1 illustrates, minerals and metals still play an important economic role even in countries not traditionally considered resource-rich.

Table 1.1. Key export minerals and metals in EECCA countries

Country	Selected minerals and metals (as percentage of national exports)
Armenia	Copper ore (20), copper (4), ferroalloys (3.9), molybdenum (0.4)
Azerbaijan	Gold (0.6), aluminium (0.5)
Belarus	Potassic fertiliser (10), iron and steel (2.9)
Georgia	Copper ore (9.3), ferroalloys (7.3), gold (4.4)
Kazakhstan	Copper (6.2), uranium (5.1), ferroalloys (3.4), zinc (1.5), chromium ore (0.35)
Kyrgyz Republic	Gold (42)
Moldova	Gypsum and aggregates (0.3)
Tajikistan	Aluminium (30), gold (17), lead ore (6.7), zinc ore (6.6)
Turkmenistan	Sulphur (1)
Ukraine	Iron and steel (21.2), iron ore (5.5)
Uzbekistan	Gold (32), copper (9)

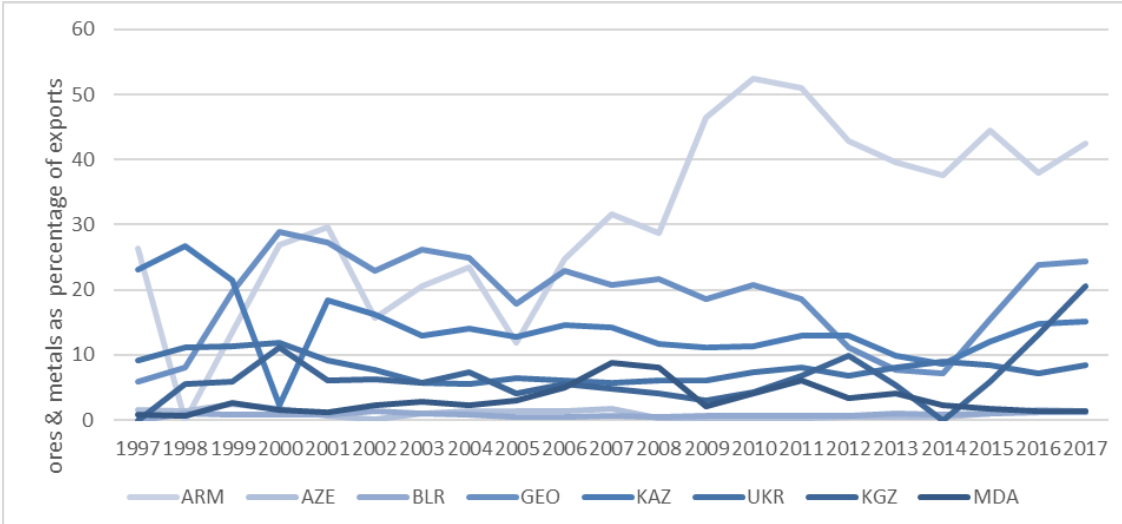
Source: UN Comtrade, Observatory of Economic Complexity, author's own calculations.

As shown in Figures 1.2 and 1.3, mining accounts for an important share of GDP. Moreover, products from the mining sector still make up substantial portions of most EECCA country exports. Strong growth in the People's Republic of China and other emerging economies from 2000-12 drove increased demand for almost all minerals and metals. Even while minerals and metals as a share of exports have remained relatively steady (Figure 1.1), increased commodity prices ensured that its importance to government revenue grew (Figure 1.2).

Beyond its contributions to export earnings and government revenue, the mining sector is also an important source of employment in many EECCA countries. In Kazakhstan, the mining and quarrying sector employees 277 000 people, amounting to approximately 3% of total employment (KAZ Stat, 2019[17]). In the Kyrgyz Republic, the Kumtor Mine is the largest private employer in the country, as well as the largest private sector purchaser of goods and services (Centerra Gold, 2019[18]). In 2014, Armenia's mining sector accounted for 10% of total industrial employment (World Bank, 2016[19]). Mining is not always a significant employer on the national scale, but mines are often in rural and remote areas in which they are regionally important employers.

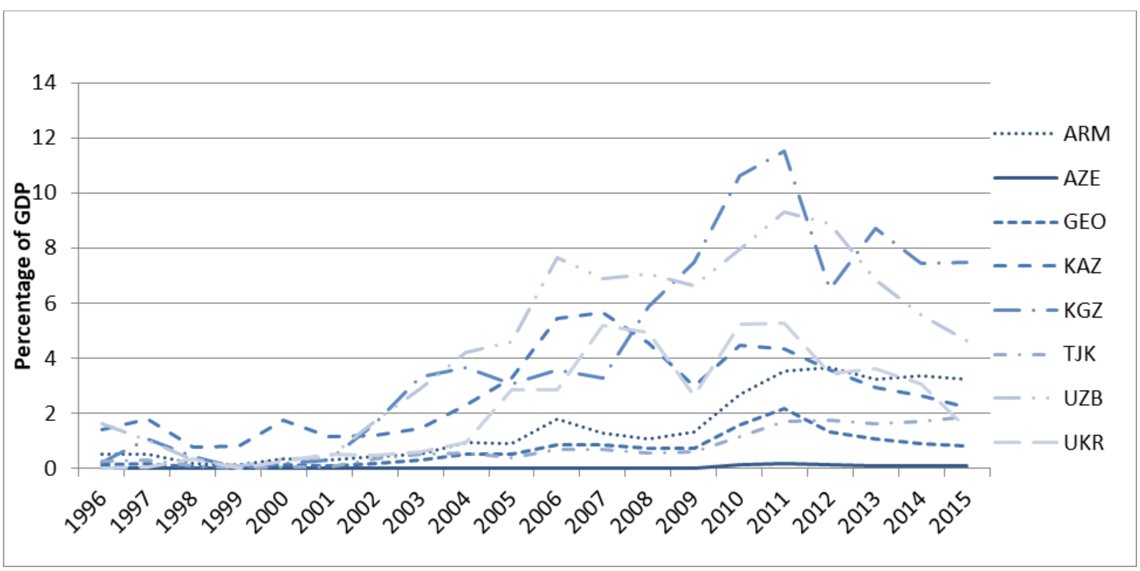
Direct employment from mines only captures one dimension of the overall impact. Other factors comprise royalty and tax revenue, goods and services purchased locally, development of related industries and horizontal linkages such as power and transportation infrastructure. In some cases, mines also support forward linkages to downstream industries.

Figure 1.2. Ores and metals as share merchandise exports for EECCA countries (1997-2017)



Note: (1) Uzbekistan and Tajikistan were not included due to insufficient data; (2) merchandise exports refers to exports of goods only (excludes services); (3) ores and metals comprise the commodities in Standard International Trade Classification sections 27 (crude fertiliser, minerals), 28 (metalliferous ores, scrap) and 68 (non-ferrous metals).
Source: World Bank Development Indicators database.

Figure 1.3. Mineral rents as percentage of GDP for selected EECCA countries (1996-2015)



Note: (1) Belarus, Moldova and Turkmenistan were not included due to insufficient data; (2) mineral rents are the difference between the value of production for a stock of minerals at world prices and their total costs of production. Minerals included in the calculation are tin, gold, lead, zinc, iron, copper, nickel, silver, bauxite and phosphate.
Source: World Bank Development Indicators database.

Almost all EECCA countries have unexploited resources. They have not been tapped for various reasons, including unfavourable investment environments, insufficient exploration data, and poor electricity and transportation infrastructure. Governments in the region have expressed interest in supporting new mining development. For example, in Kazakhstan, the government has developed a new mining code that draws on the experiences of Australia and other OECD member countries (Deloitte, 2018[20]). It has also been working to attract new investment (supported by the OECD, through the OECD-Kazakhstan Working Group on Mining Competitiveness). Tajikistan's government has pledged to support the development of its minerals sector through a better permitting process, and the establishment of a Geological Information Centre (US International Trade Administration 2015). Armenia has seen strong growth in its mining sector in recent years; it joined the Extractive Industries Transparency Initiative in 2017.

At the same time, the legacy of Soviet-era mining continues to pose a challenge, with ageing mining facilities and equipment that is inefficient and environmentally polluting. Mining waste and tailings facilities are not constructed to modern standards. Furthermore, many sites are abandoned and unmonitored, posing an ongoing environmental risk. One challenge of moving forward with the environmental performance of the mining sector in EECCA will be addressing this legacy.

1.5. Building on the foundations of ongoing OECD and GREEN Action Taskforce work

Against this backdrop of diverse drivers, countries in the EECCA region are attempting to shift towards greener economic growth, while also maintaining the extractive sector as an engine for jobs and revenue. This is true for resource giants like Kazakhstan and also for smaller countries like Armenia that export minerals as a key source of revenue. But it is equally true for countries like Tajikistan that have substantial resource potential but lack the necessary conditions or frameworks to encourage significant new mine development.

Countries in the EECCA region are faced with the ongoing legacy of environmentally damaging mining practices from the Soviet-era. They must also develop a modern approach to mining that can minimise environmental and health impacts, while maximising social and economic benefits. At the same time, many countries are eager for investment, and for the potential influx of both revenue and technology that new mining developments may bring.

The avenues to improve environmental performance in the mining sector are well documented, but considerably more complex to implement. Mining companies need to use processes that monitor and control pollution effectively. They need to invest in processes and equipment that improve input efficiency and reduce emissions. And they need to ensure the rehabilitation of environmental damage incurred during the mining process. The question is less about what to do, than how companies can get there and how governments can encourage it.

As part of a broader project on green growth and the mining sector, the report aims both to motivate and inform governments in the EECCA region, as well as companies operating there. Today, trends and new directions in the sector reveal a strong push for going green. This is motivated by the need to reduce the negative impact of mining on the environment and local communities. But companies are also increasingly going green to remain competitive in a fast-changing sector.

The report aims to help policy makers in EECCA reconcile environmental and competitiveness objectives in the mining sector. An in-depth review of environmental impacts and trends in the mining sector complements international knowledge and efforts to provide new evidence and best practices from leading mining jurisdictions.

This project has been developed in the context of the OECD's ongoing work on the mining sector, including the intersections of mining, economic growth and diversification with the environment.

- The OECD's mining competitiveness project in Kazakhstan, with a first phase that ran from 2014-18, included work on how environmental payments in the mineral sector could improve environmental performance.[3]
- The OECD through the GREEN Action Taskforce is building on this initiative. It has launched a project on reforming environmental payments in Kazakhstan generally, supporting the development of a new environmental code.
- The OECD Policy Dialogue on Natural Resource-based Development brings together governments from resource-producing economies, major extractive enterprises and civil society organisations. Together, they discuss solutions to issues around extractive-driven economic development. Environmental issues are increasingly a component of this dialogue, including recent work on the role of renewable energy in the extractive sector.[4]
- The OECD's work on mining regions held its first meeting in Chile in 2017 and second in Australia in 2018. It focuses on economic diversification and improved regional development outcomes in mining-intensive regions. It involves sub-national and national governments, as well as the private sector and civil society.[5]

1.6. Ongoing work at the international level is driving forward the discussion

At the international level, a number of the Agenda 2030 Sustainable Development Goals (SDGs) are relevant. More specifically, a number of increasingly widely adopted international conventions positively shape the mining sector towards better environmental performance. These conventions, to which many EECCA member countries are parties, provide tools, norms and approaches that countries can already adopt. They also help establish international standards, and provide frameworks to work through transboundary environmental issues arising from mining.

1.6.1. The Sustainable Development Goals and Agenda 2030

The SDGs, adopted at the United Nations as part of the 2030 Agenda for Sustainable Development in 2015, are relevant to mining across a number of different areas. This provides a framework for contextualising the need to improve the mining sector's overall environmental performance.

- SDG 6 relates to water pollution and the release of hazardous chemicals, the treatment of wastewater and efficiency of water use.
- SDG 8 promotes inclusive and sustainable economic growth and employment.
- SDG 9 promotes the safe management of industrial installations to make them sustainable.
- SDG 12 encourages the shift to more sustainable consumption and production patterns, structured over eight targets. This includes the use of natural resources and the integration of sustainable practices into production processes.
- SDG 13 requires that countries and the international community take urgent action to strengthen resilience and combat climate change and its impact.

- SDG 14 (Life below water) and 15 (Life on land) are connected to mining's impact on biodiversity.
- SDG 16 ensures participatory decision making by involving the public in discussions related to the siting and prevention of, and preparedness for, hazardous activities.

This is against the backdrop of international agreements, conventions and frameworks that can help countries improve environmental performance in the mining sector, while also standardising approaches. This, in turn, helps discourage a "race to the bottom" in which mining jurisdictions compete for investment by lowering standards.

1.6.2. United Nations Framework Classification

The United Nations Framework Classification (UNFC) provides a unified way to sustainably manage mineral resources, as well as oil, gas, uranium, different forms of renewable energy and anthropogenic resources (recycling). Vitally, anthropogenic resources focus on secondary resource use and recovery from mining wastes, tailings and other already processed materials. The UNFC provides a triple axel accounting system of socio-economic viability (including environmental impact), project feasibility and geological knowledge level. Though not focused exclusively on environmental impacts of mining, it provides governments with a holistic means to track projects and reserves through an internationally comparable system (UNECE, 2018[21]).

1.6.3. The Aarhus Convention

The UNECE Aarhus Convention on Access to Information, Public Participation in Decision Making and Access to Justice in Environmental Matters entered into force on 30 October 2001. National parties to the Convention are required to make the necessary provisions at the federal, sub-national and local levels to ensure the public (both individuals and organisations) has the following:

- **access to environmental information** held by public authorities, both through specific requests for information with a maximum of one month following a request, as well as through the active dissemination on the part of public authorities
- **the right to participate in environmental decision making** on projects that are relevant to them, including plans, proposals and projects that are likely to directly or indirectly impact the environment
- **access to justice** so that environmentally damaging actions can be challenged in court, and so that the justice system can be used as a means to enforce the first two rights listed.

Most countries in the EECCA region are either full signatories or are party to the Convention, with the exception of Uzbekistan (United Nations, 2018[22]), (UNECE, 1998[23]).

1.6.4. The Minamata Convention

The Minamata Convention on Mercury, which was signed in 2013 and entered into force in 2017, aims to improve environmental protection from mercury. Mercury occurs naturally, but various industrial processes including small-scale mining and mineral processing can release significant concentrations into the environment. These large concentrations have major ecosystem and human health impacts. The Convention bans new mercury mines, and also addresses site remediation for areas contaminated with mercury. It has 128 signatories, but does not include any of the five Central Asian countries from EECCA (UNEP, 2018[24]).

1.6.5. The Espoo Convention

The Espoo Convention on Environmental Impact Assessment in a Transboundary Context entered into force in 1991. It obliges its signatories to conduct joint environmental impact assessments (EIAs) for projects with the potential for transboundary environmental impacts. It counts Ukraine, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan and Armenia among its signatories. It has already been used as a framework for action in the region. In 2013-14, the UNECE Secretariat to the Espoo Convention supported Ukraine and Belarus in a post-project analysis of an EIA for the Hotislavskoe project in Belarus. The chalk deposits, located 250 metres from the border with Ukraine, led to the establishment of a bilateral working group to implement a joint monitoring programme. In another example, Kazakhstan and Kyrgyzstan conducted a pilot EIA in 2007. This process was supported by the Organization for Security and Co-operation in Europe under the auspices of the Espoo Convention and in co-operation with non-governmental organisations, industry and the appropriate national government bodies in Kazakhstan and Kyrgyzstan (OSCE, 2009[25]).

1.6.6. Convention on the Transboundary Effects of Industrial Accidents

The Convention, originally adopted in 1992, came into force for 26 UNECE members and the European Union in 2000. It has now risen to encompass 41 parties, including Armenia, Azerbaijan, Belarus, the Republic of Moldova and Kazakhstan. The Convention aims to reduce the frequency of industrial accidents, including those at tailings management facilities (TMFs). If accidents do happen, the Convention aims to lower their severity and mitigate their effects, protecting both human health and the environment (UNECE, 2016[26]). It includes both mining and mining waste. UNECE has two pilot projects to strengthen the safety of mining operations, particularly TMFs. The pilots run in Kazakhstan (2018-19), as well as in Tajikistan and the broader Central Asia region (2019-20). Sponsored by the Swiss Federal Office for the Environment, the projects draw on UNECE's experience in improving tailing and mine waste facilities. This experience includes two previous projects focused on Ukraine, as well as UNECE's Joint Expert Group on Water and Industrial Accidents (UNECE, 2017[27]). This group brings together industrial safety and water experts on an ad-hoc basis to support development and implementation of new guidelines that bridge disciplinary silos, in particular in EECCA and South East Europe.

1.6.7. UNECE's Environmental Policy Reviews

Within the region, the UNECE's series of Environmental Policy Reviews (EPRs) have regularly featured chapters on the mineral sector. They recommend how to improve environmental performance at every stage of the development process (from exploration to site reclamation and mine waste management). Lessons from UNECE EPRs are incorporated into this report. A recent EPR on Belarus, for example, looks at mining waste and extractive sector taxation (UNECE, 2016[28]). One on Georgia includes pollution flows from mining, damage to soil in mining regions, water contamination and mine waste among other topics (UNECE, 2016[29]).

Notes

1. The International Council on Mines and Minerals counts the world's largest mining companies and associations among its 23 members.

2. The Mining Contribution Index (MCI) is included in the publication *the Role of Mining in National Economies*. The MCI is scored based on a composite of four different indicators: the total contribution of mining to export earnings, the change in export earnings in the preceding five years, the value of mineral production as a percentage of gross domestic product (GDP) and mineral rents as a percentage of GDP. Available at: www.icmm.com/website/publications/pdfs/society-and-the-economy/161026_icmm_romine-supplement_third-edition.pdf.

3. http://www.oecd.org/env/outreach/sustainablemininginkazakhstan.htm

4. http://www.oecd.org/dev/natural-resources.htm

5. www.oecd.org/cfe/regional-policy/mining-regions.htm.

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2. The impact of technology on sustainability in the mining sector

This chapter explores how different technology trends are impacting the mining sector. Although in many cases the uptake of these technologies is driven by the potential to improve efficiency and competitiveness, they also help reduce the environmental impact of mining activities. Most of these technologies also have application beyond mining and can support linkage development to other sectors of the economy. Topics addressed include automation, remote control, electrification, renewable energy, digitalisation and remote sensing, with specific attention to both environmental and economic benefits. The impact of economic shifts towards electric vehicles, renewable energy and continuing economic digitalisation on metal demand is also discussed.

2.1. Introduction

Over thousands of years, the fundamental purpose of mining has remained the same: removing metals and minerals from the ground and separating those that are desirable from waste. A miner from 3 000 years ago would recognise the basic fact of digging into the ground to find the Earth's riches. However, both the scale of mine sites and the technology used have changed dramatically. At the same time, new technological and economic developments also determine what metals are in greatest demand, helping to shape the industry. Understanding the potential impact of new technologies is vital in moving to a more sustainable paradigm of mining.

For most of humanity's history, mining technology focused on maximising outputs of mined material and minimising the cost for doing so. This single-minded approach helped fuel economic growth and provide the raw materials needed to build new things. It also resulted in significant environmental contamination, often severely damaging ecosystems. It also led to large-scale remaking of the environment. Massive open pit mines and enormous dams reconfigured hydrological systems and not infrequently failed, sending toxic water back into the ecosystem. Considering that environmental impacts from mining operations from two millennia ago are still detectable today (Pyatt et al., 2000[30]), the industry must continue to focus on environmental issues.

Globally, over the past two decades, increased scrutiny of environmental and social issues has led major mining companies to adopt sustainability plans (Jenkins and Yakovleva, 2006[31]). At the same time, new technology trends and economic developments are shaping the future of mining. The prolonged rise in prices for minerals and metals during the commodities super cycle fuelled mining company expansion; when prices crashed in 2014, companies were forced to adopt a greater focus on increasing efficiency and bringing down cost margins.

In the Eastern Europe, Caucasus and Central Asia (EECCA) region, this pressure is acute. The centrally planned economy of the Soviet era focused on production and had little functional environmental oversight. As a result, countries in the region were particularly exposed to negative environmental impacts of mining. Once closed, mines were often simply abandoned with no efforts to remediate the environmental damage. This left a hazard for people living in the area, as well as for the larger environment. Countries in the region are faced with both the ongoing legacy of environmentally damaging mining practices from the Soviet era as well as the challenges of developing a modern approach to the mining sector that can minimise environmental and health impacts, while maximising social and economic benefits.

Greening the mining sector in the region is an opportunity to introduce innovative, environmentally sensitive practices that can positively affect other related areas of the economy. For countries with large mining sectors, this is vital. Even for countries where the mining sector is less dominant, a greener approach to mining provides a channel to introduce clean technology.

2.2. How technology is affecting mining operations

Mines have long lives. They depend on reliability and predictability, both for production and for ensuring the health and safety of workers. Consequently, mines have traditionally been conservative in deploying new technology.

Several factors are opening the sector to adoption of new technologies. From approximately 2003 until 2011, sustained high prices driven by demand from emerging economic powers, including the People's Republic of China, led to a rapid expansion in operating and planned mines. The decline of demand, first in 2008 and finally in 2011 caused a renewed focus on efficient and lean operations. This decline was compounded by a general trend across the mining sector: as the richest and most easily accessible deposits have been mined, industry is increasingly going after lower ore concentration deposits and/or lower depth deposits.

At the same time, mining companies have faced demands for better environmental performance and transparency to earn the social licence to operate. Resource companies have also begun to look at how to improve efficiency. Increasingly, they want to position the mining sector as a modern and forward-looking part of the transition to a more sustainable economy. The technologies discussed in this section explore these issues.

2.2.1. Automation

One of the most important trends in the mining sector is automation. The drivers for this trend are not primarily environmental, but instead productivity, health and safety. Mining is a dirty and often dangerous business. The use of automated mining trucks and rigs means that fewer workers need to be directly exposed to minerals. At the same time, automation allows mines to function around the clock and maximise their use of inputs (NRCan, 2016[32]). As another advantage, automation can sometimes be retrofitted onto existing equipment rather than requiring an entirely new investment. To date, major multinational mining companies like Rio Tinto have used particular mines as test cases for "mines of the future". However, as more manufacturers get on board the technology is becoming more accessible.

Automated machinery follows stricter protocols than human operation, reducing unnecessary use. Theoretically, this approach prolongs machine life, reduces operational emissions and uses inputs more efficiently. Automation takes a number of forms, with potential benefits that go beyond productivity to reduce environmental impact:

- Autonomous trucks: trucks with this technology rely on global positioning systems, lidar and sensor systems embedded in the mine structure to help navigate. They can operate almost continuously, aside from breaks for refuelling and maintenance. They benefit from a longer lifespan, reduced fuel use and fewer maintenance costs (Nebot, n.d.[33]). At Brucutu mine in Brazil, Vale estimates that vehicle lifespan will increase by 15% and fuel consumption and maintenance costs will decrease by 10%. This will result in a lower carbon footprint (Vale, 2018[34]).
- Automated drilling and tunnel-boring systems: automating drilling and tunnel boring have safety benefits. They remove humans from a potentially dangerous position due to hazards such as rockfall, gas outbursts and high temperatures underground. They also have environmental benefits. Linked with advanced sensing technology, automated drilling and boring systems can more precisely target ore deposits underground. In this way, they reduce wasted drilling time and maximise outputs (Ranjith et al., 2017[35]).
- Automated site monitoring: automation and remote sensing can potentially benefit environmental performance by ensuring that issues are caught before they become significant, or before they occur at all. Potential issues include weakening of separation barriers for tailings areas, as well as levels of emissions from mining and beneficiation itself (Wang, Yang and He, 2018[36]).

- Automated ventilation systems at underground mining sites: a major cost of underground mines is ventilation systems to the surface. This is vital to clear diesel fumes, gases and smoke from blasting, to control temperatures and to ensure safety of mine operations. Automated ventilation systems do not operate continuously. Instead, they rely on a network of sensors to move air to where it is needed at any given time. This saves up to 40% of energy (NRCan, 2016[37]).
- Autonomous long-distance trains: mines are often located far from ports, population centres and industry. Transporting ore can be expensive, carbon-intensive and potentially hazardous. To alleviate costs and increase efficiency, Rio Tinto is automating its train systems in Australia's Pilbara region. The inaugural fully automated trip took place in July 2018. Automation provides more consistent speeds with less braking and accelerating. It leads to better co-ordination between trains on the tracks and eliminates the potential for driver fatigue (Rio Tinto, 2018[38]). However, most mines do not have dedicated rail systems. Such a system makes sense for Rio Tinto due to the scale of its Pilbara mining operations and the distance to port.

Automation has impacts beyond productivity gains and a reduced environmental footprint. In many cases, it will change the employment structure, reducing opportunities for local, low-skilled jobs. While remote monitoring will create some new jobs, these positions will require a higher level of skills. Even maintenance on automated vehicles will require new training and qualifications (Cosbey et al., 2016[39]). At the same time, companies are building mines in increasingly remote locations, often with low or non-existent local populations. Increasing use of automation and remote control, requiring less direct employment, will reduce the need for large numbers of individuals to live around a mine. This will also reduce its environmental footprint (Nebot, n.d.[40]).

2.2.2. Electrification

Fossil fuel use at mining sites is a significant operational cost and source of both local particulate matter and air pollution, as well as the release of GHGs. At off-grid mining sites, diesel generators are normally used to power equipment. Shipping in fuel is expensive and carbon-intensive. At mining operations connected to electricity grids, large trucks and mining rigs generally run on diesel, releasing substantial emissions.

Box 2.1. Goldcorp's all electric underground mine

In Ontario, Canada, Goldcorp's Borden mine is completely electrified. Operating deep underground, the mine has electrified everything from loading and hauling vehicles, and transporting ore and personnel, to ventilation and drills. Although this approach carries a 25-30% premium on the cost of equipment, long-term savings are significant. Goldcorp expects savings of CAD 9 million annually in operational costs from lower diesel use. There will also be 70% reduction in GHG emissions. Advancements in battery technology have made this fully electrified mine possible (Taylor and Lewis, 2018[41]).

Mining equipment manufacturers and mining companies are increasingly experimenting with hybrid diesel/electric or full electric versions of mining trucks and machinery. The benefits of electrification are even more substantial in underground mines, where exhaust fumes pose a health and safety hazard and must be continuously ventilated. Relying on electric vehicles and machinery reduces the need for that ventilation.

Beyond electrification of vehicles, electric equipment at underground mines can also reduce ventilation and yield significant benefits. Electric motors have significantly fewer parts than internal combustion motors, require less maintenance, do not create emissions and are much quieter. However, the upfront cost can be significant. Furthermore, to benefit fully, mines need to be designed with electrification.

2.2.3. Renewable energy

Renewable energy is increasingly a viable option for off-grid sites, particularly through hybrid diesel-renewable energy systems. Commercial-scale solutions are still needed for battery technology to provide the stable supply required for purely renewable energy. However, diesel systems – mated with solar or wind – reduce emissions and the cost of trucking in diesel fuel to remote locations. Renewable/diesel hybrid systems have been deployed successfully in different contexts, including Canada and Australia. However, they have benefited from government support for their development.

Box 2.2. The mining sector as a driver for on- and off-grid renewable energy

Globally, mining enterprises are taking advantage of renewable energy to cut emissions, cut fuel costs and increase reliability. Opportunities exist for both on-grid and off-grid mines. For on-grid mines in countries with expensive electricity, purchasing agreements with renewable energy companies can cut costs and drive development of new renewable energy generation. Where mines are operating off-grid, renewable energy can reduce dependency on diesel and heavy fuel oil, cutting costs and increasing reliability.

On-grid renewable energy and mining in Chile

Copper mining is a major industry in Chile, requiring substantial amounts of energy. However, electricity rates in Chile are relatively high. Over the past decade, prices have doubled. In August 2015, for example, prices hit USD 100 per megawatt hour, twice as much as in neighbouring Peru, which also produces copper. While Peru has the advantage of domestic hydropower and natural gas reserves, Chile has had to rely on imported fuel for its power sector.

A confluence of factors has created rich potential for renewable energy in Chile for both industrial and consumer use. These factors include high energy prices, declining costs for solar photovoltaic technology and wind turbines, high wind levels and world-leading levels of solar irradiation in the northern Atacama Desert. At the same time, existing power generation was concentrated in the more heavily populated southern part of the country. In the north, this has driven the building of more and more renewable power capacity. At their current level of technology, renewables could not entirely replace baseload generation capacity. However, they have capacity to augment existing power use and reduce the need for fossil fuels or added generation capacity. For instance, the Chilean government held a power procurement action in October 2015. The auction sold 1 200 GWh of available contracts to wind and solar projects, which outcompeted proposals for coal plants based on price alone.

Off grid renewable energy in Australia

Sandfire Resources NL’s DeGrussa copper mine is located about 900 km north of Perth, Australia in a remote area without access to the electricity grid. The mine was powered initially by an on-site 20-megawatt diesel generation station that requires substantial amounts of diesel fuel to be trucked to the site. To reduce use of diesel fuel and lower both costs and emissions, Sandfire developed a large solar power generation (10.6 megawatts) and storage (6 megawatts) facility. The project, commissioned in May 2016, is one of the largest integrated off-grid solar and storage facilities on a mining site in the world.

Diesel generation is fully integrated with the hybrid plant. During the day, power is drawn from the solar panels, with the battery making up for short-term drops due to cloud cover and diesel generators still supplying some percentage of the power. During the night, diesel generators provide full power. The battery may be used during night to help smooth fluctuations and support system reliability. In total, it will offset over 20% of the mine’s annual diesel fuel use.

The project was supported by repayable finance from two Australian federal government agencies. The Australian Renewable Energy Agency (ARENA) provided almost AUD 21 million in a recoupable grant. For its part, the Clean Energy Finance

Corporation provided AUD 15 million in debt finance. ARENA was able to fill the "risk gap" for financing faced by first-of-kind projects.

Source: OECD (2017), PD-NR Compendium of Practices, www.oecd.org/dev/policy-dialogue-on-natural-resource-compendium.htm

2.2.4. Digitalisation

Advances in digital technology have drastically changed the quality and quantity of data that mining companies can access. This, in turn, supports the deployment of automation. Exploration companies can now rely on a range of different technologies to show them what is underneath the surface, to sample and to decide whether to develop a mine.

- Exploration: using remote sensing tools such as unmanned aerial vehicles and satellites can substantially reduce the ecological footprint of mining operations (European Commission, 2018[42]).
- Site operation: networked sensors, machinery and devices, combined with imagery data from satellites and other sources, have provided mine operators with unprecedented data. Widespread use of sensor technology ensures that mining operations are better aware of what is happening, and where. This includes monitoring emissions, tracking water and air quality, and minimising energy use.
- Environmental impact: remote sensing technology, including drones, holds significant benefits for ensuring good environmental outcomes following the closure of a mining site. Tailings and waste rock sites can remain toxic for decades or even centuries after a mine closure. Companies must monitor and respond to releases as quickly as possible. This is especially the case in remote locations that make in-person examination difficult. Remote sensing allows for ecosystem monitoring of land and water impacts (Charou et al., 2010[43]).

Through the use of digital sensors, mining companies have vastly more data at their fingertips than ever before. This trove of data also enables and supports automation.

2.3. How new technology is driving demand for different minerals

As recently as a decade ago, many analysts were writing about "peak oil". They believed that in a time of rising prices and spiralling global demand, the world was set to run out of fossil fuels. Instead, accelerating developments in renewable energy and electrical vehicles (EVs) have shifted projections for the demand of raw materials. Some metals, such as copper, have always been important economically. Considering that a single EV can require upwards 180 kilograms of copper, the mineral will only become more important. This same demand pattern then extends to renewable energy installations. Wind turbines, in particular, require significant amounts of copper. Broadly, anything electronic will continue to require substantial amounts of copper. As the world shifts from a fossil fuel-based economy, this will become ever more important. The same trends are also driving mining companies' interest in lithium – an essential ingredient in contemporary battery technology (MGI, 2017[44]).

Over time, demands for certain minerals may shift again. Already, some researchers argue that lithium-ion batteries have limited capacity to be scaled up. They believe a different technology will be needed to change renewable power generation into baseload generation.

To improve environmental performance, the mining sector must be agnostic when it comes to the specific material being mined. Rare earth minerals and cobalt, key ingredients for many high-tech devices, renewable energy generation, and energy storage, are often mined in ways fraught with environmental consequences. As such, many of the most important supplying mines are in countries with more permissive environmental regimes (MGI, 2017[44]). While government policies do not determine what minerals become in demand, policies must be flexible enough to respond to new technological developments.

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3. Connecting the mining sector to the green economy

This chapter explores different areas where public policy can support better environmental performance in the mining sector and build linkages to the green economy. This includes developing a whole of government approach and engaging a broad range of stakeholders. The chapter discusses regulatory approaches at different stages of the mining process, as well as the challenge of orphaned mines, and the potential to reprocess abandoned mines. It also looks at policies to support innovation and capacity building, as well as developing linkages to the circular economy. It concludes with a series of key recommendations.

3.1. Introduction

Effective environmental regulation is necessary to improve the performance of active mines, but it cannot achieve this on its own. The same dilemma is true for the proper monitoring and rehabilitation of closed and abandoned mine sites. Many countries in the Eastern Europe, Central Asia and Caucasus (EECCA) region have stringent environmental standards on paper. However, due to inconsistent compliance assurance and non-compliance enforcement, they do not have good environmental outcomes. The top-down, command and control approaches held over from the Soviet Union are difficult to enforce because of the wide number of pollutants covered. Due to low-compliance penalties, the approaches do not provide incentives to comply or go beyond compliance (OECD, 2017[45]).

Public policies can impact the environmental performance of mining companies in ways that go beyond regulatory decisions. Such policies include supporting and formalising collaborative efforts on innovation and linking the mining sector to other segments of the economy. Equally important are policies that ensure information transparency and active stakeholder consultation. Another example is policies that build capacity to ensure availability of skills to tackle new roles in the green economy.

This section presents a broad range of different policies related to better environmental performance in the mining sector. These policies are often treated differently due to the distinct dimensions they target, but in fact are linked and reinforce each other. The tools are starting points for policy makers, industry and other stakeholders to develop these policies. Solutions are unique to each country, and will vary based on national and sub-national priorities.

3.2. Government co-ordination and strategy

Governments need a co-ordinated approach to improve environmental performance of the mining sector. Inevitably, this will involve more than just a single ministry, and more than just a single layer of government.

A national strategy for the mining sector that clearly identifies goals helps governments co-ordinate their approach. In developing that strategy, engaging with a broad range of stakeholders legitimises outcomes and helps ensure action on the final product. Stakeholders include civil society, different levels and branches of government, local communities and the mining industry itself.

Governments may have different goals. Some may wish to attract investment, while ensuring that new mines reduce their environmental footprint. Others want to limit new mines and establish ecologically sensitive areas that are off-limits for development. Still others wish to focus on cleaning up old contaminated sites. Each goal requires a different mix of policies to achieve it.

A strategy resting at a supra-national level helps ensure continuity over time. In this way, it reduces duplication and policies from different government branches that contradict each other. These principles are fundamental to the OECD concept of policy coherence for sustainable development.

Mining can impact water supplies and quality, energy use, transportation infrastructure and employment, as well as the broader environment. Strategies may require the involvement of many different branches and levels of government. Integrated and coherent policies, supported by strong institutional mechanisms, are vital (OECD, 2018[46]).

Transboundary co-operation and co-ordination may also be required. Some mining activities are close to the border or close to transboundary water systems, so impacts such as downstream water pollution may be felt in other countries. As a result, it's vital for affected countries to work together with regard to risk assessment and management. The UNECE Industrial Accidents Convention is relevant in this regard. It supports countries, notably competent authorities and operators, to prevent, prepare for and respond to industrial accidents with potential transboundary effects.

3.3. Stakeholder engagement and transparency

Large-scale industrial projects have stakeholders beyond simply the project proponent and the regulator. With the construction of a mine, the stakes are exceptionally high. In a sense, the resources constitute the wealth of the nation or community: there is only one chance to develop a given deposit. Mines have environmental impacts, no matter how well executed. If the larger systems (hydrological or climate) are damaged, impacts will be felt by area residents, as well as by those further abroad. As with any audit or even with writing a paper, third parties can often bring insight, perspective and objectivity that may otherwise be missed.

The most successful mining jurisdictions in terms of environmental performance have processes to ensure broad stakeholder involvement. They also have resources and information to ensure stakeholders can be informed participants in the approvals process for mines, as well as for operations and post-operations periods.

Ensuring that companies go above and beyond the letter of the law requires that local communities have a voice. Empowering expression of such a voice can also benefit mining operations. People living in the area, for example, are often more sensitive to environmental changes that occur outside the immediate vicinity of a mining site. Historically, public participation has often been ignored or considered only until a licence has been granted. As part of moving towards a green economy, public participation should be central to environmental assessments and ongoing operations.

Modern communication technology, including social media, means the public is involved whether companies want them to be or not. By embracing this engagement, mining companies can understand the stakes more clearly. They can ensure such engagement takes place by requiring public consultation as part of any environmental impact assessment (EIA) or strategic environmental assessment (SEA).

Governments must go beyond ensuring stakeholder consultations take place. Project proponents must take results seriously and address concerns. Proponents – and regulators – must also be transparent about mining operations and closed mines, clearly informing the public about actual or potential environmental concerns.

The OECD is developing a Recommendation on Open Government, which aims to help the countries design and implement successful open government reforms. It will identify a clear, actionable, evidence-based and common framework for the governance of open government (OECD, 2017[47]).

The UNECE Aarhus Convention on Access to Information, Public Participation in Decision Making and Access to Justice in Environmental Matters is also relevant. Through the Convention, countries pledge to make the necessary provisions at the national, regional and local level. These ensure the public has access to environmental information, access to justice around environmental issues and the right to participate in environmental decision making.

3.4. Regulatory tools

How governments regulate the mining sector shape its environmental impact, its attractiveness to investors, its value to public coffers and its acceptability to local communities. Each year, the Fraser Institute Survey of Mining Companies studies companies active in the mining sector, including both major multinational giants and small junior exploration companies. A recent survey found that public policy is a major determining factor for companies' decision to invest. Respondents on average valued public policy at 40% of their investment decision – almost as important as the geology (Stedman and Green, 2017[48]). In conjunction with policy itself, mining companies also consider whether a jurisdiction is favourable to investment, stable and predictable in the business climate (Wilkerson, 2010[49]).

Strong environmental protections are not a disincentive to investment. Indeed, jurisdictions with some of the most stringent environmental regulation consistently ranked among the most attractive[1] in terms of policy environment for mining (Stedman and Green, 2017[48]). There could be two reasons for this. First, international mining companies face significant scrutiny from regulators and the public. Second, they either develop or adopt the newest technologies first, which tend to be more environmentally friendly. In 2017, the top five jurisdictions for mining in the Fraser Institute's annual survey were Ireland, Finland, Saskatchewan, Sweden and Nevada.

Companies based in less stringently regulated environments, such as countries in the EECCA region, may initially have difficulty transitioning to more stringent regulations (Hilson, 2000[50]). Even in developed economies, it might take years for industry to adapt to a new regulatory paradigm. For instance, when Canada enacted its Metal Mining Liquid Effluent Regulations in 1977, it took until 1994 to reach a 98% industry compliance rate (Hilson, 2000[50]).

The Porter hypothesis argues that well-designed environmental regulation can stimulate innovation (Porter and Linde, 1995[51]), and can potentially increase economic productivity as well. Over the past decades, these hypotheses have been tested frequently. The latter "strong" conclusion (increase economic productivity) has lately begun to show evidence for validity. However, the former "weak" conclusion (stimulate innovation) is considered well-established (Ambec et al., 2013[52]).

3.4.1. Exploration

In all major mining jurisdictions, proponents of mines need permits for their activities. Sometimes separate permits are required for exploration and mine operations. Depending on the regulatory structure, EIAs may be included as a precondition for granting of the mining permit or as a separate process.

Exploration activities in themselves can have a significant environmental impact. Exploration may require cutting survey lines through vegetation, as well as constructing roads. This can have a substantive impact on ecosystems by destroying or otherwise disturbing them. It can also break up contiguous areas, making it hard for animals to move around or have the territory they need to live.

Through requirements for new mining projects, governments can set the stage for expectations. However, enormous uncertainty remains about whether and how a mine will be constructed at this point. Therefore, most jurisdictions approach exploration as a separate matter with its own distinct EIA process.

EIA processes for the exploration stage are critical. They should also require that companies consult with communities in the area, regardless of whether the latter control or have legal veto on the land being assessed. Making community consultation a requirement also benefits mine proponents. It can help ensure some degree of social licence for the inevitable disturbance of the natural ecology. In this sense, environmental assessments enable project proponents to demonstrate to regulators – and the community – that they assessed risks properly and have a plan to mitigate them (Kokko et al., 2015[53]).

As their name suggests, the junior companies that conduct most exploration tend to be smaller than the ones that actually build and operate mines. They do not necessarily have the resources or knowledge for thorough environmental or biodiversity assessments. Companies may need to rely on environmental consultants to support environmental assessments at the exploration phase.

Environmental assessments at the exploration phase are typically less onerous than those for a full mine. However, they should still have requirements for mitigating environmental damage and rehabilitating any damage caused. In addition, even at this preliminary stage, environmental regulators must assess suitability of the area for mining, and whether there are unacceptable threats to ecosystems or human health. The exploration stage thus provides an initial point of entry for regulators to determine whether a mine is environmentally feasible. The bar will be lower than for permitting development of the mine itself because the exploration phase does not consider various factors. These include the kind of mine that might eventually be developed; its size; the techniques involved; and a detailed survey of the water table and local geology.

Box 3.1. NeXT – New exploration technologies

New Exploration Technologies (NeXT) is an EU-funded multi-country project co-ordinated by Finland. NeXT supports the development and adoption of new exploration technologies into the mining sector. It brings together partners from the research institutes, academia, service providers and industry. In so doing, it aims to develop new geological models, analysis techniques and exploration technologies that are cost-effective, environmentally sensitive and socially acceptable. To that end, it supports the reduction of costs and exploration time. By earning a social licence for mineral operation, NeXT also aims to enhance the participation of stakeholders, including civil society. The project, which runs from 2018-21, covers the most significant metallogenetic belts in the European Union.

Source: (European Commission, 2018[54]).

As discussed in Section 2.2.4., new remote sensing technology means that exploration companies typically have a better idea of where to find valuable deposits before they need more environmentally invasive and expensive physical sampling. Governments can set out requirements for use of remote sensing techniques through limits on environmental impacts for a given exploration permit. In addition, a best available techniques approach lays out recommended practices and technologies to meet emission standards.

3.4.2. Mine approval and operation

Regulators may consider both economic and environmental factors in assessing the case for a mine. Every major mining jurisdiction considers mines on a case-by-case basis. The regulatory process governing the construction of new mines tends to be complex. This is due to the potential for environmental impact, as well as the wide variety of stakeholders.

EIAs and SEAs are the first entry point for governments into whether a mine should be permitted. Properly done, EIAs and SEAs serve multiple important purposes. They force companies to clearly identify the environmental risks for their mining project. Companies must also illustrate the mitigation measures they will use during operations, as well as after mine closure. In turn, they can also help the government communicate requirements clearly to mine proponents. Crucially, assessment processes also allow governments to mandate consultations with stakeholders, including communities likely to be impacted by the mine. They also open mining proposals for scrutiny from interested stakeholders such as environmental organisations with expertise in the sector.

Box 3.2. Balancing economic benefits and environmental risks in the mining lifecycle

Mines provide valuable opportunities for public revenue and local employment. However, any given resource deposit can only be extracted once, so it should be done well, as it constitutes the collective wealth of the people living in a given country or area. The mine proponent may argue that environmental regulations make it economically unfeasible to develop the mine. If that occurs, then the time may not be right to develop the mine. Perhaps the technology needs to be advanced further until it is economical to develop the mine in a way that does not engender significant environmental risks. Prices for the commodity may need to rise. Or perhaps the area under consideration is simply too sensitive.

Another consideration is the enormous length of time that stretches after a mine is closed. Indeed, much of the most significant environmental impacts from mining operations occur after mine closure, when monitoring and scrutiny weaken. If the geology raises the risk of acid rock drainage, the need for vigilance is severe. Once vigilance slips, it is hard to turn back the clock. Determining this at the onset – rather than along the way – is critical. Careful assessment can help ensure that environmentally unsound projects, such as ones with a high propensity for acid rock leakage or damage to vulnerable ecosystems, do not get built in the first place.

Once a mine has gone through an EIA process and been approved, the regulatory regime ensures it stays within the guidelines and establishes constraints. This entails more than just setting standards for compliance. There are two broad points to consider in this conception – the underlying philosophy of the environmental regulatory system, and how it functions. In the first case, there has been a shift in the nature of regulatory systems over the past decades. These systems are moving towards incentivising and encouraging compliance rather than those punishing non-compliance. In many EECCA countries, however, regulation of the mining sector remains focused on the latter.

In terms of functionality, adopting integrated permitting for proposed mine sites and environmental assessment can harmonise different levels of government and reduce duplication. In this way, it can support better environmental performance and reduce the regulatory burden on governments.

Although OECD jurisdictions regulate mining emissions in different ways, most focus on reducing ecosystem harm rather than on punishing non-compliance. At the same time, the polluter-pays principle ensures that companies are responsible and liable for the damage they cause to ecosystems. This approach can foster an environment that encourages mining companies to go beyond the bare minimum requirements for compliance and excel, reducing their environmental footprint.

Permitting and ensuring environmental compliance

The requirements for permitting a mine vary widely by country, but all they balance the same considerations – economic and environmental impacts of a mine. A 2014 study compared the environmental regimes governing mining in Sweden, Finland, the Russian Federation (hereafter "Russia"), Canada and Australia. It found significant diversity in approaches, stemming from different governance (Söderholm et al., 2014[55]):

- Russia has based its approach on a licensing regime, which requires proponents to conduct an EIA before a licence is issued. The licence obligated the licensee to follow specific environmental requirements. For example, it would need to prevent contamination of water sources through waste accumulation. Despite more stringent technical and emission standards than other jurisdictions, enforcement was not necessarily consistent or effective (Söderholm et al., 2014[55]). As of 2018, Russia began transitioning to a system of integrated permits modelled on the EU's Industrial Emissions Directive. It added a Reference Document on best available techniques (BREF) for the mining sector. This establishes emission limit values.
- Sweden and Finland share similar mining regulatory regimes, shaped in part by their shared membership in the European Union. Both require environmental permits based on national legislation, an EIA and general environmental requirements drawn from a best available techniques (BATs) approach. In both countries, mining facilities are also impacted by EU BREFS for specific processes, even though there is no EU BREF for mining.
- Governance of the mining sector in Australia and Canada varies across different provinces/states and territories. In Australia, the federal government is only involved in specific cases triggered by national legislation like the Environmental Protection and Biodiversity Conservation Act. In Canada, the development of new mines is regulated at the provincial and federal level. They require both provincial permitting as well as federal EIAs (Söderholm et al., 2014[55]).

Permitting requirements that support the mining sector to become more environmentally innovative need to be performance-based. This is the case even if the limit values are drawn from analysis of the BATs. This helps drive innovation, as well as allowing flexibility in reaching targets (Bergquist et al., 2013[56]). Governments need to set limits that reduce the environmental impact of mining. However, mine operators are generally best suited to know what technique or technology can ensure compliance.

Compliance assurance and non-compliance responses should aim to ensure good environmental performance rather than to generate revenue. At the same time, compliance monitoring and enforcement are resource-intensive and complex. Political considerations, as well as socio-economic ones, can also impact compliance enforcement. This is especially true when a mining facility is a vital local source of employment (OECD, 2009[57]).

Compliance activities should be risk-based to prioritise resources, and transparent to promote public knowledge of specific mining operations. They should aim to help noncompliant operations to become compliant, using monetary penalties as a last resort. Support for compliance can include technical advice and support on BATs to improve environmental performance in specific circumstances (OECD, 2009[57]). An important consideration is the time allowed for operators to become compliant with regulatory changes. Longer compliance periods extend environmental damage, but allow more potential time for operators to innovate and come into compliance (Bergquist et al., 2013[56]). Thus, the focus of compliance assurance becomes better environmental outcomes rather than punishing companies for non-compliance.

3.4.3. Mine closure, site rehabilitation and biodiversity offsets

Most major OECD mining jurisdictions require mining companies to restore a mine site to something approaching its original state. Companies provide details in a closure plan that is part of the initial permitting process. Traditionally, this requirement was interpreted narrowly. Companies had merely to stabilise and revegetate the immediate mine site (Morton, Sheppard and Lonsdale, 2014[58]). More recently, site rehabilitation has focused on ecosystems – restoring the interlinked relationships between flora and fauna that existed before the mining operation. Thus, topsoil removed during mine construction is stored and then replaced once the site is closed. Native plant and tree species are seeded, and native animals are reintroduced.

Although this sounds ideal, it is exceptionally difficult to restore an ecosystem exactly as it was. Generally, ecosystems are the by-product of decades, centuries or even millennia of environmental changes. The soil bacteria, fungi and other organisms living in the topsoil may not survive years or decades of storage. The geological material now beneath the topsoil may have changed the hydrological conditions. The term "ecosystem" suggests something knowable, a whole made up of an assemblage of parts whose interactions are understood. Yet the difficulty in recreating ecosystems underscores the falsity of this belief.

In response to the challenge of restoration, mining companies are increasingly pursuing biodiversity "offsets" in addition to rehabilitation. Biodiversity offsets acknowledge that mine construction will damage ecosystem services and biodiversity; even after closure, they may not return. To offset the damage, project proponents will support conservation in an equivalent ecosystem or area. This, in turn, is part of a broader movement towards "no net loss" or "net gain" approach to mining projects (Virah-Sawmy, Ebeling and Taplin, 2014[59]). Often, this involves protecting an equivalent amount of land from use. Sometimes providing funding to a conversation organisation, or in some cases buying "offset credits" from an established market (UNDP, 2017[60]).

However, the use of offsets potentially creates moral hazard. Mining companies may no longer feel they need to properly rehabilitate the site Consequently, it is vital that requirements for rehabilitation remain. Offsets also raise questions of how we properly value ecosystems. What is considered an "equivalent" ecosystem? Does it make sense to permit destruction of one ecosystem while protecting another, especially if the latter might need protection anyway (Grinlinton, 2017[61])?

In some cases, in conjunction with offsets protecting an equivalent area, it may make sense to permit novel ecosystems on a reclaimed mine site rather than an exact reclamation. Developing a mine, whether surface or underground, changes the hydrology, geography and geology of the area. By the time a mine is closed, and assuming loss of the site has already been offset, rehabilitation can potentially be adapted to the new reality of the site. For instance, filling in an open-pit mine with the removed overburden may be ineffective at recreating what was there. However, it may be possible to develop a new functional ecosystem (Doley and Audet, 2013[62]). With that said, these sorts of decisions must only be made through consultation with objective environmental experts.

Site rehabilitation can take decades before it is completed. Regardless of whether biodiversity offsets are established, third parties must monitor closed sites regularly to ensure that hazards are contained and that progress continues on reclamation.

In addition, during the mining process itself, companies often discover new deposits and gain greater knowledge of the area's geology. They modify, expand or sometimes reduce mine plans. All this means that the timeline and footprint of mining sites often change beyond initial expectations. This affects the eventual site closure and site rehabilitation. Closure plans thus need to be updated to reflect any changes in a mine's circumstances.

3.4.4. Orphaned mine sites

Most historic mining jurisdictions grapple with the legacy of "orphaned" mines. These are defined as closed mines that no longer have an active entity considered responsible for cleaning up the site. Orphaned mines are an issue for countries in the EECCA region due in part to the legacy of Soviet-era development. This legacy is compounded by the operation of most mines from that era by state-owned enterprises, which abandoned them when they were no longer productive. These enterprises themselves no longer exists, and in their absence, liability passes to the state. However, site rehabilitation is exorbitant. Most governments do not have the funds to address rehabilitation on that scale. For example, it's estimated that Canada has more than 10 000 abandoned sites. In 2002, the Office of the Auditor General of Canada estimated the cost of rehabilitating abandoned mines in northern Ontario alone at CAD 555 million (Hogan and Tremblay, 2006[63]). In the United States, the US Government Accountability Office (GAO) estimates 161 000 abandoned sites in the 12 western states and Alaska. Of these, 33 000 have contaminated the environment. The US Environmental Protection Agency spent a median of over USD 221 million a year on rehabilitation between 1998-2008 (US GAO, 2011[64]).

As one approach to this problem, current operators could feed into an industry-wide fund that supports the rehabilitation of orphaned sites. In Alberta, Canada, companies operating in the oil and gas sector pay annual fees into a fund. The regulator sets annual contributions based on estimates of current liabilities. Other jurisdictions have also tried variations of this model, including Western Australia and across the United States (through the Comprehensive Environmental Response, Compensation and Liability Act, better known as the Superfund). However, this approach has been criticised as raising insufficient funds, as it is difficult to estimate total liabilities for abandoned mines. For instance, of 52 mining operations on federal land in the United States, the US GAO estimated that operators' financial assurances fell USD 61 million short of requirements for reclamation.

An approach to orphaned mine sites is best developed through collaboration, enabling the state and industry to share the cost burden. Because of the costs involved and the number of sites that need rehabilitation, efforts need to be prioritised through a risk-based approach. This approach should also prioritise transparency with impacted stakeholders, including civil society, as they can be valuable sources of information.

3.4.5. Reprocessing non-operational mine sites

One of the most direct applications of circular economy principles in the mining sector is the reprocessing of tailings and waste from old mining operations. This holds potential in the EECCA region, given the significant numbers of abandoned mines. Waste could be processed to recover metals, potentially creating jobs and improving environmental conditions. Reprocessing tailings can be profitable, and can also leave an abandoned mine site in better environmental condition.

However, government policies can impact the feasibility of these projects, and they may need to be treated differently from traditional mines (Box 3.3). Reprocessing waste from non-operational mine sites straddles the line between mining and recycling. Governments may want to adopt a specific tax regime to mine waste reprocessing operations that incentivises investment. This would enable royalty rates to consider the potential environmental benefits of cleaning up a hazardous site. This shift in how mining operations are defined is also relevant for the reprocessing of non-mining waste sites with significant metal, which can be integrated into commodity value chains (Knapp, 2016[65]).

Box 3.3. Mining waste – examples from Australia and Kazakhstan

Mount Morgan Mine, Australia

In Australia, the Mount Morgan mine in Central Queensland operated initially from 1882-1982, with a brief closure. During that time, environmental controls were extremely weak, and reactive waste rock and tailings were dumped into a nearby river. There was extensive environmental damage, including acid rock seepage. This resulted in dead fish as far as 40 km downstream from the site.

In 1982, a tailings reprocessing operation was begun. Due to low commodity prices and technical difficulties with recovery, however, the project caused further environmental damage. After eight years, operations were halted (Lèbre, Corder and Golev, 2017[66]). Following these events, the government took over the mine. It invested in measures such as new earthworks to prevent further leaking into the river. However, it was unable to pay the full cost of site rehabilitation, which was estimated at AUD 450 million for a partial rehabilitation. Site maintenance costs alone for the government were estimated at AUD 3 million per year (Terzon, 2018[67]).

In 2016, the company Carbine Resources completed a feasibility study to reprocess the waste at the Mount Morgan site. The study determined it would be economical to process the tailings for copper (in the form of copper sulphate), pyrite (in the form of iron pyrite concentrate) and gold bullion. The processing would also remove main acid forming materials in the tailings (in the form of sulphur) (Carbine Resources, 2018[68]).

However, in March 2018, Carbine Resources announced it could no longer continue with the project. Due to lower than anticipated levels of recoverable metal and changes in the exchange rate, returns were too marginal. The project was further impacted by the project's classification as a mining operation, which would require paying royalties (Terzon, 2018[67]).

Central Asia Metals, Kazakhstan

In Kazakhstan, near the city of Balkhash, the Kounrad copper mine was operational from 1936 until 2005. It left behind significant waste dumps containing recoverable copper. In 2007, Central Asian Metals PLC acquired an interest in the site. By 2012, it had constructed a solvent extraction – electrowinning (SX-EW) plant. The process produces copper cathode by using in-situ leaching to remove copper and other metals from the waste dump. It then uses a concentrating and electro winning process to make copper cathode, which is exported mostly to Turkey (Central Asian Metals, 2018[69]).

The mine has been profitable. As it involves only reprocessing existing waste dumps, the mine has also had a low environmental impact. In 2016, the facility was further expanded, to continue extracting more copper. Central Asian Metals is a publicly traded company that pursued the project based on market principles. However, the operations demonstrate the potential opportunities for a circular economy approach to abandoned mining sites in EECCA region countries (Central Asian Metals, 2018[69]).

3.5. Innovation and capacity building

Public policy can support technical development and technology domestication in a range of different ways. Directly, some mining jurisdictions such as Canada, Australia and Norway have public research institutions that develop new technologies and approaches, contributing to better environmental performance of the mining sector. Some research is also done in collaboration with educational institutions (universities), as well as directly with mining companies themselves. At a more indirect level, policy can also support technical development and innovation in the mining sector by supporting access to finance. This could take the form of low-interest loans, research grants or tax policies that reward spending on research and development.

3.5.1. Innovation led by the public sector

The government can help fund, co-ordinate and facilitate innovation and research in the mining sector with the same approaches that support innovation throughout the economy. At a direct level, governments can establish national research laboratories to develop new technologies for industry. Collaboratively, these institutions can also work with academia, other research institutes and the private sector to develop and commercialise new technologies. Governments can also support innovation by providing access to finance for companies attempting to develop and commercialise new technology for the mining sector.

Box 3.4. Canada's approach to supporting innovation in the mining sector

Canada's Ministry of Natural Resources has a broad range of support programmes for the mining sector. Through its Green Mining Innovation programme, this includes support for:

- enhancing mine productivity
- energy efficiency in mining
- minimising and managing mine waste
- managing water in the mining cycle.

Within each category there are other research programmes. These include improving automation and equipment, developing safer underground mines, electrifying mine sites and improving water recycling. In all cases, the ministry's CanmetMINING laboratory is leading research in collaboration with mining companies, equipment suppliers and academia. This helps ensure that research is directly relevant for industry needs. It also encourages development and deployment of new sustainable mining practices.

Source: NRCan, 2018, www.nrcan.gc.ca/mining-materials/green-mining/18312.

3.5.2. Facilitation of equipment upgrading

Public policy can help mining companies upgrade their equipment to improve environmental performance. In part, this is simply removing barriers that discourage companies to improve environmental performance beyond requirements. Removing such obstacles opens the door to investing in more efficient and effective equipment. Import duties on new equipment that supports better environmental performance, for example, can be waived. Companies can gain tax credits by investing in new equipment that improves environmental performance, whether through efficiency gains or better pollution control. This is especially important in countries with high import duties on equipment.

3.5.3. Support for skills development and vocational training

Improving the environmental performance of the mining sector requires potentially new skills from both the public and private sector. Environmental regulators need capacity and skills – as well as the numbers – to regulate the sector effectively. At the same time, mining companies need to be able to hire employees with the appropriate educational background. Third-party environmental service providers need the human capacity to conduct assessments and monitor mine sites. For their part, machinery and equipment companies need to be able to develop and construct new products. Research institutions also need in-house capacity to support innovation effectively.

By supporting environmental education criteria for mining and engineering programmes, governments can help ensure that curriculum reflects new developments in the industry. At the same time, public funding for education can help ensure that institutions are able to operate and provide courses and that education is accessible.

3.6. Developing linkages to other parts of the green economy

3.6.1. Environmental services

Any attempt to improve sustainability of the mining sector depends in part on environmental service providers. These third parties can help assess, monitor and rehabilitate mine sites, among other roles. As noted in section 3.5.3, public policies can support skills development and capacity building in this area by developing vocational training programmes. Meanwhile, environmental policies in the country and the region largely impact demand for environmental services. Unlike traditional service sectors, such as finance, telecommunications or transportation, growth in demand for environmental services tends to be driven by more stringent environmental regulation (Adlung, n.d.[70]). Regulation and social pressure, rather than economic demand, largely shape markets for environmental services.

The benefits of developing an environmental services sector go beyond the mining sector, and potentially beyond the country itself. Any significant industrial project requires EIAs, ongoing monitoring and, potentially, ecosystem rehabilitation. Although some EIA characteristics rely on industry-specific knowledge, much of it is transferable across sectors. The development of a capable environmental services sector can potentially help improve environmental performance across the board. On a regional basis, it also creates the potential for service exports.

3.6.2. Green infrastructure

In addition to their direct environmental footprint, mining projects in remote areas also require significant infrastructure to support their operations. This includes transportation to move mine output to market and to import mine inputs. It includes power generation (whether off-grid or grid-connected). Finally, it includes water to support mine development and mineral and metal beneficiation (OECD, 2016[71]).

The benefits of mine development can be enhanced by constructing infrastructure with environmental performance in mind, as well as by considering shared usage. Infrastructure should be subject to low-carbon and climate resiliency requirements. These requirements should minimise its environmental impact during construction, while ensuring its long-term stability. Regions with weak transportation linkages, water processing or power generation would benefit from infrastructure. These regions can harness mining projects as a means to provide broader benefits, including industrial development and local procurement (OECD, 2016[71]).

3.7. The circular economy, mining and waste as resources

The concept of a circular economy is gaining momentum globally among governments, consumers and industry. In this re-envisioning of economies, linear use of materials (raw materials, production, use and disposal) moves to circular use (materials reused, repurposed or recycled at every economic stage). Initially, the concept focused on manufactured products and transferring from ownership models to "goods as services". Mining was not featured prominently in the picture. Some of the most influential models of the circular economy, such as that created by the Ellen MacArthur Foundation, have mining and beneficiation processes outside of the circular loop (Lèbre, Corder and Golev, 2017[72]) (Ellen MacArthur Foundation, 2014[73]). This may be in part because removing raw materials from the ground seems like the antithesis of the circular economy (Thimmiah, 2014[74]).

However, over the last few years, mining has quickly caught up. Major business consultancies and industry associations have published analysis and position papers that frame the circular economy transition as an opportunity rather than a threat (ICMM, 2014[75]) (ICMM, 2018[76]). Common themes run through the analysis:

- Metal is infinitely recyclable, and recycling can be significantly more cost-effective than mining new metal. Some analyses are referring to the "urban mine" of industrial appliances and electronics that can be recycled and processed.
- Tailings sites from older mining facilities may contain metals due to inefficient or uneconomic extraction techniques during their initial processing; technology developments, higher mineral prices or policy incentives may now make them economical.
- The increased ability to track metal and mineral commodities from their point of origin enables the potential for new business models. Specifically, mining companies can remain responsible for the processing and recycling of the metals they sell.

- In integrated business models, mining companies act more like commodities companies. They sell metals from their own recycling facilities, as well as from mines.

At the level of the economy, disparate sources have different takes on the potential impact of the circular economy. These sources include national governments, industry associations, management consultancy firms and environmental non-governmental organisations. Despite the attraction of a zero-waste society, a market and demand for virgin resources will likely continue for the foreseeable future. However, circular economy principles can, when supported by public policy and consumer buy-in, support new models for integrating the extractive industry into the global economy.

At the firm- or mine-level, circular economy principles can also help drive much more efficient operations. Inputs can be reused as much as possible on site. In some cases, they can be reused practically infinitely. Waste from beneficiation and metallurgic processes can also be reused or repurposed. For large vertically integrated firms, recycling may already be part of the business model. For example, Mitsubishi Materials has adopted circular economy concepts across the range of different firms within its group. That includes a recycling-focused approach that combines new commodities with metal. This metal can be recovered from home appliances, aluminium cans, metal processing plants and non-ferrous smelters. It uses waste material as inputs for cement. Smelting plants then use clinker dust waste from cement creation as inputs in the smelting process (Mitsubishi Materials, 2018[77]).

At the operational level, circular economy principles can also have a powerful impact. Non-operational mines can represent enormous environmental risk factors. At the same time, they can often contain substantial amounts of valuable metals within waste rock and tailings that can be reprocessed using modern techniques. Public policy can play a role in supporting these developments. Circular economy principles reduce or eliminate waste. They also reduce the need for new mines to be developed in the first place. In this sense, they can have broadly beneficial impacts on the environmental impact of mining.

3.8. Key recommendations

Successful OECD jurisdictions demonstrate a confluence of policies that together incentivise, support and regulate mining companies to adopt greener technologies, make processes more efficient and reduce their environmental impact.

- **Implement comprehensive, clear and consistently enforced regulation.** This includes the environmental assessment process, as well as regulation and enforcement during operations. The regulatory system should promote good environmental management and prevent environmental harm rather than punish transgressors. The ultimate goal should be compliance with the regulations, or even going beyond them; it is not to generate revenue through penalties and taxes. This also means the regulatory framework needs to extend beyond the life of the mine. In so doing, it can ensure that waste dumps and tailings are properly managed and land affected by the mining operations is rehabilitated.
- **Support innovation and environmental performance in the mining sector through the funding of sector-specific and applied research.** In mining-intensive regions, government should develop innovation plans specifically targeted at the sector, independently or as part of national innovation policies. This helps facilitate collaboration between government researchers, universities,

institutions and the private sector. Government can also assist with financing to commercialise innovations.

- **Build human capacity through education, training and work experience.** Although mining companies conduct their own in-house training, ensuring that environmental concerns, solutions and new technologies are part of the curriculum in mining-related engineering and vocational programmes helps enable better environmental performance. It also helps ensure that skills are available for third parties. This will enable such parties to provide environmental services to mining companies. They could also potentially certify performance to the government or be employed directly by the regulating agency.
- **Develop policies to address abandoned and orphaned mine sites.** Legislation that ensures mine sites are monitored and rehabilitated is a relatively recent development. It has emerged in step with the growing recognition of environmental destruction in the latter half of the 20th century. Significant numbers of mine sites have been abandoned, with no party clearly responsible for their rehabilitation. If the operating company still exists, legislation can oblige them to cover the site. In many cases, however, the mines were created under entirely different economic systems or the company no longer exists. In such cases, the government needs to have an approach to orphaned mine sites. Approaches include setting aside funds by operators to cover post-mining activities, environmental liability insurance, environmental payments or earmarked royalties.
- **Ensure that mine operators can implement and, if necessary, import more efficient and environmentally sensitive equipment.** Governments need to ensure that companies are encouraged to access and uptake new technology. Furthermore, they must remove barriers to importing this technology. This may include tax structures that incentivise the purchase of new equipment or import duty exceptions on new equipment that meets environmental criteria.
- **Raise awareness about the mining industry's need to put safety and environmental sustainability first and to ensure a zero-failure objective to tailings management facilities.** Governments can facilitate this awareness in several ways. They can require mine operators to regularly update and publish disaster management plans. They can mandate third-party monitoring of mine and mine waste sites. Finally, they can require financial securities for the life of the mine, as well as transparent sharing of information with potentially impacted stakeholders.
- **Facilitate broad stakeholder participation in support of good environmental performance from mining operations.** Regulations governing the establishment, operation and closure of mines can require inclusion of all stakeholders in the process. Industry associations are valuable sources of information, and can help legitimise and communicate new policy developments to firms. The public (both locally and broadly) could be informed about new and potentially high-impact industrial development, and given space to voice their concerns. The operator can then address these concerns. These measures help involve environmental groups and other civil society organisations in both environmental assessment and compliance exercises.
- **Draw on international conventions and agreements for standards, co-ordination and information.** A broad array of international conventions and

agreements address everything from transboundary pollution to industrial incidents to general good practices. These initiatives are led by organisations such as the UN Economic Commission for Europe and the UN Environmental Programme. Together, they establish standards and frameworks for improving environmental performance in the mining sector. Valuable benchmarks include the legislation of common European standards for machinery operating within hazardous underground atmospheres; energy efficiency; and dust management.

- **Adopt a whole of government, co-ordinated approach to improving environmental performance in the mining sector.** Regulatory responsibility for a mining project may be shared over multiple agencies, depending on the pollutants, the stage of the project and the medium. Responsibility may also fall under different levels of government. Local, sub-national and national governments, for example, may regulate different aspects of the sector, introVducing challenges for governance and fiscal arrangements. Ensuring multi-level co-ordination between those actors and minimising duplication help improve clarity and efficiency with regard to communicating with operators. This also helps ensure that operators have a social licence to operate.
- **Support the development of a market for third-party green service providers in the mining sector, including accreditation processes.** Improving the environmental performance of the mining sector can be a catalyst for bringing green service providers into a country. Governments can support this outcome through access to capacity building programmes for independent consultants and support for vocational training. Policies should include accreditation for domestic and foreign green consultancy services to encourage market entrants and provide confidence to mining companies.
- **Quick wins should be prioritised, but depend on specific country contexts.** On an ongoing basis, the public sector, in collaboration with industry and civil society stakeholders, should work to diagnose the barriers and enabling factors for enhancing environmental performance in the sector to prioritise areas of action.

Notes

1. Factors considered in the Fraser survey for policy attractiveness include current regulations, environmental regulations, regulatory duplication, the legal system and taxation regime, uncertainty concerning protected areas and disputed land claims, infrastructure, socio-economic and community development conditions, trade barriers, political stability, labour regulations, quality of the geological database, security, and labour and skills availability (Stedman and Green, 2017[48]).

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