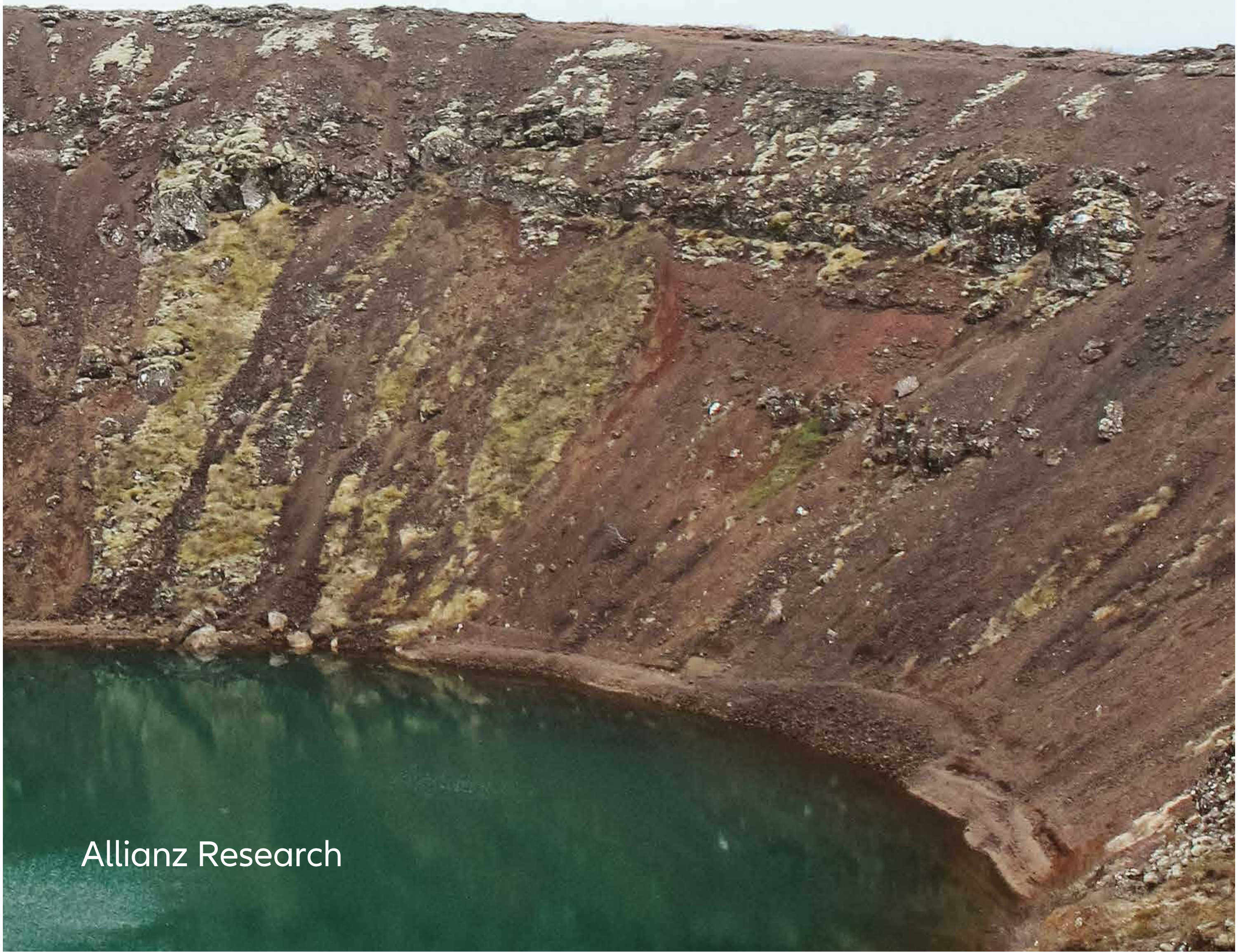
Mining for the future: Addressing liabilities and unlocking sustainable transition opportunities

25 February 2026



Allianz Research

Content

Executive Summary

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- **A twin transition is driving a surge in mineral demand as decarbonization and digitalization are reshaping the industrial base simultaneously.** Energy systems are shifting toward electrification, renewables, storage and expanded grids, while artificial intelligence is driving heavy investments in data centers and computing infrastructure. Demand for critical minerals is set to rise accordingly. The International Energy Agency projects that by 2040 lithium demand could increase fivefold; graphite and nickel may double; cobalt and rare earth elements could rise by 50–60%; and copper demand by around 30%. Meeting this surge will require not only new mines, but expanded processing capacity, infrastructure and skilled labor. Meanwhile data-center electricity demand alone is expected to more than double by 2030, reinforcing the case for grid investment and additional materials.

- **Supply is struggling to respond.** Although a more circular economy may eventually ease reliance on primary extraction, supply chains for key transition minerals remain slow to scale. New projects take years to permit and finance, and face rising environmental and social standards. The pace at which mining and refining capacity can grow is therefore a central constraint; failure to scale responsibly risks prolonging fossil-fuel dependence.

- **Environmental pressures reinforce these constraints.** Mining contributes around 2–4% of global GDP, supports millions of livelihoods and accounts for approximately 4–7% of global greenhouse gas emissions. Although less significant than agriculture or urban expansion in driving forest loss, mining directly deforested nearly 20,000 km^2 between 2001 and 2023, generating roughly 0.75 Pg of CO$_2$ - slightly more than Germany's annual emissions in 2024. Stronger operational practices, rehabilitation and credible compensation mechanisms such as biodiversity offsets and reforestation could reduce these impacts. While debated, effective implementation could help limit net forest loss as mineral demand rises.

- **Bridging this gap will require substantial capital.** We estimate cumulative investment needs of around USD 1.1trn to 2040 across mining, processing and circularity. Sustainability has become a binding production constraint: permitting, insurance and community consent now shape capacity as directly as technical factors. Company disclosures suggest roughly USD 450bn may be required for decarbonization, tailings management, recycling and environmental controls. After accounting for overlap with the roughly USD 800bn needed to develop new supply, total capital requirements remain close to USD 1.1trn.

- **Sustainable mining is integral to the transition.** Underinvestment risks leaving decommissioning liabilities to society and raising project risk. This is where improved sustainable practices and operations can be a win-win. Clear, early expectations from regulators, communities and customers would allow costs to be priced in upfront, streamline engagement and improve the credibility of approvals.

Why the transition depends on mining done right

The twin transitions in energy and digital systems are driving a structural surge in material demand. The energy system is being rebuilt around electrified end-use, renewables, storage and expanded grids; in parallel, AI is accelerating investment in data centers, network equipment and high-performance computing. Both of these shifts are often framed as “clean” or “virtual”, but ultimately they are physical. They require large volumes of metals and minerals – and the industrial capacity to refine and process them into usable inputs to manufacturing. As a result, global mineral extraction has surged to unprecedented levels in the 21st century. Krausmann et al. (2018)[1] provide a landmark account of this shift, documenting a 23-fold increase in global socioeconomic material stocks, from just 6 gigatons (Gt) in 1900 to over 1,300 Gt by 2015. According to the IEA, lithium demand is set to jump by around fivefold by 2040, graphite and nickel will roughly double, cobalt and rare earth elements will rise by around 50-60% and copper will increase by around 30%.[2] These multipliers matter because scaling supply is not just about opening new mines; it also requires increasing processing capacity, expanding transport infrastructure and growing a skilled workforce. AI introduces an additional demand vector by accelerating the build-out of data centers and associated power infrastructure. In the IEA’s base case scenario, global data center electricity demand rises from about 415 TWh in 2024 (about 1.5% of global electricity consumption) to about 945 TWh in 2030.[3] Meeting this demand implies more grid investment and, indirectly, additional demand for construction materials and critical metals (e.g. copper for cabling and transformers). From a critical-minerals perspective, rising data-center load matters for two reasons. First, it reinforces the need for faster grid expansion and resilience investments, which are copper- and aluminum-intensive. Second, it accelerates demand for hardware supply chains (servers, networking, semiconductors) that rely on a range of metals and high-purity inputs. The result is an additional layer of demand uncertainty on top of already steep growth from EVs and renewables.

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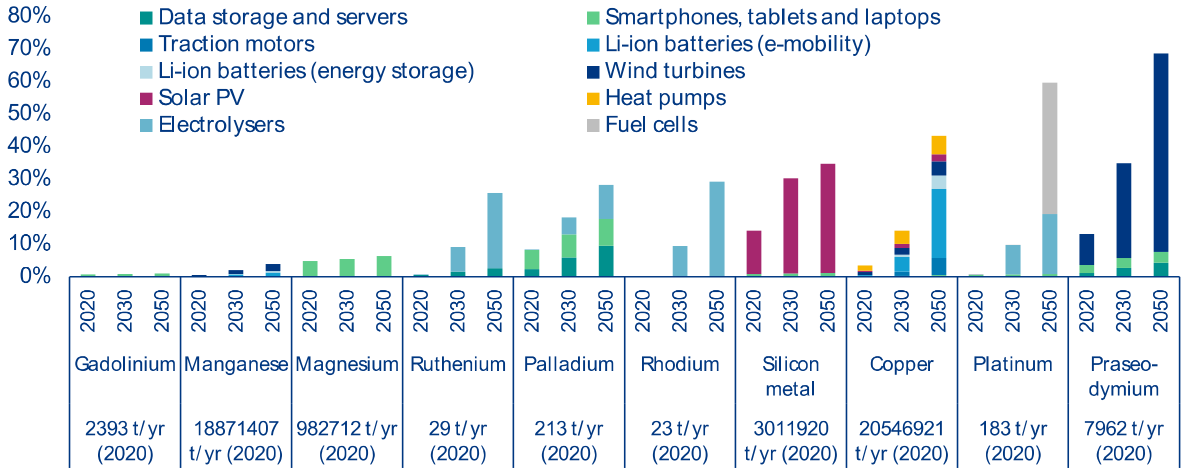
[1] From resource extraction to outflows of wastes and emissions: The socioeconomic metabolism of the global economy, 1900–2015 - ScienceDirect

[2] International Energy Agency (IEA). 2025. Global Critical Minerals Outlook 2025. Paris: IEA.

[3] International Energy Agency (IEA). 2025. Energy and AI. Paris: IEA

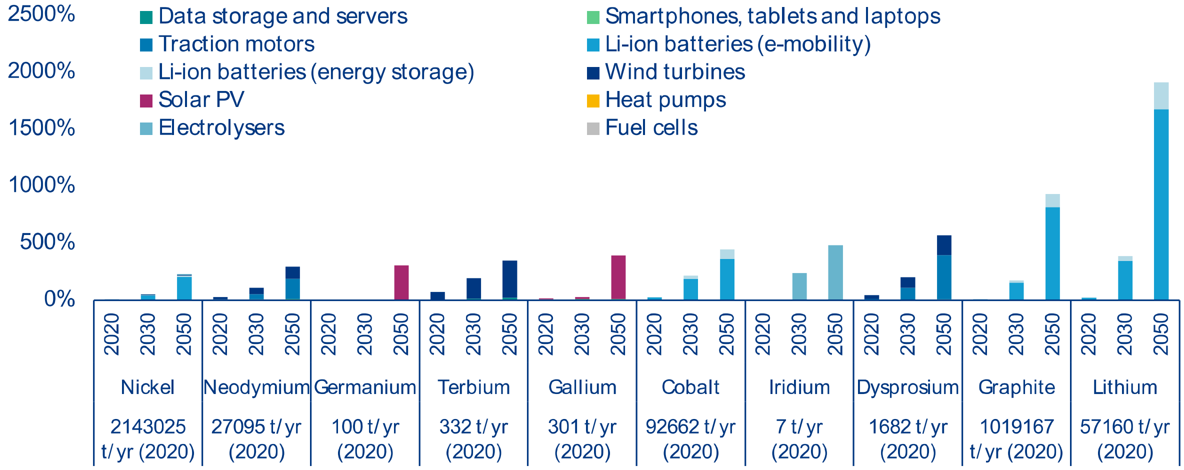
Figure 1: Global raw material demand by transition technology (in % of 2020 total production): EU strategic materials (high demand scenario), shares between 1% and 100% in 2050



Sources: JRC[4]; Allianz Research

For several Strategic Raw Materials (SRMs), projected demand growth is large enough to absorb most of today's global output - and in some cases exceed it. SRMs are a subset of Critical Raw Materials (CRMs) essential to strategic technologies underpinning the green and digital transition, as well as defense and aerospace applications[5]. Figures 1 and 2 translate technology deployment into annual raw material demand relative to current (2020) global production levels. When projected demand approaches or surpasses 100% of today's output, supply chains must expand rapidly—or demand must adjust through efficiency gains, substitution, recycling or higher prices. The challenge is particularly acute for materials produced in only a handful of countries, or primarily as by-products, such as gallium and germanium.[6]

Figure 2: Global raw material demand by transition technology (in % of 2020 total production): EU strategic materials (high demand scenario), shares above 100% in 2050.



Sources: JRC[7]; Allianz Research (Note: Germanium demand estimates for solar PV are from Carrara et al., 2020) [8]

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[4] Carrara, S., et al. 2023. "Supply Chain Analysis and Material Demand Forecast in Strategic Technologies and Sectors in the EU – A Foresight Study." Joint Research Centre, European Commission.

[5] European Commission. 2025. "RESourceEU Action Plan: Accelerating our critical raw materials strategy to adapt to a new reality." Communication from the Commission. COM(2025) 945 final, December 3, 2025.

[6] Carrara, S., et al. 2023. "Supply Chain Analysis and Material Demand Forecast in Strategic Technologies and Sectors in the EU – A Foresight Study." Joint Research Centre, European Commission.

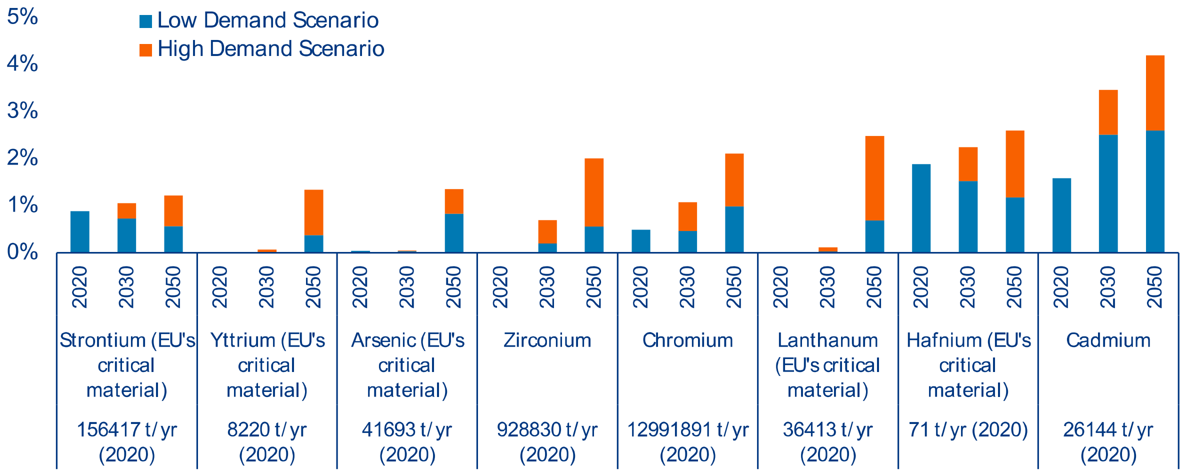
[7] Carrara, S., et al. 2023. "Supply Chain Analysis and Material Demand Forecast in Strategic Technologies and Sectors in the EU – A Foresight Study." Joint Research Centre, European Commission

[8] Carrara, S., et al. 2020. "Raw Materials Demand for Wind and Solar PV Technologies in the Transition Towards a Decarbonised Energy System." EUR 30091 EN. Joint Research Centre, European Commission. Accessed February 1, 2026.

Focusing policy on a narrow list of strategic materials risks overlooking two additional bottlenecks. First, some `ordinary' materials—such as steel, concrete, copper and aluminum—are required in very large volumes. Even in deep and diversified markets, rapid scale-up can strain production capacity, raise prices and create permitting or energy-supply constraints. Second, certain minor metals are needed only in small quantities but at very high purity, and are often produced as by-products. This makes supply slow to adjust and vulnerable to trade disruptions. Figures 3-5 illustrate projected demand for these materials relative to 2020 global production. Two patterns stand out. First, some non-strategic materials show large percentage increases but remain a small share of today's production because the underlying markets are already very large (e.g. steel and aluminum). Second, a subset of non-strategic but critical inputs – including indium, tellurium and phosphorus – can, by 2050, reach demands that exceed current production, largely driven by specific technologies such as photovoltaics and batteries. The implication for industrial planning is clear: materials need not be formally classified as 'strategic' to become binding constraints. Rapid demand growth, limited refining capacity or by-product dependence can generate price volatility and project delays.[10]

Phosphorus illustrates how transition demand can spill into essential commodity markets. It is used in batteries' lithium iron phosphate (LFP) cathodes, which are increasingly deployed because they avoid nickel and cobalt and offer cost and safety advantages. As EV and stationary storage markets expand and LFP gains market share, the battery sector can become a meaningful additional source of phosphate demand on top of its dominant use in fertilizers.[11] From a risk perspective, this creates a ‚competition for molecules' problem: a material that is essential for food security also becomes relevant for electrification. Supply is not only a mining issue; it also depends on chemical conversion and on the ability to manage environmental impacts from phosphate mining and processing.
For Europe, this strengthens the case for recycling phosphorus-containing waste streams, and for technology innovation that reduces phosphate intensity where possible.[12]

Figure 3: Global raw material demand by transition technology relative to total 2020 production: EU non-strategic materials, shares below 4.5% in 2050



Sources: JRC[13]; Allianz Research

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[10] Carrara, S., et al. 2023. "Supply Chain Analysis and Material Demand Forecast in Strategic Technologies and Sectors in the EU – A Foresight Study." Joint Research Centre, European Commission.

[11] Carrara, S., et al. 2023. "Supply Chain Analysis and Material Demand Forecast in Strategic Technologies and Sectors in the EU – A Foresight Study." Joint Research Centre, European Commission.

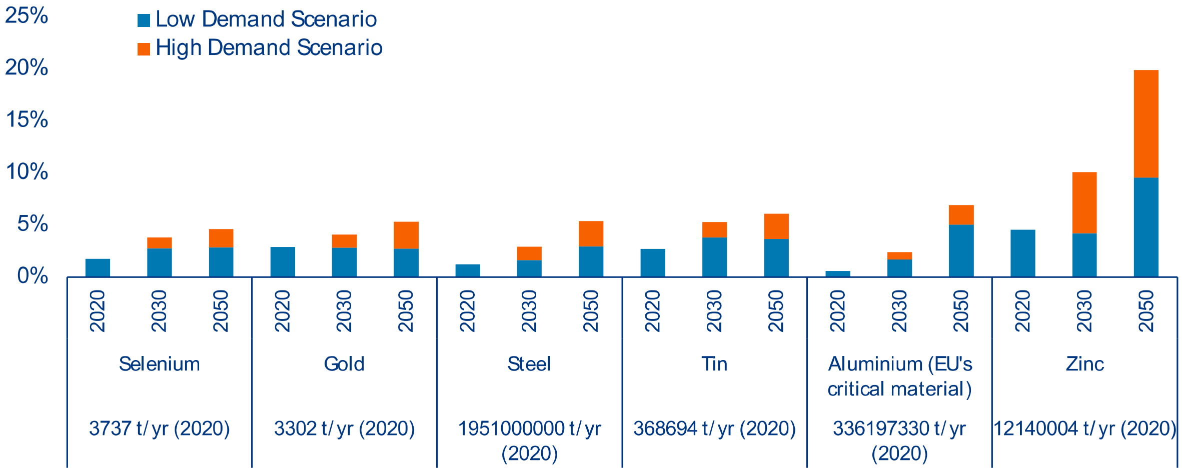
[12] European Commission. 2025. "RESourceEU Action Plan: Accelerating our critical raw materials strategy to adapt to a new reality." Communication from the Commission. COM(2025) 945 final, December 3, 2025.

[13] Carrara, S., et al. 2023. "Supply Chain Analysis and Material Demand Forecast in Strategic Technologies and Sectors in the EU – A Foresight Study." Joint Research Centre, European Commission

Rising material demands create a practical tension at the heart of the transition. On the one side, the transition offers the opportunity to move to a circular economy, one where the materials that we mine enter near infinite loops of use and re-use. In this scenario, once sufficient materials are within human control, the overall quantity of mining precipitously drops – especially of fossil fuels. However, on the other side, supply chains for several transition-relevant minerals are slow to scale: New mines and refineries currently take years of planning, studies, permitting, financing and construction. Further, projects rightly face rising performance expectations around water use, biodiversity impacts, community benefits, labor conditions, tailings safety and end-of-life liabilities. The pace at which extraction and refining capacity can be expanded is a primary bottleneck for building a decarbonized economy. If we do not get mining right to unlock the full potential of our industrial might and know-how, we risk prolonging our fossil fuel economies well past the time horizon that science and insurers have indicated will be catastrophic.[14]

What will it take to scale the "right" projects: those that are deliverable on time, financeable at scale, insurable against severe loss and seen as legitimate in the eyes of communities and regulators? Mining's legacy can often translate into lower societal trust; the challenge is therefore not only to do more and do it faster, but to keep operations safe, beneficial to communities and with acceptable levels of remediable environmental impact. It argues that "faster" only works when it is "faster because better": history teaches us that acceleration without stronger performance and governance backfires through delays, accidents, litigation and long- duration liabilities. Looking ahead, competition for batteries, grids, magnets and semiconductor inputs will intensify; midstream capacity, permitting and acquiring social license will often be the binding constraints.

Figure 4: Global raw material demand by transition technology relative to total 2020 production: EU non-strategic materials, shares between 4.5% and 20% in 2050



Sources: JRC[15]; Allianz Research

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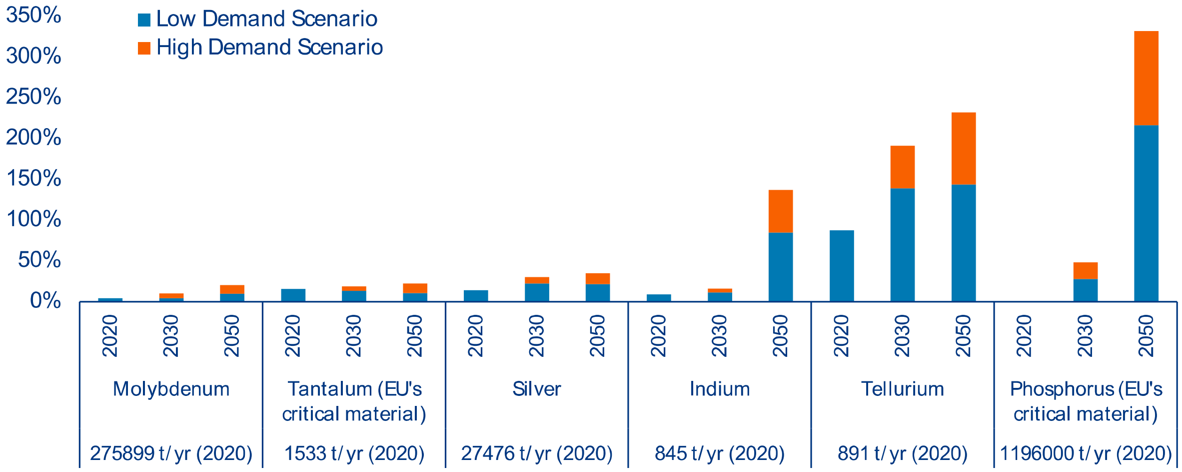
[14] IPCC (2023). CLIMATE CHANGE 2023 - Synthesis Report. Summary for Policymakers.

[15] Carrara, S., et al. 2023. "Supply Chain Analysis and Material Demand Forecast in Strategic Technologies and Sectors in the EU – A Foresight Study." Joint Research Centre, European Commission.

Figure 5: Global raw material demand by transition technology relative to total 2020 production: EU non-strategic materials, shares above 20% in 2050



Sources: JRC[16]; Allianz Research

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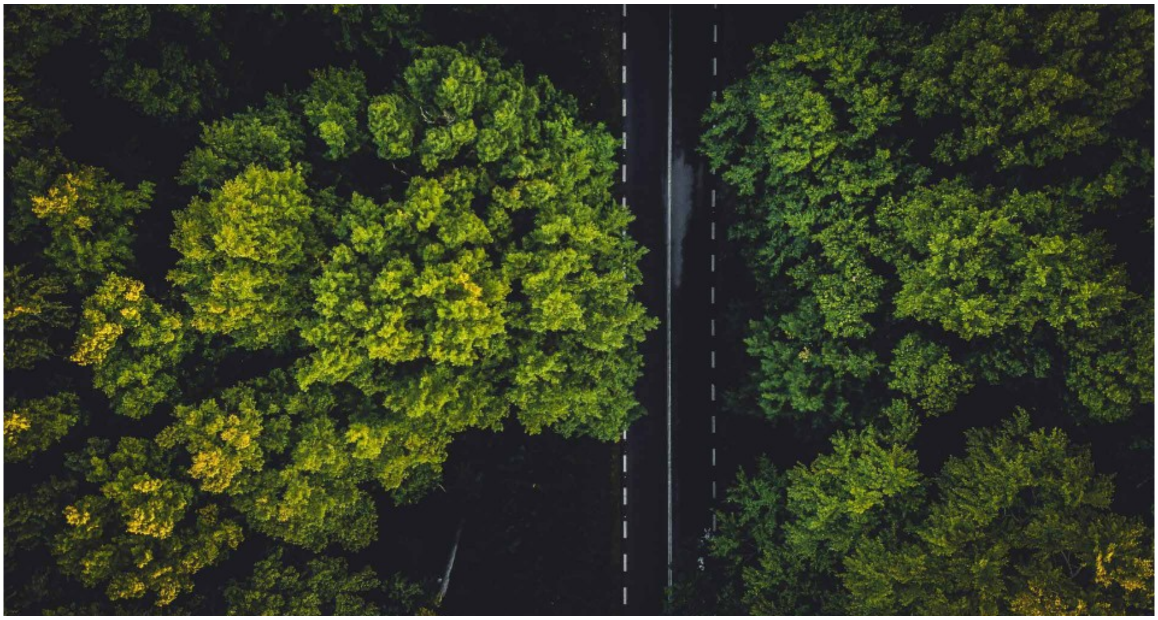
[16] .Carrara, S., et al. 2023. "Supply Chain Analysis and Material Demand Forecast in Strategic Technologies and Sectors in the EU – A Foresight Study." Joint Research Centre, European Commission.

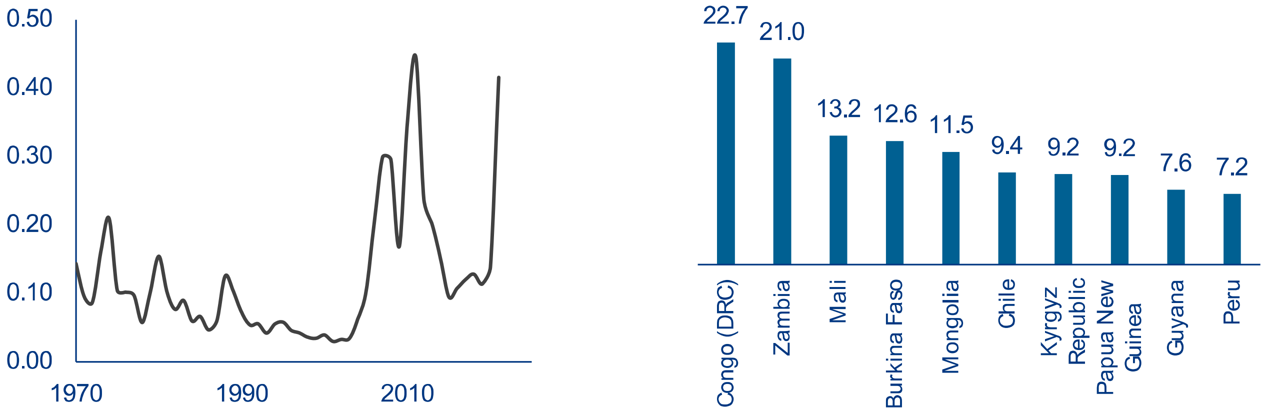


The sustainability bottleneck: The social license to deplete, environmental limits and project disruption risk

Material stocks - buildings, transport infrastructure, machinery and other long-lived assets - embody the cumulative footprint of industrialization and urbanization, particularly in high- and middle-income economies. Their construction and maintenance now consume nearly half of all raw materials extracted annually, underscoring the structural link between economic development and material throughput. Despite the rise of service-based economies, there has been no absolute decoupling of growth from resource use or environmental pressure. Expanding built environments lock societies into long-term flows of energy consumption, emissions and waste, raising questions about the sustainability of prevailing development models.

Figure 6a illustrates this trajectory, showing that mineral extraction as a share of global Gross National Income (GNI) more than tripled between 2000 and 2021, reaching its highest level in over five decades. However, while mineral depletion is rising globally, it is highly concentrated geographically. Figure 6b shows that in 2021, several resource-rich countries, such as the Democratic Republic of Congo (22.7%), Zambia (21.0%), and Mali (13.2%), saw depletion levels exceeding 10% of their GNI, underscoring how extractive activity dominates their economies. In contrast, Figure 6c reveals that most OECD countries exhibit depletion rates below 1%, highlighting a stark imbalance: the material basis of global development is disproportionately shouldered by a small group of lower-income, resource-exporting nations. This growing dependence on extractive rents places these countries at risk of a resource trap, where short-term economic gains come at the cost of long-term sustainability and structural vulnerability.

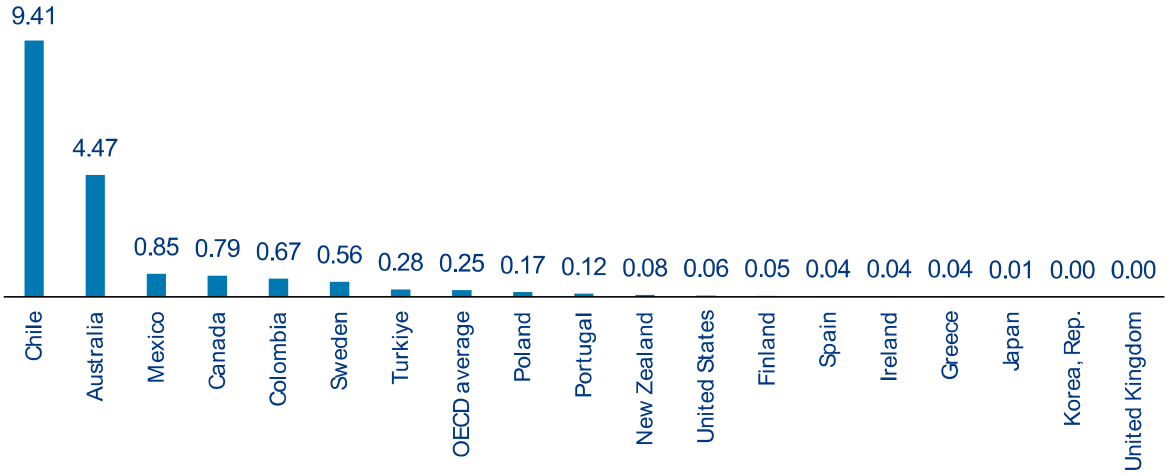
Figure 6: Mineral depletion



a) Global development (1970 – 2021) as a share of Gross National Income (GNI, %)

b) Top 10 countries with highest depletion rate in % in 2021

c) Depletion rate in OECD countries in % in 2021



Sources: World Bank Data, Allianz Research

The unequal distribution of mineral depletion as a share of national income reveals deep patterns of environmental injustice in the global resource economy. While raw material extraction remains essential to infrastructure, energy systems, and global trade, the environmental burdens of these activities fall disproportionately on resource-rich but economically vulnerable countries. According to Arendt et al. (2022)[17], the total global environmental costs from these activities are estimated to range between EUR0.4trn and EUR5trn annually, depending on the valuation method used.

The analysis considers over 190 nations and shows that in many lower-income countries, domestic environmental costs, such as air pollution, acidification and land degradation, often outweigh the GDP benefits generated by mining and processing. For instance, Rwanda exhibits the highest ratio of environmental damage to economic gain, driven by informal tantalum mining with minimal local value retention. In monetary terms, several countries, among them Gabon, Ghana, Madagascar and Afghanistan, incur environmental costs that exceed their mining-related GDP gains, indicating a net-negative

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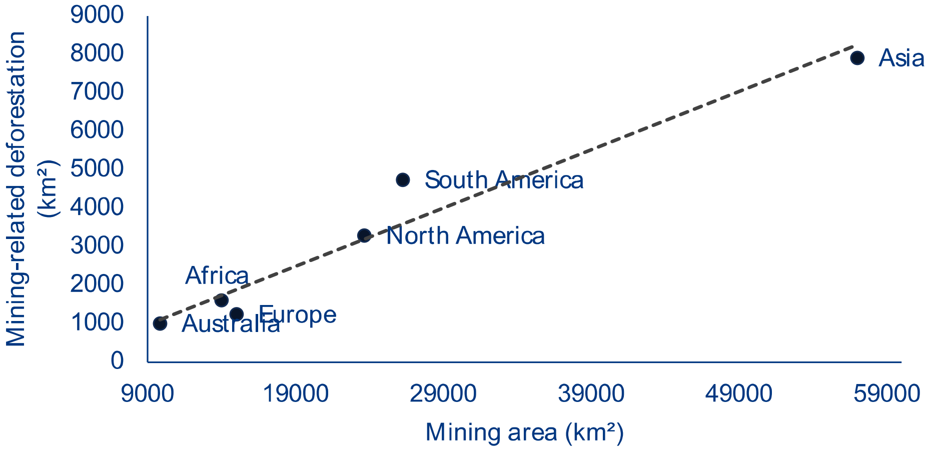
[17] The global environmental costs of mining and processing abiotic raw materials and their geographic distribution - ScienceDirect

welfare impact from extraction. Conversely, high-income economies like Germany, Japan and South Korea benefit from favorable cost–benefit ratios by importing raw materials and externalizing the most damaging stages of extraction. Countries such as China and India, while significant producers, also show low benefit-to-cost ratios, particularly due to high domestic pollution from iron, steel and aluminum production. For example, China's mining sector accounts for a disproportionate share of global particulate matter and greenhouse gas emissions per euro of GDP gain. These disparities make clear that current global supply chains structurally externalize environmental harm, concentrating damage where economic returns are lowest. As demand for critical minerals intensifies, especially for the green and digital transitions, the risk is not only ecological but developmental, trapping producer countries in high-extraction, low-benefit paths, i.e., the so-called "commodity trap".

One of the major social impacts of mining stems from the environmental harm associated with the sector, such as deforestation. While mining contributes around 2–4% of global GDP, supports millions of livelihoods and accounts for approximately 4–7% of global greenhouse gas emissions, it also is a significant driver of forest loss, although well behind leading causes of agriculture, infrastructure and urban expansion. By overlaying high-resolution global forest-loss datasets with mining areas over the period 2001–2023, Zhang et al. (2025)[18] find that 19,765 km^2 of forested land were directly deforested by mining activities. This deforestation resulted in gross carbon emissions of 0.75 Pg CO_2[19], slightly higher than annual emissions of Germany in 2024, with unrecorded mining activities accounting for 66.5% of total mining-related forest loss. Spatially, Asia experienced the largest absolute deforestation in mining areas, followed by South America, North America, Africa, Europe and Australia (Figure 7). Overall, 175 countries experienced mining-related deforestation during this period, with tropical forests disproportionately affected, emerging as global hotspots of carbon emissions.

Figure 7: The mining areas and mining-related deforestation across different regions (cumulative 2001 – 2023)



Sources: Zhang et al. (2025), Allianz Research

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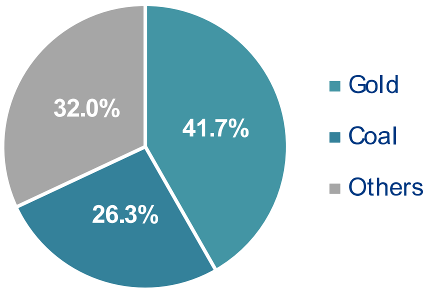
[18] Overlooked deforestation from global mining activities in the 21st century | Nature Communications

[19] 0.75 Pg CO_2 = 0.75 Gt CO_2 = 750 million tonnes of CO_2

An analysis of mining-related deforestation by primary commodity reveals a strong dominance of gold and coal extraction at the global scale (Figure 8). For instance, gold mining accounts for 41.7% of total mining-driven deforestation, followed by coal mining with 26.3%, corresponding to carbon emissions of 0.39 Pg CO_2 and 0.18 Pg CO_2, respectively. Gold-related deforestation is highly concentrated geographically, with Brazil, Russia, Indonesia, Peru, Ghana and Suriname emerging as the largest contributors. Here unrecorded mining activities account for over 73% of gold mining-related deforestation between 2001 and 2023, with particularly high shares observed in Brazil, Peru, Myanmar and Guyana. Coal mining also exhibits a substantial unrecorded component, responsible for nearly half of coal-related deforestation, with Indonesia alone contributing close to half of the global total. Temporally, deforestation linked to coal and other commodities increased until 2012 before declining thereafter, reflecting reduced coal demand amid the global energy transition. The increase in mining to drive the transition will, ultimately, lead to a reduced impact of coal mining as operations wind down.

While the shift toward renewable energy has contributed to declining coal-related deforestation, it has simultaneously increased demand for mineral inputs critical to renewable technologies and infrastructure. When categorizing mining activities by their relevance to renewable versus non-renewable energy production, deforestation has increasingly shifted toward regions extracting minerals associated with renewable energy supply chains. After 2012, nearly three-quarters of mining-related deforestation occurred in areas producing minerals used for renewable energy applications, underscoring the risk that accelerating energy transitions may intensify deforestation pressures if mineral supply chains remain weakly regulated.

Figure 8: Deforestation-related to different mining commodities (%, cumulative 2001 – 2023)



Sources: Zhang et al. (2025), Allianz Research

Importantly, the environmental footprint of mining is increasingly being addressed through compensation mechanisms. In several jurisdictions and corporate strategies, mining expansion is now accompanied by commitments to reforest or conserve ecosystems in other locations, following “no net loss” or “net gain” biodiversity frameworks. These approaches rely on biodiversity offsets, large-scale reforestation programs or conservation finance aimed at balancing deforestation induced by extractive activities. While such compensation schemes remain debated. If credibly implemented, these mechanisms could partially decouple continued mineral extraction from net forest loss, especially in the context of rising demand for transition minerals.

Beyond its environmental and climate externalities, mining is frequently associated with concerns over labor conditions and worker safety[20]. However, any assessment of labor outcomes in the sector must clearly differentiate between large-scale industrial mining (LSM) and artisanal and small-scale mining (ASM), as the nature of risks, governance and employment relations differs substantially between the two. In industrial mining, rising levels of mechanization, stronger regulatory oversight and the gradual adoption of occupational safety and health (OSH) standards have contributed to measurable improvements in workplace safety over recent decades. Fatal accident rates, while still non-negligible, have declined in many jurisdictions, reflecting better risk-management practices. The increasing reliance on automated and remotely operated machinery has also reduced direct worker exposure to physical and chemical hazards, as many high-risk tasks are now performed from control rooms rather than on site. By contrast, the labor challenges most commonly highlighted in public debates, such as unsafe working conditions, and exposure to chemical substances (e.g., mercury, cyanide etc.), are far more prevalent in ASM, where informality, limited (intellectual and economic) capital and weak institutional oversight remain dominant.

Despite its largely informal nature, ASM plays a central role in global mineral value chains. The sector represents one of the largest sources of employment in the mining industry, providing livelihoods to approximately 44.75mn workers across more than 80 countries worldwide. In many ASMs children, sometimes as young as ten years old, continue to participate in mining-related activities, highlighting persistent social and regulatory challenges (ILO 2024). ASM also contributes a substantial share of global mineral production. Estimates indicate that the sector accounts for 15–20% of total global mineral output, including around 80% of sapphires, 20% of gold and 20% of diamonds. Beyond precious stones and metals, ASM is also an important supplier of minerals that are strategically critical for modern manufacturing and electronics, notably tantalum and tin.

These structural characteristics come with significant occupational health risks, as illustrated in Figure 9, which reports mercury concentrations in the hair of mining workers across selected ASM-producing countries. Measured exposure levels substantially exceed the WHO recommended maximum of 1 mg/kg in all cases, with particularly elevated mean and maximum values observed in Ghana and Indonesia. In these contexts, recorded mercury concentrations reach levels an order of magnitude above international health thresholds, underscoring the widespread and chronic nature of toxic exposure in ASM settings.

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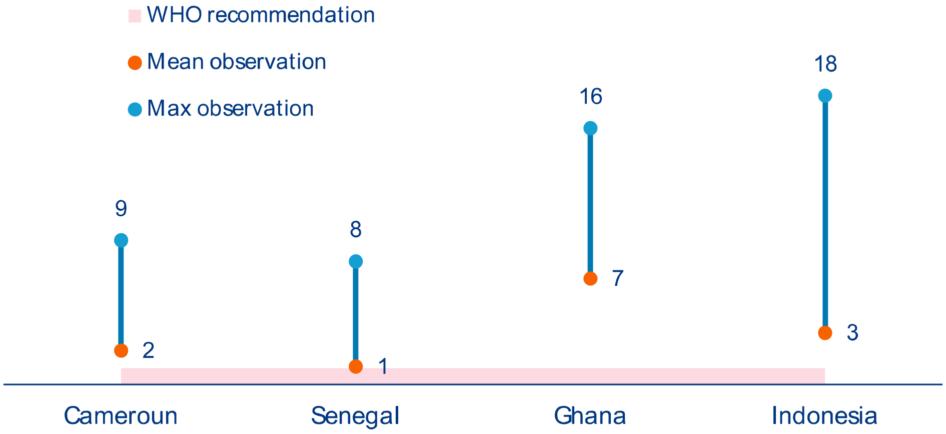
[20] Chemical exposures in mining | International Labour Organization

Figure 9: Mercury hair levels for mining workers (mg/kg)



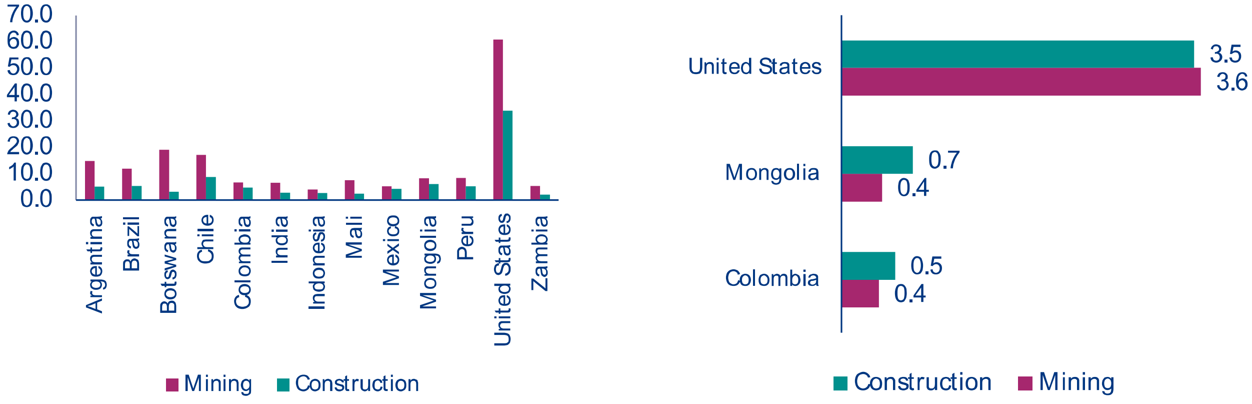
Sources: Harianja et al. (2020), Opoku et al. (2019), Birane et al. (2014), Allianz Research

Figure 10 illustrates the contrast in mining labor outcomes between developed and developing economies. Across the full country sample, average hourly wages in mining exceed those observed in several other sectors, including construction (Figure 10a). This pattern is consistent over time and remains robust when mining wages are compared with those in agriculture, services and public administration, suggesting a persistent wage premium associated with employment in the mining sector. This apparent advantage, however, masks an important structural trade-off. Higher remuneration in mining partly reflects a risk premium, compensating workers for the elevated probability of physical harm and injury. Unfortunately, although the goal should always be for injuries to be zero, this physical harm can also be life altering severe or fatal. To determine the extent of this risk premium, Figure 10b presents wages adjusted by the number of fatalities, offering a risk-weighted comparison across sectors. Once fatal risk is incorporated, the relative attractiveness of mining wages declines markedly in several developing economies. In countries such as Colombia and Mongolia, mining wages fall below those observed in construction, indicating that monetary compensation does not fully offset the level of occupational risk borne by workers. By contrast, in advanced economies such as the US, mining retains a modest wage advantage even after adjusting for fatality risk, suggesting more effective risk management, stronger enforcement of safety standards or higher compensation for residual risk.

Figure 10: Compensation in mining compared to construction

a) Average hourly wage in 2023 (USD, 2021 PPP)

b) Wage per unit of fatal risk in 2023



Sources: ILOSTAT, Allianz Research

The mining activity has been accompanied by several reported incidents, as documented by the Transition Minerals Tracker between 2010 and 2024[21]. Figure 11 provides a comprehensive overview of the allegations associated with mining expansion between 2010 and 2024, highlighting the breadth and persistence of social, labor and environmental challenges linked to the sector. Impacts on local communities dominate the reported allegations (802 allegations, Figure 11a), with particularly high incidence related to attacks against human rights defenders, loss of livelihoods, land rights violations and land grabbing. These patterns point to recurring tensions between mining projects and surrounding communities, often rooted in inadequate consultation processes, weak protection of customary land rights and uneven distribution of economic benefits. Allegations related to workers' conditions remain substantial (223 allegations, Figure 11b), with occupational health and safety issues emerging as the most frequently reported concern. Work-related deaths and restrictions on freedom of association further underscore persistent deficits in labor protection, especially in contexts characterized by weak enforcement and high levels of informality. Environmental allegations are the second most numerous, with 713 allegations (Figure 11c), where water pollution, restricted access to water and the creation of toxic or uninhabitable environments accounting for a large share of reported cases (77% of the allegations). The high incidence of water-related allegations has direct and severe implications for human health, while simultaneously exacerbating existing water scarcity pressures. In regions already experiencing water stress, mining-related water pollution and restricted access to clean water can intensify competition among users, undermine local livelihoods and increase vulnerability to water-borne diseases. These impacts are particularly acute in rural and peri-urban areas where communities rely heavily on surface and groundwater resources for drinking, agriculture and sanitation, and where alternative water supplies are limited.

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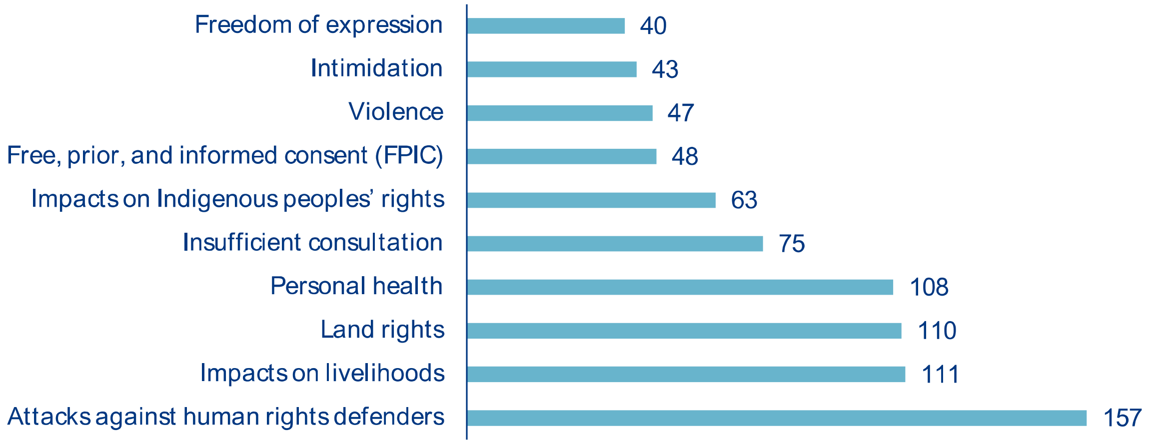
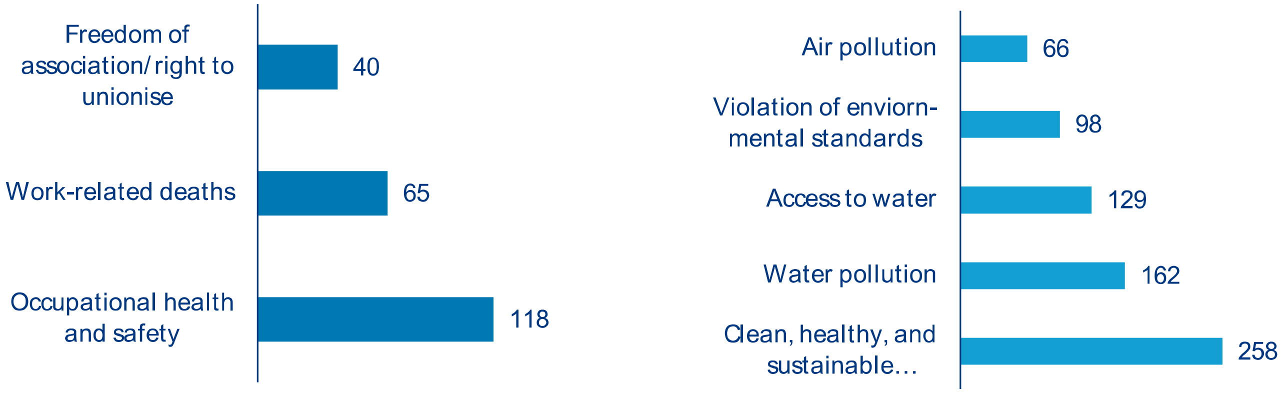
[21] Transition Minerals Tracker: 2025 Global Analysis - Business and Human Rights Centre

Figure 11: Number of allegations associated with mining expansion (2010 – 2024)

a) Impacts on local communities





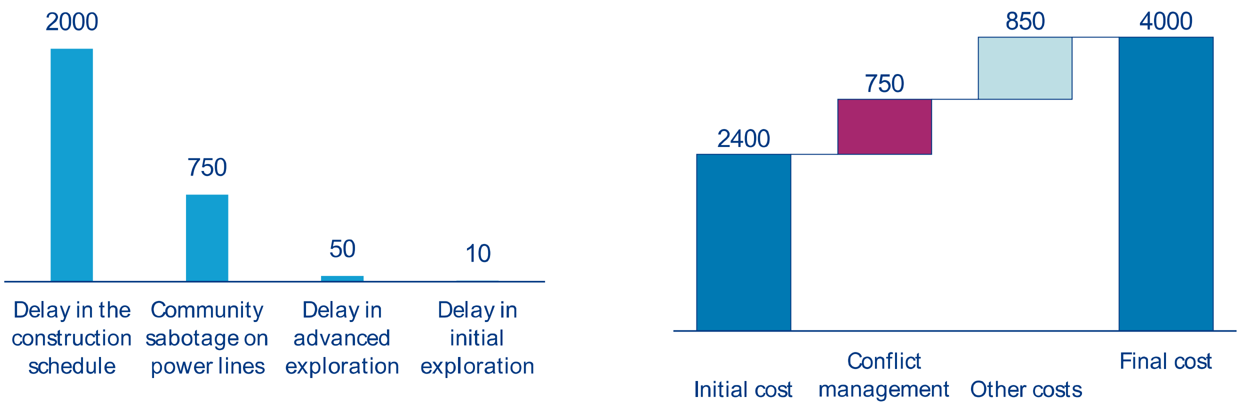
b) Impacts on workers

c) Environmental impacts

Sources: Business and Human Rights Centre, Transition Minerals Tracker, Allianz Research

Social and environmental controversies in the mining sector entail substantial economic costs that extend well beyond reputational damage. Evidence from the sustainability consultant Environmental Resources Management (ERM) indicates that 46% of major mining capital projects failed to meet planned delivery timelines between 2008 and 2016. Importantly, these delays were largely attributable to non-technical factors, with community opposition accounting for 42% of delayed projects and environmental concerns for 35%[22]. This highlights the growing role of social acceptance and environmental governance as binding constraints on project implementation. More recent ERM findings further confirm this pattern, showing that 62% of mining projects delayed at the permitting stage were affected by stakeholder opposition or concerns related to environmental impacts, rather than administrative or engineering limitations. The financial implications of such delays can be severe. Another joint study[23] estimates that social conflict can cost large-scale mining operations up to USD20mn per week of delayed production (see Figure 12 below), primarily through lost revenues. Beyond direct production losses, mining companies also face indirect costs that are often underestimated, including the diversion of senior management time as well as higher insurance premiums and increased legal expenses.

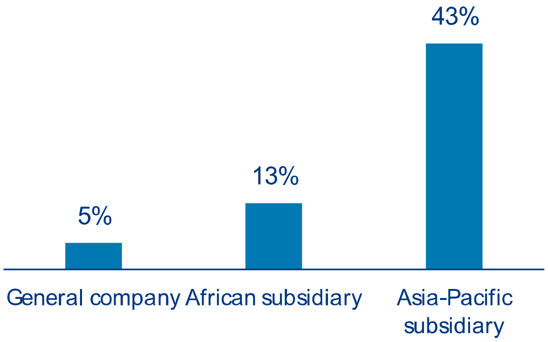
Figure 12: Economic costs of mining-related conflicts as reported by expert assessments



a) daily cost of delays (USD, thousands)

b) additional costs related to asset purchase transaction (USD, mn)

c) time in managing social risks (%)



Sources: Davis and Franks (2014), Allianz Research

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[22] Critical Mineral Security and the Social License to Operate | Oxfam

[23] Costs_of_Conflict_Davis-Franks.pdf

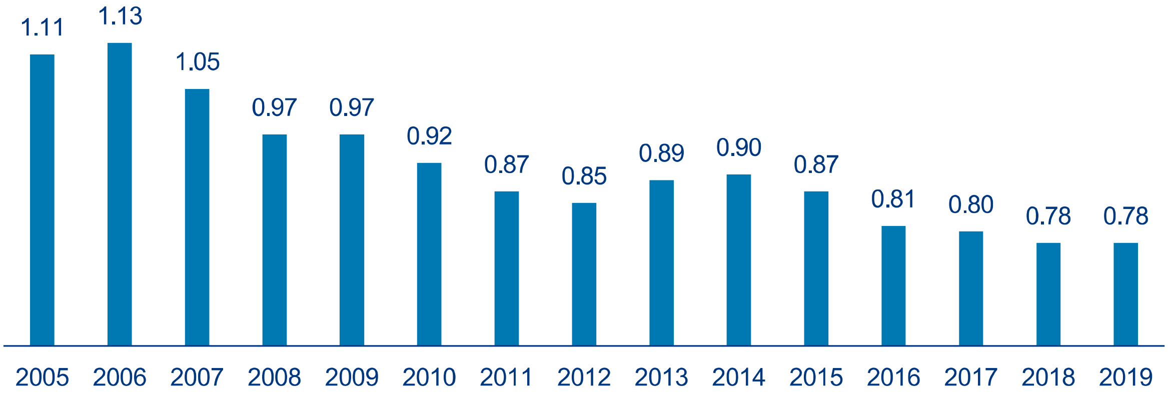
These aggregate cost estimates are further illustrated by the expert-based evidence presented in Figure 12, which decomposes the economic impacts of mining-related conflicts across different channels. Delays in construction schedules emerge as the most financially consequential outcome, with expert assessments indicating losses of up to USD2mn per day of delay (Figure 12a). These costs are driven not only by additional operational and financing expenses, but more importantly by postponed revenue streams once production is delayed. Disruptions linked to community opposition, such as sabotage of infrastructure or interruptions to power supply, add further costs, while delays during advanced exploration and initial production phases, though smaller in absolute terms, compound overall project risk.

Conflict-related costs extend beyond project timelines. In asset transactions, unresolved social issues can significantly inflate the expected total cost of ownership beyond the agreed acquisition prices. Expert evidence suggests that, in some cases, up to USD750mn in additional costs have been incurred to address community-related liabilities that were not fully identified at the time of purchase (Figure 12b). Moreover, the managerial burden associated with social risk management is substantial. While firms often assume that around 5% of senior management time is sufficient to address social risks, this share rises to 10–15% in African subsidiaries and 35–50% in parts of the Asia-Pacific region, reflecting the intensity and persistence of local conflicts (Figure 12c). These findings show how social and environmental conflicts constitute material economic risks for mining projects and should therefore be treated as core components of project risk assessment rather than peripheral externalities.

The trillion-dollar build out: Capital needs across mining, processing and circularity

Mining companies are being asked to do two contradictory things at once: raise output fast enough to meet an AI-and-electrification demand shock, while shrinking the footprint per ton as ore grades fall and scrutiny tightens. What is asked from the mining sector is quite explicit: roughly USD800bn of mining investment between now and 2040 in a net-zero pathway, with copper alone needing about USD490bn. Yet, the financing pipeline is behind schedule as less than half of the additional investment needed for net-zero critical-material demand is "on track", with long development lead times. Furthermore, to green mining operations, the sector also needs to take concrete action: electrify mines and lock in water systems for scarcity, treat biodiversity as critical and raise tailings and closure liabilities. Ore-grade decline makes this non-negotiable. For instance, copper ore grades in Chile have fallen about 30% over 15 years, mechanically lifting energy, emissions and water intensity (see Figure 13).

Figure 13: Concentrate copper ore grade in Chile (in %, 2005-2019)

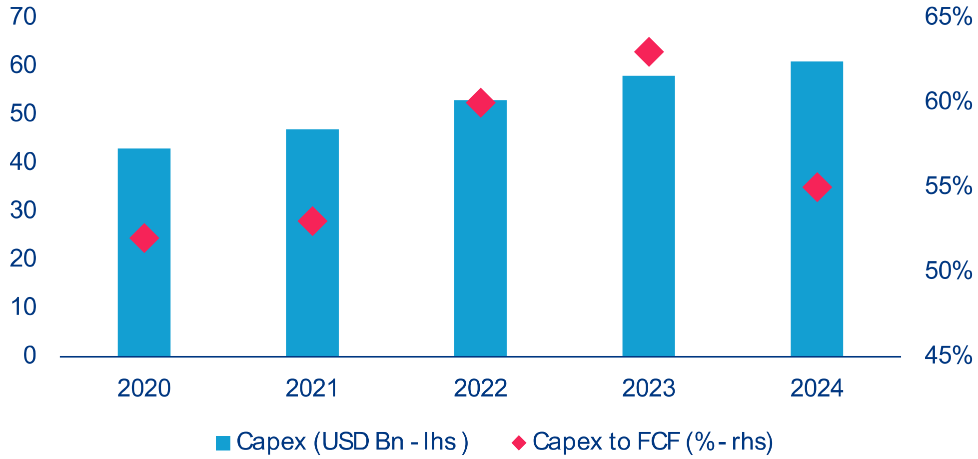


Sources: Davis and Franks (2014), Allianz Research

Demand is no longer a single-cycle story but a stacked set of pull-throughs and it changes what "enough supply" means for corporate strategy. As mentioned above, metals demand is significantly boosted by transition needs. AI adds a second-order but fast-moving vector: global data-center electricity demand could rise from about 415 TWh in 2024 to about 945 TWh in 2030. That argues for capital allocation that looks unfashionable from a pure upstream lens: mine-to-chemical and mine-to-metal chains where economics allow, more long-dated offtake structures with end-users who need certainty and selective investments in midstream capacity in the US and EU to reduce single-point-of-failure exposure, especially where policy is explicitly pulling for it.

The investment program has to be treated as an industrial mobilization problem rather than incremental growth capex. Investment growth slowed in 2024 as prices fell, even though critical-minerals mining investment still grew. Looking at top mining firms, we also notice that 2024 marked a fall in capex-to-free cash flows, underlining that miners scaled back investments relative to their capacities despite headline numbers pointing towards more investments (see Figure 14). It also stresses that low prices and weaker cash flow constrain the industry's ability to fund future growth. Copper illustrates the shape of the problem: It is ubiquitous in grids and electrification, and ore grades are falling, which raises capital per ton and stretches timelines. As a potential copper supply shortfall could materialize alongside the reality that top projects can take around 17 years from discovery to production, decisive action is required sooner rather than later. The implication is that miners cannot wait for perfect price signals: they need to lock in capital through counter-cyclical investment and risk-sharing structures. For example it could be prepayments, streaming where appropriate, and co-investment with automotive manufacturers and suppliers, utilities and even tech companies. At the same time, they should stop treating "ESG capital" as a marketing category and instead treat it as a cost-of-capital constraint.

Figure 14: Capex in the largest 15 global mining companies



Sources: LSEG Workspace, Allianz Research

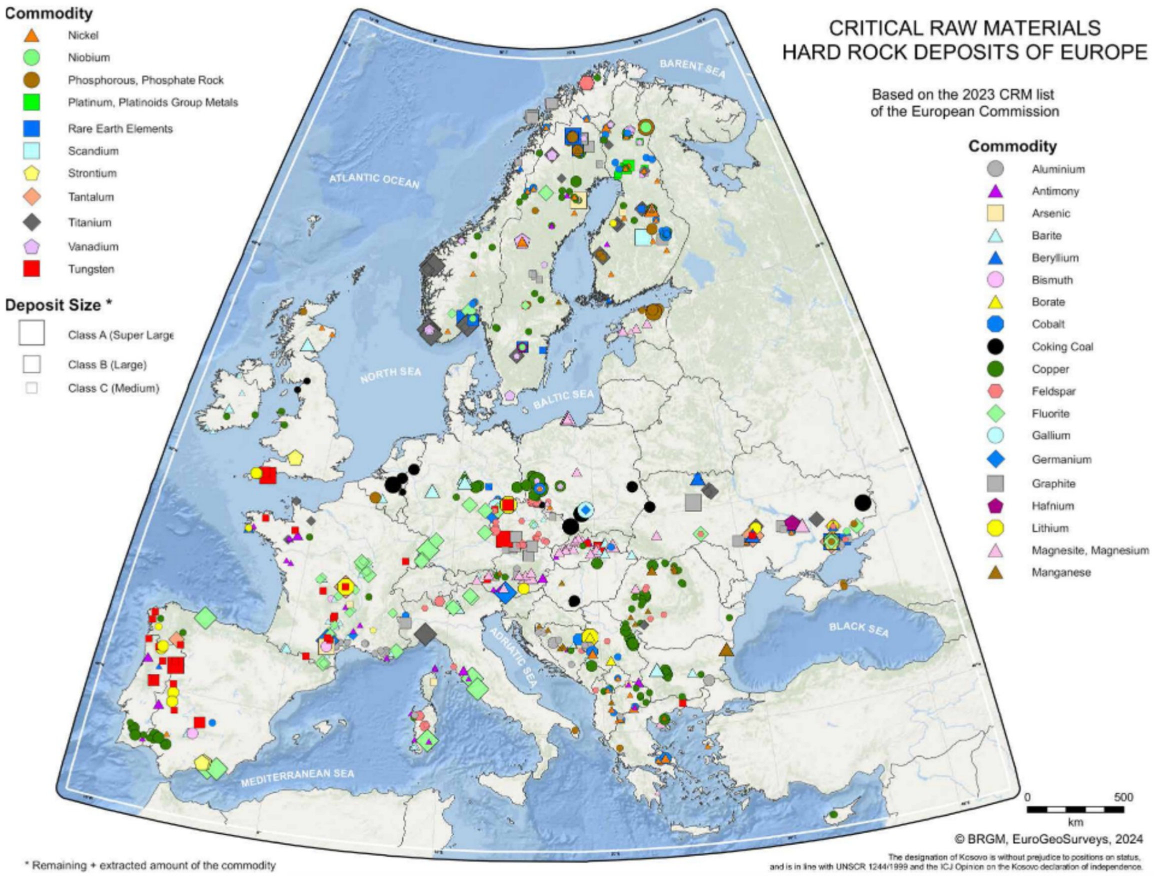
Sustainability performance is now a production input because permitting, insurance and community consent are binding constraints, and miners should manage them like they manage grade and recovery rates. The sustainability review points to the operational reality that miners' experience can worsen as grades decline, growing energy use, emissions and water use even with good intentions. That is precisely why "do more" has to mean "do differently", with measurable unit-intensity reductions and credible transition plans. Nature and biodiversity are not peripheral either: mining's impacts span land-use change, ecosystem disruption, pollution and waste through the full value chain, and sector frameworks converging into a clearer expectation in terms of risk management. Companies should assume that "partial" reporting will be treated as risk. Going forward, firms might need to go towards location-specific impact accounting (e.g. total spatial footprint, disturbed versus restored land, water withdrawals, pollutants etc.). This will be increasingly asked in a form that can be audited and compared. The same logic applies to tailings and closure: provisions for closure and rehabilitation should be treated as capital allocation, not footnotes, and structured so they survive commodity cycles. Social license must be operationalized: Robust consultation and benefit-sharing with indigenous communities where relevant is no longer reputational hygiene but a schedule-control variable, as evidenced by permitting reversals and court-driven requirements for deeper community input in multiple jurisdictions. In essence, miners should stop arguing that sustainability slows growth and start showing that sustainability is what makes growth deliverable: fewer stoppages, fewer tail risks, lower sovereign-act exposure and more stable long-term returns.

Circularity and low-carbon production are the only credible relief valves, but they would take the total bill to over a trillion dollars to 2040. The circular-economy discussion on mining illustrates both promise and constraint: resource-efficiency strategies can materially reduce primary copper demand by mid-century in an upside scenario, yet the time lag is structural because in-use metals have multi-decade lifetimes. For copper, average use-life is cited around 23 years, meaning secondary supply responds slowly to today's demand shock. That pushes miners towards a two-track strategy. First, build "low-carbon tons" as a differentiated product: electrify fleets where feasible, secure renewable PPAs for power-hungry processing, invest in heat and process electrification and disclose emissions and energy in ways that allow customers to book credible Scope 3 reductions. Second, invest selectively in recycling, urban mining and scrap-processing capacity as a growth business and a hedge against ore-grade decline: some meaningful existing recycling capacity imply that industrial-scale models exist but require upstream collection and downstream refining partnerships to grow. For critical and strategic materials with concentrated refining footprints (e.g. graphite, rare earths, cobalt), value-chain map makes the point that de-risking is often about chemicals, separation and purification rather than digging alone, and those are precisely where sustainability missteps (wastewater, hazardous by-products, local air pollution) can kill permits and social acceptance. Based on financial and transition disclosures from large mining companies which committed to strong sustainability targets, we can assume that 6% of capex should be spent for operational decarbonization, 8% for tailings/waste/closure, 3% for recycling, 2% for water & pollution controls and 1% for nature/community. Scaling this to the industry would mean about USD450bn in investments to 2040. However, some of this overlaps with the headline USD800bn. Indeed that number takes into account new mining projects that would be built in a sustainable way. With a conservative 1/3 overlap, it would mean USD1.1trn total investments to 2040: USD800bn for transition needs and another USD300bn to make mining companies sustainable.

From liabilities to legitimacy: Mining done right

Low-risk hard-rock and geothermal brine resources are essential for sustainable transition mining. Building a resilient supply of transition minerals requires balancing geological endowment with political and sustainability risks. Country-level indicators are a useful first filter, but extractive investments are additionally exposed to deal-level sovereign risk (including unexpected regulatory intervention) and to social-license risk when communities contest environmental impacts or benefit sharing. A pragmatic portfolio therefore combines domestic European resources and partnerships with stable jurisdictions, while reducing exposure to high-risk, high-concentration supply nodes. In Europe, the Geological Service for Europe (GSEU) has compiled a harmonized map of the largest medium-to-super-large hard-rock deposits for the EU's 2023 critical raw materials list (Figure 15). The map illustrates that potential critical raw material supply is geographically diverse across Europe, with prominent clusters in the Nordic shield, the Iberian Peninsula and parts of Central and South-Eastern Europe. Importantly, the dataset is a geological assessment and does not by itself imply economic, permitted or socially acceptable extractability; infrastructure, processing capacity, permitting timelines and environmental constraints remain decisive.

Figure 15: Critical Raw Materials hard-rock deposits of Europe



Sources: GSEU[24]; Allianz Research

Geothermal brines add a complementary co-production option. Many geothermal systems circulate large volumes of highly mineralized fluids that can be enriched in elements such as lithium, rubidium, antimony or tungsten and mineral recovery can be integrated with geothermal power and heat where brines are already produced and typically reinjected. Compared with conventional mining, this can reduce incremental land disturbance and avoid ore comminution and leaching, but sustainability is not automatic: site-specific life-cycle assessments show wide ranges in climate-change impacts for lithium carbonate from geothermal brines (Salton Sea, US, and Upper Rhine Graben, Germany), and impacts can exceed commonly used database values when drilling intensity is high or fossil energy is used. This reinforces the case for prioritizing projects in low-risk jurisdictions with enforceable environmental standards, and for transparent, site-specific assessment from the earliest project stages.

The EU's expanding network of strategic raw materials partnerships (e.g., MoUs/partnerships with Namibia, Zambia, the Democratic Republic of the Congo (DRC), Rwanda, Chile, Serbia, Norway, Uzbekistan and Australia) is intended to diversify supply and embed "sustainable mining" principles across upstream, processing and value chain development. However, where diversification occurs matters just as much as how much diversification happens: partner jurisdictions differ markedly in governance quality, which is a first order driver of both supply reliability and real world sustainability outcomes.

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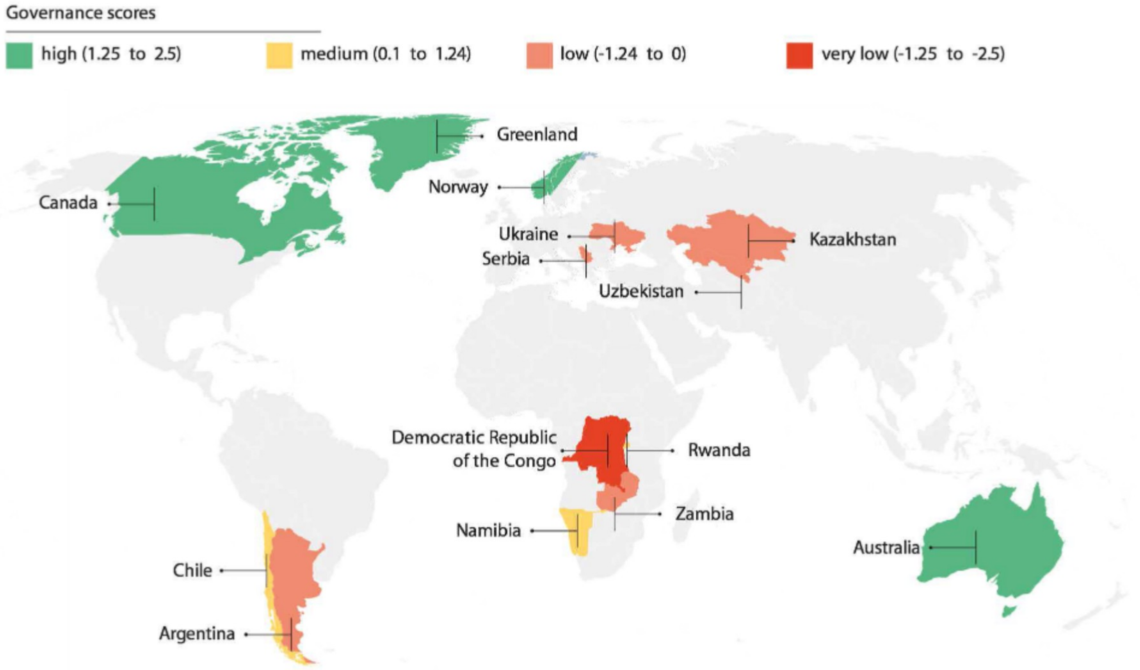
[24] Albert, C. & Bertrand, G., 2025. Map of Critical Raw Materials hard rock deposits of Europe 2024. Geological Service for Europe

Figure 16: Governance quality of EU's strategic partnership countries



Sources: ECA[25]; Allianz Research

A useful "reality check" comes from the European Court of Auditors (ECA), which mapped the EU's 14 strategic partnership countries (January 2021–June 2025) against the World Bank's Worldwide Governance Indicators (WGI, 2023).[26] The results underline the heterogeneity of the partner set: seven of the 14 partnership countries fall into the "low governance" category, and the distribution spans from high governance partners (e.g., Canada, Norway, Australia) to very low governance jurisdictions (notably the DRC) (Figure 16).

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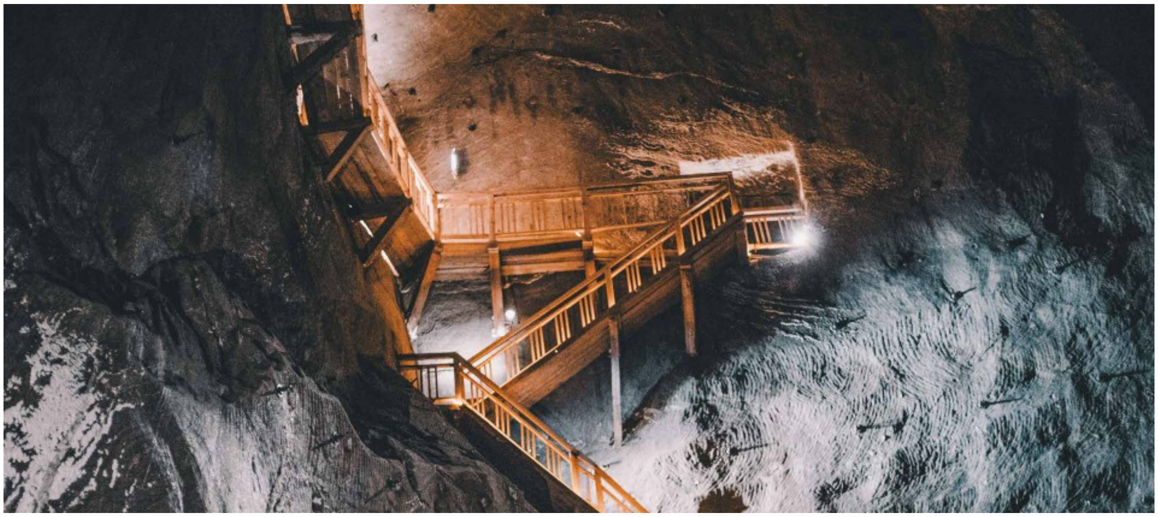
[25] ECA (2026). Special report 04/2026: Critical raw materials for the energy transition – Not a rock-solid policy.

[26] ECA (2026). Special report 04/2026: Critical raw materials for the energy transition – Not a rock-solid policy.



Sustainable mining is not optional - it is essential

Conducting mining with poor sustainability performance is not a one-time trade-off; it is a compounding liability. Long-lived obligations include tailings stewardship, community harm, land rehabilitation, post-closure monitoring and, in many cases, long-duration water treatment (Table 1). Financial assurance research highlights that post-closure costs, especially water treatment, can materially increase total closure costs, and that conservative assumptions and independently secured financing instruments to cover closure and maintenance costs are needed.[27] Tailings failures are low-frequency but high-severity events; modern governance expectations emphasize full lifecycle accountability, independent review, emergency preparedness and disclosure.[28] Biodiversity and water impacts increasingly influence permitting, cost of capital and insurability, reinforcing the need for nature-related assessment and disclosure;[29] Underestimation and underfunding reserves for rehabilitation can create a 'decommissioning gap' whereby industrial sites are never remediated to an acceptable form. This adds risks to investors being left with budget exceedances, or in the event that the operator ceases to exist, can leave society with the costs of either cleaning up the sites, or dealing with the damages they create.[30] This is where more sustainable practices can be a win-win. As communities, regulators, governments and customers of mining companies set a higher, clearer, and more reliable expectation on mining operations – before projects enter the scoping phase – costs can better be planned, stakeholder engagement conducted efficiently and projects greenlit more quickly with higher levels of trust in expedited approvals being followed by best in class operations. This helps meet the growing demand by bringing online more mining, faster, with a high level of certainty that the practices will meet stakeholder expectations.

- Policy priority: require robust financial assurance and update closure plans regularly; avoid reliance on self-bonding or optimistic discounting.
- Market priority: treat tailings and nature risks as governance and disclosure issues, not only engineering issues.

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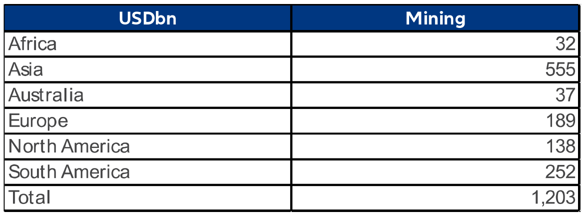
[27] Chambers, David M. 2024. Net Present Value Calculations for Mining Post-Closure Financial Assurance. Mine Water and the Environment.

[28] International Council on Mining and Metals (ICMM), United Nations Environment Programme (UNEP), and Principles for Responsible Investment (PRI). 2020. Global Industry Standard on Tailings Management.

[29] Taskforce on Nature-related Financial Disclosures (TNFD). 2023. Recommendations of the Taskforce on Nature-related Financial Disclosures

[30] European Commission. 2023. "Commission Delegated Regulation (EU) 2023/2772 … Annex I: ESRS E4

Table 1: Estimated decommissioning costs for the mining sector in respective regions for the existing infrastructure



USDbn	Mining
Africa	32
Asia	555
Australia	37
Europe	189
North America	138
South America	252
Total	1,203

Sources: BNP Paribas[31]; Allianz Research

The good news: we know that better is possible. Mining operations that can benefit communities, keep workers safe, limit environmental harms and create value for shareholders while leaving a net-positive legacy already exist. Global standards and a plethora of national or regional laws and regulations, cumulatively, demonstrate best practices that are sufficient to making mining projects attractive and beneficial to many. Pulling together key approaches to the sector and standardizing best practices by making them requirements for expedited project approval would help ensure that good practices are followed and that they meet societal needs. Such notable standards include the Initiative for Responsible Mining Assurance (IRMA), the Global Standard on Mining Tailings and Safety (GISTM), the International Council on Mining and Metals (ICMM) member guidelines and principles and the developing Consolidated Mining Standard Initiative (CMSI).

All of these standards together create a safety net that covers some of the most critical topics for the sector: (1) integrated closure planning and conservative financial assurance, (2) tailings safety frameworks and independent assurance in line with the Global Investors Standard on Tailings Management[32] (Figure 17), (3) community participation and benefit-sharing, (4) biodiversity and pollution prevention, (5) due diligence and traceability, (6) electrification and automation to reduce operational emissions and safety risks and once materials enter the economic system, by design we should focus on (7) circularity and recyclability by design to reduce long-term primary demand.[33] [34] [35]

There is a risk that as the standards and expectations proliferate and overlap, they create an untenable web of expectations, making it difficult and frustrating for industry and its stakeholders to converse on a common language and set of expectations. That is why key players in the financial sector, with the success of GISTM providing a clear example, are now coming together again with a broad set of stakeholders within the Mining 2030 initiative. Mining 2030 has set a 10 year vision that is supportive of the industry while detailing what is needed to make mining attractive again to all its critical stakeholders and investors, and address the growing gap in raw materials available to meet the needs of economic growth and technological development. The aim is to raise the attractiveness of the mining sector for investors, community members, customers and consumers to support its expansion with stronger conviction of consistent adherence to best practices. As detailed by academics from the University of British Columbia, these sorts of best practices often start with the companies themselves, and then garner legitimacy via societal partnerships and further stakeholder involvement. They later need to become minimum expectations or regulated requirements to really ensure a new level, but higher, standard of operations. The best practices and expectations of investors being developed by Mining 2030 will ultimately start to inform the minimum expectations of mining companies in the future.

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[31] BNP Paribas Asset Management (2023). Decommissioning Stranded Energy Assets: A USD 8 Trillion Challenge.

[32] GTMI. Making Mine Tailings Facilities Safer For People & The Environment.

[33] Environment Programme (UNEP), and Principles for Responsible Investment (PRI). 2020. Global Industry Standard on Tailings Management. November 28, 2020

[34] United Nations Environment Programme (UNEP). 2025. Financing the Responsible Supply of Energy Transition Minerals for Sustainable Development. October 9, 2025

[35] OECD. 2023. Handbook on Environmental Due Diligence in Mineral Supply Chains. Paris: OECD Publishing

Figure 17: GISTM global benchmark - comprising 6 topic areas and 15 principles

1. Affected communities

✓ Identify and address **human rights at risk**

✓ **Provide opportunities for meaningful engagement** of project-affected people in decisions that may have a bearing on public safety and the integrity of the tailings facility

Principles

1. Human rights, meaningful engagement and remedy for harm

2. Integrated knowledge base

✓ **Document knowledge** about the social, environmental and local economic context of a tailings facility

✓ This will **support informed decision-making** throughout the tailings facility lifecycle

Principles

2. Interdisciplinary knowledge base
3. Informed decision-making

3. Design, operation and monitoring

✓ Establish robust requirements to minimize risk of failure by **maintaining an informed knowledge base**

✓ **Evaluate performance data,** use it to frequently update monitoring programs and regularly report results

Principles

4. Plan and design to minimize risk
5. Develop a robust design
6. Minimise and manage risk across lifecycle
7. Monitor across life cycle

4. Management and governance

✓ Assign **responsibility and accountability** for key roles

✓ **Support** cross-functional collaboration, **promote** identification of problems and **protect** whistle-blowers

✓ **Establish standards** for critical systems and processes essential to upholding integrity of a facility

Principles

8. Policies, systems and accountabilities
9. Engineer of record
10. Levels of review
11. Organisational culture
12. Whistle-blower protections

5. Emergency response and long term recovery

✓ Establish a **community-focused** emergency preparedness and response plan

✓ **Support recovery** of affected communities and the environment affected by a catastrophic tailings failure

✓ Have capacity to engage with communities, public sector and other agencies, to **prepare for the event of a failure**

Principles

13. Emergency response
14. Long-term recovery

6. Public disclosure and access to information

✓ **Disclose information** to support public accountability

✓ **Participate in initiatives** for the creation of standardized, independent, industry-wide and publicly accessible information about the safety and integrity of tailings facilities

Principles

15. Public disclosure

Sources: Source: GISTM[36]; Allianz Research

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[36] GISTM. Global Industry Standard on Tailings Management.

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