Swiss Minerals Observatory - Synthesis report and policy implications

Report

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Swiss Minerals Observatory

Synthesis report and policy implications

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Gold refinery (PAMP AG)

Several cell phones. Android, Nokia and more. (Eirik Solheim on Unsplash)

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1 Introduction

1.1 The Achilles’ heel of sustainable development

Resource extraction has always been the basis of development – and this will not change in the future. Building up infrastructure for a growing population and reaching the goals of the Agenda 2030 will also depend on the availability of metals, particularly steel and copper. The ongoing digital transformation revolutionizing economies and societies with rapid technological advances in artificial intelligence, robotics, and the Internet of Things depends on a long list of critical minerals and metals. As does the energy transition and complying with the Paris Agreement. A rapid reduction in the use of fossil fuels, a switch to renewable energies, and the electrification of transport will significantly increase the demand for metals.[1,2,3]

Yet, as our research shows, metal production is a significant driver of global coal-related greenhouse gas (GHG) emissions.[4] We also find that the climate and particulate-matter (PM) related health impact of metals has almost doubled over the past two decades[5], contributing to more than 10% of global climate and PM-health impacts[6]. The increased impact of metals is driven by the infrastructure growth in emerging economies and the rise in coal combustion to process metals, particularly in China. The use of coal for metals production has increased six-fold over the past two decades, consuming one-third of global coal used today.[4] High-income countries have contributed to the rising carbon and PM-health footprint of metals, to a large extent due to increased dependency on cheaper metals, which are mostly processed in countries with a high reliance on coal-based energy and laxer environmental regulation. For example, half of the Swiss metals’ carbon footprint is currently attributed to coal combustion, primarily due to steel and aluminium being processed in China.[7]

Biodiversity loss from mining has different drivers, mainly attributed to nickel and gold mining in countries with exceptionally high ecosystem value.[7] The highest biodiversity losses involve nickel mines in New Caledonia and the Philippines, and gold mines in Ghana, Mexico, Peru, and Australia (see Figure 1). Mining operations are also a key driver of water pollution globally.[8]

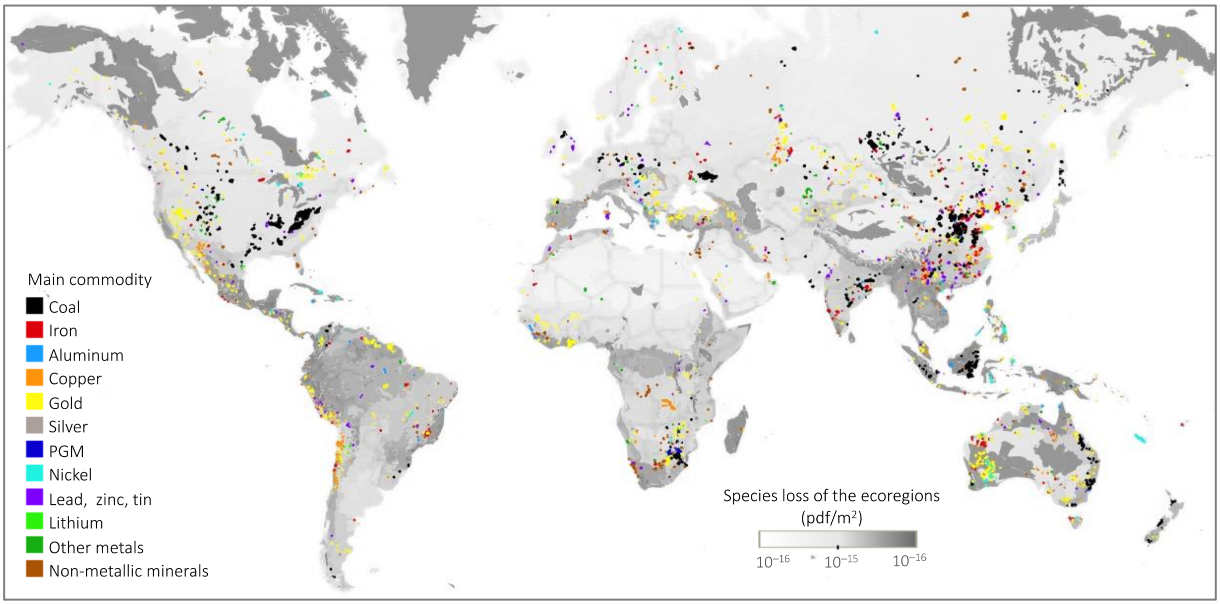

Figure 1 Global hotspots of mining-related biodiversity loss impacts:[9] Global mining areas[10] (total 57’277 km^2) coloured by primary commodity based on SNL metals and mining database[11] and their location in ecoregions[12]. The grey scale refers to the global species loss, expressed in potentially disappeared fraction (pdf) per square meter based on UNEP-SETAC.[13]

Moreover, the increasing demand for metals is likely to exacerbate existing problems in the mining industry, such as social conflicts over water allocation and pollution, health concerns of communities living around mines, displacement, conflicting demand for land, and various human rights abuses frequently associated with informal mining activities. The growing demand further accentuates the need to diversify the supply of metals to include larger amounts of secondary sources, meaning to use more recycled metals.

1.2 The policy challenges of resource governance

Reducing the negative impacts of mineral and metal supply chains requires coherent policies along the entire life cycle. This starts with policies to promote responsible extraction, continues with incentives for smart product design to minimize the need for metals, encouraging re-use of products, and includes measures to increase recovery and recycling at the end of product life. Such policies must work along global value chains where minerals are increasingly exploited in low-income countries with limited state capacity to govern the extractive sector, manufacturing concentrates in jurisdictions that tend to have weaker environmental and labour standards, and consumer markets are built on ever shorter product cycles.

Against this background, the governance challenges to promote the responsible supply and use of minerals revolve around three clusters of issues to which the Swiss Minerals Observatory research contributes (see Figure 2).

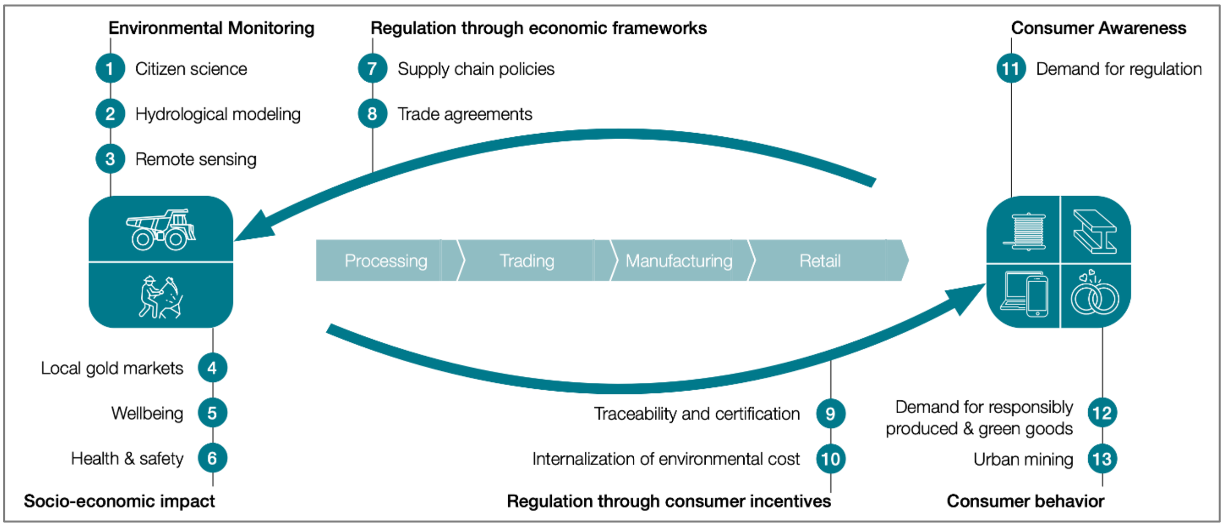

Figure 2: Contributions of the Swiss Minerals Observatory to inform policies that guide the supply and responsible use of minerals. Items 1 to 6 relate to sustainable extraction (section 2), items 7 to 10 relate to supply chain regulation (section 3) and 11 to 13 relate to consumer behaviour (section 4).

The first cluster of issues concerns **sustainable extraction** (items 1 to 6 in Figure 2), i.e., strengthening the local capacity to manage environmental impacts, also after mine closure, and translate resource extraction into well-being and development.[14,15] To manage externalities, monitoring of environmental quality is critical. However, there is little information in the public domain. Environmental data published by mining companies is commonly presented only at an aggregate level for an international audience and is not suitable for assessing impacts at the individual mine-site level.[16] The challenge lies in developing robust methods that work in capacity-constrained settings to independently monitor social and environmental effects and bridge the information gap from the extraction level to the national and international levels. In addition, translating revenues from large-scale mining into development and well-being is contingent on the host country's politics and practice of revenue generation, management, and re-investment.[17,18]

Artisanal and small-scale mining (ASM) is an essential rural, non-farm activity in sub-Saharan Africa. However, realizing its potential to alleviate poverty and promote development requires that this sector is actively integrated into the countries' economic and development plans.[19,20]

The second cluster of policy issues is preoccupied with **supply chain regulation** (items 7 to 10 in Figure 2), i.e., how to incentivize and regulate value chain actors to reduce environmental and social impact and contribute to sustainable development in resource-rich countries. The UN Guiding Principles for Business and Human Rights, the Sustainable Development Goals, OECD Due Diligence Guidance for Responsible Business Conduct, and the Paris Agreement are internationally agreed on standards and goals for carbon reduction. Nevertheless, their translation into actionable governance systems through combinations of civil society, private sector, and government-led policies is marred with legitimacy issues, coordination problems, green window dressing, free-riding, adverse market incentives, and interest politics.[21,22,23,24]

Lastly, the third cluster of policies evolves around **sustainable consumption** (items 11 to 13 in Figure 2), i.e., minimizing resource use and need for extraction. Decoupling growth from resource inputs – meaning achieving economic growth with considerably less use of resources – cannot be achieved through current decoupling rates. Instead, decoupling needs to be complemented by sufficiency-oriented strategies and the enforcement of absolute reduction targets.[25] Additionally, circular economy approaches are required to reduce primary resource use, such as through the 10R strategy (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover).[26]

From 2017 to 2022, the interdisciplinary Swiss Minerals Observatory research group contributed to improving the scientific basis for more responsible resource extraction, responsible trade, and use of mineral resources by bringing together social sciences, natural sciences, and engineering perspectives. This report is a summary of the project's final findings and recommendation along the value chain, discussing policies for sustainable extraction, supply chain regulations, and sustainable consumption.

2 Promoting sustainable extraction

The contributions of the Swiss Minerals Observatory research project towards sustainable resource extraction focus on two aspects that have been neglected in previous research: first, developing and testing methods for environmental monitoring and, second, advancing the understanding of the livelihood contribution of artisanal and small-scale mining (ASM).

2.1 Improving environmental monitoring at extractive sites

Mining's environmental effects are manifold, including impacts on water availability and quality, air quality, land availability and fertility, and forest and biodiversity loss. Various national and international governance regimes have emerged to mitigate such adverse effects.[27,28]

Less attention has been devoted to monitoring environmental impacts through local actors and developing corresponding local capacities. While demanding responsibility from actors along the value chain is well-founded, it must not come at the expense of building local capacity to manage environmental issues through host country systems. Local capacity is indispensable for sustainable environmental management, especially in the long-term and after mine closure, which is usually not covered by existing supply chain initiatives.

Our research project contributes to strengthening local monitoring by developing three complementary methods to improve water monitoring in mining areas.

2.1.1 Modelling water pollution and remediation measures for better management practice at the catchment level

Mining affects local surface water resources through pollution, water abstraction, and interference with groundwater bodies. Areas with geological deposits that are commercially exploitable often host multiple mining operations next to each other, mines are located close to related industries, and surrounding communities (see Figure 3). Therefore, in intensely mined areas it is not sufficient to manage only a mine's interactions with water resources. Rather, a catchment-based approach to environmental management is important, i.e., understanding how water use dynamics of the different mining operations affect other actors in the broader water catchment. This is important for identifying the different pollution sources and quantifying the responsibility of each operator, which in turn provides quantitative evidence to develop effective pollution remediation and accountability.

To account for these complex interdependencies, we have developed a hydro-geochemical model to simulate the effect of multiple pollutant sources and model the effect of mitigation measures.[29] It is a high-resolution tool to inform the design of environmental management strategies at the catchment level.

The modelling framework is based on the existing distributed hydrological model TOPKAPI-ETH for which we have developed and integrated two new modules, namely the *reactive solute transport module* and the *tracer-tracking module* (see Figure 3).[30] The expanded hydrological model can inform policy-making in three ways: First, by *simulating the processes of transport and transformation of chemical elements*, including trace metals, as they move through a catchment from a source upstream to downstream water bodies in a high spatial-temporal resolution.[31] Second, by *tracking the residence time and transport pathway of contaminants* at the catchment level in a distributed manner.[29] This allows quantifying the different pollution sources that joined in the same water body and show their contribution to the overall pollution load. Finally, by *simulating the impact caused by modifying external factors* such as climate variation, adding – or removing – point and non-point pollution, land-use change, and the effect of different remediation strategies on the catchment chemicals export alteration.[32]

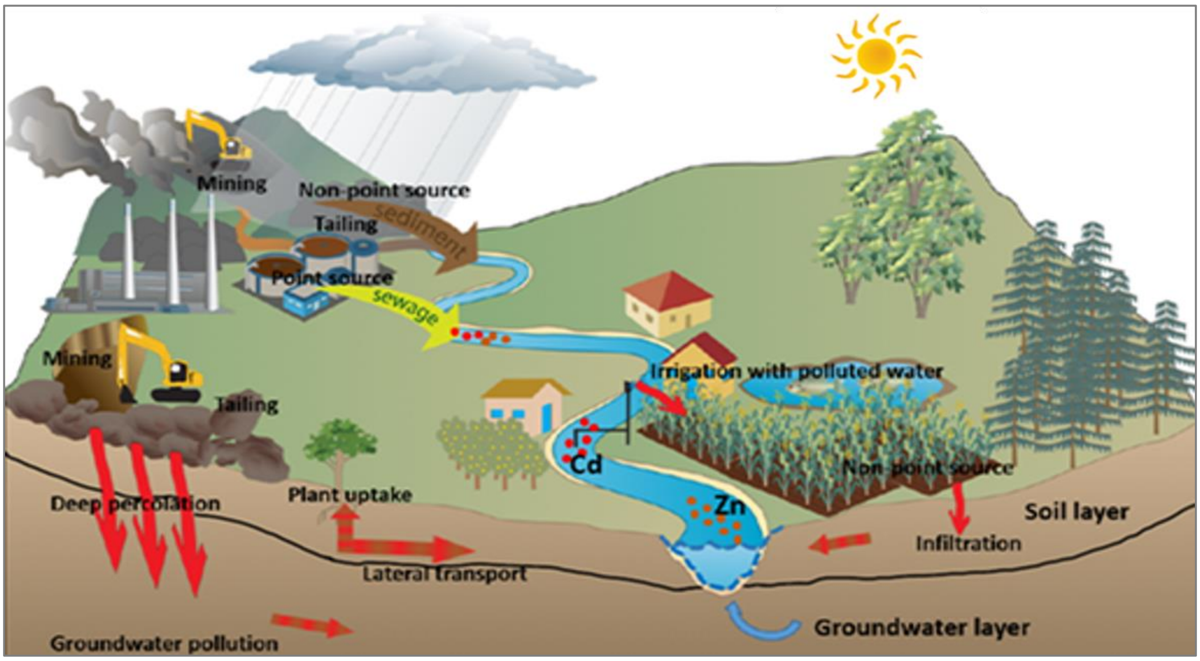

Figure 3 Trace metal transport module of TOPKAPI-ETH. The catchment-level approach takes a holistic approach by considering various demand on the water resource and interaction between multiple actors.[31]

The third function, i.e., the ability of the model to predict outcomes from different management scenarios, allows for the identification and testing of alternative management scenarios. The process of developing optimal management practices involves not only mining companies but local authorities, agriculture, and other stakeholders, making our model a tool that facilitates an integrated and strategic approach to environmental management.

In a related project, we modelled different options for water abstraction in the Salar de Atacama to minimize the drawdown of the water table due to the evaporation ponds for lithium extraction. This high-grade lithium deposit is the best-documented case for quantifying the water footprint of lithium mining in brine deposits. The study can inform future pumping of brine to limit effects on surrounding aquifers.[33]

Data availability and expertise in setting up and running such models present a significant bottleneck. However, if such models are translated into a cloud-based platform, this can go a long way in minimizing infrastructure requirements and supporting local researchers in practical implementation. Our results show that the distributed solute transport model is capable of identifying the spatiotemporal hotspots of trace-metal pollution and modelling the combined effect of point and non-point pollution sources, which can provide a basis for identifying responsible actors. For data collection, our findings show that laypeople can successfully be involved in collecting in situ data to support modelling efforts, as discussed in more detail in the next section.

2.1.2 Citizen science promotes accountability

Water has become a growing source of conflict in mining areas.[34] Between 2000 and 2017, water-related issues were implicated in more than half of mining cases lodged with the International Finance Corporation's compliance officer ombudsman. This independent recourse mechanism responds to complaints from project-affected communities.[35,36]

Water quality data is often unavailable or not in the public domain, and environmental regulators do not have the capacity to assess water quality independently. The lack of evidence on pollution and ill-defined responsibilities further complicates addressing water-related conflicts between mining companies and the local population.

Considering this lack of data on water quality, citizen science – the cooperation between citizens and scientists – can be an effective way to fill data gaps. Citizen science is well established in high-income countries.[37,38] However, our research in a coal mining area in Hwange, Zimbabwe, shows that citizen science also works with participants that have low levels of formal education and in capacity constraint and highly politicized settings.[39]

Volunteers together with researchers collected water samples in a river over a prolonged period to identify the extent and sources of pollution, and assess the related public health risks.[40,41] Community volunteers successfully used the collected evidence to convince the companies of the importance of installing drinking water wells. However, our results also demonstrate that advocacy based on bottom-up monitoring alone is limited. In the absence of reliable regulatory procedures in a politicized sector with limited civic space, citizen science can bring about isolated (albeit still important) improvements but not necessarily more systemic advances in environmental management.[39]

Team member, Dr. Désirée Ruppen, working with volunteers to gather data on water quality in Hwange, Western Zimbabwe. (Photo: Fritz Brugger)

From a policy perspective, two findings are noteworthy to improve the effectiveness of citizen science. First, a lack of laboratory infrastructure and funding for local research is a key limitation of citizen science in low-resource settings. International development partners could do more to strengthen local research capacity. Second, we also find inconsistency inherent in the patchwork architecture of global governance. Social accountability initiatives by local communities and voluntary responsible sourcing guidelines by multinational companies may both aim at promoting good environmental management, but they follow different logics – compliance with internationally agreed benchmarks for water quality versus compliance with procedural norms – and thus set different, or even incompatible, priorities. This can frustrate the development of synergies and undermine improvements in effective environmental management on the ground.

2.1.3 Satellite remote sensing

With over 18,000 tailing facilities globally,[42] and about 360 incidents during the last 100 years,[43] the risk from tailing dam collapse is significant. With the launch of the Sentinel-2 satellites by the European Space Agency, publicly available space-borne imagery has gained a higher resolution and increased sensing frequency. This allows for new applications in environmental monitoring beyond land-use change.[44] Taking the case of a tailings dam failure in Angola in 2021, we developed a workflow to analyse the effects of the incident and track the evolution and dynamics of the turbidity front over 1,400 kilometres downstream to the point where the tributary joins the Congo River in neighbouring DRC.[45]

Using satellite remote sensing allows us to establish the source and timing of tailing-dam-related incidents that lead to extreme turbidity, flooding, fish kills, and human health issues in the downstream population. The remote sensing-based analysis of such incidents can also help plan emergency responses and understand the liability for damage and repair.

The use of satellite imagery is subject to technical and capacity limitations: Technical limitations include limited resolution of satellite imagery, which prevents application to small streams, and cloud cover, which can render imagery unusable. Capacity constraints include the frequent lack of knowledge for remote sensing-based analysis and the lack of powerful computers for data-intensive processes, which are not available in many low-income countries. To build local capacity for independent monitoring and investigation of incidences, strategic support to local universities needs more attention from development partners.

2.2 Livelihoods and well-being in artisanal and small-scale mining

2.2.1 Livelihoods and well-being

Artisanal and small-scale mining (ASM) produces about 15-20% of gold and up to 64% of tantalum and 40% of tin globally, which are particularly important for the digital revolution.[46] ASM is characterized by labour-intensive methods, rudimentary working equipment, low mechanization, and high informality. ASM is also known for various human rights abuses such as child labour, hazardous working conditions, high levels of violence, and adverse environmental externalities such as mercury pollution or river siltation. Policies to regulate or eliminate the sector have been largely unsuccessful.[47]

Artisanal and small-scale gold mining (ASGM) can create a livelihood for the people living around the mines.[19] Analysing the socio-economic effects of ASGM in Burkina Faso using satellite imagery, administrative data, and DHS and LSMS survey data between 2000 and 2018, our research finds that household expenditure and assets increase by 6% in the vicinity of artisanal and small-scale mines. Despite concerns that children leave school to mine, we find that school enrolment increases by about 2% in the vicinity of an artisanal mine. While this does not eliminate the possibility of children working in their free time, on average, children do not fully substitute mining for schooling. However, we do not find additional positive benefits for local communities where an ASGM mine has a formal license.[48]

In theory, ASGM has an even more significant potential to alleviate poverty, given the high world gold price. However, local gold markets are subject to many market imperfections, and the movement of global gold prices is not always a very accurate predictor of local gold prices. For example, in contrast to the world gold price, local gold prices declined during the COVID-19 pandemic and related lockdown in Burkina Faso (see Figure 4). We find that these effects were exacerbated by imperfect local markets, including very few buyers, a lack of knowledge of world gold prices, and the inability to store gold until the local price recovers.[49]

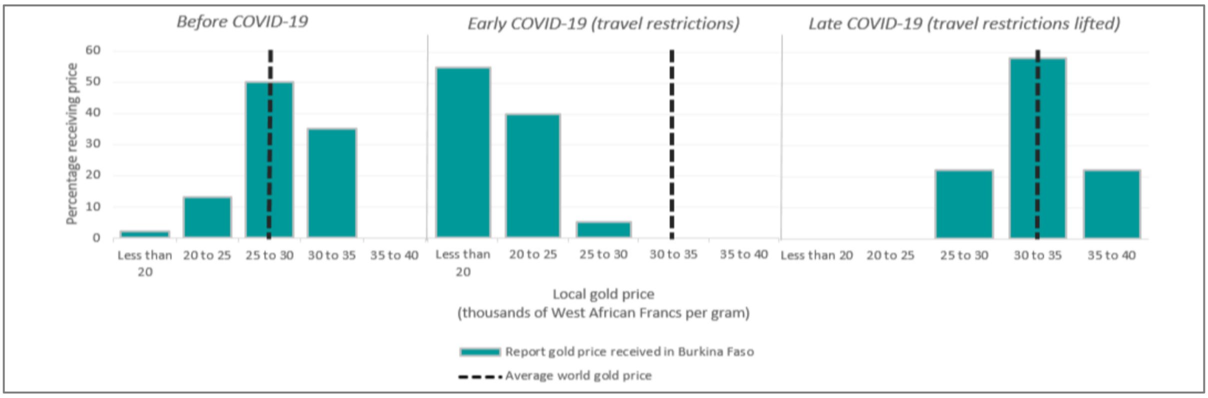

Figure 4 World gold prices and the range of reported local price in Burkina Faso. The green bar chart shows the reported gold prices miners received in a period of about one month before the pandemic (left graph), early during the pandemic when many travel restrictions were applied (middle graph) and later when the health crisis were ongoing, but travel restrictions have mostly been lifted (right graph). The black dotted line shows the average world gold price in each period. While the world gold price increased during the pandemic, local prices decreased sharply and only recovered once travel restrictions were lifted. [49]

From a development perspective, measures to foster the competitiveness of local markets by increasing the number of local buyers and creating access to credit should be prioritized. In addition, despite gold prices being easily accessible, we found extremely low levels of knowledge of world gold prices. Given the popularity of radio, broadcasting world gold prices on local radio could improve market knowledge.

However, such policies need to be complemented by corresponding support for access to protective gear, training for workers' safety at mining sites, and cleaner production methods to avoid adverse health effects from cyanide[50] and mercury[51], chemicals that artisanal miners often use to liberate gold from ore. Our field research in Burkina Faso, which included surveys, hair sampling, and a field experiment, reveals very little use of protective equipment (PPE) and insufficient knowledge about the risks of mercury. While higher knowledge has a small positive correlation on higher reported PPE use, the free distribution of PPE had a large and significant increase in reported usage. Distributing PPE to individuals with a high risk of exposure – which we identified as miners who reportedly use mercury often and gold traders who are often present when gold amalgams are heated, to oversee the process – could have significant public health benefits.[51]

3 Supply chain regulation

3.1 Swiss gold supply chain

Switzerland is of global importance concerning trade of gold. About two-thirds of the globally extracted gold is imported, refined, and re-exported by Switzerland (see Figure 5a). The Swiss gold value chain is not fully transparent, for example provenance of gold refined in Switzerland is often unknown. Accordingly, little is known about the link of Swiss gold trade to the many environmental and social issues associated with global gold extraction.

In the Swiss Minerals Observatory, we have increased the transparency of the Swiss gold value chain and the related environmental impacts. We have developed an improved methodology[5] and database based on multi-regional input-output (MRIO) analysis, a form of life-cycle assessment that allows tracking material flows and the related impacts along global value chains. We have merged several existing MRIO databases, improved the resolution, and integrated data on the extracted, refined, and traded gold amounts.[52] Moreover, we have improved the biodiversity loss impact assessment by combining a global-scale dataset of mining areas based on satellite images with most recent life-cycle impact assessment methodologies on ecoregion level.[7]

Our research shows that gold refined in Switzerland was mostly mined in Australia, Russia, the USA, Canada, Ghana, Mexico, Peru, South Africa, Uzbekistan and Brazil (Figure 5a). While the majority (55%) of the gold was directly imported by Switzerland, some was imported via other regions, mostly the United Arab Emirates, the United Kingdom, the USA, and Germany. Most of the gold refined in Switzerland was exported and finally used in India, the USA, and Turkey.

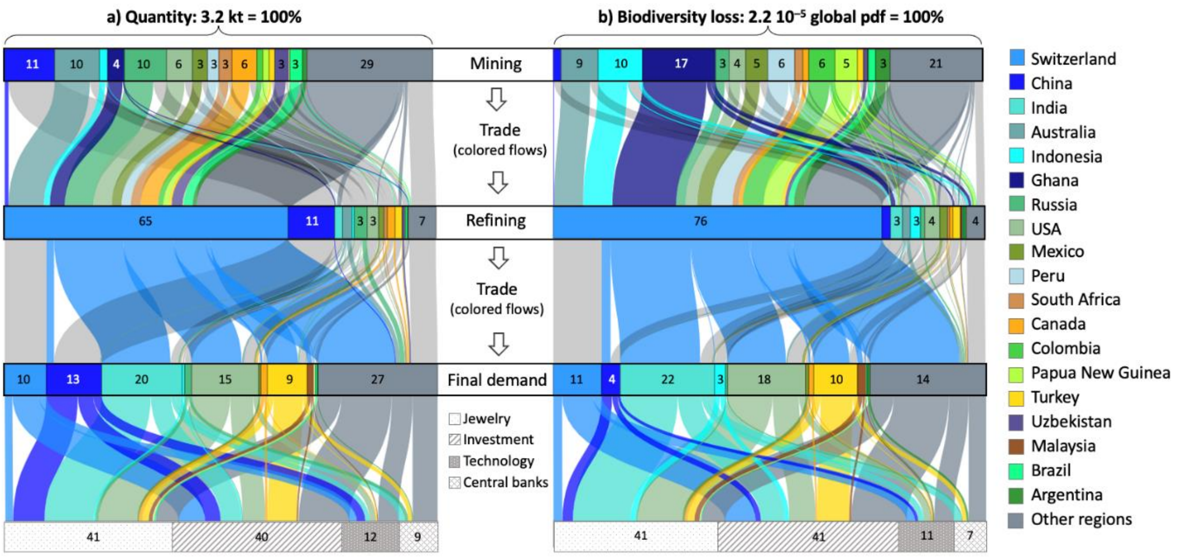

Figure 5 Supply chain analysis of a) global gold trade and b) related impacts on biodiversity due to land use of gold mining in 2020. Numbers in the graph refer to percentages.

By linking the gold supply chain analysis (Figure 5a) with the global mining-related biodiversity impact assessment (Figure 1), we found that Switzerland sources gold that is mined in particularly valuable ecosystems (Figure 5b), including Ghana, Peru, Colombia, and Mexico, where gold mining contributes strongest to local mining-related biodiversity loss. Since most gold mined in these countries are refined in Switzerland, the majority of the mining-related biodiversity loss in these countries are related to gold refined in Switzerland. For example, 95% of the total mining-related biodiversity loss in Ghana are attributed to gold refined in Switzerland.

Due to gold sourced in particularly rich ecosystems, gold refined in Switzerland accounts for more than three quarters of global biodiversity loss related to gold mining (Figure 5b). This equals 20% of total global mining-related biodiversity loss (including mining of other metals, see Figure 1). While previous research concluded that the energy transition exacerbates biodiversity threats of mining,[1,53,54] our research shows that the biodiversity loss related to Swiss gold trade is about hundred times higher compared to the biodiversity impact of global renewable electricity generation. These results highlight the need for regulation of Swiss gold supply chains to foster more sustainable gold mining.

3.2 Upstream

3.2.1 Regulation of global supply chains

The world community has debated the need for international regulation and oversight of multinational companies for several decades already. While attempts to set up international legally binding instruments have been implemented to reduce trade in minerals from conflict regions, the governance of sustainability has largely relied on voluntary private-sector and multi-stakeholder initiatives.[55]

Regulating supply chains directly through requirements towards companies can be effective in principle since around 80% of global trade is linked to the supply chains of multinationals.[56] Examples of such regulations include those against deforestation and child labour, via transparency requirements and corporate liability for due diligence.

Our research shows that, in general, policy proposals to regulate global supply chains for a wide range of goods (including minerals) attract considerable public support, not only in Switzerland but also in other high-income countries (see Figure 6).[57,58] However, the political viability and enforceability of such sustainability regulation strongly depend on the design of governance frameworks in this area and the degree of cooperation between governments and the private sector.[59] Our research provides relevant insights to be considered when designing and implementing voluntary and state-backed measures.

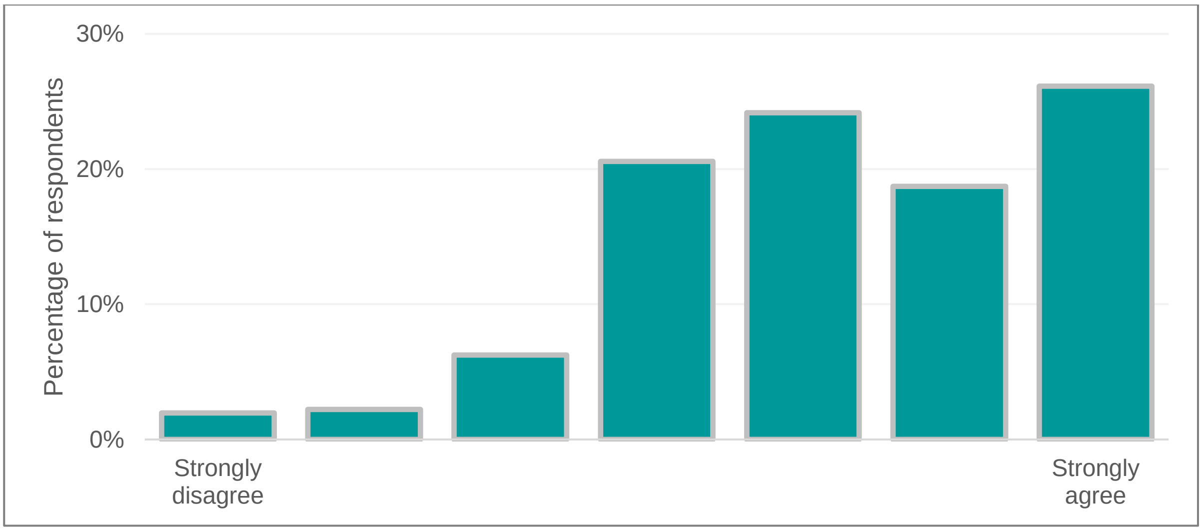

Figure 6 Support for new supply chain regulations. We find substantial public demand for a reduction of environmental burdens from the economy and regulation of global supply chains, in Switzerland and other high-income countries.[58]

First, we show that companies can gain strategic competitive advantages in interactions with governmental authorities and societal stakeholders through voluntary sustainability measures.[60,61,62,63] For example, it is worthwhile for companies to engage in voluntary measures, so that pending regulation is formulated or enforced less stringently.[63,64,65,66] Similarly, recent studies in public opinion research suggest that voluntary measures can reduce public pressure for stricter regulation.[67,68]

Second, even though hybrid (i.e. private-public) governance might be attractive because of its flexibility, policymakers should use the backing of public support to press for more robust accountability mechanisms (transparency, monitoring, regulatory triggers) to facilitate corporate contributions to sustainability.[69,70] The implementation of solid accountability mechanisms becomes even more essential considering evidence suggesting that other non-institutionalized societal control mechanisms (such as short-run shifts in public pressure on companies) are somewhat limited.[71]

Against the backdrop of substantial public demand for reducing environmental burdens from the minerals sector and other economic activities,[72,73] voluntary and hybrid governance measures to increase market transparency represent a starting point. However, to meet the high demand for action in sustainability policy, we recommend more stringent measures. We propose clearly defined sustainability targets for relevant industries (e.g., minerals) that increase in stringency over time, including provisions that significantly strengthen top-down regulatory mandates if a company-led (voluntary) policy fails to meet these targets, e.g., in the form of sanctions for non-compliance.

3.2.2 Trade agreements

Incorporating sustainability provisions into trade agreements, and preferential bilateral or regional trade agreements in particular, has become another widely adopted strategy to promote a greener and more sustainable economy.[74] However, our work[75,76] and closely related studies[77] suggest that these provisions' effect on reducing the environmental footprints of traded goods remain modest in general, and almost entirely nil in the minerals sector. In addition, the mitigating effect seems to be most substantial in trade relationships in which the exporting country already has robust environmental and labour governance.[78] Moreover, we observe that discrepancies in democracy levels between trading countries aggravate the outsourcing of environmental footprints through trade. Hence, policymakers from high-income democracies should be aware of both sides' incentive structures when negotiating trade agreements. Specifically, they should also consider potential incentives for lower-income (autocratic) countries and their elites to become pollution havens. Thus, in short, international trade agreements and environmental clauses therein cannot substitute for direct sustainability regulation of international supply chains.

3.3 Downstream

3.3.1 Certified gold: too many schemes and not enough demand

Other regulatory regimes intend to leverage consumer demand for clean products. Certification schemes have become increasingly popular to address issues in metal supply chains, including gold. We identified at least fourteen different gold certification schemes in 2021. Each certification scheme determines its standards, methodology to verify compliance, and scope of operation, including where in the world they operate, on which part of the supply chain, and whether they focus on industrial or artisanal mining, or both.[79]

While consumer demand for ethical gold is increasing, jewellers and banks are still the driving force for certified gold. However, jewellers and banks face different concerns when sourcing certified gold. Jewellers are worried that certification would reduce a product's perceived luxury and quality. For large retailers, avoiding reputational damage, and for smaller retailers such as goldsmiths, trust relationships are large drivers to sourcing certified gold.

The additional cost of certification is more significant for investors than for jewellers; since gold is only a small part of the total cost of a piece of jewellery, the certification mark-up is smaller. Certified gold comes with a premium of about 5%, requiring the willingness to pay from the investor. Further, given the low supply – Fairtrade Gold, one of the best-known gold certification schemes, supply less than 0.1% of the gold imported into Switzerland – banks would also need to diversify their sources of responsible gold to meet demand.[79] More recently, the market is moving: refiners have started offering transparency for provenance gold for investors as premium products[80], while some finance institutes only sell Fairtrade small gold bars (1 to 20 grams) to retail customers.[79]

3.3.2 Incorporating externalities in consumer prices

For a market to function, prices should reflect the total cost of goods. However, social and environmental externalities are largely absent from cost calculations. We have developed a new method to calculate the 'full cost' of metals by analysing the cost of the sustainability performance of global supply chains. We include climate change impacts, particulate-matter (PM) related health impacts, water stress, land-use-related biodiversity loss, and value-added and workforce socio-economic indicators into the life-cycle analysis.[5]

Applying the method to metals embodied in electronics, such as Swiss mobile phones, shows that the external costs of these metals are more than ten times higher than their current market price (see Figure 7).[81] These results highlight the need and the economic potential to internalize the external costs of primary metals production into the price of end products. Including all costs in the price of end-products, such as mobile phones, could incentivize recovery from slags of incineration plants.[82] In addition, calculating the total cost could create attractive economic opportunities to decarbonize and reduce supply chain impacts for consumer-facing companies in high-income regions, such as Switzerland.[83]

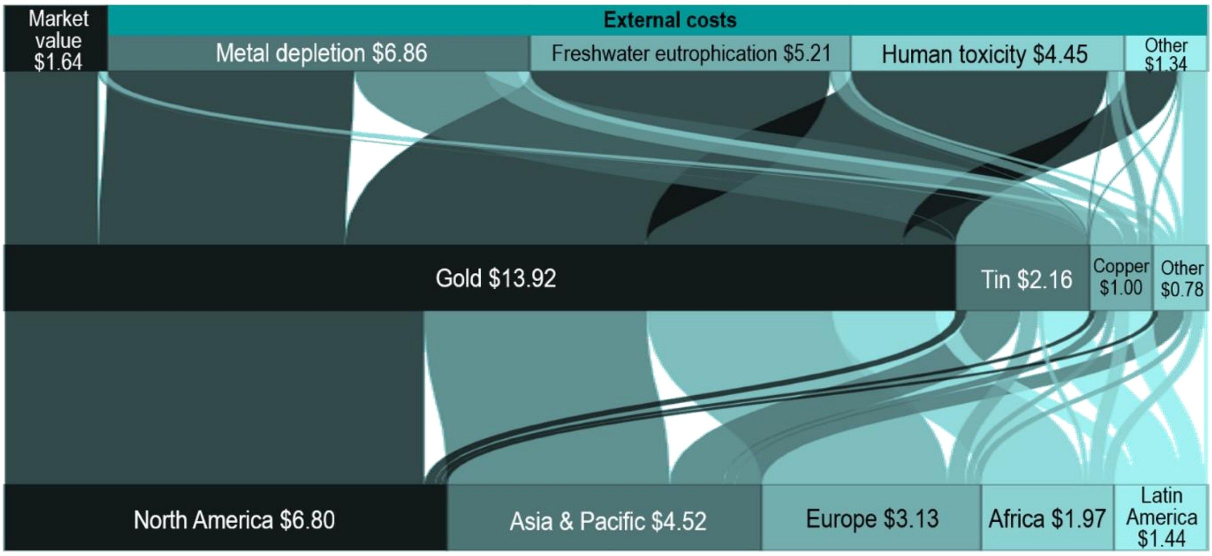

Figure 7 Total costs of metals embodied in an average Swiss mobile phone. The total market value of the eleven metals in a phone for which we have data is USD 1.64 and the total external cost is USD 17.86 (top section). Despite the small amount of gold embodied in a phone, gold contributes to the largest share of both the market value of the metals in a phone and the total environmental costs (middle section). The largest impact of gold mining is from freshwater eutrophication and human toxicity, tin also contributes considerably to the environmental costs due to metal depletion. The regions that experience the highest impact are predominantly the areas were gold is mined (bottom section).[81]

4 Sustainable consumption

4.1 The untapped potential of urban mining

Although Switzerland is proud of its high recycling quota, the recycling rate of small personal electronics, specifically mobile phones, is still relatively low. Our survey finds that about 7 million unused phones are in households in Switzerland. Consumers often do not know why they keep old phones. We estimate that these 7 million unused phones are a significant lost resource, including embedded metal worth USD 131 million (market value and environmental savings).[81]

Our field experiment on recycling behaviour shows that lowering barriers for consumers to return old phones is critical to increasing recycling (difference between grey bar and blue bars in Figure 8). Providing information on data security, the environmental benefits of recycling, and other potential concerns have little impact on increasing the recycling rate of old phones (differences in blue bars in Figure 8). The only measure that showed a significant effect was making recycling as easy as possible by including return postage on a pre-addressed envelope. This simple measure more than doubled the return rates of old phones.

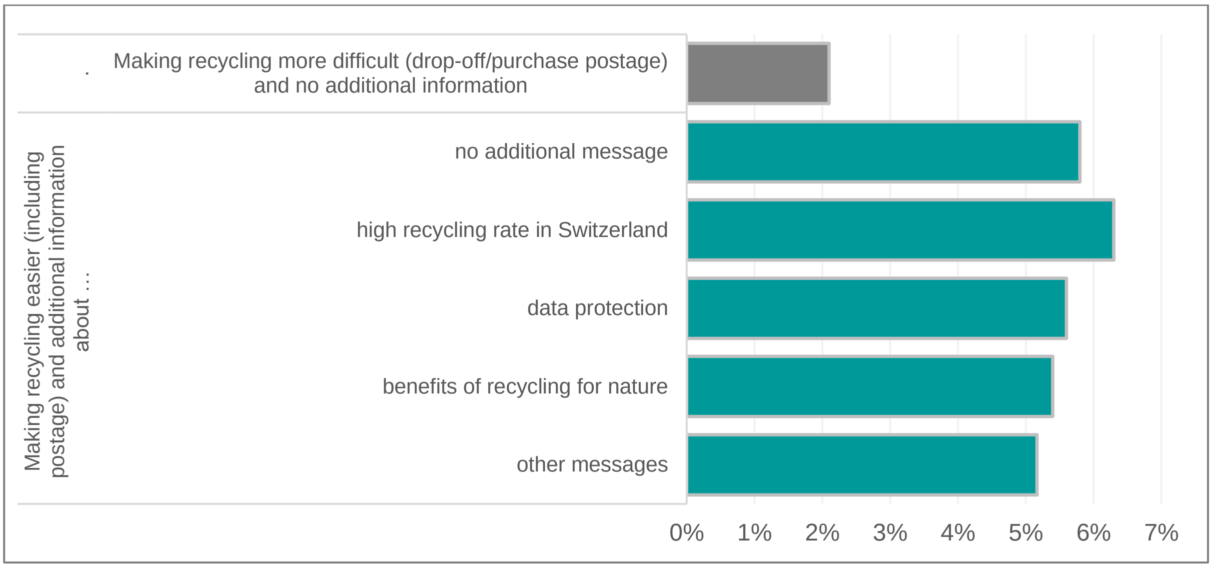

Figure 8 Various collection rates in a large-scale recycling field experiment. We randomised ease of recycling and messages about the advantage of recycling to about 15,000 employees at ETH Zürich. We found that making recycling as easy as possible had a significant impact on the return rate of old unused phones for recycling (grey bar versus blue bars). However, including various informational messages on the benefits of recycling, did not have a significant impact on return rates (differences in blue bars).[81]

Collecting phones for recycling is still expensive, resulting in a net loss if only the market value of the metals in a phone is considered. However, the collection turns profitable when we consider the monetary value of the environmental benefits of recycling instead of mining new metals to produce phones (as shown in Figure 7).

Switzerland already includes an advanced recycling fee in the sale of new devices to cover the cost of recycling. Increasing this fee to include initiatives to make returning old phones easy for consumers would offer a cost-effective solution to promote urban mining.

5 Recommendation and research priorities

5.1 More sustainable extraction

To minimize negative externalities from mining on the environment and human health, the availability of independent local expertise in monitoring is key. However, our research found significant gaps in the professional capacity and infrastructure available at the regional level, such as certified and independent laboratory capacity to analyse environmental samples and human health indicators.[40] No adequate hydrological data sources and modelling concepts are accessible in many mining areas located in low-income countries. This lack of data hampers or even prevents a catchment-based stakeholder approach to water management; although the mining industry also supports stakeholder cooperation in theory, it is rarely done and complex.[84] Developing simplified analytical tools to support decision-making for such contexts is a high priority.[85] At the global level, new remote sensing missions such as ESA's Copernicus program now offer time-series data in the public domain.[86] We have shown that such data could be used to analyse the causes and effects of incidents such as tailing-dams-related hazards.[45] Supporting the necessary information technology in low-income countries to facilitate such analyses by independent local experts is a high priority.

Our research has also examined informal mining activities, specifically artisanal mining in Burkina Faso. Since most artisanal miners operate informally, data on their activities are very scarce. Described as a global data gap,[87] lack of data imposes major limitations on our understanding of the artisanal mining sector and, therefore, and contributes to failures of programs and policies to address negative externalities. In our project, we used various methods, including survey techniques, biological sampling, field experiments, secondary data, and satellite images, to contribute to understanding the sector's ability to alleviate poverty on neighbouring households and the possibilities to improve the health and safety on mine sites.

We have not considered the interaction between industrial and artisanal mining. Given the increase in resource demand and rising commodity prices, industrial and artisanal mines increasingly compete for resources, leading to conflicting demand for land, security concerns, and displacement of local populations. Future research also needs to consider the interaction between industrial and artisanal miners, and local populations and governments. On the international level, a more holistic approach could additionally consider the conflicting interests of universities, national geological surveys, international mining companies, and the trading industry.

5.2 Supply chain regulation

In global production networks, many environmental impacts are "outsourced" from high-income (consuming) countries to low- and middle-income (producing) countries and are thus not directly visible to consumers in high-income countries. Our research has helped to improve models that account for environmental impacts of material production and consumption, including mining activities. It shows that a large share of environmental impacts from minerals and metal consumption in high-income economies, such as Switzerland, materialize in low-income countries.[5] At the same time, a mismatch exists between the value generated downstream the value chains and the environmental impacts that occur mainly upstream. If raw materials are only mined and not further processed, the value added that remains in a country is limited since mining typically generates lower benefits than the processing of materials or their use in the service sector.[88] The geographically disconnected production and consumption and the economic power gradient require regulation of global supply chains to address environmental and social inequity issues. Our research shows that more stringent regulation of international supply chains would be accepted by a large share of the population in high-income consumer countries.

We found that regulatory approaches based on voluntary actions by the private sector can create competitive advantages for the implementing companies [61] but may crowd out public support for more government-led measures.[70] Certification schemes build on incentivizing consumers to choose more sustainably produced goods. However, our research in the case of gold shows that the proliferation of competing certification standards and a lack of consumer demand prevent those schemes from scaling beyond their niches.[79]

Reporting external costs is a first step toward internalizing these costs, which might allow for the creation of funds to compensate for social and environmental impacts. Our research contributes tools to assess and monetize the impacts of mining-related products.[81]

Since researchers have largely overlooked the demand for more responsibly sourced metals, we recommend further studies in this regard. Since we found that the demand for certified gold is mostly driven by retailers, which in turn is shaped by consumers, a more nuanced understanding of consumer preferences and the communication between retailers and consumers is necessary.

Beyond certification and related approaches that rely on voluntary shifts in consumer behaviour, the effectiveness of evolving public policy based on corporate disclosure and how transparency translates into sustainability are important topics for future research.

5.3 Incentivizing consumer behaviour

The most effective way to reduce the impacts of primary material production is to consume fewer raw materials. In a growing economy, recycling is an option to satisfy demand without increasing primary production of some metals, such as gold. A challenge, however, is to tap into the resources in waste materials. Our research showed that for the example of mobile phones, a stated willingness to recycle only translates into reasonable collection rates when significantly reducing the effort required to recycle.[81]

However, recycling holds significant problems that would need further research. Despite being prohibited, e-waste is often exported to low-income countries via falsely labelling it as scrap metal.[88] Irresponsible recycling in low-income countries creates significant health and environmental problems for local populations, including women and children who work as informal recycling laborers. In addition, the design of many electronic items, such as smartphones, makes disassembling items for recycling too expensive. Modular devices would not only ease recycling but also make devices more repairable, which could prolong the lifespan and delay replacement. Encouraging other methods to prolong the lifespan of electronic devices, such as growing second-hand markets, needs further investigation.

Another difficulty with sourcing waste is disaggregating waste streams to the required recycling points. Therefore, developing effective recycling modalities accepted by consumers and the retail industry is essential. In high-income countries, developing more effective recycling modalities would include modifying the advanced recycling fee. In low-income countries, this would include policies to incorporate informal waste workers into collecting and sorting waste.

About the Swiss Minerals Observatory

The Swiss Minerals Observatory (SMO) group is a multidisciplinary research group with social science, natural science, and engineering backgrounds, developing science-based practical methodologies for promoting sustainable production, consumption, and trade of mineral resources. During their tenure from 2017 to 2022, they analysed the environmental and social impacts generated along with different steps in the global value chain of minerals. Moreover, the group developed and improved current methodologies for quantifying and evaluating social and environmental impacts induced by mineral products used in modern society.

Website: https://istp.ethz.ch/research/minerals.html

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References

[1] Sovacool, B. K., Ali, S. H., Bazilian, M., Radley, B., Nemery, B., Okatz, J., & Mulvaney, D. (2020). Sustainable minerals and metals for a low-carbon future. *Science*, *367*(6473), 30-33.

[2] Hertwich, E. G., Gibon, T., Bouman, E. A., Arvesen, A., Suh, S., Heath, G. A., ... & Shi, L. (2015). Integrated life-cycle assessment of electricity-supply scenarios confirms global environmental benefit of low-carbon technologies. *Proceedings of the National Academy of Sciences*, *112*(20), 6277-6282.

[3] Yokoi, R., Watari, T., & Motoshita, M. (2022). Future greenhouse gas emissions from metal production: gaps and opportunities towards climate goals. *Energy & Environmental Science*, *15*(1), 146-157.

[4] Cabernard, L., Pfister, S., & Hellweg, S. (2022). Improved sustainability assessment of the G20's supply chains of materials, fuels, and food. *Environmental Research Letters*, *17*(3), 034027.

[5] Cabernard, L., Pfister, S., & Hellweg, S. (2019). A new method for analyzing sustainability performance of global supply chains and its application to material resources. *Science of the Total Environment*, *684*, 164-177.

[6] Salem, J., Amonkar, Y., Maennling, N., Lall, U., Bonnafous, L., & Thakkar, K. (2018). An analysis of Peru: Is water driving mining conflicts?. *Resources Policy*, 101270.

[7] Cabernard, L. (2021). *Creating transparency in global value chains and their environmental impacts to support sustainability policies* (Doctoral dissertation, ETH Zurich).

[8] Schwarzenbach, R. P., Egli, T., Hofstetter, T. B., Von Gunten, U., & Wehrli, B. (2010). Global water pollution and human health. *Annual review of environment and resources*, *35*(1), 109-136.

[9] Cabernard, L., & Pfister, S. (2022). Hotspots of mining-related biodiversity loss in global supply chains and the potential for reduction by renewable electricity.

[10] Maus, V., Giljum, S., Gutschlhofer, J., da Silva, D. M., Probst, M., Gass, S. L., ... & McCallum, I. (2020). A global-scale data set of mining areas. *Scientific data*, *7*(1), 1-13.

[11] S&P Global Market Intelligence. (2020). SNL metals and mining database. Available online: *https://www.spglobal.com/marketintelligence/en/campaigns/metals-mining*

[12] Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V., Underwood, E. C., ... & Kassem, K. R. (2001). Terrestrial Ecoregions of the World: A New Map of Life on EarthA new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity. *BioScience*, *51*(11), 933-938.

[13] Frischknecht, R., Fantke, P., Tschümperlin, L., Niero, M., Antón, A., Bare, J., ... & Jolliet, O. (2016). Global guidance on environmental life cycle impact assessment indicators: progress and case study. *The International Journal of Life Cycle Assessment*, *21*(3), 429-442.

[14] Kirschke, S., Avellán, T., Bärlund, I., Bogardi, J. J., Carvalho, L., Chapman, D., ... & Warner, S. (2020). Capacity challenges in water quality monitoring: understanding the role of human development. *Environmental monitoring and assessment*, *192*(5), 1-16.

[15] Van der Ploeg, F., & Venables, A. J. (2017). *Extractive revenues and government spending: Short-versus long-term considerations* (No. 2017/45). WIDER Working Paper.

[16] Bezzola, S., Günther, I., Brugger, F. & Lefoll, E. (2022). "CSR and local conflicts in African mining communities." *World Development*.

[17] Dietsche, E. (2018). Political economy and governance. *Extractive Industries. The Management of Resources as a Driver of Sustainable Development*, 114-136.

[18] Bebbington, A., Abdulai, A. G., Humphreys Bebbington, D., Hinfelaar, M., & Sanborn, C. (2018). *Governing extractive industries: Politics, histories, ideas* (p. 304). Oxford University Press.

[19] Brugger, F., & Zanetti, J. (2020). "In my village, everyone uses the tractor": Gold mining, agriculture and social transformation in rural Burkina Faso. *The Extractive Industries and Society*, *7*(3), 940-953.

[20] Bugmann, A., Brugger, F., Zongo, T., & Van der Merwe, A. (2022). "Doing ASGM without mercury is like trying to make omelets without eggs". Understanding the persistence of mercury use among artisanal gold miners in Burkina Faso. *Environmental Science & Policy*, *133*, 87-97.

[21] Haack, P., & Rasche, A. (2021). The legitimacy of sustainability standards: A paradox perspective. *Organization Theory*, *2*(4), 26317877211049493.

[22] Weiss, T. G., & Wilkinson, R. (2014). Rethinking global governance? Complexity, authority, power, change. *International Studies Quarterly*, *58*(1), 207-215.

[23] Lambin, E. F., & Thorlakson, T. (2018). Sustainability standards: Interactions between private actors, civil society, and governments. *Annual Review of Environment and Resources*, *43*(1), 369-393.

[24] Deberdt, R., & Le Billon, P. (2022). The Green Transition in Context—Cobalt Responsible Sourcing for Battery Manufacturing. *Society & Natural Resources*, 1-20.

[25] Haberl, H., Wiedenhofer, D., Virág, D., Kalt, G., Plank, B., Brockway, P., ... & Creutzig, F. (2020). A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part II: synthesizing the insights. *Environmental Research Letters*, *15*(6), 065003.

[26] Potting, J., Hekkert, M. P., Worrell, E., & Hanemaaijer, A. (2017). *Circular economy: measuring innovation in the product chain* (No. 2544). PBL publishers.

[27] Sauer, P. C., & Seuring, S. (2017). Sustainable supply chain management for minerals. *Journal of Cleaner Production*, *151*, 235-249.

[28] Ayuk, E., Pedro, A., Ekins, P., Gatune, J., Milligan, B., Oberle, B., ... & Mancini, L. (2020). *Mineral Resource Governance in the 21st Century: Gearing extractive industries towards sustainable development*. International Resource Panel, United Nations Envio, Nairobi, Kenya.

[29] Sui, C., Fatichi, S., & Burlando, P. (2022). The role of sorption and degradation on changing *transit time distributions of reactive contaminants: study with distributed hydro-chemical model.* In preparation.

[30] Fatichi, S., Rimkus, S., Burlando, P., Bordoy, R., & Molnar, P. (2015). High-resolution distributed analysis of climate and anthropogenic changes on the hydrology of an Alpine catchment. *Journal of Hydrology*, *525*, 362-382.

[31] Sui, C., Fatichi, S., Burlando, P., Weber, E., & Battista, G. (2022). Modeling distributed metal pollution transport in a mine impacted catchment: Short and long-term effects. *Science of the Total Environment*, *812*, 151473.

[32] Sui, C. (2022) *Spatially Distributed Modelling Framework to Assess the Transport and Fate of Catchment Trace Metals: Development and Application.* (Doctoral dissertation, ETH Zürich)

[33] Zourek, L. (2020). Modelling past and future impacts of brine and freshwater extraction for lithium production on the water resources of the Salar de Atacama, Northern Chile, using MODFLOW. (Master's thesis, ETH Zürich)

[34] Schoderer, M., Dell'Angelo, J., & Huitema, D. (2020). Water policy and mining: Mainstreaming in international guidelines and certification schemes. *Environmental Science & Policy*, *111*, 42-54.

[35] Kunz, N. C. (2017). *Shared water, shared responsibility, shared approach: water in the mining sector* (No. 114400, pp. 1-48). The World Bank.

[36] Atkins, D., & Wildau, S. (2008). *Participatory Water Monitoring: a guide for preventing and managing conflict*. Office of the Compliance Advisor/Ombudsman.

[37] McKinley, D. C., Miller-Rushing, A. J., Ballard, H. L., Bonney, R., Brown, H., Cook-Patton, S. C., ... & Soukup, M. A. (2017). Citizen science can improve conservation science, natural resource management, and environmental protection. *Biological Conservation*, *208*, 15-28.

[38] Capdevila, A. S. L., Kokimova, A., Ray, S. S., Avellán, T., Kim, J., & Kirschke, S. (2020). Success factors for citizen science projects in water quality monitoring. *Science of the Total Environment*, *728*, 137843.

[39] Ruppen, D., & Brugger, F. (2022). "I will sample until things get better–or until I die." Potential and limits of citizen science to promote social accountability for environmental pollution. *World Development*, *157*, 105952.

[40] Ruppen, D. (2022). Effective Monitoring Strategies for Mining-Related Water Pollution. (Doctoral dissertation, ETH Zürich)

[41] Ruppen, D., Chituri, O. A., Meck, M. L., Pfenninger, N., & Wehrli, B. (2021). Community-Based Monitoring Detects Sources and Risks of Mining-Related Water Pollution in Zimbabwe. *Frontiers in Environmental Science*, 599.

[42] Islam, K., & Murakami, S. (2021). Global-scale impact analysis of mine tailings dam failures: 1915–2020. *Global Environmental Change*, *70*, 102361.

[43] Azam, S., & Li, Q. (2010). Tailings dam failures: a review of the last one hundred years. *Geotechnical news*, *28*(4), 50-54.

[44] Schulz, D., Yin, H., Tischbein, B., Verleysdonk, S., Adamou, R., & Kumar, N. (2021). Land use mapping using Sentinel-1 and Sentinel-2 time series in a heterogeneous landscape in Niger, Sahel. *ISPRS Journal of Photogrammetry and Remote Sensing*, *178*, 97-111.

[45] Ruppen D., Runnalls J., Thsimanga R., Wehrli B., Odermatt D. *Optical remote sensing of large-scale water pollution caused by the Catocal Mine tailings spill*. (under review at Hydrology and Earth System Sciences).

[46] Schütte, P., & Näher, U. (2020). Tantalum supply from artisanal and small-scale mining: A mineral economic evaluation of coltan production and trade dynamics in Africa's Great Lakes region. *Resources Policy*, *69*, 101896.

[47] Hilson, G. (2020). ‘Formalization bubbles’: a blueprint for sustainable artisanal and small-scale mining (ASM) in sub-Saharan Africa. *The Extractive Industries and society*, *7*(4), 1624-1638.

[48] Van der Merwe, A., Harttgen, K., & Günther, I. *Impact of artisanal gold mines on well-being of mining communities in Burkina Faso.* In preparation.

[49] Van der Merwe, A. Brugger, F., & Günther, I. (2022). *Rising gold prices but lower incomes for gold miners: evidence on market imperfections from Burkina Faso during COVID-19*. Journal of African Economics (in preparation)

[50] Knoblauch, A. M., Farnham, A., Ouoba, J., Zanetti, J., Müller, S., Jean-Richard, V., ... & Winkler, M. S. (2020). Potential health effects of cyanide use in artisanal and small-scale gold mining in Burkina Faso. *Journal of Cleaner Production*, *252*, 119689.

[51] Van der Merwe, A. (2022). Chapter 4: Assessing constraints to adopt protective behaviour against mercury on artisanal gold mines: knowledge, risk perception and access in Towards responsible gold supply chains: a case study from Burkina Faso to Switzerland. (Doctoral dissertation, ETH Zürich)

[52] Cabernard L., Ruppen D., Pfister S. Land-use related biodiversity impacts of Swiss gold trade. *In preparation.*

[53] Sonter, L. J., Dade, M. C., Watson, J. E., & Valenta, R. K. (2020). Renewable energy production will exacerbate mining threats to biodiversity. *Nature communications*, *11*(1), 1-6.

[54] Ali, S. H., Giurco, D., Arndt, N., Nickless, E., Brown, G., Demetriades, A., ... & Yakovleva, N. (2017). Mineral supply for sustainable development requires resource governance. *Nature*, *543*(7645), 367-372.

[55] Morgera, E. (2020). Corporate environmental accountability in international law. *Oxford University Press*, USA.

[56] Ruggie, J. G. (2018). Multinationals as global institution: Power, authority and relative autonomy. *Regulation & Governance*, *12*(3), 317-333.

[57] Rudolph, L., Kolcava, D., & Bernauer, T. (2019). International norms and public demand for home-country regulation of multinational firms abroad. *Preprint Open Science Framework*.

[58] Kolcava, D., Smith, K. & Bernauer, T. (2022) Public demand drives regulation of sustainable global supply chains in high-income countries.

[59] Home, R., Weiner, M., & Schader, C. (2021). Smart Mixes in International Supply Chains: A Definition and Analytical Tool, Illustrated with the Example of Organic Imports into Switzerland. *Administrative Sciences*, *11*(3), 99.

[60] Kolcava, D., Scholderer, J., & Bernauer, T. (2021). Do citizens provide political rewards to firms engaging in voluntary environmental action?. *Journal of Cleaner Production*, *279*, 123564.

[61] Fooks, G., Gilmore, A., Collin, J., Holden, C., & Lee, K. (2013). The limits of corporate social responsibility: techniques of neutralization, stakeholder management and political CSR. *Journal of business ethics*, *112*(2), 283-299.

[62] Werner, T. (2015). Gaining access by doing good: The effect of sociopolitical reputation on firm participation in public policy making. *Management Science*, *61*(8), 1989-2011.

[63] Baron, D. P. (2014). Self-regulation in private and public politics. *Quarterly Journal of Political Science*, *9*(2), 231-267.

[64] Fleckinger, P., & Glachant, M. (2011). Negotiating a voluntary agreement when firms self-regulate. *Journal of Environmental Economics and management*, *62*(1), 41-52.

[65] Maxwell, J. W., Lyon, T. P., & Hackett, S. C. (2000). Self-regulation and social welfare: The political economy of corporate environmentalism. *The Journal of Law and Economics*, *43*(2), 583-618.

[66] Hong, H. G., Kubik, J. D., Liskovich, I., & Scheinkman, J. (2019). Crime, punishment and the value of corporate social responsibility. *Available at SSRN 2492202*.

[67] Werner, T. (2012). *Public forces and private politics in American big business*. Cambridge University Press.

[68] Malhotra, N., Monin, B., & Tomz, M. (2019). Does private regulation preempt public regulation?. *American Political Science Review*, *113*(1), 19-37.

[69] Kolcava, D., Rudolph, L., & Bernauer, T. (2021). Voluntary business initiatives can reduce public pressure for regulating firm behaviour abroad. *Journal of European Public Policy*, *28*(4), 591-614.

[70] Kolcava, D., Rudolph, L., & Bernauer, T. (2021). Citizen preferences on private-public co-regulation in environmental governance: Evidence from Switzerland. *Global Environmental Change*, *68*, 102226.

[71] Dauvergne, P., & Lister, J. (2012). Big brand sustainability: Governance prospects and environmental limits. *Global Environmental Change*, *22*(1), 36-45.

[72] Kolcava, D. (2022). Do citizens demand government regulation if firms are accused of greenwashing?.

[73] Bernauer, T., Gomm, S., Quoss, F. & Rudolph, L. (2021). Swiss Environmental Panel Study 2018-2019, Wave 1-3, Cumulative Data. doi:10.23662/FORS-DS-1220-1

[74] Berger, A., Brandi, C., Bruhn, D., & Chi, M. (2017). *Towards "greening" trade? Tracking environmental provisions in the preferential trade agreements of emerging markets* (No. 2/2017). Discussion Paper.

[75] Kolcava, D., Nguyen, Q., & Bernauer, T. (2019). Does trade liberalization lead to environmental burden shifting in the global economy?. *Ecological Economics*, *163*, 98-112.

[76] Presberger, D. & Bernauer, T. (2022) Economic and political drivers of environmental impact shifting between countries. (In preparation)

[77] Ferrari, A., Fiorini, M., Francois, J., Hoekman, B. M., Lechner, L., Manchin, M., & Santi, F. (2021). *EU trade agreements and non-trade policy objectives* (No. 2021/48). European University Institute.

[78] Brandi, C., Schwab, J., Berger, A., & Morin, J. F. (2020). Do environmental provisions in trade agreements make exports from developing countries greener?. *World Development*, *129*, 104899.

[79] Van der Merwe, A. (2021). *Certified gold: too many schemes and not enough demand*. ETH Zurich. Available online: https://ethz.ch/content/dam/ethz/special-interest/gess/nadel-dam/Outreach/PolicyBriefs/NADEL_Policy_Brief_Certified_Gold.pdf

[80] MKS PAMP. (2021) Launch of the Swiss Positive Gold Fund for investment in impact gold. Available online: https://www.mkspamp.com/launch-swiss-positive-gold-fund-investment-impact-gold

[81] Van der Merwe, A.; Cabernard, L.; Günther, I. (2022). Viability of Urban Mining: the relevance of information, transaction costs and externalities. *Under review.*

[82] Zurich Schweiz. (n.d.) Sie machen Gold aus Abfall – die «Alchemisten» der KEZO in Hinwil. In *Klimamagazin* Nr. 6

[83] World Economic Forum. (2021). Net-Zero Challenge: The supply chain opportunity. *Insight Report January 2021*

[84] ICMM. (2015). A Practical Guide to Catchment-Based Water Management for the Mining and Metals Industry.

[85] Beveridge, C., Hossain, F., Biswas, R. K., Haque, A. A., Ahmad, S. K., Biswas, N. K., ... & Bhuyan, M. A. (2020). Stakeholder-driven development of a cloud-based, satellite remote sensing tool to monitor suspended sediment concentrations in major Bangladesh rivers. *Environmental Modelling & Software*, *133*, 104843.

[86] ESA. (2020). About Copernicus Sentinal-2. Available online: https://sentinel.esa.int/documents/247904/4180891/Sentinel-2-infographic.pdf

[87] Lahiri-Dutt, K., & McQuilken, J. (2019). DELVE state of the artisanal and small-scale mining sector-India. In *State of the Artisanal and Small-Scale Mining Sector*. World Bank Group.

[88] Van der Merwe, A. and F. Brugger (2021), "Case study: The digital device life cycle: From mining to e-waste", in Development Co-operation Report 2021: Shaping a Just Digital Transformation, OECD Publishing, Paris, https://doi.org/10.1787/31d11f68-en.

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