Environmental Impacts of Mining

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Post-workshop summary of impacts

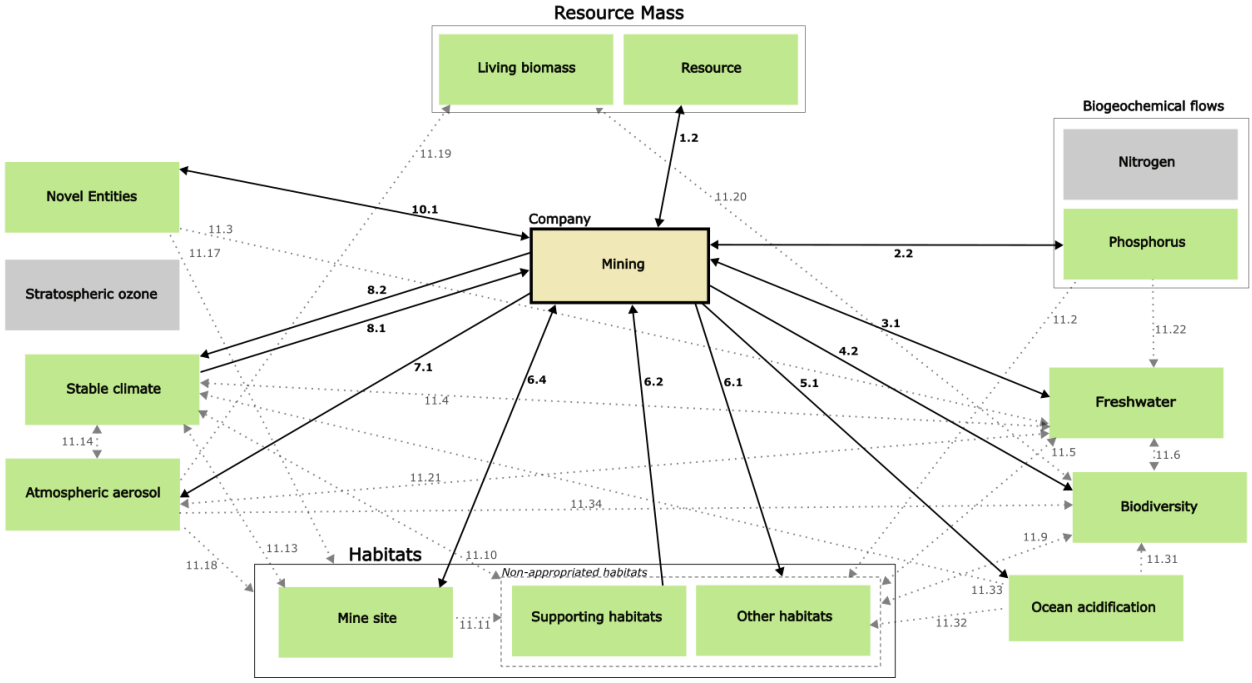

Figure 1. Conceptual systems diagram showing potential interactions between a company (yellow box) and various environmental dimensions. Dimensions are based on processes captured by the planetary boundaries framework, with the addition of natural resources. Solid lines represent direct impacts and/or dependencies of the company on various environmental dimensions. Dashed lines represent interactions between environmental dimensions. Viewed together, solid, and dashed lines represent the indirect impacts and dependencies of the company. Numbers refer to Tables 2 and 3 in this document. Boxes are shaded depending on if mechanistic links (i.e. arrows) are present (green) or not (grey).

Table 1. Direct environmental impacts and dependencies of mining sector, shown as solid lines in figure 2. Links between a company operating in this industry, and the different environmental dimensions, are visually represented in Figure 1. References are numbered, 'W' indicates data from the expert elicitation workshop.

No.	Category	Sub-category	Impact, Dependency or Both	Description of Mechanisms	References
1.2	Resource mass	Non-living mass	Both	Use of non-living resource mass as an input. However, this can lead to resource depletion, e.g. Stocks of metals and minerals are finite and non-renewable over human timescales, raising questions of resource scarcity.	1, W
2.2	Biogeochemical flows	Phosphorus	Both	Phosphate mining provides input but pollutes nearby watersheds.	2
3.1	Freshwater	-	Both	Dependency on freshwater use, e.g. for cooling machinery, dust suppression, to create leaching solutions. Mining changes hydrological flows, with impacts to aquifer and groundwater systems. Alteration of regional groundwater flow pathways, direction of groundwater flow, and levels associated with mine site aquifer dewatering processes. High volumes of freshwater extraction can also cause water scarcity, contributes to increased drought severity, frequency, saltwater intrusion to groundwater.	3
4.2	Biodiversity	-	Impact	Direct impacts on biodiversity, e.g. Non-native and invasive species introduced by vehicles or reclamation programmes using cheap and/or fast-establishment seed, disturbances (light, noise, seismic activity from blasting), increased traffic (trucks, barges), and opening of new roads.	3, W
5.1	Ocean acidification	-	Impact	Emissions of CO_2 from mining operations increase the acidity of surface seawater	4
6.1	Habitats	Non-appropriated habitats	Impact	Direct impacts of operations on various habitats, including natural, agricultural and urban land uses. Includes habitat fragmentation by overburden dumps, altered sediment dynamics, (e.g. sedimentation, freshwater or marine hyper-sedimentation, sinking of deltas due to increased sediment flow), non-natural fires, soil degradation, erosion, compromise of landscape stability leading to landslides, subsidence, and/or cave collapse. Erosion is particularly important in construction aggregate mining and is relevant to land and river systems (riverbank collapse). Deep-sea mining releases sediment plumes into the ocean, disturbing the habitat and organisms in it.	3, 5, W
6.2	Habitats	Supporting habitats	Dependency	Dependencies on supporting habitats, e.g. mass stabilisation and erosion control	3

6.4	Habitats	Appropriated habitats	Both	Use of space of appropriated habitats. This leads to land use change (11.11) including natural, agricultural and urban land uses. This can destroy habitats, e.g. through deforestation. Mining can require extremely large areas, e.g. deep sea mining. There is additional land use change above that at the mine site itself, due to the associated infrastructure required to open and operate a mine site – land for roads, housing, cultivation, etc.	6, W
7.1	Atmospheric aerosol	-	Impact	Release of atmospheric aerosols. PM_{10}, sulfate and nitrate aerosols (e.g. from coal combustion).	3
8.1	Stable climate	-	Dependency	Climate regulation offers protection for the production process	3, 5
8.2	Stable climate	-	Impact	Greenhouse gas emissions from extracting and processing mined material, energy use, and scope 3 consumption, e.g. CO_2, CH_4	7, 8
10.1	Novel entities	-	Both	Heavy metals and chemicals are used in production processes, e.g. sulphuric acid, cyanide, mercury and arsenic are used in leaching processes. As wastes, these have negative impacts on habitats, species and human health due to toxicity. Surface mining causes substantial pollution from acid mine drainage, where metal sulphides are excavated and exposed to oxygen and water, with insufficient amounts of neutralizing material. The impacts of acid mine drainage are contamination of potable and industrial water resources, extensive ecological impacts and potential human health risks. The pathways for environmental impact from wastes are both chemical and physical (failure of large infrastructure). Large-scale waste management, such as tailings storage and prevention of tailings dam failures is a key part of mine site environmental risk management.	3, 5, W

Table 2. Interactions between environmental processes relevant to mining sector, shown as dashed lines in figure 1. Links are visually represented in Figure 1. References are numbered, 'W' indicates data from the expert elicitation workshop.

No.	Categories	Description of Mechanisms	References
11.2	Biogeochemical flows, Habitats (Non-appropriated)	Mining of phosphate rock enables production of phosphorus fertilizers, a cause of eutrophication.	9
11.3	Freshwater, Novel entities	Mines can leach wastewater that is acidified or contains high concentrations of heavy metals and other toxic chemicals, polluting freshwater	3
11.4	Freshwater, Stable climate	Interactions between climate and hydrological cycles, e.g. climate change leads to heavier precipitation in some areas and drought in others	10, 11
11.5	Freshwater, Habitats (Non-appropriated)	Interactions between non-appropriated habitats and blue and green water. Ecosystems tend to decrease available blue water volume because vegetation consumes water, but ecosystems with intact groundcover and root systems improve water quality. Green water is fundamental to Earth system dynamics. Freshwater is crucial to habitat functioning, e.g. river regulation alters riparian ecosystems, soil moisture is closely linked to ground vegetation in many ecosystems.	12, 13, 14, 15
11.6	Freshwater, Biodiversity	Biodiversity provides clean water and flow regulation, which also supports biodiversity. Mining can impact biodiversity through mechanisms related to freshwater e.g. gold mining greatly increases sediment loads in rivers, which disrupts vast tracts of aquatic ecosystems. Through water emissions, mine tailings impact biological productivity of receiving ecosystems.	16, 17, 18
11.9	Biodiversity, Habitats (Non-appropriated)	Interactions between non-appropriated habitats and biodiversity, e.g. mining causes biodiversity loss through habitat loss, degradation and fragmentation, and erosion. Mineral deposits are often concentrated in biodiversity hotspots and protected areas, so mining has a severe effect on biodiversity. Sediment plumes from deep-sea mining impacts marine organisms.	6, 18, 19, W
11.10	Habitats (Non-appropriated), Stable climate	Interactions between non-appropriated habitats and climate regulation, e.g. tropical rainforests are large carbon sinks, so deforestation for livestock production is detrimental for climate stability. Forests also benefit from climate regulation.	19
11.11	Habitats (Appropriated), Habitats (Non-appropriated)	Mining causes extensive land use change and destruction of non-appropriated habitat. Surface mining in particular drives land-cover change, displacing soil, clearing vegetation, reconfiguring landscapes and leading to altered ecosystem function and services.	20, 21, 22
11.13	Habitats (Appropriated), Stable climate	Mining causes deforestation, so forests that previously contributed to a stable climate by sequestering carbon are replaced by mine sites, which provide no such value.	5

11.14	Atmospheric aerosol, Stable climate	Aerosols have complex interactions with the climate system. They have both a cooling effect, by reflecting incoming solar radiation, and a warming effect, by absorbing heat radiation and changing surface albedo, but the net impact is a cooling effect. Uncertainty arises from complexity of aerosol absorption and impacts of aerosols on cloud microphysics.	23, 4
11.17	Habitats, Novel entities	Release of acid mine drainage, chemicals and heavy metals negatively impacts habitats, such as by killing vegetation. Particularly destructive to wetlands which are highly sensitive to changes in pH.	3
11.18	Atmospheric aerosol, Habitats	Aerosols have harmful impacts on appropriated and non-appropriated habitats, e.g. exposure to ozone can damage crops and natural ecosystems. Acid precipitation causes acidification of water, soil and forest environments. Forest dieback has been associated with sulphur pollution. Pollution from the mining sector impacts more distant habitats due to long-range transport in which vaporised chemicals spread through wind.	24, 25, 26, 3
11.19	Atmospheric aerosol, Biomass	Aerosols have harmful impacts on animals and plants which might be a living resource of another sector, e.g. exposure to ozone can kill freshwater fish. Particulate matter can have toxic effects depending on chemical and physical properties, e.g. dioxins can accumulate in foods such as meat and dairy products, fish and shellfish, causing human health effects.	4, 25, 27
11.20	Living biomass, Biodiversity	Interactions between living biomass and biodiversity, e.g. acid precipitation leads to fish kills and declining fish populations due to chronic reproductive failure, potentially leading to extinction. This has implications for ecosystem structure and function.	28
11.21	Atmospheric aerosol, Freshwater	Aerosols influence the hydrological cycle by altering mechanisms that form precipitation in clouds. Aerosols may substantially influence the Asian monsoon circulation.	29, 30
11.22	Biogeochemical flows, Freshwater	Flows of biogeochemical effluents pollute freshwater resources, degrading water quality, e.g. P mining enables use of P fertilisers, and runoff causes freshwater pollution.	31
11.31	Ocean acidification, Biodiversity	Many marine organisms are highly sensitive to changes to ocean CO2 chemistry, especially those using carbonate ions to form calcium carbonate shells or structures. Ocean acidification could be deleterious to such organisms, which would constitute a major disturbance to marine ecosystems with highly uncertain impacts. Marine plankton are also vulnerable.	4
11.32	Ocean acidification, Habitats	Ocean acidification may have serious impacts on various marine and coastal habitats.	4
11.33	Ocean acidification, Climate	Oceans remove a large proportion of anthropogenic CO2, but acidification threatens the ability of oceans to continue to function as a carbon sink.	4
11.34	Atmospheric aerosol, Biodiversity	Aerosols have harmful impacts on flora and fauna, e.g. exposure to ozone can kill freshwater fish.	4, 25

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ELICITATION RECORD – Part 1

The Workshop Context

Elicitation title	Essential Environmental Impact Variables
Workshop	Mining
Date	8 November 2022
Part 1 start time	8am CET

Attendance and roles	Facilitator, Note taker, Experts 1, 2 and 3
Purpose of elicitation	1. Assessment of background review: assess the background review of impacts and ensure that all significant and salient impacts from an industry on the environment are captured in the conceptual systems diagram and the associated tables. 2. Assessment of greatest impact: assess which of these impacts have the greatest impact on the environment. By 'greatest' we mean that impacts have either 1) a large globally cumulative impact; or 2) impacts that are locally incurred but are identified as generally having the largest local effect.
This record	Participants are aware that this elicitation will be conducted using an adapted Sheffield Elicitation Framework, and that this document, including attachments, will form a record of the session.
Orientation and training	Participants received a pre-workshop participant brief.
Participants' expertise	<u>Expert 1</u> *Expertise:* Geoinformatics – data scientist, working with remote sensing, AI, ML, algorithms. Started to work with mining almost five years ago. <u>Expert 2</u> *Expertise:* Ecology background, now more of a sustainability scientist doing interdisciplinary work. Expertise in assessing impacts of infrastructure and urban development on wildlife and landscapes. Now focusing more on where the materials we use for infrastructure and urban development come from and what are the challenges

	associated with that. About six years of work with particular focus on aggregates extraction and consumption, such as sand. Main part is biodiversity, e.g. investigating which species globally are threatened by mining aggregates. Terrestrial and marine resources. Spatial scale – both globally as well as focus on particular areas in Mexico and China, e.g. the overlap between open air mining sites and areas of high biodiversity value. Expert 3 *Expertise:* Environmental engineering background. Last ten years benchmarking environmental performance in mining. First in sustainability reporting, and how it can be used for life cycle assessment (LCA) in the mining sector. A lot of LCA and techno-economic assessment. Expertise on water footprint in the sector: how mining relates to water scarcity and also climate risks affecting the industry. Now working more with battery-related elements – Cobalt, Nickel, Copper, Lithium. Work relates to mining insurance. Different sustainability certification schemes and responsible sourcing - what options companies have to demonstrate their performance.
Declarations of interests	Expert 1: None Expert 2: Recently participated in a similar elicitation project on extraction of minerals, focusing on mechanisms. That will be part of another publication. However, not leading that work. Expert 3: Some companies in the metals mining industry are involved in one project on battery-related elements. Have previously done LCA for mining companies and provided training for consultants in the sector.
Strengths and weaknesses	Expert 1 *Strengths:* Main focus with mining sector is land use and land use change. Land use is strength as work is to map land use, and expansion. Mainly global scale, not going into so much detail. Terrestrial based mining. Mostly metals and coal mining. *Weaknesses:* Not as much expertise on what comes after land use change, like biodiversity loss. Use land use as a proxy for the other impacts. Expert 2 *Strengths:* Bias is towards construction minerals, aggregates, biodiversity. *Weaknesses:* Metals and minerals not as strong.

	Expert 3 *Strengths:* Copper, but also gold, nickel, rare earth elements. Metallic. We'll be doing some work on land use in coming years. Also local energy and GHG emissions. *Weaknesses:* Coal mining – prefer to not work with
Evidence	*Clarifying question asked:* (Expert 2) I have done some work on essential variables. The diagram is very general. How are you moving from that to the development of the essential variables? Will you convert each item in the table to a variable? *Answer*: (Facilitator) In the diagram, we have the solid arrows and the dashed arrows that are indirect effects. We will, for the essential variables, we will focus on the solid arrows as they are directly linked to companies. Once we have done all workshops, we will see for how many sectors those same arrows exist, and we will convert either straight from the arrow, e.g. freshwater. These might be easier to convert straight away. Others like biodiversity it is probably harder to convert the arrow into something you can report on. We want to complement other state-based variables, so not looking at state but more the interactions or flow – how much is put in or pulled out by company. Complementary to existing variables. *Clarifying question asked:* (Expert 1) I have notes but should we fill in the form and send? *Answer:* (Facilitator) It would be good to have the form.
Structuring	The variables were not elaborated or rephrased at this stage.
Definitions	1. Assessment of background review of impacts, ensuring all significant and salient impacts from an industry sector on the environment are captured. 2. Assessment of which are the *greatest* impacts on nature, meaning that impacts have either 1) a large globally cumulative impact, or 2) impacts are more locally incurred but are the largest for individual firms.

Part 1 end time	08:27
Attachments	

ELICITATION RECORD – Part 2: Outcome 1

Eliciting Expert Knowledge on Qualitative Outcomes

Elicitation title	Essential Environmental Impact Variables
Workshop	Mining
Date	8 November 2022
Outcome	1. Assessment of background review: assess the background review of impacts and ensure that all significant and salient impacts from an industry on the environment are captured in the conceptual systems diagram and the associated tables. Specify if any impacts are missed, should be rewritten/rephrased or removed.
Anonymity	Experts are identified as Experts 1, 2 and 3 (aligned across all elicitation records).
Start time	08:43

Definition	Assessment of background review of impacts, ensuring all significant and salient impacts from an industry sector on the environment are captured.
Evidence	A participant brief was provided in advance, containing a background review and evidence.
Individual elicitation	**Missed –** Expert 3: Freshwater impacts to aquifer and groundwater systems and alteration to regional groundwater flow pathways and direction, and levels associated with mine-site aquifer dewatering processes. Large-scale waste management, such as tailings storage and prevention of tailings dam failures, etc. is a key part of mine site environmental risk management – pathways both chemical and failure of large infrastructure. Possibly within Novel Entities. Expert 2: A key impact that on my opinion is not sufficiently captured by current links is **erosion** and it covers soil erosion, landslides, caves collapse in terrestrial systems, erosion in river systems (e.g., riverbank collapse) and even in coastal systems (affecting sediment

	flow and leading to sinking deltas, coastal erosion) (**both direct and direct**) <u>Expert 1:</u> Indirect land use changes **Rewritten/rephrased –** <u>Expert 3:</u> 1.2 – It is a misinterpretation to say that "Declining grade and quality of ores is evidence of 'peak minerals'. Much of 'ore grade decline' is simply due to higher commodity prices and improved recovery efficiency rather than depletion of high grade resources. It's really quite problematic when the interpretation of this indicator is simplified to such a degree. Also in no way does it provide evidence of potential peaks in mineral extraction. 9.4 – Flood risks on average have more significant financial and operational risk than drought risks for the mining sector. So slight rephrasing to include the word flood explicitly could be useful. <u>Expert 2:</u> • I don't understand why "resource mass" and "habitats", especially the mining site, as separated. The resource mass is within the mining site, which occupies the habitats of multiple species above and below ground. • I don't understand the distinction between "living biomass" and "biodiversity". To me, biomass is a way to measure biodiversity among other metrics. Most of the links highlighted with living biomass, e.g., aerosol, should be a link with biodiversity. • Direct impacts of mining on biodiversity should include or at least mention in the table impacts from noise, increased traffic (trucks, barges), opening of new roads. • Indirect impacts of mining on biodiversity should include or at least mention in the table impact from sediment plumes. • Aren't all impacts on habitats impacting biodiversity? Why the impacts on habitats are indirectly impacting biodiversity? • Overemphasis on forest and intact ecosystems avoid the fallacy of the stressed systems. Importance to account for the impacts of mining not only in "intact landscapes" but also in

	humanized landscape with lots of cumulative effects. Degraded ecosystems do not require less concern. Expert 1: None **Removed –** Expert 3: None Expert 2: • "living biomass" within the "resource mass". Why? • I find the idea of "supporting habitats" not that applicable to the mining industry. I think that overall this activity is less directly dependent on the services from ecosystems or it is not at the same level than other industries. Expert 1: None
Matches/ Mismatches	In general, there were many points of agreement. Facilitator suggested they were more interested in adding points than removing, and all agreed. There were some differences on what to add, usually due to different perspectives rather than disagreement. Expert 3 responded to Expert 2's point on living biomass and pointed out that sometimes they report wood as an input, and depending on whether the company is also doing resource processing, biochar is used. A connection to living biomass, but not very important. Expert 1 observed that he had not thought of erosion and aerosols but agreed with them.
Group discussion	Discussion on pollution. Facilitator asked what types of pollution they consider and the mechanisms: whether added or created/released throughout the process. Expert 3 raised mineral processing requires small quantities of reagents, whereas acid mine drainage – released through the mining process – is a much larger impact. Expert 1 somewhat refuted this by pointing out mercury in gold mining. Several kilometres away from the mining area, the whole area gets a higher concentration of mercury, but it is not possible to report. Expert 3 agreed with this and added that small-scale gold mining is responsible for 20% of global mercury emissions. This is added. Expert 2 contributed that novel entities is less important for aggregates than other issues. They initially thought the term novel entities addressed exotic species.

	The Facilitator asked whether pollution is important in aggregates and if so, what type. Expert 2 said that, in terrestrial systems, sand pits and rocks, one of the main issues is dust. In terms of water and soil pollution, issues include oil spills from machines, trucks and boats, as well as increased suspended sediment and sedimentation after dredging. On land clearing, Expert 1 clarified that some of the impacts (biodiversity, living biomass) went through land clearing. He argued that land clearing or land use change is more central than represented in the diagram. All impacts could be divided into the impacts due to the habitat change, and the impacts that occur afterwards due to production processes. On biodiversity, Expert 2 clarified that they were arguing for direct links to biodiversity to get around the term 'indirect impacts'. Expert 2 viewed habitat loss as a mechanism of biodiversity loss. Afraid if no direct link represented, it would get lost. The Facilitator noted the importance of not minimising such links by calling them indirect. Expert 3 also raised the presence of the ozone box, with no arrows. They added a minor impact that refrigerants and air conditioning systems are used, so technically there could be an arrow. But these are not very important, so they suggested removing the box. Facilitator clarified the box is there due to the comparison across sectors.
Group elicitation	**Missed –** Erosion impacts, hydrological flow changes, noise/traffic/road building, aerosols, waste management/piles, indirect land-use, intact vs built/settled **Rewritten/rephrased –** Arbitrary split between boxes/question of whether this fits the mining sector, living biomass arrows should go to biodiversity. Links to habitat should also go to/affect biodiversity (land-use change affecting habitats has multiple knock-on effects), make sure that indirect links don't mask the mechanistic impact (e.g. habitats on biodiversity). **Removed –** None (should boxes without links be present?)
Chosen outcome	See above.
Discussion	Noted valuable reflection from Expert 2 on the biased literature, which favours metals and minerals over aggregates. Need to balance this out. Also noting knowledge gap that all experts had knowledge of terrestrial systems which should be supplemented with comments from experts in marine systems.

End time	11:16
Attachments	

ELICITATION RECORD – Part 2: Outcome 2

Eliciting Expert Knowledge on Qualitative Outcomes

Elicitation title	Essential Environmental Impact Variables
Workshop	Mining
Date	8 November 2022
Outcome	2. Assessment of greatest impact: assess which of these impacts have the greatest impact on the environment. By 'greatest' we mean that impacts have either 1) a large globally cumulative impact; or 2) impacts that are locally incurred but are identified as generally having the largest local effect.
Anonymity	Experts are identified as Experts 1, 2 and 3 (aligned across all elicitation records).
Start time	08:43

Definition	Assessment of which are the *greatest* impacts on nature, meaning that impacts have either 1) a large globally cumulative impact, or 2) impacts are more locally incurred but are the largest for individual firms.
Evidence	A participant brief was provided in advance, containing a background review and evidence.
Individual elicitation	<u>Expert 3:</u> **Impact:** 6.1 Atmospheric aerosol **Reason:** Dust impacts from mining cause widespread environmental degradation beyond the bounds of mining operations when poorly managed and are a key pathway for environmental toxicants and human health risks. <u>Expert 1:</u> **Impact:** Novel entities (Potential long-term risk) **Reason:** Acid Mine Drainage is the main source of pollution associated to waste and open pits when the rock is exposed to the oxygen and water. The mining waste also pose long-term risk of major disasters. **Impact:** Supporting habitats (Indirect land use changes)

	Reason: Mining requires more land than the sites itself, including land for access roads and other human activities, agriculture, urbanization, etc. Note: Direct mining land use also appropriates land previously under other uses. Expert 2: **Impact:** Carbon footprint (global) **Reason:** Directly from mining and processing, for example to produce construction materials such as cement, and indirectly from the use of buildings and infrastructure (e.g., energy consumption of the housing sector) See for example: Zu Ermgassen et al. 2022. A home for all within planetary boundaries: Pathways for meeting England's housing needs without transgressing national climate and biodiversity goals Torres et al. 2021. Sustainability of the global sand system in the Anthropocene **Impact:** Freshwater footprint from freshwater consumption and impacts on freshwater systems (direct from mining and indirect from erosion, pollution, increased traffic) (local and regional) **Reason:** Aggregates production from quarries accounts for 41% of total water consumption in concrete production, making aggregates production a significant contributor to global water demand. See for example: Torres et al. 2021. Sustainability of the global sand system in the Anthropocene Koehnken et al. 2020. Impacts of riverine sand mining on freshwater ecosystems: A review of the scientific evidence and guidance for future research **Impact:** Biodiversity (global, regional, local) **Reason:** Through habitat loss, degradation, and increased mortality. Thousands of species reported to be impacted by mining, many of which are threatened with extinction. For instance, limestone quarrying is a major driver of biodiversity loss and species extinction in SE Asia. See for example:

	Torres et al. 2022 (pre-print). Unearthing the global impact of mining construction minerals on biodiversity. Hughes (2017). Understanding the drivers of Southeast Asian biodiversity loss **Impact:** Aerosols (local) **Reason:** Aggregates production is responsible for 53.4% of the health impacts of air-pollutant emissions, resulting in US$113.9 billion annually of external health damages from inhalation-related health issues due to particulate matter emissions from rock quarrying and crushing. Air-pollutant emissions also degrade the habitat of species and ecosystems. See for example: Miller and Moore (2020). Climate and health damages from global concrete production. **Impact** Erosion or impacts on land stability **Reason:** Covers soil erosion, landslides, caves collapse in terrestrial systems, erosion in river systems (e.g., riverbank collapse) and even in coastal systems (affecting sediment flow and leading to sinking deltas, coastal erosion). Erosion can occurs not just at the point where extraction is occurring, but also in areas further away (e.g. downstream). See for example: UNEP (2022). Sand and Sustainability: 10 strategic recommendations to avert a crisis. Hackney et al. (2020). Riverbank instability from unsustainable sand mining in the lower Mekong River.
Matches/ Mismatches	Mostly agreement. Slight mismatch due to different types of mining, especially on novel entities which are less important to aggregates.
Group discussion	**Ozone** Expert 3 noted that while there could be arrows to ozone due to refrigerants and air conditioning systems underground, it is not very important. **Aerosols** Agreement on dust. Expert 3 highlighted it and Expert 2 agreed and added that it was also the case for aggregates. Expert 1 agreed but

	clarified that it was very different in different regions. Expert 1 said it was hard to rank. Facilitator clarified that the list was not ranked. **GHG emissions** On GHG emissions, Expert 2 contributed that direct emissions from mining and processing varies with industry. Cement is massive. There are also indirect emissions, such as with construction minerals mining, indirect emissions are massive from the housing sector. Expert 1 highlighted that direct emissions from fossil fuel burning or energy production are well reported, but direct and indirect emissions from land use change are not. Expert 2 agreed. Expert 3 added that fugitive emissions (e.g. methane from coal seams) are probably less well reported too. **Water** On water footprint, Expert 3 argued that changes to water flows have direct impacts on water uses, whether ecosystems or humans. Two categories: consumptive and degradative impacts. Clarified that water footprint means different things to different people. Expert 2 raised that ocean [impacts], sinking and erosion of coastal areas do not fit well with water footprint. Facilitator clarified that they were talking about changing of freshwater flows. Expert 3 agreed with Expert 2, that hydrological changes and geomorphological issues may not be within water footprint. **Novel entities** Expert 2 clarified that novel entities applies less to aggregates. For aggregates, other issues are more important. This was very important for Expert 1. Acknowledged that may not be as relevant for aggregates, but for metals and coal, acid mine drainage is a problem. It happens everywhere you break rocks, and need to ensure [the acid mine drainage] does not leach away. Expert 2 fully agreed to include it. Even if not one of the main impacts of aggregates, still important for the list and felt it was fine to have the extra category. **Erosion** Erosion – Expert 2 suggested to name it 'erosion and geomorphological changes'. Maybe more relevant for aggregates but there are issues with soil erosion and landslides in other industries such as minerals. When mining in river and coast systems, 'dynamic' ones, removing sediment can have greater impacts leading to bank

	collapse, one of greatest impacts of river and sand mining. Need to understand the amount sediment in that system to know what would be sustainable. Expert 3 agreed the geomorphological changes and stability important. Erosion is more site specific. Expert 3 tends to think of topsoil management and how it affects rehabilitation. erosion also is a cause of dust emissions, they are closely linked. Even linked to water quality issues. Did not have a strong feeling either way. Expert 1 agreed with Expert 3, very site specific and dependent on region. **Biodiversity** This was very important for Expert 2. Includes habitat loss and degradation, include many direct and indirect things, like ecological connectivity. Populations, land use changes, other direct impacts are disturbances like noise, traffic, vibrations. You can say that there are thousands of species impacted in the IUCN red list threatened by mining and quarrying. Expert 1 added that there has also been an increase in mining in recent decades to more biodiversity-rich areas. A move from global North to global South. Includes both direct and indirect impacts of land use change. Expert 3 added that mining is a physical scar on habitats. With biodiversity, different ways to quantify: Species, genetic, functional diversity. Different approaches to measuring. Existing reporting schemes address rehabilitation of x ha, without commenting on the effectiveness of that rehabilitation. Expert 2 requested to also add word 'invasive species' to biodiversity box.
Group elicitation	**Impact:** Dust/atmospheric aerosols **Reason:** General impact from all types **Impact:** Emissions/Carbon footprint **Reason:** Direct (from mining activities) and indirect (downstream uses of materials). Also emissions from land-use change. Fugitive emissions. **Impact:** Water footprint (input, output) and changes in hydrology **Reason:** Consumptive, degrative (availability of quantity and quality), wider scale implications of changing hydrology* (geomorphological issues are not usually/perhaps not best fit under water footprint). Note: Definition of footprint may vary. **Impact:** Novel entities production during mining activities **Reason:** For metals and coal, production of novel entities very big and natural/inevitable when exposing material. Input novel entities are smaller in relation to produced. Note: This is not as big an impact in aggregates.

	Impact: Erosion/Geomorphological changes **Reason:** Wider implication than on "exact" mine site, knock-on effects. Note the connections to other impacts (hydrology, aerosols). **Impact:** Biodiversity **Reason:** Through habitat loss and habitat degradation, also impact through occurs through disturbing ecological connectivity. Also impacts through noise/traffic/vibrations and invasive species. 1000s of species on IUCN red list affected by mining and quarrying activities. Increase in mining activities in last 20 years in more biodiverse rich areas – highlighting the importance/impact. Important also for rehabilitation – rehabilitated to what state?
Chosen outcome	• Dust/atmospheric aerosols • Emission/Carbon footprint • Water footprint (input, output) and changes in hydrology • Novel entities production during mining activities • Erosion/Geomorphological changes • Biodiversity
Discussion	Noted valuable reflection from Expert 2 on the biased literature, which favours metals and minerals over aggregates. Need to balance this out. Also noting knowledge gap that all experts had knowledge of terrestrial systems which should be supplemented with comments from experts in marine systems.

End time	11:16
Attachments	