14 February 2019

Climate change impacts on mining and raw material supply chains

Conference Paper

1 Background of the project

In one of the first research projects on the topic of climate change and mining, adelphi, the Institute for Energy and Environmental Research Heidelberg (ifeu) and the Sustainable Minerals Institute of the University of Queensland, Australia, are investigating how climate change can potentially affect the environmental risks associated with mining. In addition, the project addresses how raw material supply chains might be disturbed by climate change impacts.

The project "Impacts of climate change on the environmental criticality of Germany's raw material demand" (short: KlimRess; UFOPLAN, FKZ 3716 48 324 0) is commissioned by the German Environment Agency. It aims at identifying both raw materials and producing regions as well as combinations of raw materials and countries expected to be particularly affected by climate-related environmental impacts and risks and possible disruptions of supply, and at developing a proposal on how such risks could be described in systems for assessing raw material criticality. Taking into account available data for future demand of raw materials, supply risks, environmental risks of raw material production and the climate-related risks identified as part of this project, policy options for precautionary and eco-friendly raw material and natural resource policies are developed.

The project is meant to contribute to better addressing aspects of climate change and adaptation while achieving the goals for raw material supply and the use of resources as defined in the German Resource Efficiency Programme and the German Raw Material Strategy. In addition, the project sets out to provide input for the further development of the German Strategy for Adaptation to Climate Change.

Five country case studies systematically assess the vulnerability of mining and raw material production in different climatic contexts, in particular the associated risks for and impacts on the environment and the disruption of supply chains. The case studies cover five different (climatic) regions and nine minerals and metals:

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- Australia: Bauxite, coking coal and iron ore
- Chile: Copper and lithium
- Indonesia: Tin
- Canada: Tungsten and nickel
- South Africa: Platinum Group Metals (PGMs)[1] and nickel

This conference paper is divided into two parts. First, the paper presents a summary of the case studies and an expert workshop held in November 2018. It provides an overview of the links between climate change and potential environmental impacts and disruptions of raw material supply (chapter 2). The second part of the paper introduces an approach to assess the vulnerability of producing countries and reserves to climate change, highlighting bauxite, tin and iron ore as examples (chapter 3).

Potential policy entry points for adaptation on the national and international level are introduced in the discussion paper "Addressing climate change impacts in mining and raw material supply chains".

2 Climate change impacts on environmental and supply risks in mining

For the climate change impact assessments in our case studies, we developed a set of environmental categories and distinguished between different climate stimuli and direct climate impacts. Table 1 shows the environmental categories and the two groups of climate stimuli and direct climate impacts, used in our research.

Table 1: Overview of environmental categories and climate stimuli and direct climate impacts

Environmental categories	Climate stimuli and direct climate impacts	
	Slow onset, gradual change	**Sudden onset, extreme events**
Land use	Increase of mean temperature	Occurrence of heat waves
Water use	Increase of mean precipitation	Occurrence of wildfires
Energy use	Decrease of mean precipitation	Occurrence of heavy rain events
Waste	Occurrence of droughts[2]	
Air emissions		Occurrence of flooding events
Rehabilitation	Occurrence of erosion/landslide	
Biodiversity	Sea warming	Occurrence of cyclones/typhoons/hurricanes
Health	Permafrost degradation	Occurrence of heavy waves/storm surge
	Melting glaciers	Occurrence of heavy wind
	Sea-level rise	

Source: Categorisation developed in the project.

[1] Ruthenium, rhodium, palladium, osmium, iridium, and platinum.

[2] Droughts are an extreme weather event, but are linked to slow onset change (UNFCCC, 2012).

In order to provide comparable results across case studies, the potential climate change impacts were qualitatively assessed by using two kinds of assessment matrixes: First, assessment matrixes summarising the potential effects of climate stimuli and direct climate impacts on (potential and already existing) environmental impacts were prepared for each mining site and processing site and second, a matrix summarising the potential climate impacts on infrastructure and transportation routes. The identified potential climate impacts were – for each raw material (for both potential impacts on current environmental impacts/risks and potential impacts on the supply chain) – classified using the following main categories:

- **Negative potential climate impact**: Projected climatic changes are expected to affect environmental impacts or security of supply negatively.
- **Positive potential climate impact**: Projected climatic changes are expected to affect environmental impacts or security of supply positively.
- **No potential climate impact**: Projected climatic changes are not expected to affect environmental impacts or security of supply.
- **Difficult to evaluate**: The potential impacts of projected climatic changes are difficult to evaluate (for example because of lacking data).

The main findings and observations discussed in this paper are based on interrelationships identified as "negative potential climate impact". The following text box shows exemplary negative impacts for the direct climate impact "flooding" in each of the environmental categories and for supply.

Flooding as an example for direct climate impacts

Flooding is defined as the "overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas not normally submerged" (IPCC, 2014). Flooding can be caused by heavy rain, storm surges, sea level rise. In our research, we made no distinction between freshwater and saltwater flooding. A summary from the case studies shows how flooding can harm the environment at mining and processing sites and disrupt supply chains:

Water use: Flooding can negatively affect freshwater availability (e.g. brackish water from tin mining in Indonesia), and flooding due to sea level rise may induce salt-water intrusion of water containment systems (e.g. nickel mining in Canada).

Waste: Flooding can lead to an uncontrolled release of metal contaminated effluent or to physical destruction due to overspills (identified potential impact in seven out of the nine case studies).

Rehabilitation: Flooding can hamper rehabilitation efforts (identified in all case studies, except lithium mining in Chile due to mining from brines).

Biodiversity: Flooding can harm biodiversity, which is already under pressure from mining operations.

Supply: Flooding of the mining pit, transport routes, processing facilities, ports may (at least temporarily) disrupt the supply in nearly all cases; in addition, workers are put at risk.

2.1 Extreme weather events as main risk

The case studies clearly show that impacts of extreme weather events, such as heavy winds, tropical cyclones and heavy rain, stand out as the main risk in terms of environmental impacts and disruption of supply chains across different raw materials, mining sites and climatic zones. For example, flooding, caused by heavy rain or surges, poses dangerous risks especially with regard to hazardous or toxic waste storage (spillover, dam failure), fresh water supply and rehabilitation, and may lead to disruptions of operation. Drought poses dangerous risks especially with regard to water use, which will be less available for dust suppression, ecosystems or local communities. Less water availability for dust control may also affect the work force and lead to disruptions of operation.

Case study examples: Combination or sequence of extreme events

A combination or sequence of extreme events can increase risks, for example, an extreme wet weather event during a period of prolonged drought can increase the risk of environmental impacts of mining and processing operations. This is the case for the Mount Whaleback iron ore mine in Australia, situated in a region, which is projected to face more intense droughts as well as an increased intensity of rainfalls and cyclones. Water loss by evaporation during drought events can lead to the development of hypersaline water bodies. In the case of the Goonyella Riverside coking coal mine in Australia, the risk of acid mine drainage is higher during drought events and high evaporation losses, when water infill of pits is used to prevent the generation of acid mine water. In both cases, the risk for harmful saline and/or acid drainage is considerably higher if extreme rainfall occurs in combination with drought.

In general, especially tailing dams and slime ponds are highly vulnerable to climate change risks. Most of the tailing dam failures have occurred after torrential rains such as at the Ok Tedi River, Papua New Guinea (1984)[3] or in Baia Mare, Romania (2000)[4]. In addition, acid mine and/or rock drainage collection systems and treatment plants for mines during operation and after closure are generally designed for certain maximum flows. These may be surpassed in the case of extreme weather events, causing spillovers, thereby releasing untreated, heavy metal polluted waters to the environment.

Large open pit mines can also be affected by extreme weather events such as heavy rain and consequent flooding, leading to high pumping costs or even disruption of exploitation when deeper work areas may flood. Larger open cuts will have to adjust to extreme precipitations. As energy costs are high, dewatering and/or drainage pumps are generally designed in a way that (in terms of capacity) they work at optimum load. Therefore, their adaptation ability to flooding is limited and additional stand-by pumps are required.

Moreover, a number of specific mining operations are at risk from extreme weather events such as heap leaching operations (which are dependent on predictable weather conditions), salt evaporation plants (including lithium brine exploitations), as well as alluvial operations in rivers, which are operating on the shore (dredges are generally floating devices and can cope with water level rises, as long as the draft of the river does not surpass critical levels). Open

[3] Ok Tedi is a gold and copper mine, which has disposed more than two billion tonnes of contaminated material in the rivers Ok Tedi and Fly since production began in 1984. To date, more than 2 000 km^2 of floodplain have been destroyed (Seib, 2016). Kirsch (1996) notes, that heavy rainfall swept the tailings into the rain forest, swamps and creeks, and led to about 30 km^2 of dead forest. The United Nations Environment Programme (2007) noted that the Ok Tedi mine site is responsible for uncontrolled discharge of 70 million tonnes of waste and mine tailings annually. Consequences were raising riverbeds and causing flooding, sediment deposition and damage to the local rain forest.

[4] After a sequence of extreme weather events, the tailings of the Baia Mare gold mine overflowed and tore a 25 m long gap in the embankment wall. 100 000 m^3 of tailing sludge (containing heavy metals) and water containing around 120 tonnes of cyanide got into local waterways down to the Danube (Baia Mare Task Force, 2000).

casts in sediments may suffer from instability of slopes, if the drainage system is insufficient or the precipitation too high.

However, not only the type, but also the scale of mining operation is important for assessing the risks posed by extreme weather events. The experts at the workshop agreed that it is important to distinguish between artisanal/small-scale mining (ASM) and industrialised, large-scale mining (LSM). Although it was difficult to assign certain climate change induced environmental risks to ASM and LSM in the case studies (e.g. tin mining in Indonesia), the vulnerability to different impacts varies and especially ASM often does not have the sufficient adaptive capacities.

Another aspect to consider which was highlighted at the expert workshop is the extent of vulnerability of different climate regions and/or vegetation zones. For example, forests, and especially mangroves strengthen the resilience of ecosystems while both increasing extreme weather events and mining contribute to deforestation and thus potentially reduce the resilience of sites.

Expert input

Our expert workshop indicated that the finding "extreme events are the main risk for mining" should be further assessed, because the comparability between the two groups (sudden and slow onset) is more complex than it seems at first sight. One reason for that finding could be that more information is available on short-term impacts and less on long-term, slow onset impacts.

2.2 Climate change and environmental risk of mining

The following chapter presents short definitions of selected environmental categories and summarizes the main findings regarding the potential impacts of climate change.

2.2.1 Land use

This category describes the area of land consumption for mining and processing activities. Significant land footprints result from open pit mining with large overburden and tailings deposition facilities. In general, climate impacts do not change land consumption, since the size of the mining pit and tailings is generally not affected by climatic changes. However, in mining areas where degradation, sedimentation and flooding already result from changes of topsoil and vegetation cover, an increasing risk of erosion/landslides and flooding can additionally contribute to land degradation, as for example in the case study on tin mining in Indonesia. This is due to bucket-line dredging of placer tin deposits, which removes the top soil of large areas.

In addition, climate change might lead to an increase in land use if mining companies abandon e.g. flooded sites and move operations to other pits or open new mining projects at other locations to diversify their operations. In case that the production at one site is reduced due to flooding, the production can be increased at another site, which is not affected. As pointed out at the expert workshop, the shifting of operations to alternative locations due to climate change can be observed in other sectors (e.g. in agriculture).

In contrast, an increase of land use due to the building of more shallow dams for dam safety is not expected. Dam safety will rather be achieved by other dam construction types which are more expensive (e.g. concrete dams instead of large upstream soil compacted dams). An increase of land use may take place with increasing energy demand and transition to renewable energies like solar or waterpower to reduce GHG emissions.

2.2.2 Energy use

Energy use depends on the raw material sourced and the processes used for extraction and treatment. Energy needed for mining is mainly diesel fuel and electricity. From the case studies, we have not identified direct climate change induced impacts on energy use. However, some indirect impacts could be detected. For example, increasing water scarcity may increase energy demand (desalination, increased on-site water pumping).

Today, energy is important for industrial mining operations and supply shortages are one of the major bottlenecks for expansion. In the future, energy demand is expected to increase not only because of potentially increasing water scarcity but also due to mining of lower ore grades. Nevertheless, there are potentials for reducing the specific energy demand of mines. New and more efficient technologies can be applied especially for milling which uses a lot of energy in processing (Harder, 2017).

2.2.3 Water use and dust emission

The category water use describes the use of water for mining and processing. Important parameters are the total amount of water used and the general water availability in the mining area/region. Water use is mostly affected by drought, not only in arid regions but also in regions with a significant dry period (e.g. Australia, Weipa/bauxite). Additionally, water use is affected by flooding and erosion/landslides in the case studies analysed. Water is primarily used for processing and for dust suppression in mining. A further aspect may be water use for energy generation.

The most relevant aspect identified across sites analysed is "less water availability for dust control". In addition, flooding and erosion/landslides may affect water containment or water reservoir systems (e.g. Canada, nickel and Indonesia, tin) leading to reduced freshwater availability. The competition for water is expected to increase in particular where different user groups, such as agriculture, industry, domestic use, have limited water access (e.g. South Africa, PGM/nickel).

At the expert workshop, droughts, especially occurring erratically, were considered as major cause for a potential increase of competition in water usage with local communities and other sectors. Water storage could be an adaptation measure, but is itself potentially at risk in times of flooding and increasing risks of erosion/landslide. A sequence or combination of rainfall and drought causes additional difficulties. For this case and in general it is a problem, when usual rainfall patterns do not apply any longer, and the predictability of changing events becomes more difficult.

To reduce the competition in water poor regions, water losses can be minimised by recycling of processed water, when storing slimes from the concentration plant on dry stockpiles. This also reduces the evaporation of water from tailings, which also can be reduced by covering ponds with white light-reflecting floating devices.

Water management in mining and processing

Less water availability for dust control was identified as an important challenge in the case studies regarding climate change impacts on water use. Water use for wetting roads can vary between 0 and 15% of total water consumption according to Cochilco (2008). The amount of fresh water used could be reduced by using low quality water. In general, water use in mining operations is oriented towards the availability of natural water sources. Where water is available in abundance there is no recycling, where water is scarce, it is treated and reservoirs are built or water is even transported over large distances to the mine site (e.g. desalinated marine water for copper mining in Chile). In principle, water is typically less of a problem in terms of availability but rather an obstacle to mining, e.g. when water levels need to be lowered or water needs to be pumped out for access. Water demand in mining is mainly relevant for processing, especially most of the separation processes (hydro-gravimetrical, flotation, leaching, amalgamation etc.). Minerals with a higher water demand for processing are usually minerals with a low grade due to geochemistry and mineralogy. The finer the intergrowth of ore minerals and the finer the ore needs to be milled, the larger is the amount of water required. When ore deposits are located in water scarce areas, processing is sometimes relocated to areas where more water is available.

2.2.4 Biodiversity and rehabilitation

The International Council on Mining & Metals (ICMM) defines land rehabilitation as “the return of disturbed land to a stable and productive condition” (ICMM, n.d.). Rehabilitation and biodiversity are closely interrelated and the negative potential climate impacts that were identified across sites in the case studies account likewise for both categories.

Mining and processing often affects biodiversity or ecosystems, including the degradation of soil, waterways, vegetation and habitat of animals. During and at the end of mining operation, rehabilitation addresses the return of mined sites to stable and functioning ecosystems ideally following rehabilitation plans. Rehabilitation is affected by nearly all climate impacts in all case studies. All indicated climate stimuli and direct climate impacts potentially impede revegetation and rehabilitation measures at mining sites, e.g. temperature increase, precipitation change, extreme weather events.

Both biodiversity and rehabilitation are especially affected in countries with weak governance, as environmental monitoring is generally weaker and in regions that are already confronted with extreme weather events.

2.3 Climate change and supply chain disruptions

In addition to the impacts on environmentally relevant factors, we also identified impacts on the security of supply. From our analysis of the case studies, flooding, erosion/landslides and heavy winds are the most dangerous risks in terms of damaging sites, transport routes and putting workers at risk. Additionally, fires, drought (due to less water available for dust suppression) and heat waves endanger the workforce, potentially leading to lower production levels.

Case study examples: Past weather extremes

Temporary disruptions of operations due to extreme weather events already happen frequently. For example, bauxite mining in Weipa, Australia, was interrupted due to weather impacts on operations in 2016, which was the main cause for a production decrease by 7% compared to the previous year (Rio Tinto, 2017). Several coal-mining operations in Queensland, Australia, were severely affected by floods in 2010-2011 and 2017. The 2010-11 floods affected 85 per cent of Queensland’s coal mines, reducing production or leading to the closure of mines. The mines needed several months to fully recover (Queensland Flood Commission of Inquiry 2012). The export disruptions led to increased coal prices (White, 2010). In March 2017, Cyclone Debbie caused damages to the railway system delivering coal to the ports leading to a significantly reduced rail capacity (BHP Billiton, 2017). Railway operators needed up to four weeks to reopen (Aurizon, 2017).

In Indonesia, in 2016, flooding on Bangka Island led to limited access to tin smelters and mining sites, and the operator PT Timah shut one mining site during the flooding (ITRI, 2016).

In Canada, tungsten mining at the Cantung mining site was severely affected in 2012, where extreme weather events led to mudslides and washouts, and North American Tungsten had to stop its operations for about a week, due to food and fuel shortages (Tobin, 2012).

Although these incidents are local and do not always affect global supply, they are expected to increase due to climate change, both in frequency and geographic distribution.

Potential supply chain disruptions may especially occur when mining takes place in regions with potential increases of flooding, erosion/landslide and heavy wind. In addition, regions with potential increases of drought, fires and heat waves may be affected by temporary supply chain disruptions. Furthermore, mining sites at remote areas are more vulnerable to potential supply chain disruption, especially due to long transportation distances through sparsely populated or uninhabited areas.

Slow or long-term changes such as temperature increase and changes in precipitation are not expected to directly increase the risk of physical supply chain disruptions, but temperature and precipitation changes can have indirect impacts. With regard to transport routes both negative and positive impacts are possible: land-based transport routes in permafrost regions are exposed to risks from melting permafrost, including road slope instability and accelerated erosion. By contrast, sea ice melting potentially offers new alternative transport routes. In general, land-based transport routes via roads have a higher flexibility than rail-bound transports.

Infrastructure for mining, processing and transport are known to experience damage due to sudden extreme events. In contrast, slow-onset stimuli and direct climate impacts are harder to identify for producers and researchers due to the lack of past experiences. Temperature-sensitive processes can be affected by slow, gradual changes. However, some slow onset aspects are predictable. For example, some mining areas in the Andes of Peru, Bolivia and Chile depend on water sources fed by glaciers that are retreating due to climate change, forcing mines to consider adaptation strategies. In the short term, increased melting leads to higher drainage of the glaciers (water supply, but risk of flooding), but in the long term, the water supply will become less or even cease completely.

Demand for equipment: supply dependencies of mines

Supply chains are not only directed from mine to market. It also has to be considered that the mine itself depends on certain supplies for running operations: power (mines connected to the central grid), fuel, and materials are essential for operation. Disruption of these flows can hit the production as well as cutting of transport routes needed for the delivery of mining products to markets.

2.4 Are there positive climate change induced impacts?

A small number of case studies showed potentially positive impacts with regard to the production process and the supply chain. For example, sea routes in arctic and/or permafrost regions (e.g. in Canada) could potentially be expanded in the case of sea ice change. Lithium mining from brines in Chile might benefit from increasing temperatures, which could result in a faster evaporation of the brines. In this case, the land use could be potentially reduced, as smaller evaporation ponds function more effectively.

However, new supply routes may require negotiations with locals and authorities, and solar evaporation from ponds may not be further accelerated if the humidity level is already very low.

In general, it has to be noted that potentially positive impacts need to be closely assessed. The consequences are very specific and depend on the local situation.

3 Climate change vulnerability assessment of main producing countries and reserves

As the case study findings show, climate change is projected to adversely affect mining operations around the world, partly exacerbating environmental risks at mining and processing sites as well as disrupting supply chains. However, there are raw material producing countries that are more vulnerable to the adverse impacts of climate change than others as they are more exposed to weather and climate hazards or less capable to adapt to climatic changes.

To identify which countries with significant raw material production are particularly at risk from climate change, we conducted a climate change vulnerability assessment for the main producing countries of the nine minerals and metals selected in this project.[5] We covered at least 75 percent of the current world production for each mineral and metal. In order to assess risks in the future, we focused on the countries with main reserves. Following the approach introduced by Coulomb et al. (2015) we assumed that the distribution of production might gradually converge towards the the distribution of reserves.

After comparing different open source climate change vulnerability indices, we decided to use the Notre Dame Global Adaptation Country Index (ND-GAIN)[6] as the basis for the vulnerability assessment. ND-GAIN measures climate change vulnerability based on a country's exposure, sensitivity and adaptive capacity and the readiness of countries to "leverage private and public sector investment for adaptive actions" (Chen et al., 2015: 2). To answer our research question, we focused on vulnerability and its three underlying variables.

ND-GAIN defines vulnerability as the "propensity or predisposition of human societies to be negatively impacted by climate hazards" (Chen et al. 2015: 3). The three variables, which compose vulnerability, are defined the following way:

- **Exposure**: "The extent to which human society and its supporting sectors are stressed by the future changing climate conditions. Exposure in ND-GAIN captures the physical factors external to the system that contribute to vulnerability" (Chen et al. 2015: 3). The exposure score answers the question: How exposed is a country to weather and climate hazards? The least exposed country according to the ND-GAIN is Andorra (exposure score: 0.247), the most exposed is the Maldives (exposure score: 0.722).
- **Sensitivity**: "The degree to which people and the sectors they depend upon are affected by climate related perturbations. The factors increasing sensitivity include the degree of dependency on sectors that are climate-sensitive and proportion of populations sensitive to climate hazard due to factors such as topography and demography" (Chen et al. 2015: 3-4). The sensitivity score answers the question: How climate-sensitive are a country's sectors and population? The least sensitive country in the ranking is Australia (sensitivity score: 0.119), the most sensitive one is Guinea-Bissau (sensitivity score: 0.618).
- **Adaptive capacity**: "The ability of society and its supporting sectors to adjust to reduce potential damage and to respond to the negative consequences of climate events. In ND-

[5] The nine minerals and metals are bauxite, coking coal, cooper, iron ore, lithium, nickel, PGM, tin and tungsten.

[6] The index was developed by the Notre Dame Global Adaptation Initiative hosted at the University of Notre Dame.

GAIN adaptive capacity indicators seek to capture a collection of means, readily deployable to deal with sector-specific climate change impacts" (Chen et al. 2015: 4). The adaptive capacity score answers the question: How capable is a country to adapt to climate change? Italy has the strongest adaptive capacity in the ranking (adaptive capacity score: 0.175), Somalia is last in the ranking (adaptive capacity score: 0.877).

For each variable, we created four score groups (see Table 2) in order to directly rank and compare the countries with significant production and reserves.

Table 2: ND-GAIN score groups

Score group	Vulnerability	Exposure	Sensitivity	Adaptive Capacity
Low//strong ≤ 25% quantile	**Low**: 0.274-0.373	**Low**: 0.247-0.378	**Low**: 0.119-0.322	**Strong**: 0.175-0.379
Low to medium//strong to medium > 25% quantile and ≤ 50% quantile	**Low to medium**: 0.374-0.423	**Low to medium**: 0.379-0.442	**Low to medium**: 0.323-0.389	**Strong to medium**: 0.380-0.471
Medium to high//medium to weak > 50% quantile and ≤ 75% quantile	**Medium to high**: 0.424-0.520	**Medium to high**: 0.443-0.491	**Medium to high**: 0.390-0.469	**Medium to weak**: 0.472-0.618
High//weak > 75% quantile	**High**: 0.521-0.680	**High**: 0.492-0.722	**High**: 0.470-0.618	**Weak**: 0.619-0.877

Source: Categorisation developed in the project based on ND-GAIN (2018).

These score groups were created based on the quartiles of the entire range of a score per variable. This means, for example, that the group "low vulnerability" contains the 25 percent of all countries included in ND-GAIN with the lowest vulnerability score, hence, representing the least vulnerable countries. After the creation of the groups, the countries covered by this study were assigned to one of the four groups according to their respective score.

In the following sub-chapter, we show the assessment for bauxite as one example for a raw material climate change vulnerability assessment. This is followed by a comparison of the vulnerability of producing countries and reserves for all nine raw materials. Finally, the importance of exposure and adaptive capacity in determining vulnerability is illustrated by tin and iron ore producing countries and reserves.

3.1 Bauxite

Over 86 percent of bauxite production is concentrated in six countries. The market is currently dominated by Australia and China, which together account for over half of the current world production. While Australia is the top producer, Guinea has the largest reserves. Australia has a higher exposure to weather and climate hazards than Guinea, but a much stronger adaptive capacity. Therefore, Australia's vulnerability is considerably lower than Guinea's vulnerability (Guinea has the highest vulnerability score for bauxite producing countries). Vietnam has the third largest reserves. The country's exposure is higher than Guinea's exposure, but the adaptive capacity is stronger. Vietnam has medium to high vulnerability.

Table 3: Bauxite - Top Producing Countries (2016) and corresponding NG-Gain scores

Country	Share of world production	Share of world reserves	Vulnerability	Exposure	Sensitivity	Adaptive Capacity
Australia	29.82% (Rank 1)	20.00% (Rank 2)	0.294	0.480	0.119	0.273
China	23.64% (Rank 2)	3.33% (Rank 6)	0.389	0.448	0.324	0.394
Brazil	12.51% (Rank 3)	8.67% (Rank 4)	0.381	0.501	0.256	0.385
Guinea	11.45% (Rank 4)	24.67% (Rank 1)	0.537	0.436	0.403	0.729
India[7]	8.69% (Rank 5)	2.77% (Rank 9)	0.497	0.572	0.383	0.536
Vietnam[8]	0.44% (Rank 19)	12.33% (Rank 3)	0.475	0.491	0.451	0.482
Total[9]	**86.55%**	**71.76%**				

Own figure, results based on USGS (2018), ND-GAIN (2018).

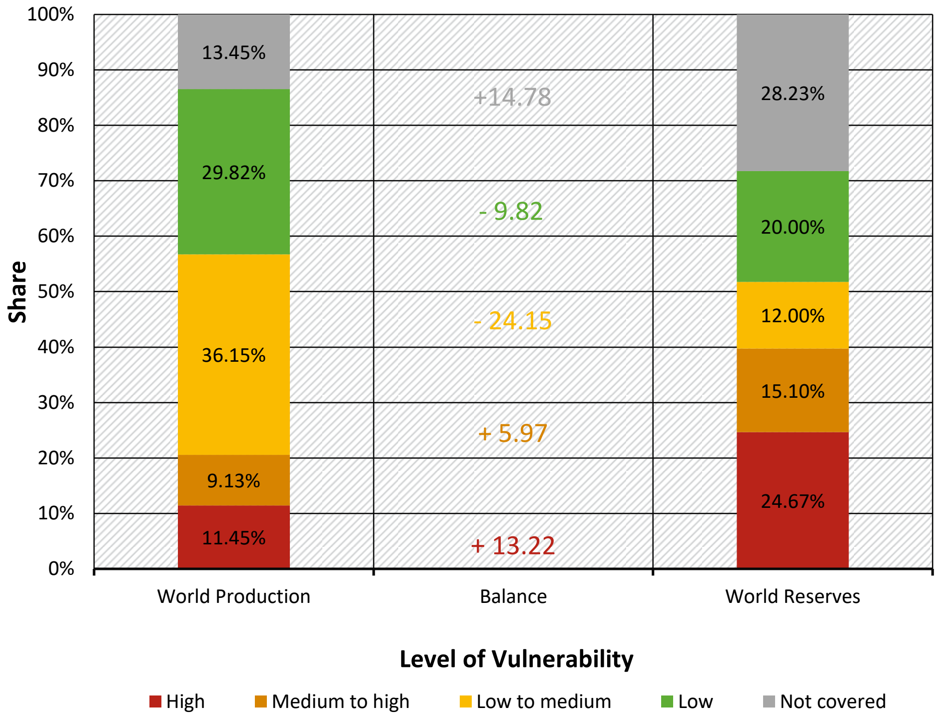
Comparing the total share of bauxite production and reserves, we can see that the share of reserves in countries with high vulnerability and medium to high vulnerability increases while the share of reserves in countries with low to medium and low vulnerability decreases (Figure 1). This is due to large reserves in the highly vulnerable country Guinea and the medium to highly vulnerable country Vietnam. The production of bauxite could therefore become more vulnerable in the future, increasing the risk negative environmental impacts and supply disruptions.

[7] Although the top four producing countries already produce more than 75%, India is included because its current world production is still considerable and it is facing serious climate challenges.

[8] Vietnam's contribution to the current world production is insignificant. However, it possesses the third largest amount of reserves, which is why it was included.

[9] Without India and Vietnam, the value would be 77.42%.

Figure 1: Bauxite Production and Reserves - Vulnerability



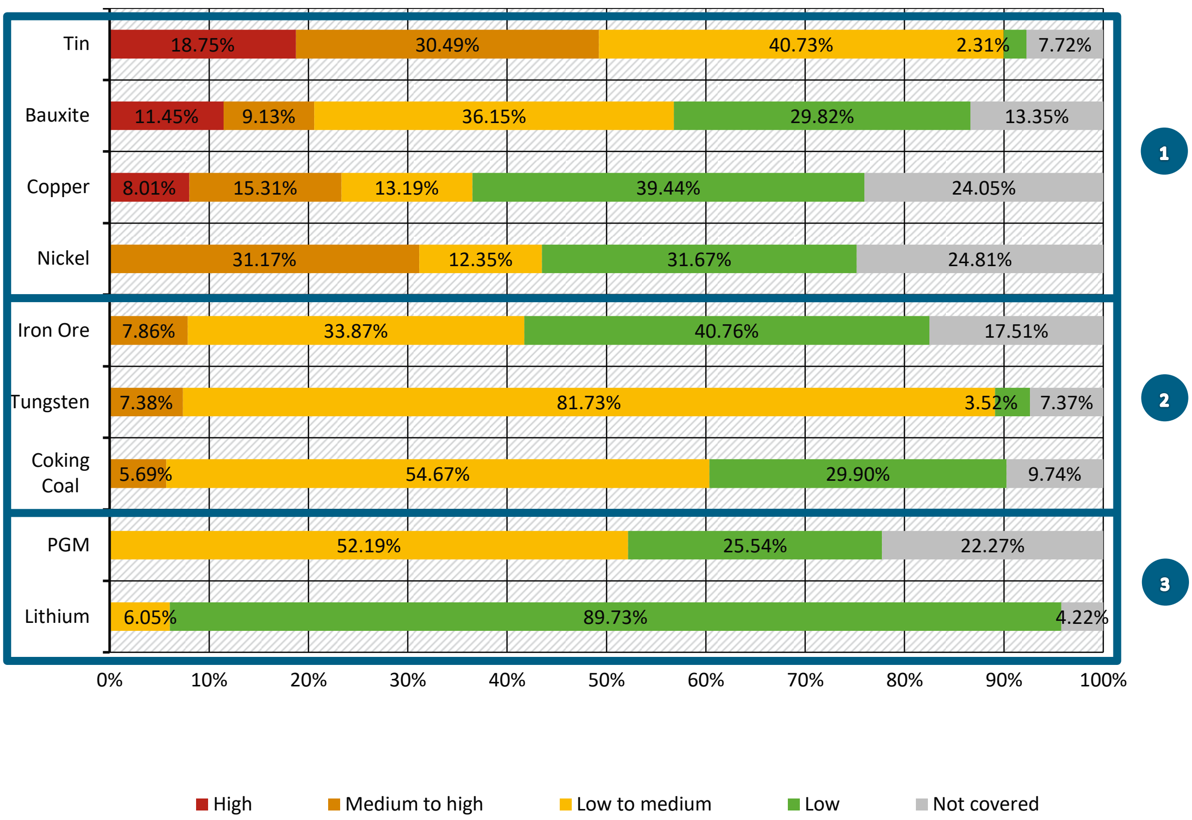
Own figure, results based on USGS (2018), ND-GAIN (2018).

3.2 Vulnerability ranking of all nine raw materials

To provide an overview of all nine raw materials assessed, we ranked the respective results according to the vulnerability of their producing countries (Figure 2). Comparing the results, the raw materials can be divided into three groups according to the vulnerability of the countries they are produced in:

- Group 1: Raw materials, which are produced in countries with a high to medium vulnerability: Tin, bauxite, copper and nickel.
- Group 2: Raw materials, which are produced in countries with a medium to low vulnerability: Iron ore, tungsten and coking coal.
- Group 3: Raw materials, which are produced in countries with low vulnerability: PGM and lithium.

Figure 2: Comparison of the vulnerability of producing countries

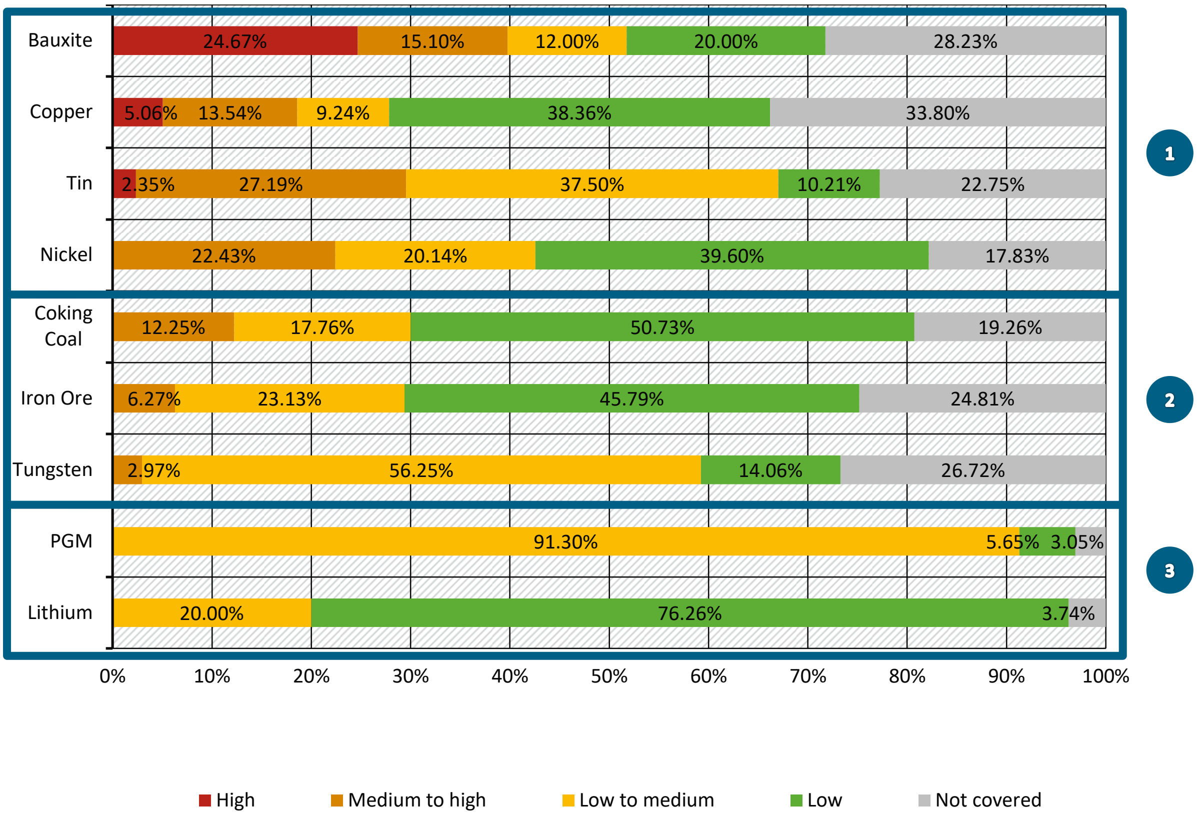


Own figure, results based on USGS (2018), ND-GAIN (2018).

As described in a previous paragraph, the forecast is based on the share of reserves to assess which countries might become more important in the future. By focusing on reserves, the picture slightly changes (Figure 3). The raw materials stay in the same vulnerability group, yet the ranking of raw materials per group changes:

- Group 1: Countries with bauxite reserves are more vulnerable than bauxite producing countries. Countries with copper, tin and nickel reserves are less vulnerable than the respective producing countries.
- Group 2: Countries with coking coal reserves are a bit more vulnerable than coking coal producing countries. The vulnerability for countries with iron ore reserves remains almost the same. The vulnerability of countries with tungsten reserves is lower than for tungsten producing countries.
- Group 3: Countries with PGM and lithium reserves keep the same rank. Yet, the share of countries with low to medium vulnerability is higher than for producing countries.

Figure 3: Comparison of the vulnerability of reserves

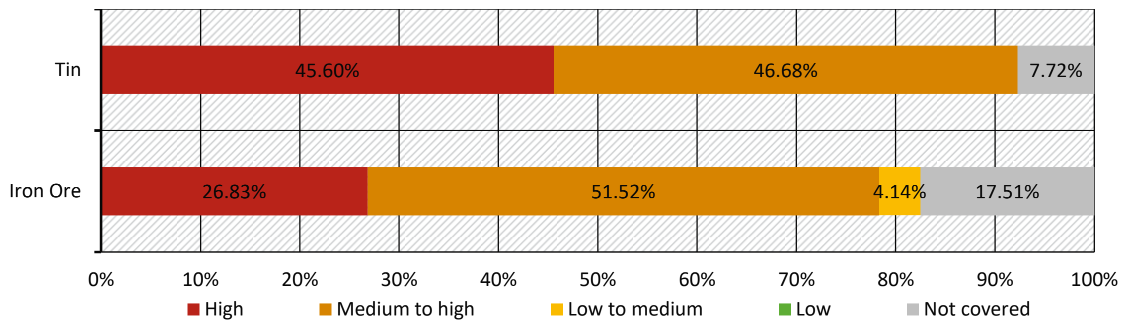


Own figure, results based on USGS (2018), ND-GAIN (2018).

3.3 Crucial factors in determining vulnerability: Exposure and adaptive capacity

The results of the climate change vulnerability assessment of the different raw materials underline the relevance of a country's exposure and adaptive capacity. To illustrate that we compare these two variables and the vulnerability of countries which produce tin and iron ore. For exposure, among the assessed raw materials both tin and iron ore producing countries have a high score (Figure 4).

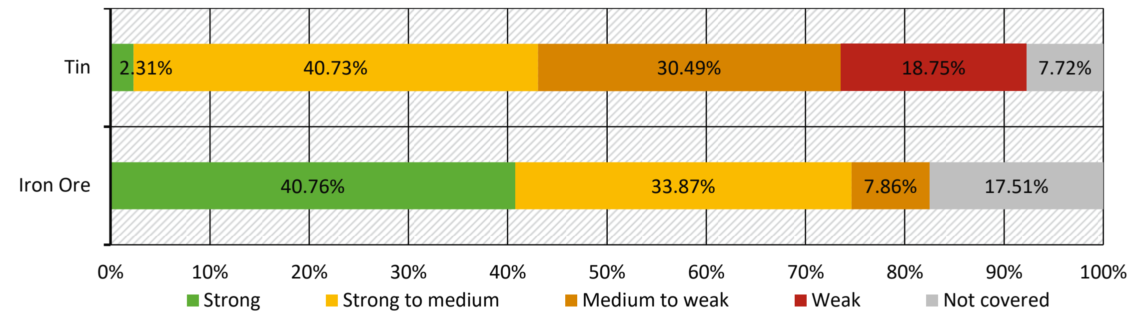
Figure 4: Tin and Iron Ore Production - Exposure



Own figure, results based on USGS (2018), ND-GAIN (2018).

However, tin and iron ore producing countries have very different levels of adaptive capacity. While tin producing countries have a weak and medium to weak adaptive capacity, iron ore producing countries have a strong and strong to medium adaptive capacity (Figure 5).

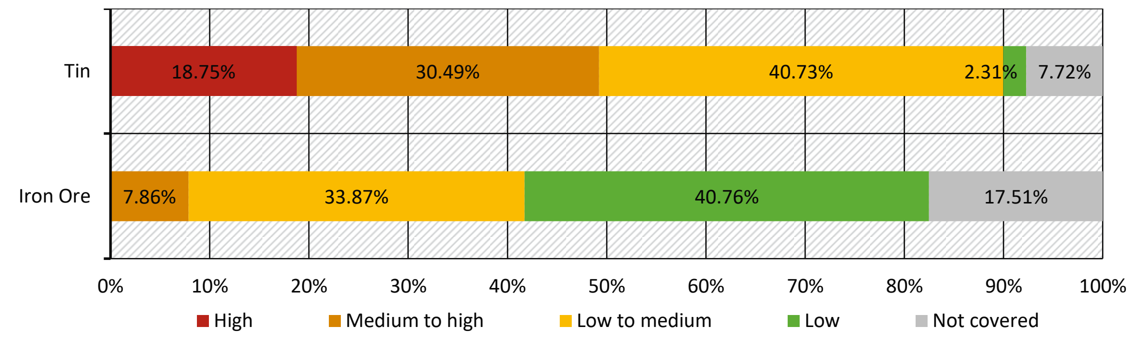
Figure 5: Tin and Iron Ore Production - Adaptive Capacity



Own figure, results based on USGS (2018), ND-GAIN (2018).

This means in terms of vulnerability that tin producing countries have a quite high vulnerability while the vulnerability of iron ore producing countries is mostly low or low to medium (Figure 6).

Figure 6: Tin and Iron Ore Production - Vulnerability



Own figure, results based on USGS (2018), ND-GAIN (2018).

This underlines the importance of improving adaptation capacities: Vulnerability is considerably lower when adaptive capacity is strong. The adaptive capacity of countries can be improved to make them more resilient.

However, exposure is still a very relevant factor. Experiences have shown that also countries with a high adaptive capacity can be negatively impacted by climate change impacts (e.g. the severe floods in Australia in 2010).

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