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KlimRess – Impacts of climate change on mining, related environmental risks and raw material supply

Case study on tungsten and nickel mining in Canada

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KlimRess – Impacts of climate change on mining, related environmental risks and raw material supply

Case study on tungsten and nickel mining in Canada

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Abstract

The following case study is one of five country case studies carried out as part of the project 'Impacts of climate change on the environmental criticality of Germany's raw material demand' (KlimRess), commissioned by the German Federal Environment Agency (Umweltbundesamt, UBA). The project team comprised adelphi, ifeu Heidelberg and the Sustainable Minerals Institute of the University of Queensland. The aim of the project was to assess how climate change potentially affects the environmental risks of mining and raw material supply chains.

This case study analyses three production facilities in Canada: the Voisey's Bay (nickel) mine and the refinery at Long Harbour, located in northeastern Canada and the Cantung (tungsten) mine located in the Northwest Territories. Both of are subarctic climate regions. At the Cantung mining site, which largely operates underground, land use is mostly associated with processing facilities, tailings ponds, and ore stockpiles. While waste rock from mining and tailings from the processing plant constitute the major solid waste streams, waste rock is utilised as a backfill and tailings are disposed in the tailings pond. Most of the process water is recovered and reused, and the remaining water undergoes a treatment process before it is discharged into the environment. This applies to the Voisey's Bay (nickel) mining site, too. While the mining infrastructure at Voisey's Bay has a minimal impact on the surrounding ecosystem thanks in part to the mine operator's progressive reclamation program, it still has a large land footprint and emits large amounts of dust, being an open pit mining operation. At the nearby Long Harbour nickel refinery, most of the environmental impacts are related to emissions and waste production. The refining process also generates potentially acid generating waste, which requires neutralization and permanent underwater storage.

The projected temperature increases in both regions could lead to an increase in forest fires. Fires could damage the mining sites, reducing or interrupting mining production, and put mineworkers and biodiversity at risk. An overflow or breach of the tailing storage facilities at the Cantung mining site could lead to damages and/or contamination of the nearby river system. While it is unknown whether permafrost degradation, which is a risk specific to (sub)arctic climate regions, could negatively impact the Cantung mining site, the Voisey's Bay mine was designed to manage these impacts. The nickel refinery at Long Harbour could also be impacted by flooding events that release sediment-laden water into the environment. The potential hazard of such an event is difficult to estimate. Climate change could also affect the dispersion and behaviour of air emissions. Finally, as both mining sites are located in remote regions, climate impacts such as heavy wind, heavy rain, flooding, erosion, landslides and fires can lead to supply interruptions.

Kurzbeschreibung

Die vorliegende Fallstudie ist eine von fünf Länderfallstudien des im Auftrag des Umweltbundesamtes (UBA) durchgeführten Projekts „Auswirkungen des Klimawandels auf die ökologische Kritikalität des deutschen Rohstoffbedarfs“ (KlimRess). adelphi, das ifeu (Institut für Energie- und Umweltforschung Heidelberg) und das Sustainable Minerals Institute der University of Queensland untersuchten dabei die möglichen Auswirkungen des Klimawandels auf mit dem Bergbau einhergehende Umweltrisiken und Rohstofflieferketten.

Diese Fallstudie analysiert drei kanadische Produktionsstätten mit subarktischem Klima: Im Nordosten wird Nickel im Bergwerk Voisey's Bay abgebaut und in Long Harbour verhüttet, während Wolfram im Cantung-Bergwerk in den Northwest Territories gewonnen wird. Feste Abfallströme ergeben sich hauptsächlich durch den Abraum aus dem Bergbau und die Reststoffe aus der Aufbereitungsanlage. Der größte Teil des Prozesswassers wird in Cantung und in Voisey's Bay wiederverwendet. Insgesamt sind die Auswirkungen auf die Ökosysteme um Voisey's Bay (Nickel) – zum Teil durch das progressive Rekultivierungsprogramm des Minenbetreibers – nur minimal. Der Tagebau hat jedoch einen hohen

Landverbrauch und verursacht zusätzlich große Mengen an Staub. Cantung (Wolfram) hingegen ist weitgehend durch Untertagebergbau gekennzeichnet, daher entfällt hier der meiste Landverbrauch auf Verarbeitungsanlagen, Absatzteiche und Halden. In der Nickelverhüttung in Long Harbour entstehen die meisten Umweltauswirkungen durch feste Reststoffe, die zudem potentiell säurebildend sind, und Emissionen.

Die erwarteten Temperaturanstiege in beiden Regionen lassen auf ein erhöhtes Risiko für Waldbrände schließen. Brände könnten die Abbaustätten beschädigen, die Produktion unterbrechen sowie Bergleute und die lokale Biodiversität gefährden. Eine Beeinträchtigung des Rückhaltebeckens am Wolframabbauort Cantung könnte zur Verschmutzung des nahegelegenen Flusssystems führen. Während das Nickelbergwerk in Voisey's Bay auf variablen Permafrost eingestellt ist, ist es unklar, ob das Abschmelzen von Permafrost das Cantung-Wolframbergwerk beinträchtigen könnte. Die Weiterverarbeitungsstätte für Nickel in Long Harbour könnte auch von Überschwemmungen betroffen sein, was potentiell zu Wasserverschmutzung in der Gegend führen könnte. Der Klimawandel könnte auch Luftemissionen beeinflussen. Starker Wind, starker Regen, Überschwemmungen, Erosion, Erdrutsche und Brände können in beiden abgelegenen Abbaugebieten zu Unterbrechungen der Produktion sowie der Versorgung der Bergwerke mit Lieferungen führen.

Table of Contents

List of Figures 7

List of Abbreviations 8

1 Introduction 9

1.1 Project background 9

1.2 Selection of case studies 9

1.3 Content and structure of case studies 10

2 Overview of climatic conditions and projected changes 12

2.1 Polar or subpolar regions 12

2.2 Coastal regions 13

2.3 Canada 13

3 Overview of the mining sector 15

4 Overview of mining sector governance 16

4.1 Disaster risk management and climate change adaptation 16

4.2 Environmental governance 17

4.3 Indigenous people 18

4.4 Mining-related conflicts 19

5 Case study: tungsten mining 21

5.1 The global value chain of tungsten 21

5.2 Site specific overview – Cantung mine, Canada 21

5.2.1 Overview of transportation systems and routes 22

5.3 Extraction and processing technologies 23

5.3.1 Extraction and processing technologies at Cantung mine 23

5.4 Environmental impacts and mitigation measures 23

5.4.1 Cantung mine 23

5.5 Current climate impacts and risks 25

5.5.1 Current climate 25

5.5.2 Past weather extremes 25

5.6 Climate change impact assessment 25

5.6.1 Potential climate impacts on the Cantung mine 26

5.6.2 Potential climate impacts on the transport routes and air transportation 27

6 Case study: nickel mining 29

6.1 The global value chain of nickel 29

6.2 Site specific overview – Voisey’s Bay, Labrador, Canada 29

6.2.1 Overview of transportation systems and routes 30

6.3 Extraction and processing technologies 30
  6.3.1 Extraction and processing technologies at Voisey’s Bay 30
6.4 Environmental impacts and mitigation measures 31
  6.4.1 Voisey’s Bay mining area 31
  6.4.2 Long Harbour nickel refinery area 33
6.5 Current climate impacts and risks 34
  6.5.1 Current climate 34
  6.5.2 Past weather extremes 34
6.6 Climate change impact assessment 35
  6.6.1 Potential climate impacts on the Voisey’s Bay mine 36
  6.6.2 Potential climate impacts on the transport routes, air and maritime transportation 37
  6.6.3 Potential climate impacts on the Long Harbour refinery 37
  6.6.4 Potential climate impacts on the ports 38
7 Summary and conclusions 40
8 References 44

List of Figures

Figure 1: Map of Canada indicating Köppen-Geiger climate classification and location of mining sites......10

Figure 2: Tungsten global value chain and ranking for selected countries (2016)......21

Figure 3: Climate impact chain for tungsten......28

Figure 4: Nickel global value chain and ranking for selected countries (2016).29

Figure 5: Climate impact chain for nickel......39

List of Abbreviations

AMD	Acid and Metalliferous Drainage
APT	Ammonium Paratungstate
AR4	Fourth Assessment Report
AR5	Fifth Assessment Report
CRCM	Canadian Regional Climate Model
EA	Environmental Assessment
GDP	Gross Domestic Product
MAC	Mining Association of Canada
MoU	Memorandum of Understanding
NATCL	North American Tungsten Corporation Ltd
PAG	Potentially Acid Generating
PGM	Platin Group Metal
RCP	Representative Concentration Pathway (Scenario)
UBA	Umweltbundesamt (German Federal Environment Agency)
UNDRIP	United Nations Declaration on the Rights of Indigenous People
VNL	Vale Newfoundland and Labrador Limited

1 Introduction

1.1 Project background

The following case study is one of five country case studies of the project 'Impacts of climate change on the environmental criticality of Germany's raw material demand' (KlimRess), commissioned by the German Federal Environment Agency (*Umweltbundesamt*, UBA). The project team comprised adelphi, ifeu Heidelberg and the Sustainable Minerals Institute of the University of Queensland. The aim of the project was to assess how climate change can potentially impact the environmental risks of mining and affect raw material supply chains.

Based on a systematic assessment of the case study results, the project team identified the most significant climate impacts across case studies. The project team also explored the links between climate change and a newly developed method to evaluate environmental hazard potentials as part of an environmental criticality assessment (OekoRess method) in order to inform the discussion of environmental criticality. Lastly, the project team combined data on current production and expected future production of nine raw materials with data on countries' vulnerability to climate change in order to identify patterns of particularly vulnerable raw materials and producing countries. The results are published in the final report of the project (see Rüttinger et al., 2019).

Based on these results, the project team developed recommendations on how to best adapt the mining sector, how to incentivise climate change adaptation measures in mining and how to foster effective mechanisms for the exchange of knowledge and expertise on the topic globally. These policy recommendations were published separately in the form of a recommendation paper (see van Ackern et al., 2019).

1.2 Selection of case studies

The case studies conducted as part of the project covered five different (climatic) regions:

1. Arid regions with water stress
2. Humid tropical regions
3. Polar or subpolar regions
4. Temperate regions
5. Coastal regions

In addition, the case studies covered nine raw materials that were identified and selected based on the following criteria:

- The importance of minerals and metals for future and environmental technologies
- Base metals, alloys and auxiliary materials important for the German economy

Other criteria that informed the case study selection were the climate change vulnerability of countries, their governance contexts and the prevalence of conflicts related to mining. The aim was to select a set of most different cases. Further selection criteria were the political relevance for Germany, the research institutions' partner networks and the availability of data.

The selected metals and minerals were: bauxite, coking coal, copper, iron ore, lithium, nickel, PGMs, tin and tungsten.

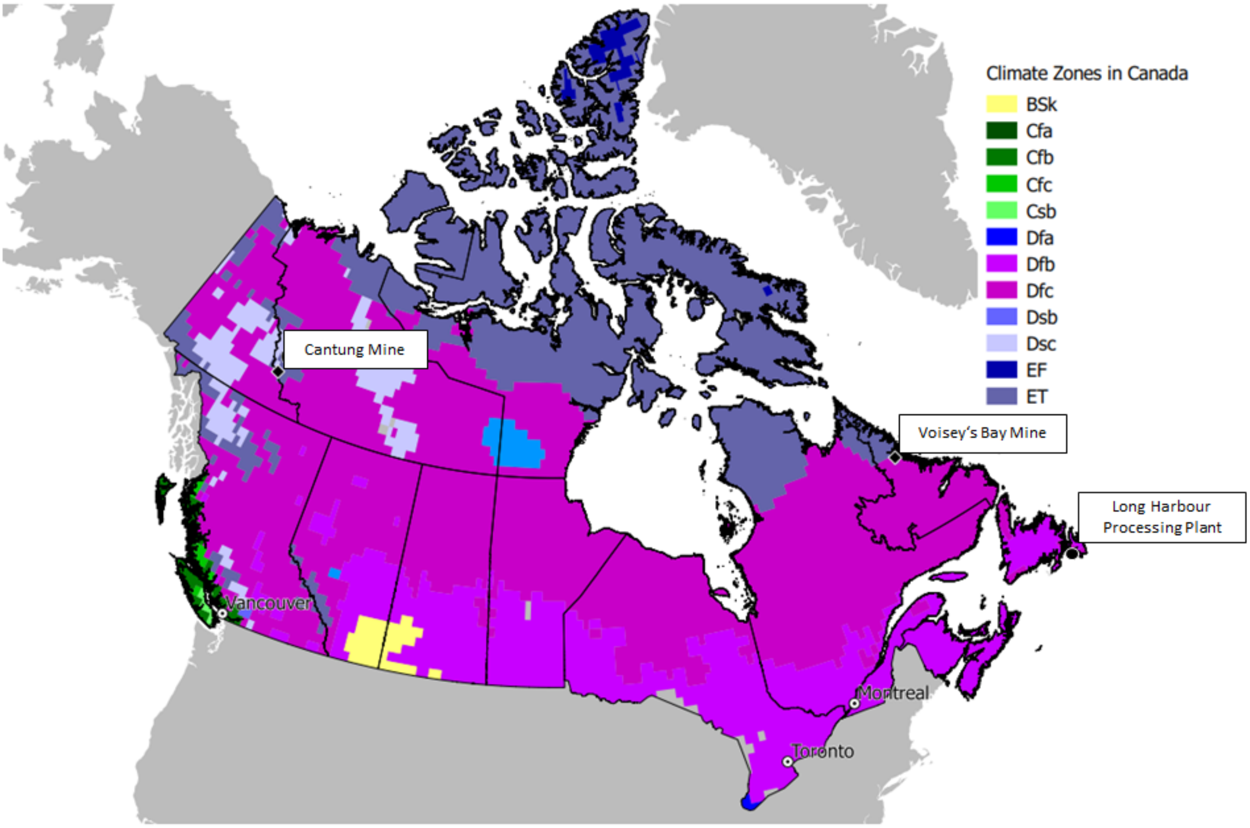
Each case study analysed a chosen mine site and the processing steps (to the extent these take place in the relevant country). The project team evaluated the environmental and supply risks potentially caused by climate stimuli and/or direct climate impacts for each of the mining and processing sites.

1.3 Content and structure of case studies

This study focuses on the following resources and mining sites in Canada (see Figure 1):

- Tungsten: Cantung mine on the Northwest Territories-Yukon border (subarctic climate)[1]
- Nickel: Voisey's Bay mine in Newfoundland and Labrador (subarctic climate)

Figure 1: Map of Canada indicating Köppen-Geiger climate classification and location of mining sites



Source: Maps prepared by adelphi using QGIS Geographic Information System (http://qgis.osgeo.org); climatic regions based on Rubel and Kottek, 2010.

The case studies are based on extensive secondary research, including the scientific literature, as well as reports and statements published by national government agencies, civil society organisations, mining and processing companies and the media.

First, the case studies provide a brief overview of the climatic conditions and projected climatic changes (in the case of this study, for polar/subpolar and coastal regions and for Canada as a whole). The studies then present an overview of the country's mining sector and its economic relevance as well as a summary of the country's mining governance (including disaster risk management, climate change adaptation, the environment, indigenous people and mining-related conflicts).

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[1] The Cantung mine stopped tungsten production in 2015 due to low global metal prices. Prior, it was one of the most significant tungsten producers outside of China. Cantung's known reserves allow for a few more years of operation, however combined with the proposed Mactung mine (located close to the existing mine, in similar geological settings), both mines account for about 15% of the world's tungsten reserves. Therefore, it is likely that the Cantung and the proposed Mactung mine will continue production if global tungsten prices rise again.

Second, we analyse the resources separately, covering the following topics:

- The global value chain of the respective resource
- Site-specific overview of the mine site
- Extraction and processing technologies
- Current environmental impacts and mitigation measures
- Current climate impacts and risks
- Climate change impact assessment:

The climate impact assessments are based on the *Guidelines for Climate Impact and Vulnerability Assessment*, published by the UBA (Buth et al., 2017). The Guidelines propose a combination of concepts outlined in the *Fourth Assessment Report* (AR4) (IPCC, 2007) and *Fifth Assessment Report* (AR5) (IPCC, 2014) of the Intergovernmental Panel on Climate Change. We use the terminology proposed by the Guidelines. To increase the compatibility across the Guidelines and the new AR5 approaches, we also indicate in the right margin the AR5 terminology in the climate impact chain diagrams (i.e. hazards, exposure and risks).

Finally, we summarise and discuss main findings of the case study.

2 Overview of climatic conditions and projected changes

The regions in Canada, where the nickel and tungsten mining operations analysed in the case study are located, are characterised by a subarctic climate and have long coastlines.

2.1 Polar or subpolar regions

Polar and subpolar regions are located around the South and the North Poles. They are characterized by low temperatures throughout the year and a pronounced seasonality. These areas can be defined by astronomical features (Arctic/Subarctic Circle) or physical characteristics of the environment (climate, vegetation) (NSIDC, 2018). The Arctic Circle, for example, draws the line for the polar region at 66.34°N/S, demarcating an area where the sun does not set during summer solstice or rise during winter solstice. However, when taking both climate and vegetation into account, this results in a geographically wider distribution of the polar and subpolar region. Based on these environmental characteristics, polar regions can be defined as areas north of the arctic tree line (resp. south of the subarctic tree line) or areas with polar climate (NSIDC, 2018). According to the Köppen-Geiger climate classification, polar climates (all climate types E) include all areas in which the average temperature of the warmest month (July) stays below 10°C (ET), or even below 0°C (EF) (Peel et al., 2007). Subpolar or boreal climates are the most poleward D climates, which generally occur in the 50 and low 60 degrees of North latitude. According to Köppen-Geiger, D climates are continental/microthermal climates with an average temperature above 10°C in their warmest months and the coldest month average below 3°C.

There are several changes that can be observed and related to global warming in these zones. The tree line, which is mainly influenced by climatic conditions and which is an indicator for the division between polar and subpolar (boreal) climates, is generally, though not in all regions, shifting northward (resp. southward on the southern hemisphere) and upwards (in mountain ranges) (Larsen et al., 2014). Moreover, there is significant evidence of an increased shrub growth both in the sub-Arctic and Arctic areas, which is an indicator for a warming climate (Larsen et al., 2014; Pajunen et al., 2012; Lara et al., 2018). Also, as evident in Canada, forests in the subpolar region (boreal) have increased in density (Danby and Hik, 2007). The larger biomass that is being built-up creates a heightened risk of wildfires (Gillis and Fountain, 2016).

In addition, climate change is impacting terrestrial and freshwater ecosystems, as well as the ranges, distribution and diversity of animal species in polar and subpolar regions (Larsen et al., 2014; ACIA, 2004). Snow and ice, essential parts of the polar ecosystems, are also affected: ice in the Arctic has decreased significantly, particularly during summers and autumns (Bush et al., 2014; Melillo et al., 2014). Since 1978, minimum Arctic sea ice extent decreased by over 40% and its thickness by over 50%; depending on the scenario, the Arctic has been projected to be ice-free in summer before the mid-century. Similarly, snow cover on land has decreased over the last decades, especially during springs (Melillo et al., 2014).

In the future, these trends are likely to continue and intensify, and projected impacts also include: increased coastal erosion as the sea level rises further; destruction of transportation, buildings and other infrastructure; higher UV-radiation; as well as an increased marine access for transport and to resources (ACIA, 2004).

Regions in high latitudes are most prone to global warming and experience the most striking transformations due to climate change. This effect is called the arctic or polar amplification[2] and relates to the phenomena that arctic regions react more sensitively to changes in the global climate. The temperature pattern in the arctic is dominated by heat transfer from the equator poleward. This heat transfer happens by atmospheric and oceanic circulations. The stronger the atmospheric greenhouse effect is,

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[2] More background information on the arctic amplification see i.e. Lee (2014); Pithan and Mauritsen (2014).

the more powerful the poleward heat transfer gets (Lee, 2014). In addition to that, local processes such as melting ice caps amplify warming effects (Pithan and Mauritsen, 2014).

2.2 Coastal regions

Coastal regions are geographical areas that lie in all climatic zones. Coastal systems and low-lying areas are defined as areas close to the mean sea level (Wong et al., 2014).

According to AR5, the global sea level is very likely to rise. There is high confidence that coasts will be impacted by submergence, flooding, coastal erosion and salt water intrusion caused by relative sea level rise which can vary substantially from the projected global mean sea level rise based on location. General sea level rise will also mean an increase in extreme sea levels[3] (Wong et al., 2014).

Coastal ecosystems will suffer from increasing ocean acidification and warming (Wong et al., 2014). In terms of extreme weather events, in the tropics, cyclone frequency is likely to decrease or not to change, while the intensity of tropical cyclones is likely to increase (Wong et al., 2014). The intensified impacts of cyclones (e.g. storm surges, storm waves, coastal flooding, erosion and the potential damage to coastal infrastructures) would be felt most strongly in coastal regions (Corlett, 2014). Projections for increased winds and waves generally have low confidence (Wong et al., 2014).

Population growth, economic development and increasing urbanisation in coastal areas will put additional pressure on natural and human coastal systems. Coastal populations, especially in tropical countries, are most vulnerable to sea level rise (Wong et al., 2014; Trewin, 2014). AR5 states with high confidence: “Without adaptation, hundreds of millions of people will be affected by coastal flooding and will be displaced due to land loss by year 2100; the majority of those affected are from East, Southeast, and South Asia” (Wong et al., 2014: 364).

2.3 Canada

Due to its geographic position in high latitudes and its vast extend, Canada is characterised by temperate and oceanic climates as well as continental and harsh polar (artic) climates. The major part of the country is covered by boreal forest and subpolar (boreal) climate is predominant. On the west coast, temperate oceanic (Cfb, Cfc) climates can be found. Most parts of the south are characterized as warm summer humid continental climate (Dfb), but in some parts of the central south (south Alberta and south-west Saskatchewan) cold steppe climate (BSk) occurs. At the northern coast, the climate is arctic tundra (ET) and ice climate (EF) (Rubel and Kottek, 2010).

Climate observations for Canada are available from the mid of the twentieth century onward. This data shows a significant warming trend which has been well above the global average and most pronounced in the north. This is especially notable in the winter season, where minimum temperatures experienced the fastest rise and winters tend to become milder (Warren and Lemmen, 2014; ECCC, 2017).

This trend is likely to continue with projected temperature increases being the highest for the winter season. In the period 2081-2100, the projected warming ranges from 2.4°C (RCP2.6) to 8.9°C (RCP 8.5), most pronounced in the arctic provinces Nunavut (from 3.0°C under the RCP2.6 scenario to 12.9°C under the RCP8.5 scenario) and Northwest Territories (from 3.1°C under the RCP2.6 scenario to 12.3°C under the RCP8.5 scenario). Summers are also projected to get warmer; though the rise of temperatures is not as severe as for the winter season (Canadian average ranges from 1.3°C to 5.6°C for the RCP2.6 scenario and for the RCP8.5 scenario, respectively). The strongest rise of summer temperatures is projected for Manitoba and Ontario in Canada’s south east (ECCC, 2017).

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[3] Description of extreme sea levels: “Extreme sea levels are those that arise from combinations of factors including astronomical tides, storm surges, wind waves and swell, and interannual variability in sea levels. Storm surges are caused by the falling atmospheric pressures and surface wind stress associated with storms such as tropical and ETCs [extratropical cyclones] and therefore may change if storms are affected by climate change” (Wong et al., 2014: 370).

Also precipitation levels are increasing. The country has become wetter. Similar to temperatures, this trend is also more pronounced in the northern arctic regions. With milder winters, the precipitation is also projected to increase throughout most of the country. On a national average, projections show a precipitation increase of 9% in the mid and end of 21st century under the RCP2.6 scenario and 38% for end of the century under the RCP8.5 scenario. Summer precipitation changes only little with regional exceptions in the Northwest Territories, Nunavut and Yukon (~ +20% under the RCP8.5 scenario). Projections do not show a considerable decrease of precipitation for any region in Canada (ECCC, 2017).

The Canadian Regional Climate Model (CRCM) projects "an increase in future 20-year (and longer) return values of 1 to 7 day precipitation extremes for most parts of Canada (i.e. the 20-year events were projected to have larger precipitation totals)" (using the A2 emission scenario) (Warren and Lemmen, 2014: 36). However, projections of extreme precipitation are often associated with large uncertainties and findings suggest that "the CRCM underestimates precipitation extremes over most of Canada, when evaluated against observed changes" (Warren and Lemmen, 2014: 36).

Warmer and dryer summers increase the frequency and severity of wildfires in boreal forests, which endangers infrastructure and human health (Warren and Lemmen, 2014).

Areas characterised by permafrost[4] are a particular challenge. Permafrost is distributed over almost all the northern parts of the country. It is crucial, not only for an intact environment but also for intact buildings, infrastructure and a functioning transportation sector. But it is highly climate sensitive and threatened by warmer and wetter conditions (Warren and Lemmen 2014; Matthews 2014). Mild and rainy winters degrade permafrost soils. The thawing ice destabilizes the ground of buildings and infrastructure. A late onset of frost seasons and early melting shortens the timeframe, when winter roads (i.e. roads on frozen lakes) can be used to connect remote areas (Matthews, 2014; Hori, 2016). This complicates the supply not just for mines, but also for other branches and for many remote settlements. Hence, large parts of the infrastructure in the north depend on winter freezing of the soil and the lakes (Warren and Lemmen, 2014). In addition, thawing permafrost and decreasing sea ice enhance coastal erosion. Canada coastline is highly at risk, because it has the longest coastlines that fall into one national territory. Lastly, permafrost thawing is not only triggered by climate change but is also contributing itself to climate change: The thawing frees stored carbon and leading to wetter landscapes and higher methane emissions into the atmosphere (Miller et al., 2018).

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[4] Natural Resources Canada defines permafrost as a state of the ground (i.e. soil or rock) "that remains at or below a temperature of 0°C for long periods […]. The minimum period is from one winter, through the following summer, and into the next winter; however, most permafrost has existed for much longer" (Natural Resources Canada, 1995).

3 Overview of the mining sector

Canada has rich natural resources and produces a wide range of minerals and metals. It is among the top five producer countries worldwide for potash, uranium, niobium, nickel, gemstones, cobalt, aluminium, platinum group metals (PGMs), indium, sulphur, diamonds, titanium and gold (Marshall, 2017). Until 2015, it was also one of the major global tungsten producers (USGS, 2017b).

Mining operations take place in all Canadian provinces and territories. As of 2016, there were 1,201 operating mines in Canada, of which 65 were metal mines and 1,135 were non-metal mines. Regarding further mineral processing, Canada has 33 non-ferrous metal smelters in seven different provinces (Marshall, 2017).

In 2015, the mining sector contributed C$60.2 billion to the Canadian GDP which was 3.2% of the country's total GDP. While mineral extraction and support activities accounted for C$27.9 billion, downstream mineral processing and manufacturing accounted for C$32.3 billion (Natural Resources Canada, 2016). In 2016, the extractive sector[5] payed C$7.1 billion in taxes, royalties and other forms of disbursements to Canadian governments (Marshall, 2017).

The mining industry directly employed 403,000 persons[6] in 2016 (Natural Resources Canada, 2017a). The sector pays the highest wages in Canada (Marshall, 2017). Natural Resources Canada estimates that the minerals and metals sector generated 193,000 additional jobs in other sectors than mining (i.e. indirect employment) (Natural Resources Canada, 2017a).

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[5] Includes also the oil and gas sector.

[6] This figure comprises mining (including services) and primary manufacturing, downstream of the minerals sector.

4 Overview of mining sector governance

4.1 Disaster risk management and climate change adaptation

Although Canada already experiences above average temperature increases and other climate change impacts, the OECD environmental review for Canada finds that adaptation implementation is still in its beginnings (OECD, 2017). In 2011, the Canadian government created the Federal Adaptation Policy Framework which guides domestic climate change adaptation activities and establishes the role of the federal government, visions and objectives for adaption action (Government of Canada, 2011). In 2012, Natural Resources Canada (i.e. Canadian ministry responsible for natural resources) launched Canada's Climate Change Adaptation Platform. The platform serves as forum for the national adaptation community: "Members include representatives from federal, provincial, and territorial governments, industry, communities, academics, and Indigenous, professional, and not-for-profit organizations" (Natural Resources Canada, 2017b). There are several issue- and sector-specific working groups, including one on mining.

In December 2016, the Canadian government and the first ministers of 11 out of 13 provinces and territories[7] agreed on the Pan-Canadian Framework on Clean Growth and Climate Change which is both a commitment to and a plan for Canada's climate change action (Pan-Canadian Framework, 2017). The framework was developed in a collaborative and participatory process, involving indigenous peoples, civil society and businesses (Pan-Canadian Framework, 2017; OECD, 2017). One of the four pillars of the framework is climate change adaptation and resilience building (Pan-Canadian Framework, 2017). Since 2017, the federal government made several important announcements which support the climate change adaptation pillar of the framework including the establishment of a Disaster Mitigation and Adaptation Fund with a budget of C$2 billion, the launch of a new Canadian Centre for Climate Services[8] and the creation of an expert panel on climate change adaptation and resilience (OECD, 2017; Government of Canada, 2018a; Government of Canada, 2018b). It remains to be seen how these policies and initiatives are implemented.

Over the past years, awareness for climate change adaptation in the mining sector increased significantly. In 2008, Natural Resources Canada published a comprehensive assessment of climate change impacts and adaptation – *From Impacts to Adaptation: Canada in a Changing Climate*. This assessment took a regional approach. Although mining was not discussed as intensively as other resource sectors, it identified several climate impacts for the mining sector which require adaptive measures, especially in Northern Canada and in Ontario (Lemmen et al., 2008; Warren and Lemmen, 2014).

The Climate Change Adaptation Platform working group dedicated to mining "helps facilitate a more resilient and sustainable mining sector in a changing climate" (Natural Resources Canada, 2017b). The mining working group undertook several projects which resulted in a number of studies. Supported by the mining working group, the Mining Association of Canada commissioned a survey to assess how its member companies perceive climate change risks and what actions they take to address them. The survey found that one-third of the polled companies view climate change as a low-level to medium-level risk to their business. Approximately the same number of companies has implemented concrete risk mitigation measures, mostly related to engineering and infrastructure improvement (Delphi Group, 2014).

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[7] The province of Saskatchewan is not part of the framework. Manitoba, initially neither part of the framework, joined in February 2018 (Manitoba, 2018).

[8] Environment and Climate Change Canada offers already information and data on historical climate, trends and scenarios (Seventh National Communication). The provinces and territories have also climate information services (Seventh National Communication).

In 2014, the federal government released an updated report on climate change impacts and adaptation – *Canada in a Changing Climate: Sector Perspectives in Impacts and Adaptation*. Instead of being structured according to regions as its precursor, this report accounted for climate change impacts and adaption in different sectors: natural resources (forestry, energy and mining), food production, industry, biodiversity and protected areas, human health and infrastructure (Warren and Lemmen, 2014). The mining sector received more attention and a separate chapter highlights a number of risks and opportunities linked to climate change for the sector along the whole mining cycle, including built infrastructure, transportation infrastructure, extraction and processing and daily operations (Lemmen et al., 2014). In its sixth national communication on climate change, Canada announced specific climate change impacts and adaptation assessments for marine coasts, transportation and mining sector (Sixth National Communication). While Natural Recourses Canada has published the assessments for marine coasts and transportation to date, an assessment of the mining sector is not yet available. However, both the assessment for marine coasts and transportation draw links to the mining sector (Lemmen et al., 2016; Palko and Lemmen, 2017).

In 2016, the Mining Association of Canada (MAC) and its member companies have decided to take further action on climate change mitigation and adaption. With regard to adaptation, they aim at linking climate change actions to the “Towards Sustainable Mining” protocol requirements and engaging further in the Adaptation Platform mining working group and the Mine Environment Neutral Drainage Program (MAC, 2016).

The Voisey’s Bay mine was included as a case study into the 2014 report *Canada in a Changing Climate: Sector Perspectives in Impacts and Adaptation*. While Vale acknowledges climate change and commits to climate change mitigation, the mine currently does not have a climate change adaptation plan. However, the mine has adaptive management practices in place, such as monitoring, observation and risk assessment of sea ice changes (Lemmen et al. 2014).

There is no information available whether the Cantung mine had adaptation measures in place while operating. If reopened in the future, it would be a good opportunity to plan and implement climate change adaptation measures.

4.2 Environmental governance

The environmental governance of the mining sector is multi-layered in Canada as the country has a federal system, consisting of ten provinces and three territories. Jurisdiction over environmental and mining affairs lies mostly with the provinces and territories, however, there are several overlaps with the federal government (Abdel-Barr and MacMillan, 2016; OECD, 2017).

The Canadian Environmental Protection Act 1999 (updated in 2012) is the main federal environmental statute, administered by the Minister of Environment and Climate Change (Government of Canada, 2017; OECD, 2017). Other key federal laws and regulations with particular relevance for the mining sector are the Metal Mining Effluent Regulation under the Fishers Act and the Canadian Environmental Assessment Act (Office of the Auditor General of Canada, 2010).

Under the Canadian Environmental Assessment Act, proponents of a mining project are required to report possible environmental impacts linked to federal matters such as indigenous peoples, fisheries, migratory birds, and cross-border impacts to the federal government (Hart and Hoogeveen, 2012). Depending on the project and the region, Environmental Assessment (EA) processes can vary substantially (Noble, 2016). Most provincial and territorial jurisdictions[9] require an EA in the early planning phase of a major mining project which follows several steps and has to consult with the public (Hart and Hoogeveen, 2012). Agreements between federal and provincial/territorial governments aim at reducing duplications of EA processes under different jurisdictions (OECD, 2017).

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[9] In the territories, federal statutes regulate the EA process (OECD, 2017).

Because the environmental assessment process was subject to criticism (also see paragraph 4.3 on indigenous people), the Minister of Environment and Climate Change appointed an expert panel which was tasked to evaluate the process in 2016 (OECD, 2017). This review had the aim of enhancing the credibility of EA in the public and the participation of indigenous peoples (OECD, 2017).

Following the recommendations of the expert panel, the Government of Canada proposed new legislation to reform the EA system substantially in February 2018 (Government of Canada, 2018c). The reform foresees, among other things, the establishment of a single agency responsible for assessments and the shift from EA to impact assessment, which also includes climate change considerations systematically into the assessment process. The assessment process is also subject to change. A new early planning and engagement phase, improved indigenous engagement and partnerships as well as enhanced public participation opportunities are important features of the new process (Government of Canada, 2018d). It remains to be seen whether this proposed legislation will be passed by the parliament.

Once an EA is granted, federal, provincial and territorial agencies environmental assume compliance assurance measures during mining construction, production and after closure (i.e. the promotion, monitoring and enforcement of compliance; liability for environmental damage). Environment and Climate Change Canada conducts inspections and investigations to monitor compliance, mostly under the Canadian Environmental Protection Act. There are various enforcement tools, e.g. warnings, criminal sanctions (courts impose fines) or administrative sanctions. Canada has several liability regimes which require clean up or compensation measures from polluters (OECD, 2017).

Regarding mine closure, mining companies are required to develop a mine closure and rehabilitation plan (Hart and Hoogeveen, 2012). Yet, only in a few provinces and territories, such a plan must be submitted before mining operations begin (Abdel-Barr and MacMillan, 2016). In addition, mining companies have to ensure that rehabilitation is also financed in cases of bankruptcies or mine site abandonment (Hart and Hoogeveen 2012).

Although Canada’s environmental governance is well developed, some problems still occur, as the following examples show. After the Cantung mine’s closure, inspectors of Indigenous and Northern Affairs Canada visited the mining site and found insufficient structures to control erosion, lagged spill reporting, a sediment leak from the mine’s quarry and various fuel leaks. The inspectors issued a warning, ordered clean ups and the maintenance of leaking structures (CBC News, 2016). Newspapers also reported on a 1,000 to 2,000 litres spill of mill tailings from a broken pipe and a 37,000 litres spill of partly-treated wastewater in 2015 (CBC News, 2015). While there is no information available whether the company was fined for the spill incidents, the Dehcho First Nation publicly raised concerns over the mill tailings spill as their water sources lie downstream from the mine (Zingel, 2015).

In 2016, a provincial court decided that Vale had to pay a C$30,000 fine for an untreated and lethal wastewater discharge from Voisey’s Bay mine into the Anaktalak Bay in 2013, violating the federal Fisheries Act. Canada’s Environmental Damages Fund received the majority of the fine (Government of Canada, 2016; Canadian Manufacturing, 2016).

4.3 Indigenous people

The 2016 Census registered over 1.6 million Canadians who identify themselves as indigenous, representing 4.9 per cent of the total population (Statistics Canada, 2017). There are three major groups of indigenous people: First Nations, Inuit and Métis (Indigenous and Northern Affairs Canada, 2017).

Section 35 of the Constitution Act from 1982 lays down the rights of indigenous peoples in Canada, but does not define what these rights imply. Several important Supreme Court decisions established that Section 35 requires the so-called duty to consult and accommodate in situations when the state’s activities might have adverse impacts for indigenous peoples (Ariss et al., 2017). In 2011, the federal government issued guidelines on how fulfil this duty in the federal context (Government of Canada, 2011).

The guidelines recommend that the government and government agencies should build on existing consultation mechanisms, such as EA processes (Government of Canada, 2011). A Supreme Court decision ruled that proponents of a mining project can implement the consultation process in lieu of the government. Provincial and territorial jurisdictions have their own approaches to the consultation of indigenous peoples, ranging from no or only community-specific policies to draft or interim guidelines (Bains and Ishkanian, 2016).

Although there exists the duty to consult and accommodate, Canada's indigenous population often feel excluded from decision-making over natural resource projects and have to face damages to their communities that go far beyond the benefits of those developments (OECD, 2017).

The agencies responsible for government decision-making increasingly turn to EA processes as instrument for consulting with indigenous communities (Craik, 2016). Yet, Canada's EA process has often failed at providing meaningful and fair participation to indigenous communities, as several court challenges against resource projects show (Noble, 2016). However, there are some EA processes that have "created an opportunity for Aboriginal communities to meaningfully influence projects, the scope of the assessment and, in some cases, the project's outcome" (Noble, 2016: 7).

The EA process for the Voisey's Bay mine is one example for meaningful indigenous participation (Noble, 2016). After years of conflict and legal challenge, two indigenous communities – the Innu Nation and the Labrador Inuit Association (preceded by the Nunatsiavut Government) – and the federal and provincial governments agreed on a memorandum of understanding (MoU) which laid down mutually agreed procedures for a joint EA process. Although the Innu and Inuit had no recognized land claims at that time, the MOU acknowledged them as legitimate decision-makers in the EA process (Noble, 2016). One major achievement of the EA process was the establishment of an Environmental Management Board which involves the Innu and Inuit and monitors the projects impacts after completion of the EA process. As additional outcomes, Vale and the Innu and Inuit entered into a shipping agreement which guaranteed the indigenous communities safe over-ice travel and hunting in winter as well as into an impact and benefit agreement (Noble, 2016).The agreement stipulated specific business, employment and training opportunities for the indigenous communities at Voisey's Bay mine (Natural Resource Canada, 2017c).

North American Tungsten Corporation signed an impact and benefit agreement with the indigenous community Nahanni Butte Dene Band for its Cantung mine in 2011 (ReSDA Atlas, 2016; Natural Resources Canada, 2018). However, there is no detailed information on the EA process or agreement available.

A recent important development is that Canada finally adopted the United Nations Declaration on the Rights of Indigenous People (UNDRIP) in May 2016 after having objected UNDRIP for almost 10 years (Fontaine, 2016). To follow up UNDRIP and further its implementation into Canadian law, as well as to better define Section 35 of the Constitution, Prime Minister Trudeau announced in February 2018 that the federal government will develop together with indigenous partners a fundamentally new legal framework, the Recognition and Implementation of Rights Framework (Tasker, 2018; Prime Minister of Canada, 2018; Smith, 2018). The Prime Minister plans to implement the new framework by October 2019 after a comprehensive consultative process (Prime Minister of Canada, 2018). It remains to be seen whether the framework will improve indigenous rights in Canada.

4.4 Mining-related conflicts

While most headlines feature grievances and social conflicts associated with Canadian mining companies operating outside of Canada (e.g. McSheffrey 2016), Canada also experiences domestic conflicts related to natural resource extraction (Cassels Brock, 2014). Most public discontent is directed towards fossil fuel projects (liquefied natural gas, tar sand and pipeline projects), although there were also several conflicts associated with minerals and metals mining projects (Cassels Brock, 2014).

Most mining-related conflicts in Canada are closely linked to the struggle for indigenous rights (Procter, 2015). Indeed, it has been mainly indigenous communities that have suffered under the widespread environmental impacts and health threats emanating from mines, both from those in operation and those already abandoned (Keeling and Sandlos, 2016). Generally, it is not the issue of distributional equity which is at the foreground of these mining conflicts. Instead, they are often perceived by the indigenous people to be part of the wider historical injustices they have experienced through colonialism (Keeling and Sandlos, 2009). Therefore, they use public hearings, consultations and environmental assessments as parts of remediation processes, for instance, in order to struggle for rectification (Sandlos and Keeling, 2016).

Whereas such participative means exist today, representatives of the Innu and Inuit, for instance, have pointed out in relation to the nickel mining project near Voisey's Bay that mere participation in discussions with the mining proponents was insufficient and that they felt a need to also use direct action, e.g. through protests, sit-ins and roadblocks and court actions, to make their voices heard (Gibson, 2006). On the other hand, some indigenous governments appear to increasingly seek to strike impact and benefit agreements with the mining companies, such as in the case of the Highland Valley Copper mine (Procter, 2015; Brylowsk, 2018).

Social conflicts over mineral extractions in Canada and protests by environmental activists also exist. Mine workers' strikes for better working conditions and the right to workers unions in the 1940s and 1950s were of great importance (Université de Sherbrooke, 2018a, Université de Sherbrooke, 2018b). At Voisey's Bay, workers engaged in a strike for better pay and working conditions in August 2009. After 18 months, Vale offered higher wages and more benefits (Klare, 2012).

5 Case study: tungsten mining

5.1 The global value chain of tungsten

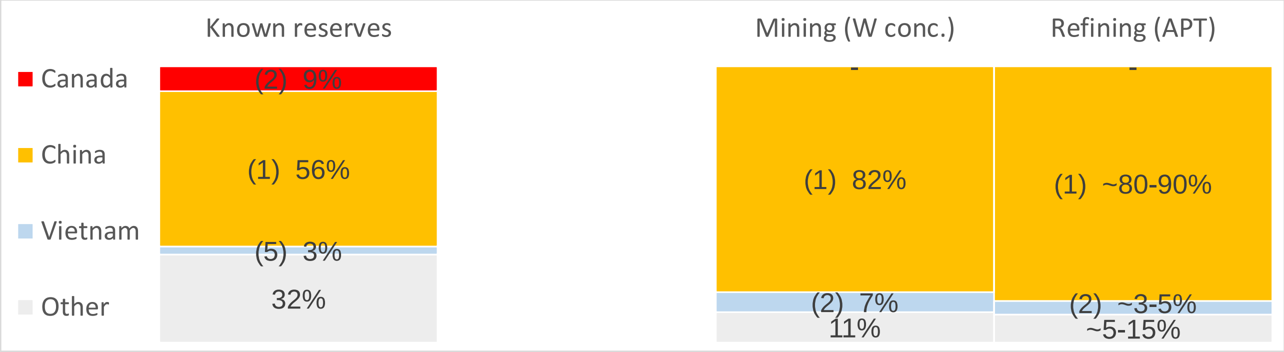
Tungsten (also known as wolfram, W) is an extremely hard, very dense metal with the highest melting point of all pure metals. Its unique properties are indispensable to a wide range of applications where hardness, high density, high wear and high temperature resistance are required. The major use for tungsten is within cemented carbides (~60% of total), whose hardness is close to that of diamond, used for cutting tools and in wear-resistant materials for mining, oil drilling, construction and in other sectors. Tungsten and its alloys are also used in electronics, power plants and nuclear reactors, aerospace and defence (BGS, 2011; Roskill, 2017).

Tungsten occurs in nature in two major minerals – wolframite ($(Fe,Mn)WO_4$) and scheelite ($CaWO_4$). These cannot be readily melted into a pure tungsten metal and require more sophisticated chemical processing methods. At the mine site, tungsten is typically concentrated from an ore containing 0.2% - 1.5% WO_3 to a concentrate with 30-73% WO_3 which is then sold to tungsten refiners. The two major tungsten intermediate products are ferrotungsten (FeW), which can be directly used for producing steels and alloys, and ammonium paratungstate (APT) ($(NH_4)_{10}(H_2W_{12}O_{42})\cdot 4H_2O$). APT is used for producing tungsten oxides, carbide and metal powders, and accounts for the majority of international tungsten trade (Roskill, 2017).

China holds about 56% of the worlds' known tungsten reserves. Other countries with significant tungsten reserves include Canada (9%), Russia (5%), the USA (4%), and Vietnam (3%) (USGS, 2017a; USGS, 2018). China is also by far the largest producer of primary tungsten (82%), followed by Vietnam (7%), Russia (3%), Bolivia (1%), Austria (1%), Rwanda, UK, Mongolia, Spain, Portugal and several other countries (USGS, 2018). Until 2015, Canada was also one of the world's major tungsten suppliers, however due to low metal prices the operations at the existing mine (Cantung, Northwest Territories) were suspended and potential new projects have been delayed (Roskill, 2017).

Tungsten refining only occurs in a few countries compared to mining, with China and Vietnam being the largest suppliers to international markets. A significant part of tungsten produced in China is also consumed domestically (Roskill, 2017).

Figure 2: Tungsten global value chain and ranking for selected countries (2016)



Note: figures in brackets show the country's global ranking. Percentage shares for refining are estimates. Data sources: (USGS, 2017a; USGS, 2018). W conc.: tungsten concentrate; APT: ammonium paratungstate.

5.2 Site specific overview – Cantung mine, Canada

Until 2015 (and currently on hold), the Cantung mine, owned by North American Tungsten Corporation Ltd (NATCL), was one of the most significant tungsten producers outside of China. It is a tungsten-copper (scheelite-chalcopyrite) skarn-type deposit, with its mineralization related to a granitic intrusion and the associated intrusive dykes, where scheelite is present in a pyrrhotite skarn or a calc-silicate skarn. The mine is located in the Flat River valley of the MacKenzie and Selwyn Mountains, in the Nahanni area of western Northwest Territories, and it is a part of the Selwyn Tungsten Belt which runs along the Yukon – North Territories border in Canada (McKenzie, 2014).

Operations at Cantung started in 1962 with a small open pit, and later extended to underground workings. Over time, the mine experienced a number of shutdowns and re-starts, mainly due to tungsten price fluctuations on the global markets. The last active mining periods were in 2002-2003, 2005-2009, and 2010-2015. Before stopping production in 2015, the mine was producing ore at a rate of 1,490 dry tonnes per day. Cantung's known reserves allow only for a few more years of operation, however combined with the proposed NATCL's Mactung mine (approximately 160 km north from the existing mine, in similar geological settings), both mines account for about 15% of the world's tungsten reserves. NATCL received a positive environmental assessment of the Mactung project in 2014. However, until tungsten prices recover, the development of this site will be limited (NATCL, 2015).

The historic open pit at Cantung was mined from 1962 to 1973, at about 1,500 meters elevation. Access to the open pit is limited to about five months during the summer period, and mining can occur from late June to the end of September depending on weather conditions (Delaney and Bakker, 2014). While there is still an opportunity to strip some remaining low-grade ore and waste from the open pit, the primary focus is on underground operations which can be run throughout the year. This would be also the case with the Mactung mine, where the open pit is considered only as an option to extend the operations at the end of underground mining (NATCL, 2015).

With the last re-start in 2010, NATCL has completed an upgrade of the plant's equipment, infrastructure and facilities, deepened its program below the existing workings, and installed new diesel generators and waste heat recovery system. The underground and seasonal surface diamond drilling programs have extended the life of mine for another five years (McKenzie, 2014). The latest technical report, satisfying NI 43-101[10] for the Cantung mine, as of 31 July 2014, indicated probable mineral reserves of 1.82 Mt with a grade of 0.81% WO_3; indicated resources of 3.84 Mt with a grade of 0.97% WO_3; and inferred mineral resources of 1.4 Mt with a grade of 0.80% WO_3 (NATCL, 2015). The company continues identifying new areas in the mine to add to the resources which potentially can extend the life of mine. The Mactung mine has an indicated resources of 33 Mt at 0.88% WO_3 (NATCL, 2015).

5.2.1 Overview of transportation systems and routes

The Cantung mine is located in Northwest Territories, on the border with Yukon. It is relatively remote, with employees and materials either flown or transported to the site. The closest settlement and the staging area for trucking the tungsten concentrates is Watson Lake, Yukon, about 300 km by road southeast from the mine site. The mine is responsible for maintaining the access road to the mine site (to km 134, Nahanni Range Road), while the Yukon government is responsible for the remainder of the road (Delaney and Bakker, 2014).

NATCL was selling the tungsten concentrates based on free market values for APT (with a certain discount), primarily to Europe and North America. The shipping volumes are about 7,000 tonnes of tungsten concentrates per year (Delaney and Bakker, 2014). It is not reported from which port or ports the concentrate is shipped.

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[10] The national instrument for the Standards of Disclosure for Mineral Projects within Canada.

5.3 Extraction and processing technologies

5.3.1 Extraction and processing technologies at Cantung mine

The existing tungsten mines worldwide are relatively small, and mining mainly occurs underground. Both scheelite ore and wolframite ore can be concentrated by gravity, often combined with froth flotation and sometimes with magnetic separation (ITIA, 2011).

Historically, Cantung mine had both open-pit and underground operations, however most of the remaining reserves are underground. Using a variety of mining methods in the past, the current primary method is sub-level longhole stoping with delayed backfill, with cut and fill being employed in areas where the ore zone is too narrow for efficient longhole mining. The underground workings extend vertically from about 1,100 m to 1,300 m, and cover a strike length of approximately 1,500 m (McKenzie, 2014).

The mined ore is processed by gravity separation and flotation circuits at the site. The mill processing facilities include primary, secondary and tertiary crushing, general gravity and flotation circuits, mine backfill preparation, and reagents and supplies storage. The reported mill's capacity is 1,350 tons of ore per day at a recovery rate of 83% of WO_3, including from 60% to 70% as premium gravity concentrate (with 65% WO_3 content) and from 30% to 40% as flotation concentrate (35% WO_3). A by-product is copper concentrate (28% Cu). The final concentrates are filtered, dried and bagged, and stored in covered areas while awaiting shipment (Delaney and Bakker, 2014).

5.4 Environmental impacts and mitigation measures

5.4.1 Cantung mine

Land use

The total area of Cantung mine, including all claims and leases, is about 10,000 hectares (Delaney and Bakker, 2014). Most mining operations occur underground with limited land impact, while the surface land use is primarily associated with the processing facilities, tailings ponds, and ore stockpiles.

Water use

There are two major sources of water at the Cantung mine: the nearby Flat river and mine water from the underground workings as a part of mine drainage and dewatering. Water withdrawal from the river is restricted by the water licence to 45,000 m^3 per week (Delaney and Bakker, 2014).

The underground mine is relatively dry, due to the mine elevation and relatively low permeability of the rocks hosting the ore body. The water from the mine workings above the 1,200 m level is drained by gravity via ditches and a number of decant holes, while the workings below the 1,200 m level are dewatered by the use of sump pumps and pipelines. The mine water discharge is in the range of 15,000 m^3 per day, and approximately half is reused in the operations (Delaney and Bakker, 2014).

A significant part of process water from the gravity separation and flotation circuits is also recovered and reused, while final tailings are pumped to the tailings pond. Supernatant from tailings pond is treated at the waste water treatment facility to remove suspended solids before discharge to the environment. The discharge is limited to 4,500-8,000 m^3 per day, depending on the water flow in the river (Delaney and Bakker, 2014).

Energy use

The main energy sources at Cantung mine are diesel and gas, regularly delivered by trucks via the Nahanni Range Road. The electricity is generated on site by diesel generators, with total installed capacity of 8.5 MW, while the demand in cold weather approaches 4.5 MW. The heat energy from electricity generation is recovered for heating the mill and other buildings. The average fuel consumption for power generation is about 22,000 L/day (Delaney and Bakker, 2014).

Mine waste

There are two major solid waste streams at Cantung mine: waste rock from mining and tailings from the processing plant. Waste rock from the site is carbonate rich, consisting of limestone, argillite and skarn minerals (e.g. pyroxene, quartz, and calcite), which can be important in preventing or buffering potential acid mine drainage. It is utilised as a backfill both in the longhole and cut and fill stopes. The longhole mining sequence is designed to mine the stopes from the bottom up and fill them in before mining the next stope in the sequence (Delaney and Bakker, 2014).

Tailings are currently disposed in the tailings pond #5 (TP5). The final elevation of TP5 dam will be 1,151 m. Afterwards, NATCL plans to move to dry stack tailings, which is more sustainable, environmentally responsible method of tailings disposal. Another reason for the latter is the identified risk of tailings liquefaction in the TP4 facility under a seismic event. This may cause instability of one of the TP4 berms that extends parallel to the Flat River, resulting in tailings release. Depending on the breach and the amount of waste material released this could lead to contamination of the river system, particularly with heavy metals and result in physical damage as a result of flooding and displacement. Based on dam safety, environmental and economic considerations, NATCL plans to decommission and reprocess the tailings in TP4, moving the reprocessed tailings to new storage facilities located further back from the Flat River. There is about 5 Mt of historical tailings on site that can be considered for reprocessing (Delaney and Bakker, 2014).

Due to sulphide minerals content in tailings (mainly pyrrhotite, iron sulphide mineral), there is a risk for acid mine drainage, however this is partially offset by high carbonate minerals content. It was estimated that for fully exposed tailings there can be up to 40 year time lag before tailings become net acid generating (for the remaining sulphides content) (NATCL, 2010). This may require additional investigation and incorporation of possible solutions in the future mine site closure plan.

Emissions

The main sources of GHG emissions in tungsten mining are associated with the use of fuels to power machinery (mainly diesel), for electricity production (diesel generator), and tungsten concentrate transportation on trucks to the transport hub in Watson Lake, Yukon. The underground extraction of tungsten at Cantung mine prevents a direct cause of dust compared with an open-pit operation.

Biodiversity

The mine site is located in the Flat River Valley, within the MacKenzie and Selwyn Mountain Range, just outside the Nahanni National Park Reserve and World Heritage Site. It is characterised by steep mountains and narrow valley bottoms, with elevations from 1,130 m above sea level (at the Flat River valley) to 2,750 m (on the mountain peaks). The ecoregion is characterised by alpine tundra at upper elevations and by subalpine open woodland vegetation at lower elevations. The tree line is found from about 1,220 m elevation. Local alpine glaciers exist in the highest ranges of this ecoregion, as well as extensive permafrost (Delaney and Bakker, 2014).

Over the life of Cantung mine, there has been little evidence of any significant impact on wildlife (NATCL, 2010).

Rehabilitation

Currently, the Cantung mine is on care and maintenance. The company has prepared a number of mine abandonment and reclamation plans for the site. The latest (October 2014) reclamation cost estimate by Wenck Associates Inc. is C$13.1 million (Delaney and Bakker, 2014).

Health

No health related impacts from tungsten mining at the Cantung mine have been reported to date.

5.5 Current climate impacts and risks

5.5.1 Current climate

The Cantung mine is located in the area of the MacKenzie and Selwyn mountains, where climatic conditions vary with elevation. The climate conditions can be characterised as subarctic, with significant precipitation throughout the year. The Köppen-Geiger climate classification for the site is not clear-cut, as the categories Dfc, Dsc and ET apply.[11] The Tungsten town site and mine facilities are located at an elevation of about 1,128 m, the underground mine portal is at 1,204 m, and the open pit is above the underground workings at 1,524 m. The total annual precipitation is about 650 mm, and occurs half as rain and half as snow. The mean annual temperature is approximately -4.5°C, with a summer mean of 9.5°C and a winter mean of -19.5°C. Severe winter conditions prevail from October to May with temperatures as low as -40°C and substantial snowfall (Delaney and Bakker, 2014). The mine's region is characterized by extensive discontinuous permafrost (Natural Resources Canada, 1995).

5.5.2 Past weather extremes

The most severe extreme weather event in the past years which affected the Cantung mining site was reported in June 2012. A combination of high snowpack, an unseasonable late snow melt and above-average heavy rains led to the several mudslides and washouts at river crossings along the Nahanni Range Road in Yukon, cutting off access to the Cantung mine (Abdullah and Suleman, 2013; CBC News, 2012). The mudslides and washouts were reported to be on an unprecedented scale (Keevil, 2012). North American Tungsten had to stop its operations at the Cantung mine for about a week, due to food and fuel shortages. Concentrate could not be shipped to customers during that time (Tobin, 2012).

In September 2017, the federal government and the Yukon government announced to invest C$360 million in the Nahanni Range Road and another road in Yukon. The aim is to improve both roads and to upgrade bridges, culvers and stream crossings (Yukon Government, 2017).

The mine's provinces have experienced extreme fire seasons recently. In 2014, the Northwest Territories saw a record fire season with 3.4 million hectares burned (largest area burned in recent decades). Yukon saw an extreme wildfire year in 2004 (Streiker, 2016). There are no reports available whether wildfires had a direct impact on Cantung mine in the recent years.

5.6 Climate change impact assessment[12]

To date, there are no comprehensive climate change projections for the area of the Cantung mine available. Where possible, the analysis refers to downscaled climate models for the Yukon, which borders

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[11] Dfc: D Cold (continental), f (without dry season), c (cold summer); Dsc: D Cold, s (dry summer), c (cold summer), ET: E Polar, T (Tundra) (Peel et al., 2007).

[12] For an overview see Figure 3.

the area where the mine is located. If downscaled models were not available, the analysis is based on information from global climate models and projections for Canada as a whole.

According to the CMIP3 multi-model mean which comprises results from over 20 major global climate models, average surface temperatures are projected to rise relative to 1961-1990 averages. Both under a low (B1) and medium-high (A2) SRES emission scenario, temperatures are projected to increase by up to 2°C in spring, summer and autumn and by up to 3°C in winter in the mine's region until 2050. Looking further into the future, until 2080, projections show a temperature increase of 2 to 3°C in spring, summer and autumn and a 3 to 4°C increase in winter (under the low B1 SRES emission scenario). Under the A2 SRES medium-high emission scenario, temperatures are projected to rise by 2.5 to 4.5°C (Bush et al., 2014).

Climate models show greater variability for projections of precipitation change and these projections are therefore less robust than projections for temperature. According to the CMIP3 multi-model mean, the area of the mine is projected to become wetter over the next decades. Under both emission scenarios and for both 2050 and 2080, precipitation is projected to increase by up to 5.5% in the summer. In all other seasons, higher increases in precipitation – by up to 20% – are projected (Bush et al., 2014).

According to projections for the Yukon, flood risk will increase: "Rain and storm events are projected to increase; late season freeze-thaw cycles on rivers are creating ice which is more prone to ice-jam damming [i.e. blocking the flow of a river]; heavy snowpack with warmer springs is leading to freshet flooding" (Streiker, 2016: 29). In addition, the melting of glaciers increases (Streiker, 2016).

Permafrost which is already characterized as being discontinuous in the region is projected to thaw under changing climatic conditions (Streiker, 2016; Furgal and Prowse, 2008).

Forest fires which are a common hazard in the area are projected to increase (in both frequency and severity), due to "[i]nsect outbreaks, variability in precipitation, warming temperatures, longer shoulder seasons, and increased winds" (Streiker, 2016: 34). Forest fires can also contribute to permafrost degradation, as vegetation cover is burnt and therefore loses its ground insulating function (Streiker, 2016).

5.6.1 Potential climate impacts on the Cantung mine

As the Cantung mining site is characterized by subarctic climate and is in a remote location, operations are quite challenging. While underground mining is possible throughout the year, open-pit mining is restricted to a few months during the summer period of the year. The mining site is expected to face several climate change-related impacts today and in the future.

Mean precipitation and rainfall events are projected to increase in the region where the Cantung mining site is located. Increased temperatures could lead to more precipitation occurring as rain instead of snow, and more runoff might occur as glacial melt is increasing. Therefore, flooding could potentially occur more often at the site. However, it is important to note that flooding does not only stem from extreme rainfall events and additional water flows, but can also occur when regular levels of precipitation coincide with other conditions, such as "early spring warm periods [i.e. earlier snow melt], rain-on-snow events, rainfall on frozen ground and heavy rain on saturated soils" (Fraser Basin Council, 2014: 4). Melting glaciers can further contribute to flooding events.

This could mean, for underground operations, that more pumping is required to dewater the mine, potentially negatively affecting the productivity of the mine. The overflow or breach of tailings storage facilities due to flooding could potentially lead to the contamination of the nearby river system, mainly with heavy metals. In addition, such an event would have a damaging impact on the mining site and the local ecosystem.

Projected climatic changes can contribute to the occurrence of landslides, triggered by "intense rainfall or snowmelt events, permafrost degradation, forest fires, river erosion, [and] groundwater flow"

(Benkert et al., 2015: 45). Although it is not possible to fully evaluate the potential increased risk for erosion and landslides at the pit and the tailing facilities, such events could affect the productivity of the mine negatively, disturbing the mining operations, as well as having adverse impacts on rehabilitation efforts and biodiversity in the region. Also workers might be put at risk by erosion or landslides.

It is not possible to evaluate whether permafrost degradation could have negative impacts on the mining site, as there are no information available on whether the mine's infrastructure was designed for changing permafrost conditions. However, the impacts of permafrost degradation should be closely monitored, especially with regard to the stability of tailing storage facilities. Permafrost degradation could negatively impact rehabilitation efforts and biodiversity in the region.

Projections suggest that fires could occur more often and in a higher intensity in the regions. Fires could lead to damages at the mining site and put workers at risk. This would in turn decrease or interrupt the production of tungsten. In addition, forest fires could also harm mine workers even if not reaching the mining site, as they produce air pollution. Also, revegetation efforts and biodiversity could be hampered by fires. In addition, increased mean temperatures could have negative impacts for rehabilitation and biodiversity in the region.

There are no projections for wind available. However, even if wind intensity increased, no significant impacts are expected as dust emissions are relatively low, as most mining occurs underground. Heavy wind could potentially have negative impacts on rehabilitation, biodiversity and workers' health.

5.6.2 Potential climate impacts on the transport routes and air transportation

Transportation to and from the remote mining site relies on favourable weather conditions. This means that extreme weather events could have severe negative impacts.

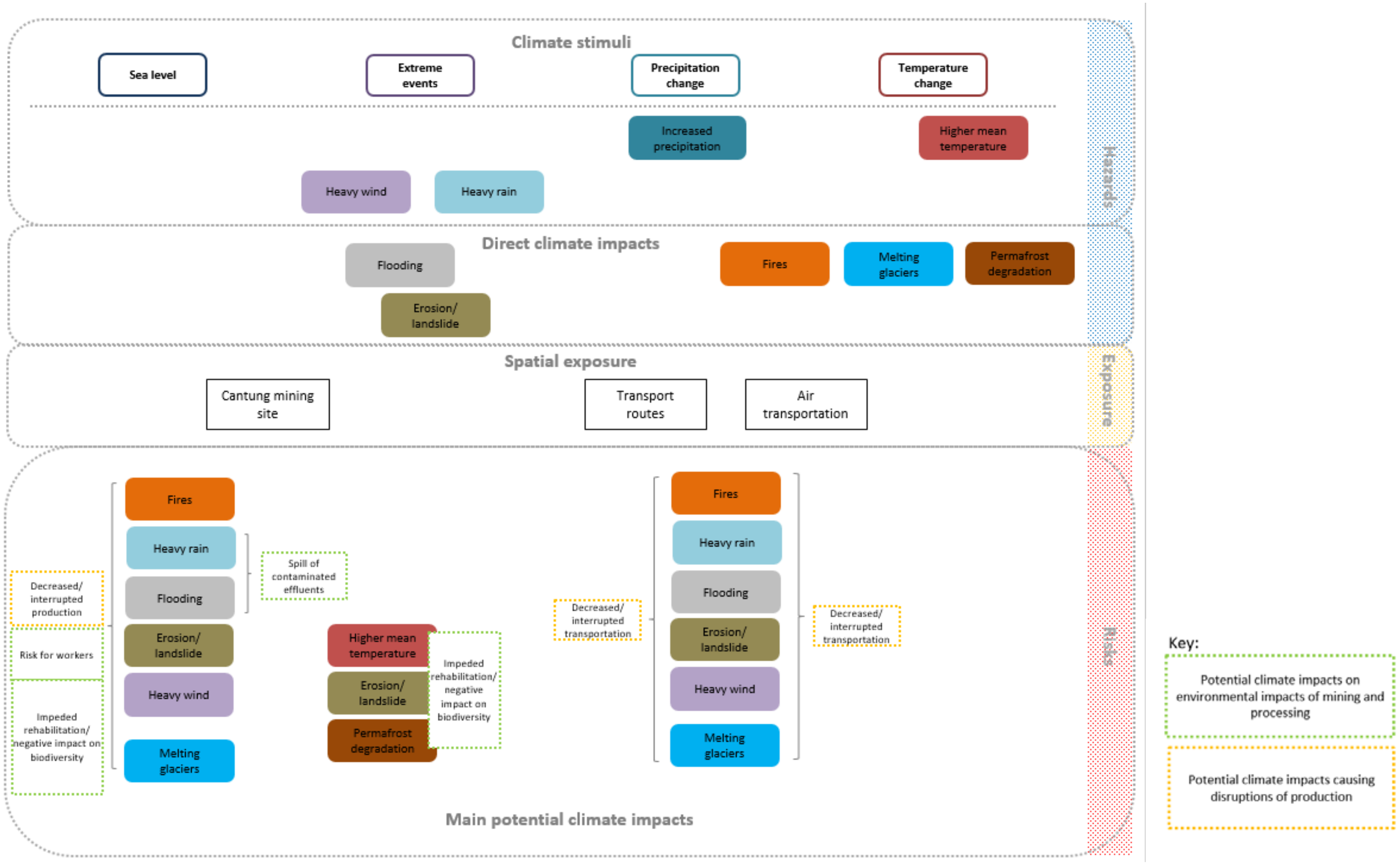
Flooding, erosion and landslides in particular could render the Nahanni Range Road, connecting the mining site to the next settlement and staging area for trucking the concentrates, as well as the airport runway, unusable. The 2012 extreme wet weather event heavily impacted the Nahanni Range Road, halting the mine's operations as food and fuel ran short. The shipment of concentrate to customers was also interrupted. The announced improvement of the road could render it less vulnerable to future extreme weather events. However, it is unknown when the construction works will take place and to what extend the road upgrade will improve its resilience to extreme weather events (see paragraph 5.5.2 on past weather extremes).

The impacts of thawing permafrost on road and the airport are difficult to evaluate, as information on road and airport design and conditions are not available. However, the planned road upgrade might reduce the road's vulnerability to permafrost degradation.

Heavy wind and rain could impact both air and maritime transportation, potentially leading to interruptions and delays. Forest fire could impact all types of transportation negatively: it could damage routes, the airport and could develop smoke, hindering the take-off and landing of planes.

Interrupted transportation would affect the supply of the mine with fuel and other material necessary for the production or shipping of concentrate to markets and therefore would have a negative impact on tungsten supply security. In addition, an interruption of supply could also have severe consequences for the staff working at the mine. Workers well-being might be affected if supplies (e.g. food) run short or the transportation of the workers themselves from or to the site is compromised. Alongside the individual detriments, the potentially reduced workforce could impact the productivity of the mine.

Figure 3: Climate impact chain for tungsten



The diagram illustrates the specific climate stimuli, the spatial exposure, the direct climate impacts and the potential climate impacts. In order to visualise the links between these components of the climate impact chain, the colours of the frames of the potential climate impacts are used accordant to the corresponding climate stimuli and direct climate impacts.

6 Case study: nickel mining

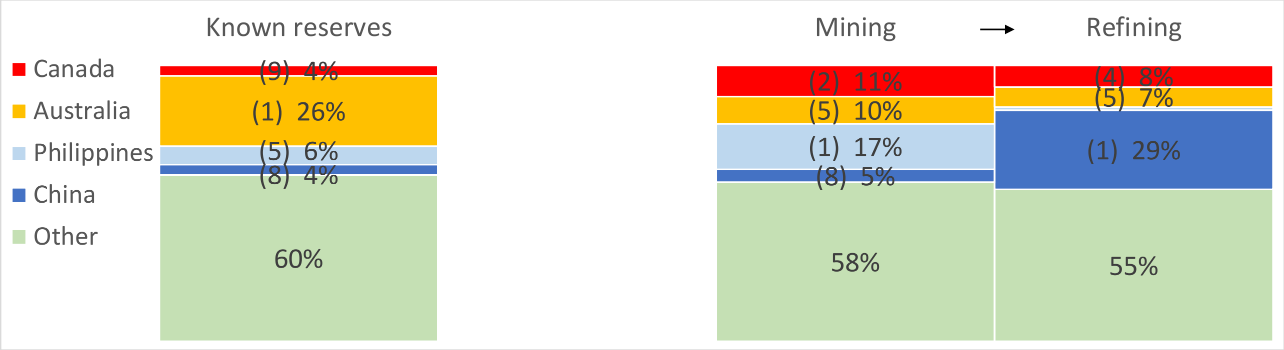
6.1 The global value chain of nickel

Nickel is characterised as a hard, ductible, and malleable metal with low thermal and electrical conductivities, which can also be magnetised. Nickel alloys' strength, resistance to oxidation and corrosion, and various electrical, magnetic and heat resistant properties have made them crucial in a range of industrial applications (BGS, 2008). More than 65% of nickel output is used in the production of stainless steel, widely applied in the chemical industry, construction, vehicles and consumer products manufacturing (Geoscience Australia, 2015).

There are two major sources of nickel ores: magmatic sulphides and laterites, representing about 40% and 60% of identified (land-based) nickel resources, respectively (USGS, 2018). At present, sulphide deposits contribute more than 60% of mined nickel, with ore grades ranging from 0.15% to 8% Ni (BGS, 2008). Nickel laterites are formed by surface weathering in the tropical and subtropical climates, and usually have lower grades compared to sulphide ores. The most important nickel sulphide mineral is pentlandite ($(Fe, Ni)_9S_8$), which typically occurs with pyrrohotite, chalcopyrite and pyrite in mafic and ultramafic igneous rocks. Nickel minerals in laterites are garnierite ($(NiMg)_3Si_2O_5(OH)_4$) and nickeliferous limonite ($(Fe,Ni)O(OH)$) (BGS, 2008).

Global nickel mining output was estimated at about 2.1 million tonnes in 2016 and refined nickel production at 2.0 million tonnes (NRC, 2017). Major nickel reserves are located in Australia (26%), followed by Brazil (16%) and Russia (10%). A major nickel mining country is the Philippines (17%), while nickel refining is dominated by China (29%). Canada is the second largest miner and fourth largest refiner, holding about 4% of the world known nickel reserves (NRC, 2017; USGS, 2018).

Figure 4: Nickel global value chain and ranking for selected countries (2016)



Note: figures in brackets show the country's global ranking. Data sources: (NRC, 2017; USGS, 2018).

The international trade of nickel is represented by ores, concentrates, intermediate products (such as mattes, sinters, and oxides), ferronickel and unwrought metal (BGS, 2008). A significant part of nickel used in final products can be recycled to supplement primary supply (Nickel Institute, 2018).

Global nickel use is dominated by stainless steel (68%), followed by alloys (16%), plating (9%), casting (3%), and batteries (3%) (OCE, 2017). An increasing amount of nickel is used in batteries, particularly lithium-ion batteries for electric vehicles, where nickel is used in the cathode materials. It is forecasted that nickel application in batteries will grow from about 3% to 15-20% in the 10-year time (Roskill, 2018).

6.2 Site specific overview – Voisey's Bay, Labrador, Canada

The Voisey's Bay mine is one of the world's largest nickel producers. It is located in northern Labrador, on a peninsula bordered by Anaktalak Bay and Voisey's Bay, about 35 km south-east of Nain and

80 km north-west of Utshimassits (VBNC, 1997). The mine's operator is Vale Newfoundland and Labrador Limited (VNL), a subsidiary of Vale Canada Limited. Production began in 2005 in the open pit which is expected to continue until 2021. The company is in the process of transition to underground mining, starting in 2020, which will extend the operations until at least 2032 (Vale, 2017).

The mine is located at a remote site on the coast, with elevations ranging from 175 m to 500 m above the sea level, and major transportation links via ocean shipping. The site is generally sparsely vegetated, with a well treed lower valley system and barren highlands in the mountainous region (IRC, 2005; Norris, 2006).

The total reserve plus resource estimate for Voisey's Bay is about 141 Mt, with average grades of 1.63% Ni, 0.85% Cu and 0.09% Co (Kerr, 2003). Most of this is contained within three zones: the Ovoid, Eastern Deeps and Reid Brook. The Ovoid zone (open pit) is represented by higher grade ore (2.8% Ni on average), and contains about 40% of total nickel resource (Kerr, 2003).

6.2.1 Overview of transportation systems and routes

The Voisey's Bay mine has a quite remote location. The nickel and copper concentrates produced at the mine are trucked on gravel roads to the nearby storage facilities at the mine's port at Anaktalak Bay. The ocean transportation can occur over extended shipping season with the use of icebreakers, with no shipping only during the period of initial ice formation and during early spring (Norris, 2006). Mining supplies, food and diesel for the mine's energy-generating station are shipped via sea to the mine. Mine workers are being flown in and out (The Economist, 2014).

Originally, the nickel concentrate produced from Voisey's Bay was processed at Vale's operations in Sudbury and Thompson, Canada. Since 2016, most of it is shipped to the newly built nickel refinery at Long Harbour on Newfoundland's Avalon peninsula , about 1,000 km from the mine, for processing into nickel, and copper and cobalt products (Vale, 2017).

6.3 Extraction and processing technologies

6.3.1 Extraction and processing technologies at Voisey's Bay

Mining

Nickel sulphide deposits can be mined by underground or open-pit methods, or a combination of both, while laterite deposits are typically mined from an open pit (BGS, 2008). The Ovoid deposit at Voisey's Bay is mined by a conventional open-pit method, which includes removing the overburden, digging and blasting the ore in the pit, followed by ore transportation. The drilling is performed on 5 m benches, the ore is loaded onto 90-tonne haul trucks and transported to the primary crusher located at the mill (BGS, 2008). Waste rock and overburden are deposited on dumps located within close proximity to the pit, while waste materials identified as potentially acid generating (PAG) are hauled to Headwater Pond for underwater deposition, which is a common approach to prevent further oxidation and leaching of metals. A second tailings pond (the North Tailings Basin) will be used later, for depositing PAG waste from underground mining (IRC, 2005). Infrastructure design (i.e. pit slopes, roads and tailing dams) take the sporadic and discontinuous permafrost conditions at the site into account (VBNC, 2018).

Beneficiation

Mined ore (1-4% Ni) is transported to the mill and processed into concentrate (10-20% Ni) using primary and secondary crushing, wet grinding and froth flotation (Norris, 2006). The first stage of froth flotation removes copper concentrate, while second stage produces a nickel concentrate. Due to subarctic conditions, the whole mill process takes place in an enclosed heated building. The metal concentrates are dewatered in thickeners, filtered and dried, and then transported by trucks to the port for storage and further loading on a ship (BGS, 2008).

Nickel concentrates from the Voisey's Bay mine are currently shipped to and processed at Vale's nickel matte and hydrometallurgy plants, located in Long Harbour (Vale, 2017).

Smelting and refining

In the smelting process, dry nickel concentrate is fed into the furnace with a preheated air or oxygen to produce liquid matte, containing up to 70% of Ni, iron rich slag, and sulphur dioxide (BGS, 2008).

Pyrometallurgy and hydrometallurgy methods are used in metal refining. In pyrometallurgy, nickel is separated from the other constituents of the matte using differences in melting points and densities, while in hydrometallurgy differences in solubility and electrochemical properties allow for separating the metals in solution. Ammonia leaching (under high pressure) or chlorine leaching (under atmospheric conditions) processes are typically used. After leaching, high purity nickel is recovered by electrowinning (BGS, 2008).

6.4 Environmental impacts and mitigation measures

6.4.1 Voisey's Bay mining area

Land use

The Voisey's Bay mine is located in a remote area, with limited land use options for other economic activities. It is expected that after the mine closure (post 2032) most of the affected land will be restored and returned back to natural habitat (VBNC, 1997) (see paragraph on rehabilitation for more information).

Water use

The major water use at the mine site is associated with beneficiation processes, namely froth flotation. A significant part of process water is reclaimed and recycled, including decant water from tailings ponds, while any excess water is treated at the water treatment plant (Norris, 2006). Water drainage and seepage into the open pit are pumped to a settling pond, and then also treated before discharge into environment (VBNC, 1997). No details on water use have been reported to date.

Camp Pond, filled up by natural precipitation during the year, is the major source for additional freshwater withdrawal – up to 1.1 million m^3 per year (VBNC, 1997). According to the original plant design, the annual water consumption is up to 11.5 million m^3 (mainly as recirculated water) (VBNC, 1997).

As a part of deposition design for potentially acid generating waste, two natural ponds (Headwater Pond and the North Tailings Basin) have been converted into underwater storage areas. This caused a permanent loss of fish habitat, however the overall impact to biodiversity is considered to be relatively small, with limited seepage into the marine environment and no other significant long-term negative effects (VBNC, 1997).

Energy use

The main energy use is associated with fuels to power machinery, diesel generating power plant to supply electricity for ore beneficiation and other processes, and the use of explosives to break the rock during mining operations. No details on energy use at the Voisey's Bay have been reported to date.

Mine waste

Waste rock from mining operations and tailings from ore beneficiation are two major waste streams at the mine site. Voisey's Bay deposit contains highly reactive sulphide minerals, therefore waste segregation and proper containment of potentially acid generating materials is a critical issue to avoid or minimise the long-term acid and metalliferous drainage (AMD) issue (Barbour et al., 1999).

Benign waste rock is deposited in areas near the mine site and is reused in the process of progressive land rehabilitation, while waste rock with AMD potential is deposited under water at Headwater Pond along with tailings materials (Barbour et al., 1999). The daily rate of tailings deposition in Headwater Pond is up to 15,000 tonnes (Barbour et al., 1999). The second tailings facility (the North Tailings Basin) will be used for tailings deposition when underground operations commence (post 2020).

Emissions

The main sources of emissions (and dust) at the mine site include land clearing, blasting and other activities in the open pit, truck haulage along unpaved roads, wind erosion from rock and overburden storage areas, operation of the crusher plant and conveyors, concentrate loading at the port and emissions from vehicles and power generators. Mitigation measures include the use of low sulphur content fuels, water and dust-reducing agents to haul roads, dust collectors and scrubbers in the milling process, the use of closed conveyors and transfer points, and progressive reclamation of waste rock piles (Barbour et al., 1999). No details on GHG emissions from the Voisey’s Bay operations have been reported to date.

Biodiversity

The ecosystems in Labrador support a variety of wildlife species, including large and small mammals, birds, aquatic life in rivers and lakes, and marine life (VBNC, 1997). The construction of the mine and its infrastructure has removed some habitat, however the overall disruption seems to be limited, partly due to a limited land footprint, as well as a result of an extensive local species habitat research and environmental planning prior to commencing industrial activities at the site (VBNC, 1997).

Several species of wildlife were identified as requiring particular attention during the environmental baseline study program, based on views expressed by hunters, the general public, federal and provincial resource agencies, and the scientists. The appropriate measures to minimize wild life disturbance have been developed and implemented, particularly in regards George River Caribou Herd (reindeers), by identifying where animal trails cross the site roads and introducing speed limits and other operating procedures (VBNC, 1997).

Rehabilitation

VNL performs some progressive reclamation activities throughout the mine development, such as preparing waste rock slopes to resemble the surrounding hills for future re-vegetation. At the end of mining operations, the entire site will be decommissioned, including removing all structures, contouring the land and re-vegetation, restoring water quality and water flow patterns (VBNC, 1997).

The open pit will likely be filled with water, however waste materials deposition in pit can also be considered. Segregated and separately deposited acid generating materials will be permanently kept under water to exclude any further oxidation. The water quality monitoring may be required for an extended period of time after the mine closure. Additional research and monitoring are also necessary to determine the final plan for the mine site rehabilitation.

Health

No health related impacts from nickel mining at the Voisey's Bay mine have been reported to date.

6.4.2 Long Harbour nickel refinery area

The Long Harbour nickel refinery (which includes matte plant for smelting and hydrometallurgical plant) first began production in 2014, but due to operational issues the full scale operations have been delayed until 2016 (Vale, 2017). There has been no environmental reporting for this facility yet. However, the major environmental impacts over the expected 15 years of life (or for as long as the ore supply from the Voisey's Bay mine lasts) were outlined in the 2008 environmental impact assessment for this project.

Land use

The refinery is located in a partially brown-field site on the south side of Long Harbour, previously disturbed by industrial activities, therefore minimal additional land impact is expected. The major infrastructure development includes processing plants, port facilities, pipelines for water supply, and tailings storage facilities which will permanently remain after the refinery closure. The total area disturbed by industrial operations is about 190 ha (Vale Inco, 2008).

Water use

The estimated water consumption for the Long Harbour nickel refinery is about 7 million m^3 a year, supplied from Rattling Brook Big Pond, 2 km southeast of the site (Vale Inco, 2008). A significant part of water is aimed for reuse, while treated effluent is discharged into the sea at Long Harbour, through a diffused outfall at a depth of 50 to 70 m (Vale Inco, 2008). No details on the actual water consumption and effluent discharge have been reported to date.

Emissions

The expected air emissions are mainly represented by sulphur dioxide (400 tonnes a year), nitrogen oxides (150 tonnes), and particle matter (170 tonnes) (Vale Inco, 2008). Direct GHG emissions are likely to be relatively minor due the electricity supply being from the grid. No details on the actual emissions have been reported to date.

Energy use

The main energy use in nickel refining is associated with electricity and fuel to power machinery and generate steam. According to the plant design at full scale operation, the estimated electricity consumption (from the provincial grid) is 94 MW for the hydromet plant and 74 MW for the matte plant (Vale Inco, 2008). No details on the actual energy use have been reported to date.

Waste

The matte plant produces a gypsum waste, which is relatively benign and can be stored above ground, while residue from the hydrometallurgical process are potentially acid-generating, requiring neutralization and permanent underwater storage similar to tailings deposition at the mine site (Vale Inco, 2008).

Biodiversity

The impact on biodiversity is estimated to be minimal due to the refinery's location in a partially brown-field site, as well as relatively small overall land footprint (Vale Inco, 2008).

Rehabilitation

At the end of operations, all facilities will be decommissioned, the land will be rehabilitated and returned to the environment, apart from the residue storage facilities which will require a long-term monitoring and maintenance (Vale Inco, 2008).

Health

No health related impacts from nickel refining at Long Harbour have been reported to date.

6.5 Current climate impacts and risks

6.5.1 Current climate

The climate at Voisey's Bay can be described as being subarctic, ranging between cold continental and polar, with significant rainfall during the year. It is classified as Dfc and ET by Köppen and Geiger.[13] At the closest populated area to the mine site (Nain), the annual temperature averages -2.5°C, while the total annual precipitation is about 925 mm per year. About half of the precipitation occurs as rain (450 mm), the other half as snow (475 mm). August is the warmest month (daily average is 11°C), while January is the coldest (with a daily average of -17.6°C) (Government of Canada, 2018e). Because of the harsh climate, most workers do not reside permanently at the site (Klare, 2012). There is sporadic and discontinuous permafrost in the area of the mine, mainly at north-facing slopes and in low-lying areas (VBNC, 2018).

At Long Harbour, the climate is characterised as Dfb and Dfc (cold continental) according to the Köppen-Geiger climate classification.[14] At the climate station St. John's in the proximity of Long Harbour, the annual temperature average is 5°C and the total annual precipitation is about 1,534 mm. Almost 80% of the precipitation occurs as rain, while 20% occur as snow. The warmest month is August (the daily average is 16.1°C), while February is the coldest (the daily average is -4.9°C) (Government of Canada, 2018f).

6.5.2 Past weather extremes

There is no information available on past extreme weather events that impacted Voisey's Bay mine or the refinery at Long Harbour.

However, the province of Newfoundland and Labrador, has often witnessed weather extremes and their impacts. Coastal flooding and coastal erosion (at about 50 cm per year) are common hazards in Newfoundland and Labrador (Batterson and Liverman, 2010). In 2007, a destructive landslide occurred at Daniel's Harbour. As a consequence, the Northern Peninsula Highway was shifted farther inland (Batterson and Liverman, 2010).

Inland flooding is also an issue. For example, the Town of Stephenville in Western Newfoundland experienced harmful flooding after an extreme precipitation event which led to the overflow of local rivers in 2005 (Department of Municipal Affairs and Environment of Newfoundland and Labrador, 2016a). A more recent example is the flooding in western Newfoundland in January 2018: "Heavy rains and unseasonably high temperatures caused several road washouts and flooding to public and private property" (CBC, 2018).

Another weather extreme experienced by the region are strong winds and hurricanes. In 2010, Hurricane Igor hit Newfoundland and Labrador, causing C$200 million in damages (Department of Municipal Affairs and Environment of Newfoundland and Labrador, 2016b).

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[13] Dfc: D Cold (continental), f (without dry season), c (cold summer); ET: E Polar, T (Tundra) (Peel et al., 2007).

[14] Dfb: D Cold, f (without dry season), b (warm summer); Dfc: D Cold (continental), f (without dry season), c (cold summer) (Peel et al., 2007).

Strong winds in combination with snow squalls occurred at Port aux Basques in January 2018. Sailings and flights were cancelled and main transmission lines were affected, leaving residents in the regions without electricity (McNeish, 2018).

In 2013, a severe forest fire burned over 27,000 hectares of forest in Quebec and Labrador, leading to the precautionary evacuation of the Town of Wabush (Department of Municipal Affairs and Environment of Newfoundland and Labrador, 2016c). Forest fires are considered an essential element of boreal systems. Boreal forest areas usually burn down once every 50 to 200 years (Schultz, 2000).

6.6 Climate change impact assessment[15]

Climate projections for Labrador and the island of Newfoundland, where Voisey's Bay mine and the Long Harbour refinery are located, indicate various changes.[16] The clearest changes are related to temperature rise, especially in winter. Nain is expected to experience a 2.3°C to 5.3°C increase in daily mean temperatures in winter months for the mid-21st century (2038-2070), respective to its 20th century mean (1968-2000). Summer average daily mean temperatures are projected to rise to a lesser extent, between 1.3°C and 2.9°C. Seasonal differences are smaller in St. John's. Winter average daily mean temperatures are projected to rise between 1.2°C and 3.4°C, while the projected summer average daily mean temperature rise ranges between 1.4°C and 2.2°C.

The number of days with sub-zero temperatures is projected to decrease in both locations, yet to varying degrees. While projections show only a small decrease in days with sub-zero temperatures for winter and spring in Nain, the number of days with sub-zero temperatures is projected to decrease by 6 to 18 days in summer and 8 to 16 days in fall. In St. John's frost days are projected to decrease in winter, spring and fall (by 6 to 17 days in winter, by 14 to 19 days in spring and by 4 to 10 days in fall), while in summer changes to the number of frost days are not pronounced. Although permafrost is not studied in the report by Finnis (2013), warmer temperatures and fewer frost days suggest a retreat of permafrost in the region, potentially leading to a higher risk of erosion and groundwater rise. Furthermore, winter ice formation which is already extremely variable might be affected. Winter ice formation and growth along the Labrador coast is subject to great annual variability: "Local residents have observed recent changes in the natural ice cycle, noting that the ice: takes longer to freeze, accumulates less snow cover, breaks-up earlier, and is thinner at the end of the winter" (Dickins and Dempsey, 2016: 5). Warmer temperatures and fewer frost days indicate the continuation of these trends.

At present, heat waves are very rare in Nain and St. John's and projections do not suggest a change. Droughts are neither a concern in the region, nor do projections indicated a change for the future.

The projected changes in average daily precipitation are negligible for both Nain and St. John's in all periods of the year, ranging between -0.1 to 0.4 mm (Nain) and 0.01 and 0.38 mm (St. John's). This trend is also shown in values for extreme or longer precipitation events, with also negligible changes of intensities. However, extreme precipitation events remain a risk. Increased temperatures could lead to more precipitation occurring as rain.

There are no regional projections for wind patterns and waves available.

There is considerable uncertainty regarding sea-level rise projections. Rough estimates indicate a 70 to 90 cm rise at the Nain area coast and an above 100 cm rise at the coast of Avalon Peninsula for 2099, relative to 1990 sea levels (Batterson and Liverman, 2010). Batterson and Liverman do not specify on which model or scenario their projections are based.

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[15] For an overview see Figure 5.

[16] All climate change projections are based on Finnis (2013), unless otherwise stated. Finnis conducted an assessment of projected impacts of climate changes for the province of Newfoundland and Labrador, including downscaled projections for various locations. Data for the close-by town Nain serves as a proxy for Voisey's Bay mine and data for St. John's on Avalon Peninsula serves as a proxy for the Long Harbor refinery. Finnis derived projections from an ensemble of seven regional climate model simulations produced for the North American Regional Climate Change Assessment Project (Finnis, 2013).

6.6.1 Potential climate impacts on the Voisey's Bay mine

Similar to the Cantung operations, at Voisey's Bay climatic conditions – especially the harsh winters – and the remote location are already today very challenging for daily operations. The mining site is expected to face various climate-related impacts today and in the future.

Neither mean precipitation, nor extreme rainfall is projected to increase significantly in the near future. Nevertheless, flooding could potentially have adverse impacts on the Voisey's Bay mining site. As mentioned above, flooding does not only occur due to extreme rainfall events, but can also occur when regular precipitation happens together with other conditions. In addition, precipitation could occur more often as rain than as snow compared to the current rain-to-snow ratio, due to increased temperatures.

If flooding occurred, water containment systems would be stressed. In past environmental progress reports, the mine operator has stated that surface water management is problematic, especially during times of spring runoff. The water containment systems at the site are either developed to withstand a 1 in 100 year storm or a 1 in 25 year storm (data as per 2009, Pearce et al., 2009). Such flooding event could also put mine workers at risk.

The underwater deposited PAG waste at Headwater Pont is designed to prevent the leaching of metals and further oxidation. A flooding event could lead to the overflow of the deposition pond, potentially leading to uncontrolled release of metal contaminated effluent. This could negatively affect both surface and groundwater quality. However, the "Voisey's Bay deposit is remote from most settlement in Labrador and effects to groundwater water will be isolated from aquifers used for potable water" (AECOM, 2013: 61). In addition to the potential environmental impacts, flooding of the mining site can also lead to a decreased or interrupted nickel production through preventive closure or damages at the mining site.

It is not possible to evaluate the risk for erosion and landslides at the pit and the tailing facilities during rain and flood events, as mass movements depend on a number of factors (e.g. geological and geomorphological conditions, surface texture, surface coverage with vegetation, etc.). However, erosion and landslides could affect the productivity of the mine negatively, disturbing the mining operations, as well as having adverse impacts on rehabilitation efforts and biodiversity in the region. Also workers might be put at risk by erosion or landslides.

Although temperatures are expected to increase, drought is not projected to be an issue in the future. Therefore, there is no risk of exposure of underwater deposited tailings to air and resulting increased AMD (Stratos, 2011). Temperature, along with other factors, has an effect on the oxidation rate of abiotic and bacterially mediated sulphides. In general, a higher temperature means a higher reaction rate (Stratos, 2011). It is difficult to evaluate whether the projected increases in temperature will have an impact on reaction rates at the Voisey's Bay operations. However, the effects of this and other climatic changes on AMD should be closely monitored. Increased mean temperatures could have negative impacts for rehabilitation and biodiversity in the region.

Although there are no regional projections available, changing conditions could mean that forest fires could occur more often and in a higher intensity in the future (see chapter 5.6 on climate projections for the Cantung mine). Forest fires could damage the mining site and its infrastructure, resulting in a decreased or interrupted production of nickel. Fire might also put the mine workers at risk, through air pollution from smoke or the fire itself. Also, revegetation efforts and biodiversity could be hampered by fires.

Thawing permafrost is not expected to impact the mining operations, as the mine's infrastructure design was developed expecting discontinuous permafrost conditions. However, permafrost degradation could negatively impact rehabilitation efforts and biodiversity in the region.

There are no projections for wind available. However, if wind intensity increased, it could mean that dust fallout at the mining site intensifies, requiring additional mitigation measures.

As the mining site is located at elevations ranging from 175 m to 500 m above the sea level, it is not expected to be impacted by the projected sea level rise. Yet, it is difficult to evaluate whether sea level extremes, such as heavy waves, would impact the mining site.

6.6.2 Potential climate impacts on the transport routes, air and maritime transportation

Similar to the transportation to and from the Cantung mining site, transportation at Voisey's Bay relies on favourable weather conditions. Therefore, extreme weather events could have severe negative impacts.

Flooding, erosion and landslides could render gravel roads, connecting the mine to the nearby port, as well as the airport runway unusable. As it is the case in the impact assessment for transportation at the Cantung mine, the impacts of thawing permafrost on road and the airport at Voisey's Bay are difficult to evaluate, as information on road and airport design and conditions are missing.

Heavy wind and rain could impact both air and maritime transportation, leading to interruptions and delays. Forest fire could impact various types of transportation negatively: it could damage routes and the airport and could develop smoke, hindering the take-off and landing of planes.

Sea ice change could lead to a longer ice-free period and therefore potentially more sea routes or a prolonged shipping period. This is a potential positive impact for the shipping of nickel concentrate. However, local Indigenous people could be adversely affected by changing ice dynamics and shipping traffic, as they rely on landfast ice for hunting and travelling. The current shipping agreement between the mine and the local communities requires the mine to uphold sea ice access routes and therefore limits shipping during the initial freeze-up period. Therefore, the mine operators could not harness the new shipping potential unless it reaches a new agreement with the community.

Interrupted transportation would affect the supply of the mine with fuel and other material necessary for production or the shipping of nickel concentrate to markets and therefore would have a negative impact on nickel supply security. In addition, an interruption of supply could also have severe consequences for the staff working at the mine. Workers well-being might be affected if supplies (e.g. food) run short or the transportation of the workers themselves from or to the site is compromised. Alongside the individual detriments, the potentially reduced workforce could impact the productivity of the mine.

6.6.3 Potential climate impacts on the Long Harbour refinery

The Long Harbour refinery would be mainly threatened by the impacts of flooding, especially caused by heavy rains or waves, as it is located directly at the sea.

Flooding could lead to the discharge of potentially sediment-laden water from nickel concentrate storage sites or tailings, either through a precautionary and controlled release or an uncontrolled spill. It is difficult to evaluate whether a spill of nickel concentrate into the sea would be harmful to the environment. Vale reports that some components of the concentrate are hazardous for human health, but does not state whether it is harmful to the environment (Vale, 2012). An overflow of the underwater storage of the PAG tailing at the processing plant would have similar environmental impacts as an overflow of the tailings deposition at the mining site (see chapter 6.6.1 on potential climate impacts on the Voisey's Bay mine). A spill of gypsum waste which is stored above ground is not expected to be environmentally harmful, as it is relatively benign. However, such incidents could decrease or interrupt the refinery's production of nickel concentrate.

Another issue is related to sulphur dioxide and other emissions. The dispersion and behaviour of air emissions is affected by weather conditions, such as wind speed and direction, air temperature and precipitation. Especially periods of temperature inversion and light wind can lead to elevated levels of air emissions (Potvin Air Management Consulting, 2004). It is difficult to evaluate whether climatic changes will lead to an increased frequency of such unfavourable weather conditions. However, if that were the case, it would have a negative environmental impact and could lead to production curtailments in response to elevated levels of air emissions, especially of sulphur dioxide (Fraser Basin Council, 2014). Extreme weather events, such as flooding or a hurricane, could damage the refinery. However, it is difficult to evaluate whether such an event could lead to the release of additional emissions and what the environmental impact would be.

Revegetation efforts and biodiversity could be negatively impacted by increased mean temperatures, fires, heavy rain, flooding, erosion and landslides, permafrost degradation (when applicable), heavy wind and heavy waves. Most of these impacts, apart from increased mean temperatures and permafrost degradation are also potentially harmful for workers at the refinery.

6.6.4 Potential climate impacts on the ports

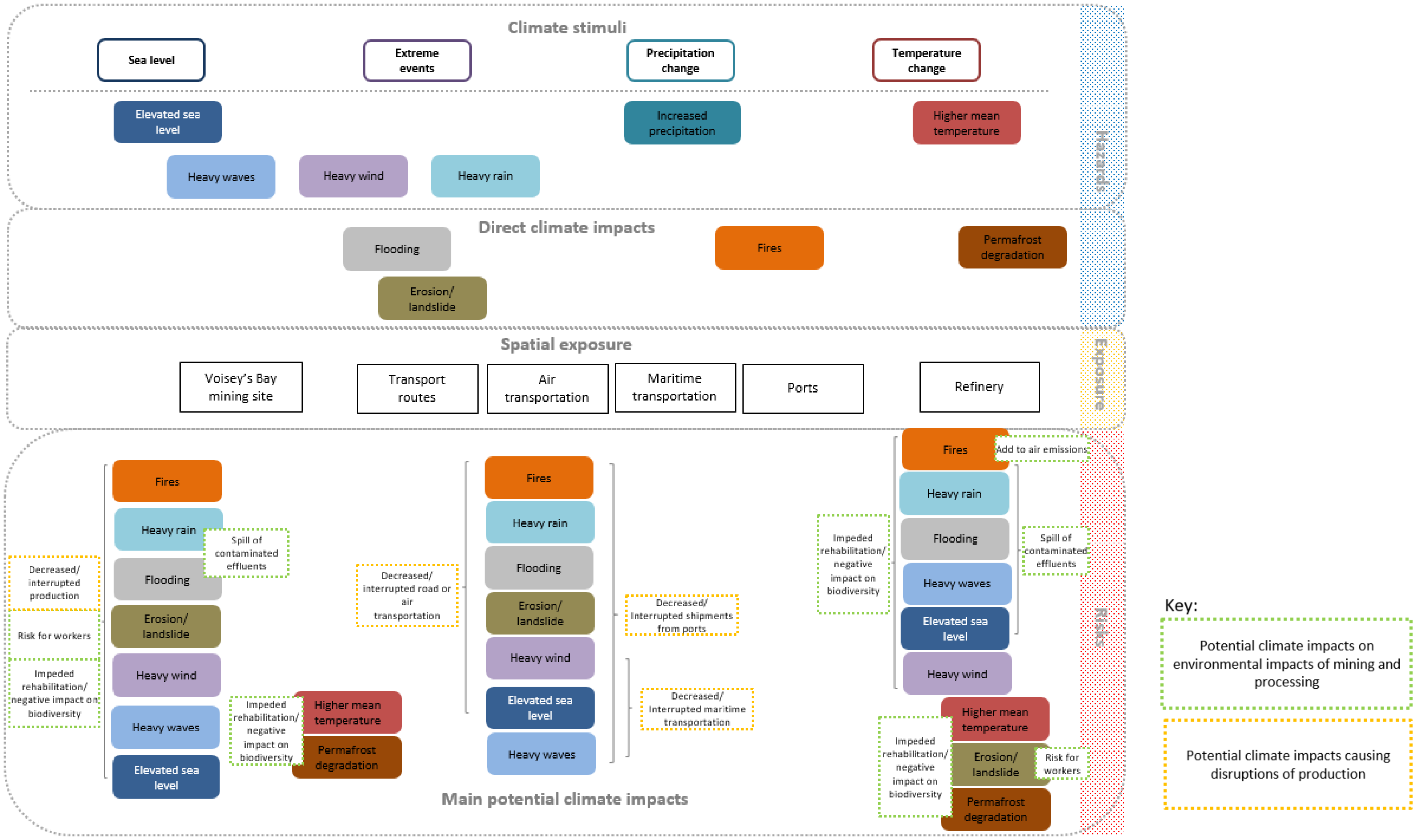
The main potential climate impacts for the ports at the mine and at the Long Harbour processing plant could be caused by more intense extreme weather events, in particular heavy wind and rain, which can cause heavy waves, leading to the flooding of coastal areas. However, there are no projections for wind and extreme rain events available.

The risk of coastal flooding is exacerbated by elevated sea levels. As described in the foregoing section, water excess or flooding caused by heavy rain or sea water could potentially lead to a spill of nickel concentrates. Furthermore, flooding could lead to damages to the ports which might result in decreased or interrupted transport.

As precautionary measure, ports can be instructed by the ports' or maritime authorities to halt operations when there is warning for bad weather, including heavy waves. This minimises the risk of damage but leads to an interruption of transport.

Based on the sea level projections for 2099, sea level rise could potentially harm the ports operations, unless adaptive measures are taken.

Figure 5: Climate impact chain for nickel



The diagram illustrates the specific climate stimuli, the spatial exposure, the direct climate impacts and the potential climate impacts. In order to visualise the links between these components of the climate impact chain, the colours of the frames of the potential climate impacts are used accordant to the corresponding climate stimuli and direct climate impacts.

7 Summary and conclusions

Canada is a large and mineral-rich country which extends over different climatic regions and often experiences extreme weather conditions, leading, for example, to harsh winters and forest fires in summer. The provinces Yukon, Northwest Territories and Newfoundland and Labrador, where the tungsten and nickel production sites assessed in this study are located, are characterized by subarctic climate. Both mining sites are located at remote sites.

Canada is already facing various climatic changes and it is expected to continue in the future, specifically affecting the north of the country. Climate models project pronounced increases in temperature – especially in winter – and precipitation. Although there remain uncertainties in the existing projections, extreme precipitation events and wildfires are expected to increase in frequency and severity. Thawing permafrost is a particular challenge for the north of the country, threatening the environment, as well as buildings, infrastructure and transport.

Climate change projections for the mining locations are subject to uncertainties. Nevertheless, based on the available information, it is possible to identify several potential climate change impacts for the mining and processing sites as well as transport infrastructure. Projections show increases in temperature in both locations, especially in winter. In the area of the Cantung mine (tungsten mining), precipitation is projected to increase, while projected precipitation changes are marginal in the area of the Voisey's Bay mine (nickel mining). However, flooding is expected to be a risk in both locations. More forest fires could occur as well. There are no regional projections for wind patterns and waves available.

Environmental impacts of mining and processing

The case study identified the following key environmental impacts resulting from tungsten and nickel mining and processing:

Tungsten: The Cantung tungsten operations cover a total area of about 10,000 hectares, including claims and leases. Land use is mostly associated with processing facilities, tailings ponds, and ore stockpiles, as tungsten mining at the site occurs mostly underground.

Waste rock from mining and tailings from the processing plant constitute the major solid waste streams. Waste rock is utilised as a backfill, tailings are disposed in the tailings pond. There is the risk of tailings liquefaction in storage facilities in case of an extreme weather event, resulting in tailings release which could contaminate the river system and lead to physical damage. There are plans to reprocess the tailings and to improve the storage facilities, moving them further away from the river. There is a risk for acid mine drainage, as tailings contain sulphide minerals, however this is partially offset by the high carbonate minerals content.

Supernatant from the tailings pond is treated at the waste water treatment facility to remove suspended solids and then discharged into the environment. Large parts of the process water from gravity separation and flotation is recovered and reused. The underground mine has relative little water discharge, due to the elevation of the mine and low permeability of the rocks. About half of the discharged water is reused for the mine's operations. The remaining required water is extracted from a nearby river.

As most tungsten extraction occurs underground, dust is mostly prevented. GHG emissions mostly originate from the use of fuels to power machinery, for electricity production, and transportation.

The mining site is located in the proximity of a national park reserve and world heritage site. There is only little evidence of impacts of the mining operations on biodiversity.

The company has prepared mine abandonment and reclamation plans for the mine site. However, inspections at the closed site found insufficient erosion control, lagged spill reporting, a sediment leak from the mine's quarry and various fuel leaks which need to be addressed. To date, the Cantung mining operations are not associated with any health related impacts.

Nickel: The Voisey's Bay mine is also located in a remote area. Water is mainly used for beneficiation and primarily extracted from Camp Pond. Large parts of the process water are reused while the remaining water and water from the settling pond are treated before discharge into the environment. The mine's deposit holds highly reactive sulphide minerals. To prevent seepage into the marine environment due to metal leaching or oxidation, PAG waste is deposited into underwater storage areas. Main emissions are related to dust produced by mining operations and transport.

The construction of the mine and its infrastructure only had a limited impact on the nearby ecosystem. The mine operator has a progressive reclamation program in place which e.g. already prepares waste rock slopes for future re-vegetation. PAG waste will be permanently kept underwater, requiring water quality monitoring also after the mine's closure. Similar to the Cantung mining operations, there are no reported health related impacts at Voisey's Bay mine or refinery to date.

Many environmental impacts at the Long Harbour refinery are associated with emissions and waste production. The plant emits sulphur dioxide, nitrogen oxides, and particle matter. The matte plant produces a relatively benign gypsum waste. The hydrometallurgical process generates PAG waste which requires neutralization and permanent underwater storage similar to tailings deposition at the mine site.

Climatic changes potentially affect environmental impacts of mining and processing and could curtail supply security

There are a number of current and potential climate impacts specific to subarctic regions. Climatic conditions, such as harsh winters, are challenging for daily operations at both mining sites.

Flooding could become an increasingly important risk at both mining sites. Rising temperatures which lead to more precipitation occurring as rain rather than snow, or earlier snow melt together with other factors could trigger more frequent and/or intense flooding events. An overflow or breach of tailing storage facilities at the Cantung mine could lead to damages and/or the contamination of the river system close to the site. Also at Voisey's Bay, an overflow of the underwater deposition pond could lead to the release of metal contaminated effluent. However, the impacts on water supply for the region are expected to be limited in case of such an event. Flooding poses a risk for workers at the site.

Although it is not possible to evaluate the risk for erosion and landslides, those events could certainly affect the productivity of the mine negatively, as well as adversely impact rehabilitation efforts and the region's biodiversity. Similar to flooding, also erosion or landslides might put workers at risk.

Forest fires occur in both mining regions and could potentially occur more often in the future. Potential impacts would be similar at both sites. Fires could damage the mining site and its infrastructure, resulting in a decreased or interrupted mining production. Fire might also put the mine workers at risk, as well as revegetation efforts and biodiversity.

Permafrost degradation is a specific issue of (sub)arctic climate regions and could in general destabilise mining infrastructure. From an environmental perspective, especially the potentially resulting destabilising of tailing storage facilities could be a negative consequence of degraded permafrost. While it is not possible to evaluate whether permafrost degradation could have negative impacts on the Cantung mining site, thawing permafrost is not expected to impact Voisey's Bay mining operations, as the mine's infrastructure design was developed expecting discontinuous permafrost conditions.

There are no projections for wind available. However, if wind intensity increased, it could mean that dust fallout at the Voisey's open pit operations site intensifies, while this is not expected to be an issue at the Cantung mine, as mining operations occurred mostly underground.

For nickel, potential climatic impacts on the Long Harbour refinery were also assessed. The refinery could be especially impacted by flooding events. A spill from nickel concentrate storage sites, tailings or underwater storage of tailings could lead to the release of sediment-laden water into the environment. It is difficult to evaluate whether such a spill would be environmentally hazardous. Sulphur dioxide and other emissions are another important issue at the refinery. As the dispersion and behaviour of air emissions are affected by weather conditions, climatic changes could impact levels of air emissions. However, an assessment of such changes based on the publicly available information was not possible. It can be noted that both flooding and elevated levels of sulphur dioxide and other emission could lead to production curtailments at the refinery, as emissions should not exceed certain regulated levels.

Remote locations amplify supply risks

Road, air and maritime transportation can be regarded as supply chain bottlenecks, as both mining sites are located in very remote regions. The climate change impact assessments suggest that various climate impacts, such as heavy wind, heavy rain, flooding, erosion, landslides and fire, can lead to supply interruptions. On the one hand, the mining production could be limited as the supply with necessary equipment, such as fuel, is disrupted. On the other hand, the shipment of tungsten or nickel concentrate to refineries or markets could be impeded as means of transportation are disturbed by extreme weather events. The 2012 mudslides and washouts along the Nahanni Range Road in Yukon which connects the Cantung mine to the next town is a past example of such an incident. The mine production had to be halted for a week as fuel and food shortages occurred. The shipment of tungsten concentrate was also interrupted during that time.

In addition to the impacts on production and supply, the well-being of workers can also be significantly affected by interruptions of transportation.

Permafrost degradation could be a transportation issue specific for subarctic regions, especially for roads and airports. However, its impact on the transportation from and to the Cantung mine and Voisey’s Bay could not be evaluated, as information on transport infrastructure design is not available.

Indigenous relations are important and need to be strengthened

The current implementation of the duty to consult and accommodate in the context natural resources often proved deficient. However, the relationship between the Canadian government and indigenous people is evolving. The adoption of the UNDRIP, the announcement of the Recognition and Implementation of Rights Framework and the proposed reform of the EA process are all promising developments which could entitle indigenous people with important rights and enhance their participation substantially. Nevertheless, these recent changes or proposals still need to be implemented and it remains to be seen to what extend the situation of indigenous people will be improved.

Both mines have agreements with nearby indigenous communities. The agreement established at Voisey’s Bay is especially remarkable as the consultation process acknowledged the indigenous communities as legitimate decision-makers fostering meaningful participation. As the climate changes, changes to these agreements might become necessary. For example, sea ice change could open up new shipping routes or prolong the shipping season at Voisey’s Bay. Yet, indigenous communities would have to agree to new shipping routes or a prolonged shipping season and the current agreement would need to be modified.

Mining sector governance and adaptation

Canada’s environmental governance is well developed and national actions on adaptation are evolving. The 2011 Federal Adaptation Policy Framework, the 2016 Pan-Canadian Framework on Clean Growth and Climate Change and several recent announcements related to climate change adaptation (i.e. the establishment of a Disaster Mitigation and Adaptation Fund, the new Canadian Centre for Climate Services and the creation of an expert panel on climate change adaptation and resilience) are relevant developments for climate change adaptation in Canada.

The awareness for adaptation needs in the mining sector is generally increasing. Comprehensive national reports on climate change impacts and adaptation from 2008 and 2014 identify risks and opportunities for the Canadian mining sector. The national Climate Change Adaptation Platform established a working group on mining which produced several studies, providing specific information and case studies for the mining sector.

While Vale recognises climate change as a challenge for its operations, it has no climate change adaptation plan in place at its Voisey's Bay mine. However, adaptive management practices are established for Voisey's Bay operations. It is not disclosed whether the Cantung mine had adaptation measures in place while operating. A future reopening of the Cantung mine would be a good opportunity to implement new adaptation measures.

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