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106/2020

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

Case studies on bauxite, coking coal and iron ore mining in Australia

For our Environment

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

Case studies on bauxite, coking coal and iron ore mining in Australia

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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 mining operations in Australia: Rio Tinto's Weipa bauxite mining operations in Queensland (tropical climate), the Goonyella Riverside coking coal mining operations also in Queensland (sub-tropical climate) and the Mount Whaleback iron ore mining operations in Western Australia (arid hot desert climate). All three mining operations have a large land footprint. The beneficiation of mined bauxite does not entail high environmental risks since no chemicals are used. In contrast, refining and smelter processes pose higher risks to the environment (e.g. high energy use at the smelter; highly alkaline red mud residue and high water use at the refinery). Saline and/or acid water seepage from coking coal and iron ore mining pits and mine waste pose environmental risks for surrounding soils and the groundwater. Coal mining additionally causes air pollution.

Overall, the impacts of climatic changes are expected to aggravate or add to current environmental risks. Extreme weather events stand out as the main risks across the three mining sites. In particular, more intense wet weather extremes can lead to the flooding of mining areas, exacerbating the environmental risks of drainage or discharge of hazardous waters at coking coal and iron ore mining operations. In these kinds of operations, flooding can also interrupt transportation, whereas bauxite transportation may be affected to a lesser extent. Droughts could affect mining and processing operations, for example, by restricting water use, potentially halting production of bauxite, coking coal or iron ore.

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 Bergwerke in Australien: Rio Tintos Bauxitbergwerk in Weipa (tropisches Klima), das Kokskohle Bergwerk Goonyella Riverside (subtropisches Klima) und das Eisenerzbergwerk Mount Whaleback (trockenes, heißes Wüstenklima). Alle drei Bergwerke weisen einen hohen Landverbrauch auf. Die Weiterverarbeitung des abgebauten Bauxits birgt keine hohen Umweltrisiken, da keine Chemikalien verwendet werden. Im Gegensatz dazu stellen Raffinations- und Schmelzprozesse ein höheres Umweltrisiko dar (z.B. hoher Energieverbrauch bei der Verhüttung; hochalkalischer Rotschlamm und hoher Wasserverbrauch im Umschmelzwerk). Das Austreten von salinen oder sauren Grubenwässern stellt Umweltrisiken sowohl beim Kokskohle- als auch beim Eisenerzabbau dar. Der Kohleabbau verursacht zudem Luftverschmutzung.

Insgesamt kann davon ausgegangen werden, dass die Auswirkungen des Klimawandels die derzeitigen Umweltrisiken des Bergbaus an den untersuchten Standorten verschärfen. Starkregenereignisse stellen ein Haupttrisiko an allen drei Abbaustätten dar, welche Überschwemmungen zur Folge haben und zum Austritt von belastetem Wasser beim Kokskohle- und Eisenerzabbau führen können. Überschwemmungen können auch Transportunterbrechungen an den untersuchten Kokskohle- und

Eisenerzbergwerken mit sich bringen, während der Transport von Bauxit wahrscheinlich nur in geringerem Maße beeinträchtigt würde. Dürren könnten zu einer Einschränkung des Wasserverbrauchs führen, was den Abbau, die Aufbereitung, die Verhüttung und das Umschmelzen beeinträchtigen könnte. Diese Einschränkungen könnten eine Drosselung der Produktion von Bauxit, Kokskohle oder Eisenerz erforderlich machen.

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List of Abbreviations

AMD	Acid Mine Drainage
AR4	Fourth Assessment Report of the Intergovernmental Panel on Climate Change
AR5	Fifth Assessment Report of the Intergovernmental Panel on Climate Change
BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (*German: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit*)
BOM	Bureau of Meteorology
BSL	Boyne Smelters Limited
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CID	Channel Iron Deposit
DBCT	Dalrymple Bay Coal Terminal
EAF	Electric Arc Furnace
ENSO	El Niño Southern Oscillation
ETC	Extratropical Cyclones
FPIC	Free Prior and Informed Consent
GHG	Greenhouse Gas
HPCT	Hay Point Coal Terminal
OHP	Ore Handling Plant
PGM	Platinum Group Metals
QAL	Queensland Alumina Limited
RCP	Representative Concentration Pathway
RTA	Rio Tinto Alcan
TSS	Total Suspended Solids
UBA	German Federal Environment Agency (*German: Umweltbundesamt*)
WA	Western Australia

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., 2020).

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., 2020).

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.

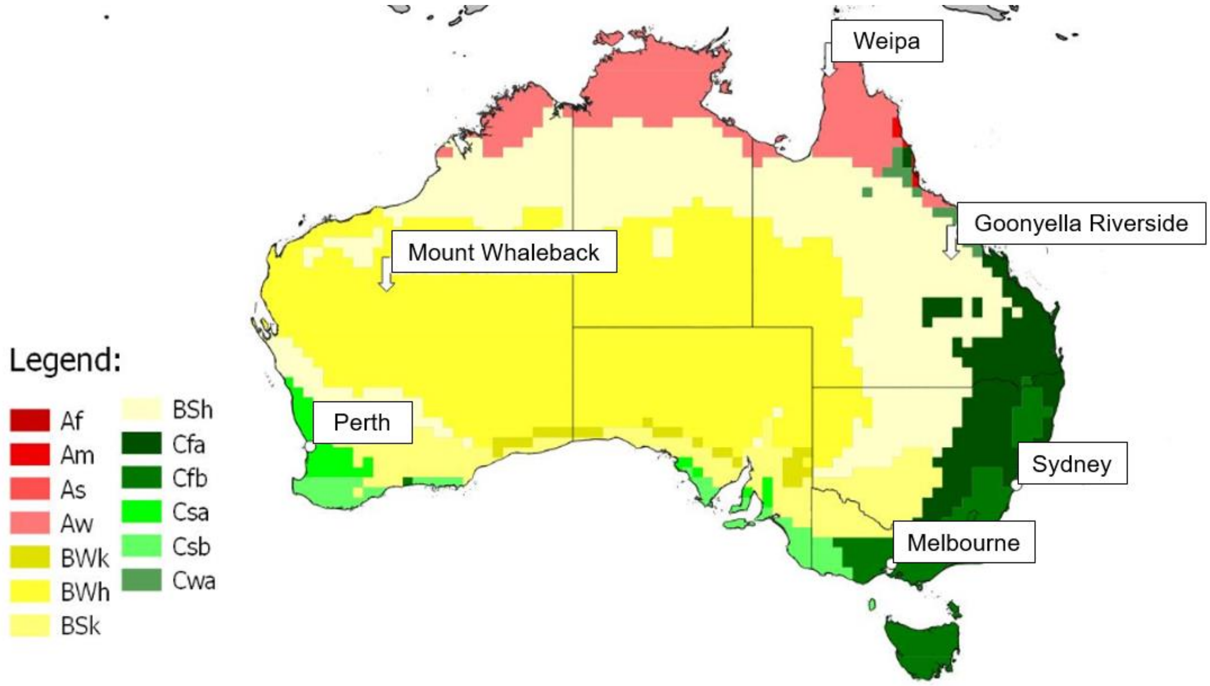
Each case study analysed a chosen mine site and the processing steps (to the extent these take place in the relevant country). The project team evaluated the environmental and supply risks potentially caused by climate stimuli and/or direct climate impacts for each of the mining and processing sites.

1.3 Content and structure

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

- Bauxite mine in Weipa, Queensland (tropical climate)
- Coking coal mine Goonyella Riverside, Queensland (sub-tropical climate)
- Iron ore mine Mount Whaleback, Western Australia (arid hot desert climate)

Figure 1: Map of Australia indicating Köppen-Geiger climate classification and examined sites



Source: Maps prepared by adelphi using QGIS Geographic Information System (http://qgis.osgeo.org); climatic regions based on Rubel and Kottek, 2010. Arrows point to mine sites; dots indicate large cities.

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 tropic, arid and coastal regions and for Australia 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).

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 climatic changes

Australia is characterized by different climatic zones. The mining sites analysed in this case study are located in tropical as well as arid climatic zones. One mine is situated at the coast; all other mines are located inland. All mines deliver their products to ports for export. The following chapter provides a quick overview over these climatic zones, coastal regions as well as the Australian continent and predicted climatic changes at the respective locations.

2.1 The tropics

The climate classification outlined by Köppen-Geiger defines the tropics as a region where the mean temperature of the coolest month is 18°C or higher (Peel et al., 2007). This climatic zone has three subtypes, defined by precipitation criteria: wet equatorial climate or tropical rainforest climate[1], tropical monsoon and trade-wind littoral climate[2] and tropical wet-dry climate or tropical savannah climate[3] (Arnfield, 2016; Peel et al., 2007). The tropics cover 19 per cent of the global land area (Peel et al., 2007).

The region is characterised by a warm climate, with mean annual temperatures exceeding 20°C and in many parts even 25°C (Trewin, 2014). The temperature varies little during the year. The annual ranges of temperature of tropical locations are usually very small; near the equator, the mean temperature of the hottest months is only marginally higher than the mean temperature of the coolest months (Trewin, 2014). Day-to-day temperature fluctuations are also very small (Trewin, 2014). In contrast to the relatively constant temperature, precipitation regimes differ considerably throughout the tropics, ranging from the driest places on earth (e.g. in the South American Atacama desert with less than 1 mm mean annual rainfall) to the wettest (e.g. some locations in Hawaii with more than 10,000 mm mean annual rainfall) (Trewin, 2014). In regions with wet equatorial or tropical rainforest climates, rain occurs regularly throughout the year. Tropical monsoon and trade-wind littoral climate zones can be characterised by a well-defined, but brief dry season, while zones with tropical wet-dry/tropical savannah climate usually have a longer dry season. For locations on islands or near the coast, temperature and precipitation slightly vary.

The El Niño-Southern Oscillation (ENSO) causes high natural climatic variability in the tropics, which makes it harder to detect the impacts of anthropogenic climate change (Corlett, 2014). Other human impacts, such as deforestation and urbanisation, also have impacts on the region's climate (Corlett, 2014). A lack of climatic data, especially for continental Africa, the Amazon and the tropical Pacific, constrains projections (Trewin, 2014). Nevertheless, there has been an observable warming by 0.7 to 0.8 °C over the last century. This has led to some visible impacts on land and in the sea: high-mountain flora and fauna have moved upslope, glaciers in the Andes and East Africa have shrunk and extreme mass coral bleaching periods have occurred in the oceans (Corlett, 2014).

Rainfall trends for the tropics are less clear, since the amount of rainfall fluctuates from year to year, partly due to ENSO. However, the last 30 years have shown a general increase in precipitation, with some parts of the tropics experiencing a decrease (e.g. in parts of Brazil and the central equatorial Pacific) (Trewin, 2014).

Tropical cyclones are important tropical atmospheric phenomena. They can have particular destructive forces, as they combine extreme winds, extreme rainfall (can cause freshwater flooding and landslides) and storm surges (can cause elevated sea levels and flooding). Storm surges caused by cyclones have led to many fatalities in the past, especially along low-lying coastal areas with large

[1] Precipitation in the driest month is at least 60 mm.

[2] Precipitation in the driest month is less than 60 mm but equal to or greater than 100-average annual precipitation total mm/25.

[3] Precipitation in the driest month is less than 60 mm but less than 100-average annual precipitation total mm/25.

populations (Trewin, 2014). The number of tropical cyclones per year has stayed notably constant from year to year, between 75 and 100 cyclones per year. In terms of intensity, there are no clear trends in the observed cyclone activities (Trewin, 2014).

Climate projections expect a further temperature increase of 1°C by 2050 and a 1-2°C increase by 2100 under the lowest-emission scenario, whereas high-emission scenarios assume increases of 1-2°C (by 2050) and 3-4°C (by 2100) (Trewin, 2014). This is slightly less warming than in other climatic regions. For rainfall projections, there is generally low confidence and therefore high uncertainty. Rainfall might increase, seasons with rainfall might intensify (with wetter and longer wet seasons and drier dry seasons) and extreme rainfall events might occur more often (Trewin, 2014). Projections show that the number of cyclones will either decrease or stay more or less the same, but that there will be a larger share of intense cyclones (Trewin, 2014). Heatwaves are also likely to increase in frequency and severity. These changes can have severe impacts on many less developed tropical countries due to their high vulnerability to extreme weather events, especially concerning poor people in urban informal settlements and rural areas with less access to supporting infrastructure and public services (Trewin, 2014; Corlett, 2014).

2.2 Arid regions

Arid climates have low mean annual precipitation rates, high year-to-year variability in precipitation and a relatively low humidity (Arnfield, 2016; Peel et al., 2007). This climatic zone has four subtypes: an arid desert climate, either of hotter[4] or cooler[5] nature, and a semi-arid steppe climate, also either of hotter or cooler nature. Arid climate is the world's dominant climate zone, covering over 30 per cent of the global land area (Peel et al., 2007).

Over the next century, precipitation in many arid regions is expected to decrease by at least 20 per cent (Arab Water Council, 2009). Although rainfall will likely be less frequent, it is expected to be more intense (Arab Water Council, 2009). Increasing temperatures will also result in higher evaporation and drier conditions, and this, combined with the decline in the frequency but increase in intensity of rainfall, will result in droughts and floods (Arab Water Council, 2009).

2.3 Coastal regions

Coastal regions lie in all climatic zones[6]. Coastal systems and low-lying areas can be defined as areas close to the mean sea level (Wong et al., 2014).

According to the *Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (AR5), the global sea level is very likely to raise (Wong et al., 2014). 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(Wong et al., 2014). General sea level rise will also mean an increase in extreme sea levels[7] (Wong et al., 2014).

Coastal ecosystems will suffer from increasing ocean acidification and warming (Wong et al., 2014). In terms of extreme weather events, tropical cyclone frequency is likely to decrease or not to change; however, 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 consequently causing potential damage to coastal infrastructures) would be felt most strongly in coastal regions

[4] Average annual temperature is to or greater than 18°C.

[5] Average annual temperature is less than 18°C.

[6] An overview on coasts in polar region will be included in the case study on Canada.

[7] 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).

(Corlett, 2014). Projections for increased winds and waves have only low confidence (Wong et al., 2014).

Population growth, economic development and further urbanisation in coastal areas will put additional pressure on coastal systems. Furthermore, coastal populations, especially in tropical countries, are most vulnerable to sea level rise (Wong et al., 2014; Trewin, 2014). The *Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (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).

2.4 Australia

According to the Köppen-Geiger climate types, the Australian continent can be subdivided into three main climate zones: arid (covers 77.8 per cent of land area), temperate (covers 13.9 per cent of land area) and tropical (covers 8.3 per cent of land area) (Peel et al., 2007: 1642). The analysed mining sites are located in different climate regions. Weipa is located in northern Queensland and Goonyella Riverside is located in central Queensland. While Weipa is characterised by a tropical climate, Goonyella has a typical semi-arid climate. Weipa lies on the coast and Goonyella Riverside is located inland. Mount Whaleback is located in Western Australia and has an arid hot desert climate.

Australia has a very high natural climatic variability, most importantly in regard to its rainfall patterns, which are mainly linked to the ENSO (Reisinger et al., 2014). This natural variability makes it difficult to distinguish and project anthropogenic climate change and the impacts it has on Australia (Reisinger et al., 2014). However, the *Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (AR5) finds with high confidence that Australia's long-term climatic trends are changing (Reisinger et al., 2014).

The latest *State of the Climate* report, published by the Australian Bureau of Meteorology (BOM) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) gives an overview of observed current changes in Australia's climate and predictions for future developments (BOM/CSIRO, 2016). The report states that the mean surface air temperature has increased by 1°C on average since 1910, rising particularly since the 1950s. Also, the number of days per year with temperatures above 35°C has increased in large parts of the Australian continent since the 1950s. While rainfall has decreased in southern Australia since 1970 (during the agriculturally important season between May and July), it has increased in northern Australia (during the monsoon season between October and April). As for the oceans surrounding Australia, there are three important observations: the temperature and the acidity levels of the oceans have increased, sea levels have risen and, consequently, there has also been an increase in high tides and storm surges.

BOM and CSIRO project[8] that most of these trends will continue: the mean temperature will increase further, there will be more hot days, rainfall will be more intense in some regions and will decrease in other regions. The oceans around Australia will heat up further, ocean acidification levels will increase and the sea level will continue to rise.

[8] In this report, the authors are not differentiating between different RCP scenarios.

3 Overview of the mining sector in Australia and its economic relevance

Australia is one of the world's major producers of minerals and has almost 400 mines where 19 minerals are sourced in significant quantities (Geoscience Australia, 2017). In 2015, Australia had the world's largest resources[9] of diamond, gold, iron ore, lead, nickel, rutile, tantalum, uranium, zinc and zircon. Further, it had the second largest resources of bauxite, brown coal (lignite), cobalt, copper, ilmenite, manganese ore, niobium, silver, thorium and tungsten in the same year. It had the fifths largest resources of black coal[10]. In terms of global production, Australia ranked first in the production of bauxite, rutile and zircon; second in diamond, gold, ilmenite, iron ore, lead, rare earths and zinc production; and third in brown coal, manganese ore and uranium production. (Britt el al., 2016, data referring to 2015). To illustrate further, the three minerals analysed in this study – iron ore, bauxite and black coal – accounted for 25 per cent (iron ore), 29 per cent (bauxite) and 8 per cent (black coal) of the global production in 2015 (Britt el al., 2016). Almost all iron ore (98 per cent) is produced in Western Australia (Department of State Development, 2017). Coal is mostly produced in Queensland (54 per cent of total Australian production) and New South Wales (44 per cent of total Australian production) (Department of Industry, Innovation and Science, 2016c). For bauxite, production is concentrated in Western Australia (55 per cent of total Australian production) and Queensland (34 per cent of total Australian production) (Department of Industry, Innovation and Science, 2016b)

Mining is of high importance to the Australian economy. After Services (output $1,015 billion, 61.1 per cent of GDP) and Construction (output $134.2 billion, 8.1 per cent of GDP), it is the sector with the third highest contribution to the national economy (Office of the Chief Economist, 2016). The mining industry[11] had an output of $114.9 billion in 2015-2016, which equals a 6.9 per cent share of the total GDP (Office of the Chief Economist, 2016).

Table 1: Major sectors of the Australian industry, 2015-2016

Industry sector	Output	Share of GDP	Share of employment
Services	$1,015.0 billion	61.1 %	79.2 %
Construction	$134.2 billion	8.1 %	8.8 %
Mining	$114.9 billion	6.9 %	1.9 %

Source: Office of the Chief Economist 2016: 33.

The Australian total export value was $312 billion in 2015–2016. Mining products were among the top exports. Iron ore had the largest export value with $47.7 billion, followed by coking and thermal coal with the second largest export value of $34.3 billion (Office of the Chief Economist, 2016). $10.2 billion of export value originated from bauxite, alumina and aluminium (Department of Industry, Innovation and Science, 2016a). On worldwide comparison, Australia is the largest exporter of iron ore, coking coal and alumina (Department of Industry, Innovation and Science, 2017).

Compared to its important economic output, the mining sector does require a relatively small workforce. In 2015-2016, the sector employed about 200.000 people, which makes up 1.9 per cent of the total employment in all industries (Office of the Chief Economist, 2016). However, it is the sector with the highest salaries on average (AMMA, 2017).

In general, the mining sector has strong impacts on the national economy. In times where employment in mining is high, the local economy and the housing market profit from the money available for

[9] Resources are defined as Economic Demonstrated Resources in Britt et al, 2016.

[10] Two major types of black coal are thermal or steaming coal that is used for generating electricity and coking or metallurgic coal which is used for steel making.

[11] Includes not only mineral mining but also natural gas production.

spending (The Economist, 2017). Also, construction and importing industries do well in times of a mining boom. In contrast, the strong value of the Australian dollar – a corollary of high mining export prices – has a negative impact on other exporting industries, such as agriculture (Downes et al., 2014).

Yet, the mining sector is volatile and considerably smaller today than during boom times, providing less employment than previously (Letts, 2016). Simultaneously, a cheaper Australian dollar is strengthening other industries (e.g. agriculture and tourism) (The Economist, 2017).

4 Overview of the mining governance of Australia

The governance of the mining sector lies on different levels of government. Yet, authorities on the state and territory government[12] level are the predominant regulators of the mining sector (Everingham et al., 2013). They allocate mining licences, regulate the royalty system and access to land and water, and they grant planning approvals, including environmental authorisations (Everingham et al., 2013; Woods and Knight, 2016). Local governments are responsible for local property taxes, for local infrastructure (e.g. roads and waste management) and buildings, and environment, health and community matters (Everingham et al., 2013). The federal government oversees and regulates foreign investments, uranium-related matters and other areas of taxation (Everingham et al., 2013). Yet, there are also overlaps. For example, the federal government and the state/territory governments have shared responsibilities with regard to the regulation of native lands and heritage matters as well as environmental protection. State/territory and local governments jointly handle regional social and economic issues as well as planning approval.

Further, "[m]andated consultation processes [e.g. in the case of an environmental impact assessment] provide for nongovernmental stakeholders to influence local and regional developments in mining-intensive areas. These stakeholders include significant interest groups such as indigenous groups, regional boards, and civil society organizations" (Everingham et al., 2013: 589). In addition, the mining industry commits itself in some cases to self-regulatory processes (Everingham et al., 2013).

Although the involvement of the three government levels, various government departments and bodies as well as non-government stakeholders increases the complexity of the sector's governance, the overall governance of the mining sector is well functioning.

4.1 Disaster risk reduction and climate change adaptation policies

Among developed countries, Australia has one of the highest levels of vulnerability to the effects of climate change (Forino et al., 2014). The Government of Australia acknowledges that it will experience high losses due to natural disasters in the near future. It estimates that costs will triple by 2050, amounting to US$ 17.7 billion (McClean, 2017).

Several agencies at the national level are responsible for climate change adaptation and disaster risk reduction, e.g. Emergency Management Australia as part of the Attorney-General's Department and the Department of the Environment and Energy. Additionally, Australia has a meteorological service – the Bureau of Meteorology – that provides detailed and timely forecasts, warnings (e.g. for severe thunderstorms, cyclones, tsunamis and bushfires) and long-term outlooks. Concerning post-disaster reconstruction, the federal government provides funding to states and territories as well as to individuals for recovery.

However, Australia's climate actions have been "inconsistent and lacking direction" over the past three decades – not only with regard to climate mitigation, but also concerning disaster risk reduction and climate change adaptation (Forino et al., 2014: 3). Climate policies of the main political parties in Australia have changed repeatedly and there is a lack of coordination between the federal, state/territory and local governments for disaster risk reduction and climate change adaptation (Forino et al., 2014).

To strengthen cooperation between government levels and to link climate change adaptation to the disaster risk reduction agenda, the Council of Australian Government brought several initiatives

[12] There are six states in Australia (New South Wales, Queensland, South Australia, Tasmania, Victoria and Western Australia) and two mainland territories (the Australian Capital Territory and the Northern Territory). The states have their own constitutions and legislative, executive and judiciary. The territories are similar to the states, with the main difference being that the Commonwealth (i.e. federal) Parliament is entitled to alter or revoke the territories' powers of self-government (Australian Government, 2017).

forward, e.g. the *National Climate Change Adaptation Framework (2007)* and the *National Strategy for Disaster Resilience (2011)* (Forino et al., 2017). In 2015, the federal government published its *National Climate Resilience and Adaptation Strategy* (Department of the Environment and Energy, 2017).

Regional level

In addition to national agencies, every state and territory has its own strategies and institutions, for example, the Western Australia Climate Change strategy "Adaption to our changing climate". Queensland has modified its institutions over the past years. In the aftermath of the 2010-11 Queensland floods, the Queensland government set up the Queensland Reconstruction Authority, initially for a limited period of time (Queensland Government, 2017a). As a reaction to the increasing number and intensity of extreme weather events and subsequent disasters, the agency became permanent in June 2015 (Robertson, 2015). It is the first permanent disaster recovery agency at the state level in Australia and has an annual budget of AUD$ 30 million (Robertson, 2015). Furthermore, Queensland updated its Strategy for Disaster Resilience in early 2017 (Queensland Government, 2017b).

Local level

In the *National Climate Change Adaptation Framework*, the Council of Australian Governments places important responsibilities on local governments for climate change response and disaster risk management (Forino et al., 2017: 100-101). However, local government responses to climate change are highly variable, depending on their sizes, assets and locations[13], among other factors (Forino et al., 2017). Examples for local disaster management are the Local Disaster Management Plans of the Gladstone Regional Council and Weipa Town Authority (Gladstone Regional Council, 2017; Weipa Town Authority, 2017).

Mining companies

Mining companies also have adaptation strategies in place. For example, BHP Billiton has set up environmental and climate change requirements that apply when undertaking business activities or making investment decisions. These requirements include climate change adaptation (BHP Billiton, 2016). For the Western Australia Iron Ore operations, BHP Billiton developed a Climate Resilience Plan (BHP Billiton, 2017a). Rio Tinto has a corporate Energy, Environment and Climate Change group since 2002. The group evaluates the risk to Rio Tinto's business from climate change. For its bauxite mine in Weipa, Rio Tinto has developed a Climate Change Sensitivity Framework which helps the company to assess climate change risks for operations and infrastructure (Peace et al., 2013).

4.2 Environmental governance

All stages of the mining life-cycle require environmental authorisation in Australia (Woods and Knight, 2016). State and territory governments are in charge of granting environmental approvals. In Queensland, the responsible authority is the Department of Environment and Heritage Protection, and in Western Australia, it is the Department of Water and Environmental Regulation[14]. Standard approvals for operations with minor environmental disturbance are generally easy to obtain, while significant and large-scale operations need a more comprehensive environmental approval which requires environmental impact statements and a consultation with people who could be potentially affected by the operations (Woods and Knight, 2016). If a mining operation is likely to cause

[13] Densely populated regions on the coast show generally a higher level of commitment (Fallon and Sullivan, 2014).

[14] The Western Australian Department of Water and Environment Regulation is a merger of the Department of Environment Regulation, the Department of Water and the Office of the Environmental Protection Authority. It was established in July 2017. Prior to that, the Office of the Environmental Protection Authority was in charge of the environmental impact assessment process (Environmental Protection Authority, 2017).

environmental impacts with national significance (e.g. national heritage areas), the federal government needs to be involved, as well (Woods and Knight, 2016).

During and after mining operations, the states' and territories' environmental authorities control and monitor the companies' environmental performance. The Queensland Department of Environmental and Heritage Protection oversees over 25 legislative Acts to safeguard environmental protection and health and ensures compliance with these Acts either in a proactive way or in reaction to complaints or incidents (Department of Environmental and Heritage Protection, 2017). In Western Australia, the Department of Water and Environmental Regulation has similar duties.

A recent example of environmental management and regulation was in the aftermath of the destructive Cyclone Debbie in March 2017, when the Queensland Department of Environmental and Heritage Protection carried out a series of investigations into the coal port spill from the Abbot Point Coal Terminal into the Caley Valley Wetland and its potential damaging impacts.[15]

Environmental authorities can also enforce sanctions, such as "formal letters of warning, infringement notices, modified penalty fines or court prosecution" (Department of Water and Environmental Regulation, 2017a). In Western Australia, the Department of Water and Environmental Regulation has reported several fines of AUD$25,000 each imposed on mining companies for the discharge of 20,000 to 288,000 litres hypersaline water into the environment (Department of Water and Environmental Regulation, 2017b).

Although Australian states and territories have generally strong environmental management and regulation systems in place, there are some claims that more monitoring is needed. For example, the environmental law firm *Environmental Justice Australia* states that harmful air pollution from coal mining in central Queensland is not well monitored and that air quality data is hard to access, which makes it difficult for people to make well-informed decisions concerning their health (Lodge, 2016; Edwards, 2016).

4.3 Indigenous people and mining

According to the 2016 Census, indigenous people make up 3.3 per cent of the total Australian population (Biddle and Markham, 2017). In regions where the analysed mining sites are located, the share of the indigenous people is higher. In the Cape York region, 51.6 per cent of the population identify as indigenous, whereas 19.5 per cent of Weipa town residents are indigenous (Australian Bureau of Statistics, 2017a; 2017f). In the Isaac region, the indigenous population has a share of 3.6 per cent of the total population and in the town of Moranbah 3.9 per cent of the total population is indigenous (Australian Bureau of Statistics, 2017c; 2017d). In East Pilbara, 17.9 per cent of the population is indigenous, with 12.9 per cent of the population living in Newman being indigenous (Australian Bureau of Statistics, 2017b; 2017e).

Australian indigenous people have faced a long history of discrimination since the first European settlers arrived on the Australian continent in 1788. In general, they have significantly lower levels of education, lower employment rates, poorer health and lower life expectancy than non-indigenous Australians (Closing the Gap report, 2017).

Considering the impacts of extreme weather event and climate change, indigenous people are generally more vulnerable than non-indigenous people. A scoping study for the Australian Department of Climate Change and Energy Efficiency[16] found in 2009 that "[t]he existing social and economic disadvantage that exacerbates many remote Indigenous communities' vulnerability to climate change

[15] Further details on that case are provided in the section on recent weather extremes (see case study on coking coal mining, section 6.5.1).

[16] The Department was dissolved in March 2013 and superseded by the Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education which was dissolved in September 2013. The division on climate change is now incorporated in the Department of the Environment and Energy.

cannot be overstated" (Green et al., 2009: 140). Poor housing quality, lack of health services, failure-prone communication facilities and power and water services are major issues that reduce the resilience of Indigenous people (Green et al., 2009). Furthermore, dependence on natural resources for livelihoods and strong cultural connections to the land increases the vulnerability of indigenous people (Green et al., 2009).

Although Australian indigenous people do not always oppose mining, the relationship between indigenous groups and the mining industry is shaped by struggles over access to land and benefit sharing. The period between the mid-1960s and the mid-1990s was characterised by a number of conflicts between indigenous groups and the mining industry (Langton, 2015). This situation started to improve after the introduction of the Native Title Act in 1993[17], which laid down a legal framework for the recognition and protection of indigenous lands (Langton, 2015). The Native Title Act grants indigenous people the right to negotiate an agreement with the entity that wants to use their land; however, there is no veto right in line with the principle of Free Prior and Informed Consent (FPIC), which means indigenous people do not have the formal right to withhold their approval of a mining project (Doyle, 2015). An exception can be found in the Northern Territory's legislation where the principle of FPIC is stipulated by law since 1976 (Doyle, 2015).

The number of agreements between indigenous groups and mining companies and/or local, State/Territory and federal governments or other bodies has increased from one or two in the 1970s to around 4,000 agreements (Langton, 2015). Although the quality and successful implementation of these agreements is not always evident, some improvements for Indigenous people have been achieved (Langton, 2015).

In the case of bauxite mining in Weipa, after several years of struggle against the mining operations, Traditional Owner groups and indigenous community Councils of the Wik people, the Cape York Land Council, the Comalco Aluminium Limited (now part of Rio Tinto Alcan) and the government of Queensland reached the Western Cape Communities Co-existence Agreement in 2001 (Doyle, 2015). There are also two other agreements in place: the Ely Bauxite Mining Project Agreement and the Weipa Township Agreement (Doyle, 2015). All three agreements can be considered significant achievements as they "provide economic, education and employment benefits as well as cultural heritage support and formal consultation processes between the company and the Traditional Owners of the land on which Rio Tinto Alcan operates" (Doyle, 2015: 59). In the context of the South of Embley project, Rio Tinto and the local indigenous people have agreed on the Communities, Heritage and Environment Management Plan in 2014, which e.g. includes the protection of certain sacred areas and employment opportunities (Rio Tinto Alcan and WCCCA, 2014).

In the Pilbara, BHP Billiton Iron Ore entered into its first major agreement with local indigenous people in August 2012, which also covers the Mount Whaleback mine. After four years of negotiations, the Nyiyaparli People achieved an agreement of financial and non-financial benefits, e.g. the protection of their most important heritage sites (YMAC, 2012). Other indigenous people, the Banjima of the central Pilbara, had to go to court to achieve the recognition of their native title claim in 2013 (Jabour, 2013). The government of Western Australia and the Banjima were not able to reach an agreement outside of court during 13 years of negotiation (Jabour, 2013). Additionally, the Banjima People agreed on a comprehensive deal with BHP Billiton in 2015 (Wahlquist, 2015).

There are no known agreements with indigenous communities concerning the Goonyella Riverside mine.

Indigenous people face various challenges with regard to mining activities on their traditional lands and reaching agreements. The recognition of a native title is not always granted by the state; sometimes group representation and governance is difficult; and there are often concerns over the

[17] Amended in 1998 and 2017.

indigenous bargaining power in relation to mining companies (Behrendt & Strehlein, 2001, Trigger et al., 2014).

4.4 Other mining-related conflicts

Mining-related conflicts in Australia do not only involve indigenous people; people living in the vicinity of mining, conservationists and climate activists also engage in activities to limit or stop mining.

One of the most recent examples is the controversial Carmichael mine project by the Indian company Adani. If completed, the mine would be the first and largest of several new thermal coal mining projects in the Queensland Galilee Basin[18] (Rolfe, 2014). The controversies around the Carmichael mine project showcase several conflicts and divergent interests that are typically linked to mining projects. A relatively new conflict dimension is the concern over the mine's impacts on climate change (Rolfe, 2014).

People in favor of the new mining project highlight the economic benefits and direct and indirect jobs the mine will create for the region and Australia, while opponents of the project point to local and global environmental risks, especially concerning groundwater, the Great Barrier Reef and the global climate. In addition, there are also indigenous rights issues.

Since the project's announcement in 2010, people opposing the project have engaged in various protests and campaigns[19]. Furthermore, several lawsuits were brought before courts (Environmental Law Australia, 2017). For example, the Wangan and Jagalingou Traditional Owners Family Council has legally challenged the approval of mining leases for the mining project in 2016 which was granted without their consent (Brigg et al., 2017). In addition, they also aim to change Australia's native title system with their campaign (Brigg et al., 2017). Yet, there is no unanimity among indigenous groups towards the proposed mine (Robertson, 2017).

Farmers also criticise the new Adani coal mine. The future mine will use large amounts of water and famers fear this might impact water availability (Stephens, 2017). Furthermore, they also fear biodiversity losses in the mining area and the impacts of coal combustion on climate change[20] (Stephens, 2017).

Local and international climate activists consider the mine as a threat to international efforts on climate change mitigation and warn about the impacts of climate change. They highlight in particular the Great Barrier Reef, which suffers from unprecedented coral bleaching, largely caused by consequences of climate change (e.g. Wahlquist, 2017).

[18] As of December 2016, the Office of the Chief Economist listed 36 major coal projects – including both coking coal and thermal coal – for total Queensland (Office of the Chief Economist, 2016). Nine proposed projects are located in the Galilee Basin (Greenpeace, 2012).

[19] An alliance of 13 environmental groups (the Stop Adani Alliance) bundles the various claims against the mining project (Karp, 2017).

[20] Greenpeace (2012) estimates that all nine proposed mining projects in the Galilee Basin would produce 330 million tonnes of coal per annum which is more than Australia's total coal exports for 2010-2011. The combustion of the Galilee Basin's coal would cause approximately 705 million tonnes of CO_2 per annum– more than the emissions of Canada in 2009 (Greenpeace, 2012).

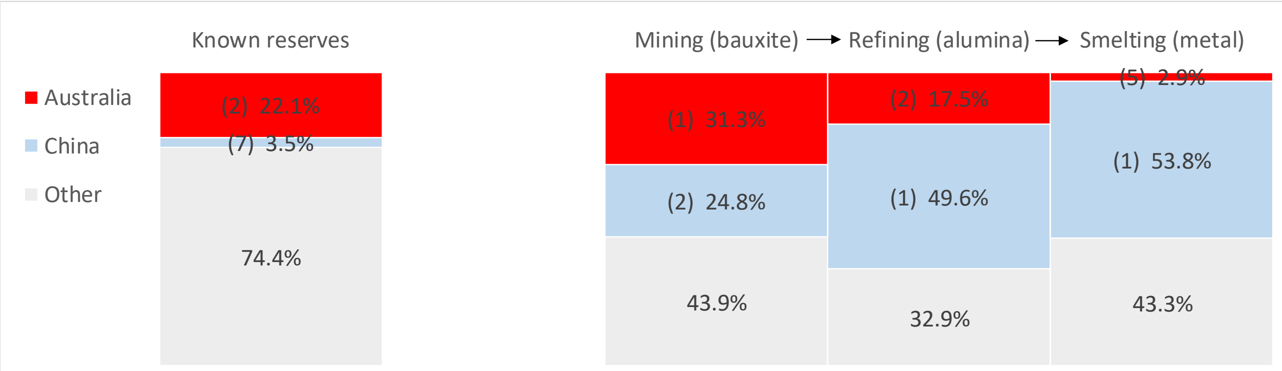
5 Case study bauxite mining

5.1 The global value chain of primary aluminium

Aluminium is the most abundant metal in the Earth crust (about 8 per cent wt.), with a wide variety of applications – from packaging and beverage containers to transportation and aerospace industry. Bauxite ($Al_2O_3 \cdot nH_2O$) is the main raw material for its commercial production. More than 90 per cent of globally mined bauxite is used to produce alumina (Al_2O_3); about two thirds of the latter goes to primary aluminium smelting, with the rest being utilised in non-metallurgical applications (abrasives, ceramics, chemicals, and refractories) (USGS, 2017; Geoscience Australia, 2013).

The raw materials for aluminium production are evenly distributed across the world, however the most significant known reserves and mines in operation are concentrated in the tropics (about 70-80 per cent). Australia and China are the two most significant players in the aluminium sector, combined accounting for more than 50 per cent in every stage of the supply chain (Figure 1), followed by Brazil, India, Guinea, Russia, Canada, Saudi Arabia, and UAE.

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



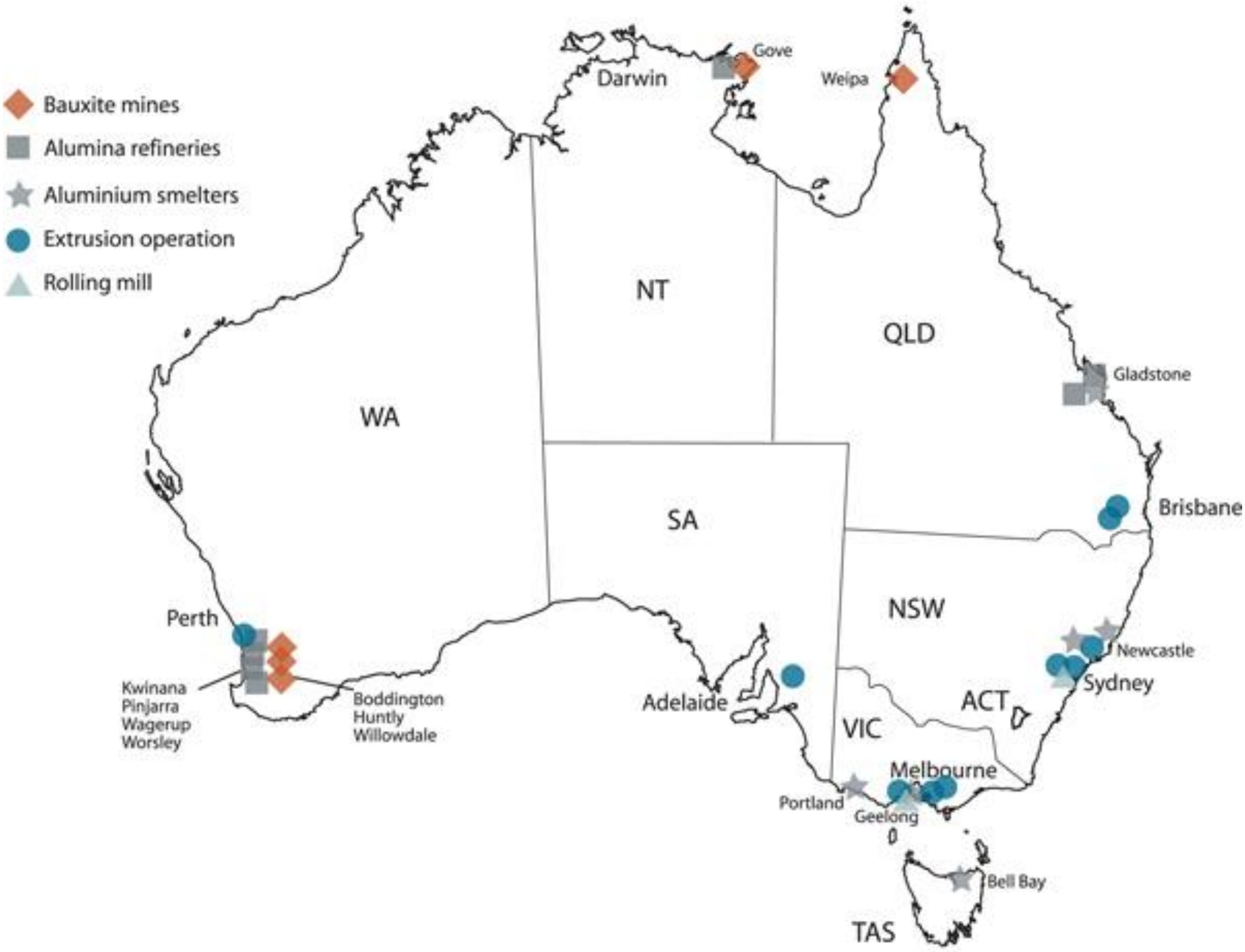
Note: figures in brackets show the country's global ranking. Data source: USGS 2017.

Bauxite and alumina are commonly transported to other places in the world in order to refine or smelt the material. The transportation of aluminium raw materials occurs primarily via ocean shipping. A low cost and reliable energy source is one of the most crucial factors for smelter locations, followed by the associated shipping costs and available infrastructure (Australian Aluminium Council, 2013). The major transport routes within the global aluminium supply chain include export of bauxite and alumina from Australia to China due to much lower energy costs in China.

5.2 Weipa bauxite mining area and Gladstone's alumina refineries and smelter

The Australian aluminium industry currently consists of five bauxite mines, seven alumina refineries, and four aluminium smelters. All refineries and smelters are located close to or on the coastline (Australian Aluminium Council, 2013). Australian aluminium fabrication operations (e.g. rolling mills) are insignificant, and have decreased in recent years.

Figure 3: Map of the Australian aluminium sector



Source: Australian Aluminium Council 2013, used with permission.

5.2.1 Overview of the Weipa bauxite mining area

Weipa, on western Cape York Peninsula, about 600 km by air from Cairns, is one of the world's premium quality bauxite deposits with significant reserves (which is enough for about a 100 years of operations under the current scale of production). The ore reserves are about 1500 Mt in an area of approximately 2,500 sq km (at an average grade of 52.8 per cent Al_2O_3), plus additional resources of 1922 Mt at 51.3 per cent Al_2O_3 (Geoscience Australia, 2013). The bauxite ore at Weipa occurs naturally in pisolitic form, is located immediate below the soils and varies in thickness from 3 to 10 metres. It consists of 55 per cent gibbsite (aluminium trihydroxide) and 14 per cent boehmite (aluminium hydroxide) (Australian Aluminium Council, 2013). Commercial mining at Weipa began in 1961, and current operations export over 27 million tonnes of bauxite annually (Rio Tinto, 2017b).

There are two mines in operation at Weipa (East Weipa and Andoom), two beneficiation plants, and 19 kilometres of railway to transport mined bauxite to the port area. A new large mining project owned by Rio Tinto is under development – Amrun, which is expected to gradually take over the existing mines. Its initial capacity is 15 Mt per annum (with a potential of up to 50 Mt), with first shipment planned for 2019. Most of the mined bauxite is shipped from the port of Weipa for further processing to two alumina refineries in Gladstone (Queensland Alumina Limited and Yarwun Alumina Refinery) (Rio Tinto, 2017b). Parts of the refined bauxite (then alumina) go for smelting to the nearby smelter Boyne Smelters Limited. Finally, the primary aluminium is shipped from the Gladstone ports for export.

The geology of the Weipa peninsula consists of indurated or partially indurated marine silty sandstone and siltstone which overly mudstone of the Cretaceous age (Coffey and Hollingsworth, 1971). The sedimentary formation overlying this basement rock was deposited from alluvial fans, which transported sediments westwards by rivers during the Tertiary, when the east was uplifted. It is assumed that the bauxite deposit has formed as a result of seasonal tropical weathering events. Intensive weathering removed less stable mineral compounds with alumina and iron oxides remaining. Bauxite forms as gibbsite and de-hydrates to boehmite. At Weipa, larger quantities of boehmite can only be found close to the top, but it is not found in depths below 2-3 m where gibbsite dominates.

The bauxite layer consists of an upper nodular iron enriched substrate and mottled sandy clay and a lower coarse sand layer, which plays an important role as a regional aquifer.

The mine, port and associated infrastructure areas are located within the Weipa Plateaux Subregion of the Cape York Peninsula Bioregion. The Cape York Peninsula is very biodiverse and is considered as one of Australia's biggest and most significant wilderness areas (WWF, 2017). The area is relatively homogeneous in vegetation and landform, and is primarily characterised by tall woodlands (*Eucalyptus tetrodonta, Corymbia nesophila*). Weipa's aquatic ecosystems include swamps, lagoons, freshwater channels, and estuaries. The area is also relatively close to the Great Barrier Reef Marine Park.

5.2.2 Overview of Gladstone's alumina refineries

Gladstone is the largest industrial area in Queensland, Australia. The area is about 550 km north of Brisbane, and 100 km south-east of Rockhampton.

Gladstone is well known for its aluminium sector, but also includes several other industries such as coal power station, cement producer, ammonia nitrate producer, as well as large coal and liquefied natural gas export terminals. A key feature of this location is its access to deep water ports facilities (Golev et al., 2014).

The two alumina refineries in Gladstone are Queensland Alumina Limited (QAL) and Rio Tinto Alcan Yarwun (RTA).

QAL is one of the world largest refineries, commenced in 1967, producing some 3.95 Mt of the world's best smelter grade alumina per year which represents about 5 per cent of the world production and about 20 per cent of alumina production in Australia. Its primary shareholder (80 per cent) is Rio Tinto group, and about 30 per cent of its total production output goes to Gladstone's Boyne Smelters Ltd. for the aluminium metal production. The refinery covers 80 hectares of a 3050 hectare site on the south-east outskirts of the city of Gladstone. Adjacent to the plant is a wharf and bauxite residue storage facility on South Trees Island, connected to the mainland by a bridge (Australian Aluminium Council, 2013).

RTA, 100 per cent Rio Tinto's company, is situated in the Yarwun area, 10 km north-west of Gladstone. Established in 2004, it has relatively new and more efficient production line compared to QAL. RTA has also recently upgraded its capacity from 1.4 Mt to 3.4 Mt of alumina per year (Rio Tinto, 2017b).

5.2.3 Overview of Gladstone's Boyne aluminium smelter

Boyne Smelters Limited (BSL) is Australia's largest aluminium smelter with an annual production of 560 Mt. The smelter is situated on Boyne Island about 20 kilometres south of Gladstone. The main suppliers for the plant are QAL (alumina) and Gladstone's NRG coal-fired power station (electricity). BSL's major product outputs are aluminium ingots and billets, which are consumed in Australia and exported to other countries for producing aluminium casting and extruded products (BSL, 2017).

5.2.4 Overview of transportation systems

The major transport links within the supply chain of this case study include the ocean shipping of mined bauxite from the port of Weipa to alumina refineries in Gladstone, shipping of alumina to aluminium smelters in Australia and overseas, and aluminium ingots and billets from Boyne Smelters (primarily to Japan and Korea) (Gladstone Ports Corporation, 2017). The Gladstone ports handle the overseas shipping of alumina and aluminium metal.

Table 2: Cargo statistics for Gladstone Ports in 2016

Product	Origin	Destination	Tonnes	Vessel Count
Bauxite	Weipa	Gladstone	19,085,216	271
Alumina	Gladstone	Australia	1,467,874	
		Russian Federation	961,502	
		Oman	711,144	
		China	513,960	
		Other	1,956,486	
		Total	5,610,966	150
Aluminium	Gladstone	Japan	237,276	
		Korea	167,032	
		Other	14,772	
		Total	419,080	24

Source: Gladstone Ports Corporation 2017.

5.3 Extraction and processing technologies

5.3.1 Extraction and processing technologies at the Weipa bauxite mining area

At Weipa's bauxite deposits, first the top soil is stripped (for reuse in mined land rehabilitation). Next, the front-end loaders use a shallow, open-cut technique to extract and load the bauxite into bottom dump trucks that carry the ore to the dump station. Mined bauxite is transported to the beneficiation plant via conveyors or rail transport, where the ore is screened, washed and then placed into stockpiles prior to loading onto ships (Australian Aluminium Council, 2013; Mulligan, 1996).

5.3.2 Processing technologies at Gladstone's alumina refineries

Both refineries in Gladstone use Bayer Process to convert bauxite ores into alumina (aluminium oxide) – the raw material for producing aluminium metal. This process comprises four major stages – digestion, clarification, precipitation, and calcination. First, the alumina content of finely ground bauxite is dissolved in the presence of caustic soda and steam under pressure and high temperature. The solution of alumina and caustic soda is then separated from the remaining ore, and is cooled and stirred until alumina crystals are formed. The precipitated crystals are washed and filtered, followed by the final calcination stage which includes heating and dewatering at more than 1,100°C, resulting in the alumina product (International Aluminium Institute, 2017).

The ore composition may significantly vary in terms of aluminium content and impurities (e.g. silica). The bauxites from Weipa are characterised by relatively high 50 per cent available alumina and low silica content. In comparison, the Darling Range (Western Australia) bauxites contain only around 30 per cent available alumina and higher silica (Australian Aluminium Council, 2013). As a result, the refineries in Gladstone generate smaller amount of bauxite residue per tonne of final product (see section on Bauxite residues below).

5.3.3 Processing technologies at Boyne Smelters

Boyne Smelters uses the Hall-Heroult process to smelter alumina into aluminium ingots and billets. QAL alumina is transported directly via a conveyor 10 km long, and around 3,000 tonnes of alumina is consumed daily to make 1,560 tonnes of aluminium. The smelter has three major sections: 1) carbon plant, which makes the carbon 'anodes'; 2) reduction lines, where the electrolytic reduction reaction occurs; 3) metal products, where molten aluminium is cast into its final product. The Hall-Heroult process is extremely energy intensive and Boyne Smelters draws approximately 900 MW from Gladstone's NRG coal-fired power station (BSL, 2017).

5.4 Current environmental impacts and risks

5.4.1 Weipa bauxite mining area

Land use

Bauxite mining is characterised by a significant land footprint, which is a result of the thickness of the ore body (world average is about 5 m) and a large scale mining in most cases. As a result of bauxite operations at Weipa, the entire landscape is lowered by several meters, equivalent to the thickness of the ore body. The ironstone floor, underlying the ore body, becomes very compacted due to mine traffic, representing additional challenges in managing the drainage of the site when in operation, and difficulties for revegetation at the end of mining operations (Mulligan, 1996).

Water use

Weipa is a region with water excess, due to the tropical and monsoonal climate. The four primary sources of water at the mine site are ranked in a sourcing hierarchy developed by RTA with key stakeholders, which effectively places an implicit value on the natural sources of water. Operations are meant to source water in hierarchical sequence from decant water from the tailings dam (from bauxite washing operations); rainfall run-off; shallow aquifers underlying the area; and deeper aquifers of the Great Artesian Basin. The sensitivity of the shallow aquifers and the Great Artesian Basin has previously been identified leading to formal establishment of water sources hierarchy with a focus on their long term sustainability, particularly in the case of Great Artesian basin which has a slower recharge rate (Klimenko and Evans, 2009).

The major water use at the mine site is for bauxite washing operations, with some opportunities for this water being recirculated as well as captured at the tailings storage facility as decant water (tailings are mainly represented by washed off bauxite fines). The freshwater withdrawn has been reported at 0.79 kilolitres per tonne of bauxite produced in 2015, with recycled rate of 27 per cent (Rio Tinto, 2016). Other water uses at Weipa include road dust suppression in dry season, as well as water supply to workforce and communities (Klimenko and Evans, 2009).

For the new mining project under development (Amrun), in order to minimize an increase in artesian groundwater extraction and ensure the relative drawdown within the limits of local aquifers, a water supply dam (Dam C) will be added to mining infrastructure. Its capacity and average annual supply rate will grow alongside with project expansions (from 7.8 to 25.4 million m^3 a year), ultimately covering up to 60 per cent of the overall fresh water withdrawal (Rio Tinto, 2017b).

Energy use and Emissions

The energy use and greenhouse gas emissions at Weipa are primarily associated with diesel use – for the two diesel-fired power stations at the beneficiation plants, and mining trucks fleet. At the end of

2015, Rio Tinto announced the completion of 1.7 megawatt solar plant in Weipa, being first of its kind for the remote mining location in Australia. According to the company's press release, this can save up to 600,000 litres of diesel each year, reduce the overall carbon footprint from mining operations, and become an exemplar project to apply elsewhere (Rio Tinto, 2016).

Waste

Mined bauxite at the beneficiation plant goes through sizing, screening, washing and dewatering. The resulting fine waste materials (mainly bauxite fines) are discharged to tailings storage facilities, also allowing for additional water extraction via decant sump. No chemicals are used in the process, and tailings solids and liquids are not classified as hazardous waste. However, there is risk for a dam wall break (rated as "significant"), which determines the design criteria and storage allowance, specifically for accumulating and discharging water during the wet season. Any runoff or leachate from tailings is not anticipated to have an adverse effect on surface or groundwater (Rio Tinto, 2017b).

Rehabilitation

The land rehabilitation at Weipa is undertaken annually at the end of each year prior to the wet season, and progresses alongside with continuous mining operations. In recent years, one of the primary environmental aims was to achieve a ratio of land disturbed to land rehabilitated of 1:1 (Rio Tinto, 2015a). Both figures average at about 1,000 hectares per year, with totals being close to 20,000 hectares since mining commenced.

Before the site is mined, vegetation is removed and top soil is stripped and stockpiled. Stockpiled soil is used to rebuild the soil profile for rehabilitation. The removal of bauxite has lowered the topography of the mined environment and rehabilitated areas experience much moister conditions than prior to mining above all during the wet season. In addition, the lower parts of the profile are naturally more dense, but also have been compacted by heavy machinery during mining, which reduces the drainage capacity in a shortened rebuilt soil profile even further. The high intensity of weathering has formed naturally poor soils with low nutrient holding capacity and attempts to rehabilitate the land for different purposes, including forest, farming and pasture for agricultural use have not been successful. Most previous trials and tests attempting alternative land uses at Weipa have failed or showed low potential, only. The only (long-term) sustainable practice under existing conditions is the establishment of native vegetation (Mulligan, 1996), however with varying success.

Nevertheless, progressive rehabilitation of mined areas at Weipa limits the amount of habitat displaced at any one time, with Rio Tinto expecting most of habitat to be rehabilitated at the end of mining operations (Rio Tinto, 2015a).

Biodiversity

The initial vegetation at the mining site usually has only little commercial value because of infestation with e.g. termites and is usually burnt before the mining operation starts.

Nevertheless, the avoidance and mitigation of environmental impacts from mining to flora and fauna include assessing and recognising areas (within the mining lease) of high suitability habitat; these become part of an environmental buffer system contributing to biodiversity conservation.

In addition to the direct impacts on ecosystems at the mining site, the Weipa area is relatively close to the Great Barrier Reef Marine Park. However the only potential impacts from mining operations are those associated with domestic shipping activities. The estimated bauxite ship movements through the Inner Great Barrier Reef Designated Shipping Area are less than 5 per cent of total ship movements (Rio Tinto, 2017b).

Health

No major health related impacts from bauxite mining at Weipa have been recently reported.

5.4.2 Gladstone alumina refineries

Water use

The fresh water for industrial and domestic uses in the Gladstone area is provided by Gladstone Area Water Board (GAWB) that operates the 40m Awoonga Dam on the Boyne river – the main source of fresh water in the area. The GAWB's current water allocation is 78 million m^3/year, with water supply to customers at about 50 million m^3/year (GAWB, 2017). The prolonged dry and wet seasons can significantly affect the water level in the dam, with historical minimal levels recorded over 2001-2008 resulting in severe water restrictions (50 per cent for domestic use, and 25 per cent for industries).

Alumina refineries QAL and RTA are the largest consumers of fresh water in the area, combined accounting for about 20 million m^3/year (Rio Tinto, 2015b).

Importantly, due to recognised potential fresh water supply limitations, QAL established two projects for the reuse of city's secondary treated effluents (in 2002 and 2015), allowing for over 3 million m^3/year of additional water supply. This water can be directly used in industrial processes, also saving the costs on tertiary treatment system.

In addition to fresh water use, both companies use sea water for bauxite residue neutralisation and pumping to disposal areas, up to 70 million m^3/year, which is then separated from the residue, treated and returned back to the sea. This allows for reduced fresh water consumption and the associated costs.

Energy use and emissions

Major energy use at alumina refineries includes coal, natural gas and electricity supply from the grid. As a result of recent transition from coal fired to natural gas fired boilers, there have been significant improvements in GHG emissions from Gladstone's alumina refineries per tonne of final product. QAL's emissions figure has dropped from over than 1.3t in 1990s to a current level of 1.05t of CO_2-eq. emissions per tonne of alumina, while RTA's GHG efficiency is in the range of 0.7-0.8t (Rio Tinto, 2015b).

Waste

The major waste by-product from the Bayer process is bauxite residue, often referred to as 'red mud' (see section on processing technologies at Gladstone's alumina refineries above). It typically requires special lined waste storage facilities to prevent seepage into the groundwater, designed in compliance with the engineered standards for large dams and regional legislation.

In Australia and globally, alumina refineries continue investigating ways to improve the management of bauxite residue and minimize the long-term environmental impacts from storage areas, including opportunities for red mud reuse in different applications. For example, Rio Tinto's QAL and RTA refineries in Gladstone introduced the use of sea water for red mud neutralisation, while Alcoa's refineries in Western Australia developed a carbonation and wash process for red mud to produce Red Sand™ suitable for road construction (Australian Aluminium Council, 2013).

Unlike most other 'red mud' tailings storage facilities, Gladstone's bauxite residue is neutralised, with relatively low remaining alkalinity (pH 8-8.5). Being progressively dried and compacted (with the use of red mud farming techniques), it also represents lower risk for uncontrolled release, e.g. in the case of dam wall break. The physical impact from dam's failure is likely to be the major concern, especially in the case of QAL's tailings storage facility located in close proximity to the sea coastline. Both QAL and RTA continue to monitor and investigate potential impacts from climate change on the stability and future rehabilitation of tailings dams; however no public release of information has occurred to date.

Land use

The land use at alumina refineries is associated with the processing facilities, ore stockpiles, and bauxite residue storage facilities. The residue storage facilities typically occupy a major percentage of the total land, and currently account for about 1000 ha at QAL and 300 ha at RTA (with a potential future expansion to 900 ha) (Rio Tinto, 2017b).

Rehabilitation

No plans for site decommissioning have been announced, and the operations are expected to last into the foreseeable future, e.g. at least 60 years for QAL (QAL, 2018).The bauxite residue storage facilities will require rehabilitation by the end of operations, however no final design has been announced yet. QAL has recently started a revegetation trial on a 2 hectares block, aiming for direct accelerated biologically assisted transformation of the residue into a soil like medium, substituting top soil with locally available waste streams such as fly ash from power generation and green waste from the community, and selecting appropriate plant species (QAL, 2018). The final aim is to achieve stable and safe landscape, and a self-sustaining ecosystem. If successful, this 'eco-engineered soils' approach will be applied at both refineries in Gladstone, as well as potentially at other refineries in Australia and worldwide.

Biodiversity

Gladstone's alumina refineries are situated within the Brigalow Belt bioregion of Queensland. A rapid and extensive loss of habitat has been recorded for this bioregion due to extensive tree clearing in the past, previous and present high grazing practices, and proliferation of some exotic species (Young et al, 1999). However, the impact on biodiversity from refineries is likely to be minimal due to relatively small land footprint (e.g. compared to agricultural activities), as well as being predominantly situated on previously disturbed land.

Health

No major health related impacts from alumina production in Gladstone have been reported recently.

5.4.3 Gladstone Boyne alumina smelter

Water use

The water consumption in aluminium smelting is significantly lower compared to previous stages – bauxite mining and alumina production. The overall fresh water use at BSL in 2015 was 0.82 million m^3 (BSL, 2016). On-site settling ponds are used to capture and treat all process and storm water before discharge from site.

Energy use and emissions

Aluminium smelting is an electrolytic highly energy intensive process. In most cases it is only economical if there are inexpensive sources of electricity (such as hydropower) and/or special rebates from the government are in place. A large amount of carbon in the form of carbon anodes is also used in this process, and about 90 per cent of the scope 1 (direct) GHG emissions at BSL in Gladstone are due to the latter (BSL, 2016). For the scope 2, the major part (up to 90 per cent) of GHG emissions is associated with electricity generation. The Rio-Tinto Group is the primary owner of the Gladstone's coal-fired power station which supplies electricity to BSL.

One way to drastically decrease energy use in aluminium production is to recycle aluminium from industrial scrap and end-of-life products, which requires only 5 per cent of energy compared to primary metal smelting. In 2015, BSL became Australia's largest aluminium can recycling facility, after the closure of dedicated secondary aluminium producers in the country due to high production costs and redirecting the collected aluminium cans flows to Gladstone (BSL, 2016). The overall recycled metal represents only minor output for BSL, but it is expected to grow.

Waste

One of the major environmental hazards associated with aluminium smelting is fluoride waste and emissions, which can negatively impact on local vegetation and human health. The current BSL's licence limit is 1.0kg of fluoride per tonne of produced aluminium, with 2015 result of 0.65kg which fully meets the regulatory requirement (BSL, 2016).

The major solid waste at BSL includes spent carbon anodes and spent cell linings – both waste streams are currently recycled. The first is used to produce new anodes which contain approximately 30 per cent recycled material, while spent cell linings are sent to the local cement producer to be recycled as an alternative raw and energy material in cement production.

Land use

The smelter is situated on Boyne Island, adjacent to QAL's bauxite residue storage area. The major land use is associated with the processing facilities and supporting infrastructure.

Rehabilitation

No plans for site decommission have been announced, and the operations are expected to last into the foreseeable future.

Biodiversity

BSL is situated within the Brigalow Belt bioregion of Queensland. The impact on biodiversity is likely to be minimal due to the relatively small overall land footprint.

Health

No major health related impacts from aluminium smelting in Gladstone have been reported recently.

The level of fluoride emissions from BSL, being a concern in the past, is compliant with current regulation. The assessment of the overall air quality in Gladstone, as a result of combined influence from several large industries present in the region and other emitters, indicated that apart from elevated levels of particulates during the regional dust storms or local bush fires there are no contaminants that can pose unacceptable health risks, while many are below the reporting level of the available analytical techniques (DERM, 2011).

5.5 Current climate impacts and risks

5.5.1 Weipa bauxite mining area

Current climate

The climate of Weipa is classified as equatorial, winter dry following Köppen-Geiger and as tropical monsoonal with a distinct wet and dry season by BOM (2017a). The temperature ranges between 31°C and 35°C for daily maximum temperature and 18°C and 24°C for daily minimum temperature across seasons. Rainfall amounts to monthly means >400mm in the wet season months (December to March) and almost complete absence of rain between June and September. Daily maximum rainfall amounts can be as high as 350mm (BOM, 2017b). The Weipa peninsula can experience cyclonic weather events during the wet season.

Past weather extremes

As Weipa is characterised by a tropical climate, the region experiences extreme weather events regularly. For example, the heavy rainfall in the wake of Cyclone Oswald in January 2013 led to flooding in the Weipa area which disrupted communication and power (Telstra 2013). In May 2016, news reported record-breaking rain in Weipa and other places in far north Queensland (Agius 2016). At the end of 2016, Queensland was hit by a strong heat wave (Jacques and Furler 2016)

There are only few reports by the mining company or the media about weather events that have disrupted or harmed mining operations in Weipa during the past years. In 2017, Rio Tinto stated in its report of the first quarter that its bauxite "[p]roduction decreased by seven per cent compared with the fourth quarter of 2016, due mainly to weather impacting the Weipa operations during the quarter" (Rio Tinto 2017a). However, details are lacking as the company does not specify further.

5.5.2 Gladstone alumina refineries and smelter

Current climate

The coastal town of Gladstone experiences a humid subtropical climate, with average annual temperature of 23°C, and about 890 mm of rainfall (BOM, 2017a; BOM, 2017b). The climate is seasonal with wet summers and dry winter months (June-September). Single daily rain events can amount to >250mm of rainfall. Usually, summers are hot (average summer temperature 27°C) and moist and winters are dry and warm (average winter temperature 15°C), with sporadic frost in the southern part of the region.

Past weather extremes

Drought had an impact on the QAL alumina refinery in 2002. The declaration of drought conditions in 2002 was followed by water restrictions for industrial, commercial and residential users. These restrictions and their impact on the refinery's operations led to a new project to treat and reuse municipal effluent for the refinery (Mason, 2013).

The Gladstone area was hit by the 2010-11 floods and Cyclone Debbie in March 2017 (Queensland Government, 2012; Barnham, 2017). Although there are reports on how these events impacted coal production and exports[21], neither the involved companies nor the media have reported impacts on the bauxite refineries, smelter or port. However, the refineries have disclosed in their 2013 and 2014 sustainability reports that extreme rainfall events caused environmental incidents, e.g. the discharge of storm water and bauxite residues (Rio Tinto Alcan, 2014; Rio Tinto Alcan, 2015).

5.6 Climate change impact assessment[22]

Weipa (located in the Cape York region) as well as Gladstone (located in the Gladstone region) are expected to face numerous climate change-related impacts in the future, caused by changes in temperature, precipitation and sea level as well as more frequent and more intense extreme events.[23]

Temperatures in the Cape York Region are projected to increase by 0.5 to 1.2°C by 2030, both under a lower and higher emission scenario.[24] By 2070, for a low emission scenario an increase in temperature of 1.1 to 2.2°C is projected, whereas for a higher emission scenario an increase of 1.8 to 3.3°C is projected. In the Gladstone region, temperatures are expected to increase by 0.4 to 1.5°C by 2030, both for lower and higher emission scenarios. A lower emission scenario could mean an increase of 1.0 to 2.7°C by 2070, whereas a higher emission scenario could mean an increase of 1.8 to 3.8°C. Alongside an increased mean temperature, both regions are expected to experience more intense heat, a higher frequency of hot days and a longer duration of hot spells.

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[21] See details below in the case study on coking coal (section 6.5.1).

[22] For an overview see Figure 4.

[23] All climate projections for Cape York and Gladstone regions are based on climate change factsheets published by the Queensland Department of Environment and Heritage Protection (Department of Environment and Heritage Protection, 2016a; 2016c), except for sea level rise projections which are based on CSIRO's Climate Change in Australia website. These sources report projections for 2030 and 2070 or 2030 and 2090 respectively.

[24] The lower emission scenario uses the RCP4.5 scenario and the high emission scenario uses the RCP8.5 scenario.

In the Cape York and the Gladstone region, high rainfall variability is likely to continue. Both regions are expected to face an increase in the intensity of heavy rainfall events. The eastern parts of the Gladstone region are expected to experience longer periods of drought by the end of the century under a high emission scenario. Projections for other extreme events include more extreme fires, as well as less frequent but more intense tropical cyclones.

In Weipa, sea levels are projected to rise by 0.07m to 0.16m under both a lower and a higher emission scenario by 2030. By 2090, sea levels are projected to rise by 0.27m to 0.62m, under a lower emission scenario, or by 0.4m to 0.83m, under a higher emission scenario. In Gladstone, sea levels are expected to rise by 0.09m to 0.17m or by 0.09m to 0.18m above present-day levels by 2030 for a lower and a higher emission scenario respectively. By 2090, sea levels are projected to rise by 0.3m to 0.64m under a lower emission scenario or by 0.44m to 0.86m under a higher emission scenario. Sea-level extremes are expected to be more frequent, increasing the risk of coastal hazards (e.g. storm tide inundation).

5.6.1 Weipa bauxite mining area

The projected climatic changes and intensified weather extremes could impact the Weipa mining operations, in particular wet weather extremes and temperature-related phenomena.

Wet weather extremes, e.g. flooding events caused by extreme rainfall or in connection with cyclones could lead to the flooding of the mine site. This might significantly compromise mining operations and lead to a decreased or interrupted production as well as cause some environmental impacts. Namely, the tailings dams could be affected by water excess, potentially resulting in uncontrolled release of accumulated materials, though the major impact would be limited to physical destruction rather than contamination. The likelihood of overflow and discharge of tailings with the suspended load reaching the sea would be low although the consequence if it did occur could be significant. In addition, strong winds that occur in connection with cyclones could damage the site and tailings dam, leading to similar risks for production and the environment. Changes in severity of weather events, such as heavy rainfall, would have a major impact on the likelihood of success of rehabilitation programs.

A number of temperature-related impacts are also expected. A higher mean temperature would impede revegetation, e.g. the germination of seeds could become more difficult. Hotter days and a higher frequency of hot days can result in more heatwaves which would impact the health of the mine's workers. Alongside the individual risk, the reduced workforce could impact the productivity of the mine. Fires[25] which are likely to be more intense in the future could damage the mining site and its infrastructure, resulting in a decreased or interrupted production of bauxite. Fire might also put the mine workers at risk. Also, revegetation could be impeded by fires.

The tailings dams are situated close to the sea and just above the seawater level. At the end of the century, sea water level rise may have an impact on the tailings dam stability and may require enforcements of the dam walls.

5.6.2 Potential climate impacts on refinery and smelter

The refineries and smelter in Gladstone would be mainly threatened by the impacts of more intense rainfall events and cyclones as well as by longer drought events.

Large amounts of rain or a cyclone could lead to the discharge of sediment-laden water or red mud from the refinery sites, either through a precautionary and controlled release by the refinery, an uncontrolled spill or damaged storm water ponds or bauxite residue storage sites. Given that red mud is seawater neutralised, the impact of discharged red mud would have a minor effect on the local river and the surrounding marine environment. The magnitude impact would be dependent on the size of the discharge. The most harmful impact at the smelter would be damage to the smelter's facilities

[25] Fires are not only temperature-related but depend on various factors, e.g. wind conditions.

caused by a cyclone, leading to an uncontrolled release of hazardous fluoride emission. Large amounts of fluoride emission would pose a major environmental risk. The settling ponds on the smelter site could be also affected by extreme wet weather events, although the likely impact would be minor as the function of the settling ponds are to produce clean water for discharge. Alongside harmful impacts for the environment, such incidents could decrease or interrupt the production output.

Prolonged drought events can lead to water shortages, as they can require public authorities to impose water restrictions. The refinery and smelter processes require water inputs; therefore the alumina and aluminium production could be decreased or halted during times of water shortage.

In addition to water excess or flooding and drought impacting the refineries and smelter, heatwaves might impact the refineries' and smelter's operations, as their workers' health could be put at risk. This could lead to a decreased or interrupted production.

5.6.3 Potential climate impacts on the ports in Weipa and Gladstone

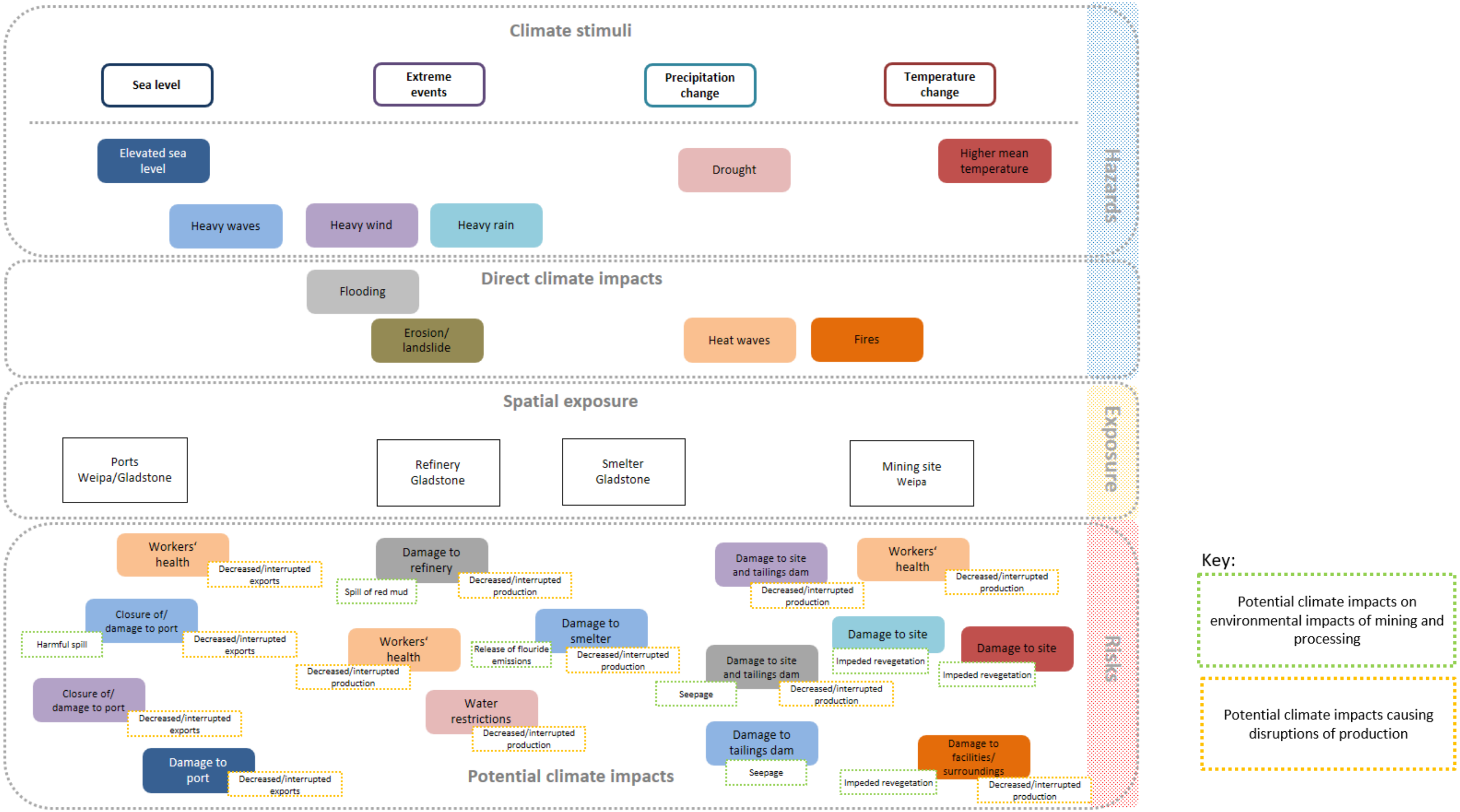
The main potential climate impacts and risks for the Weipa and Gladstone ports could be caused by more intense extreme weather events, in particular heavy wind and rain, which alongside cyclones can cause storm surges, leading to the flooding of coastal areas. The risk of coastal flooding is exacerbated by elevated sea levels. Water excess or flooding could cause damages to the port which might result in decreased or interrupted export. At Weipa, there is no danger of a water spill as bauxite is not water soluble.

As precautionary measure, ports are instructed by the port's authorities to halt operations when there is a cyclone warning. This minimises the risk of damage but leads necessarily to an interruption of exports.

Based on the sea level projections for 2030, sea level rise is not expected to directly impact the port. In contrast, the projected sea levels for 2090, particularly under a higher emission scenario, could harm the ports operations, unless adaptive measures are taken.

Cyclones might further put the workers at risk. Heatwaves could also potentially impact the port workers' health. If the ports workforce is impacted, the ports operations will be also affected, potentially leading to decreased or interrupted exports.

Figure 4: Climate impact chain for bauxite



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 coking coal mining

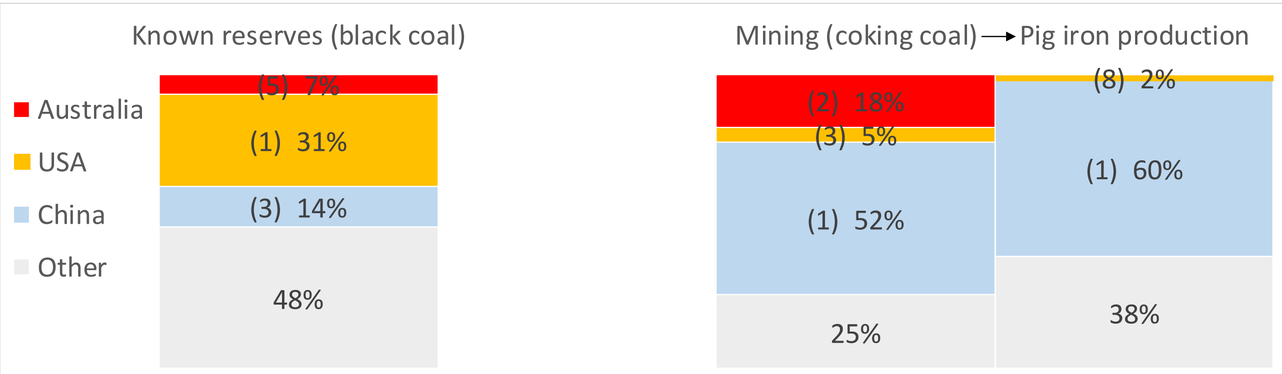
6.1 The global value chain of coking coal

Coking or metallurgical coal is a special type of (black) coal used to produce coke for the steel making process, usually also resulting in several by-products including coal tar, ammonia, light oils and coal gas. These coals must have low sulphur and phosphorus contents, are relatively scarce and attract a higher price than thermal coals which are mainly used for power generation. The production of one tonne of steel from iron ore requires about 800 kilograms of coking coal.

The coal deposits are widely spread across the world and in operation in more than 60 countries (EIA, 2017), while mining of coking coal is more narrowly concentrated and accounts for only 15 per cent of coal output. China is the world's largest producer and consumer of coking coal, about 90 per cent of country's needs are met through domestic production with the remaining shortage of supply being imported. More than 30 per cent of global demand is currently met through international trade, with Australia being the largest exporter with a share of about 60 per cent. Other significant exporters of coking coal are the USA, Canada, and Russia. Major importers besides China are India, Japan, the EU and South Korea. The total world demand for coking coal, about 1-1.1 billion tonnes, is forecasted to remain steady over the next few years (OCE, 2017).

Australia's main competitive advantages in (coking) coal mining and supply include relatively simple geology, large reserve base, high quality, established heavy haul rail networks, and proximity of mines to ocean ports allowing to minimise transportation and handling costs for exporting coal, primarily to Asia.

Figure 5: Coking coal global value chain and ranking for selected countries (2016)

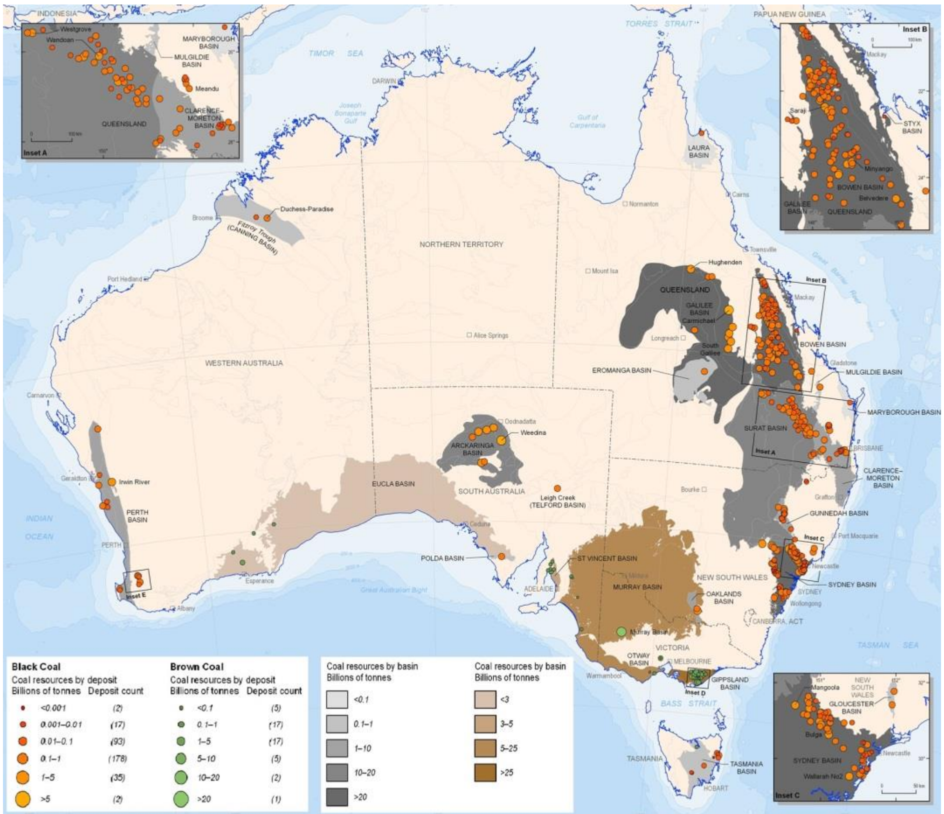


Note: figures in brackets show the country's global ranking. Data sources: OCE, 2017, IEA, 2016, USGS, 2017.

6.2 Goonyella Riverside coking coal mine

Australia's resources of black coal are sufficient to sustain mining at the current rate for nearly 100 years. Among major coal deposit areas, the Bowen Basin in Central Queensland contains the largest reserves, including most of the known mineable coking coal in Australia. It covers an area about 600 km long and 250 km wide (over 60,000 square kilometres), and delivers almost 100 per cent of the state's coking coal, as well as 60 per cent of its thermal coal.

Figure 6: Australian In Situ Coal Resources.



Source: Geoscience Australia, 2012a (CC BY 4.0).

Goonyella Riverside is a large surface coal mine in Bowen Basin, located about 30 km north of Moranbah and 190 km south west of Mackay, and is operated by BM Alliance Coal Operations Pty Ltd (BMA, a joint venture between BHP Billiton and Mitsubishi). In addition to mining operations, it includes two coal processing plants where mined coal is sorted, washed and blended to meet customer‘s specifications. The operational mining leases cover an area 22 km long and 10 km wide.

Before merging in 1989, Goonyella mine commenced operations in 1971 and the Riverside mine – in 1983. In 2005, the underground, punch long wall mine, Broadmeadow, was developed in an existing highwall of the open cut operation (extending to the east). This is a specialised type of mining, only applicable where a seam is exposed at the highwall and the mine has reached the economic limit for open cut mining. The initial punch longwall extraction has been superseded by longwall top coal caving in 2012, a similar mining method but specifically designed for the extraction of thicker coal seams (> 5.0 metres) (BMA, 2015).

All types of coal seams mined at Goonyella Riverside and Broadmeadow are high quality, medium volatile coking coals. The mine has economic open cut reserves of more than 500 Mt, with total in situ resources of about 1.5 billion tonnes. It is the largest coking coal producer in Australia, with an output of 18 Mt in 2016 financial year (or almost 10 per cent of the country’s production). The final product is transported by rail to the Port of Hay Point south of Mackay.

6.2.1 Overview of Goonyella Riverside mining area

The mine site Goonyella Riverside is located in the central part of the Bowen Basin, close to the town of Moranbah.

Geologically, the Bowen Basin formed during the Permian and Triassic as a consequence of subsidence and deposition of sediments. The coal measures originate from freshwater environments, but can also be deposited in a tidal and marine sedimentation environment.

Landforms in the Bowen Basin are characterized by their different lithological types with steeper slopes on resistant quartzose sandstones and volcanics and gently undulating landforms on mixed sediments slightly affected by deep weathering. The landforms on tertiary strata in the vicinity of Goonyella Mine are flat with slopes <5 per cent. Soils have formed mainly from sedimentary, sandy substrate and are classified as Sodosols, i.e. soils with a sodic horizon typical for a high proportion of exchangeable sodium. These soils have a very low agricultural potential and are used for extensive grazing and are prone to erosion.

Spoil dumps from open-cut mining are not required to be backfilled and the often saline waste dumps are rehabilitated with only minor landform shaping. The topsoil cover is very shallow and sometimes not thicker than 0.1 m.

The region surrounding Goonyella mine is part of the Brigalow belt, named after the dominant species Acacia harpophylla (Brigalow). Cultivation and transformation into grazing country formed grass dominated pastures with the introduced species of buffel grass dominating the species distribution. This species is commonly used also for rehabilitation of the spoil waste from mining as it is drought tolerant and although being a tussock grass is reducing the risk of surface erosion more likely than other grass species.

6.2.2 Overview of transportation systems

The coking coal from Goonyella Riverside mine is transported by rail, part of an integrated rail-port network, to the Port of Hay Point – one of the largest coal export ports in the world, located about 40 kilometres south of Mackay, which services the mines in the Bowen Basin. It includes two separate coal export terminals: Dalrymple Bay Coal Terminal (DBCT), leased from the State Government by DBCT Management Pty Ltd, and the Hay Point Coal Terminal (HPCT), owned by BHP Billiton Mitsubishi Alliance and operated by Hay Point Services. Coal terminals comprise rail in-loading facilities, onshore stockpiles, and offshore wharves serviced by conveyor systems allowing to load coal on bulk carriers in deep water.

Table 3: Export statistics for port of Hay Point (QLD) in 2016.

Product	Coal terminals	Tonnes
Black coal	DBCT	68,458,927
Black coal	HPCT	49,041,726
	Total	**117,500,653**

Note: information on the type of coal exported and its destination are not disclosed. Data source: NQBPC, 2017.

6.3 Extraction and processing technologies

6.3.1 Extraction and processing technologies at Goonyella Riverside

Depending on the geology of the deposit, coal is mined by surface (or opencut) and/or underground mining methods. Around 80 per cent of Australia's coal is produced from opencut mines, while the same figure for the world coal production is only 40 per cent (Geoscience Australia, 2015a). Opencut mining usually has lower mining costs and recovers a higher proportion of the coal deposit than underground mining.

The land footprint of modern opencut coal mines can be very extensive (e.g. many square kilometres), with a depth of up to 200m. Large draglines are typically employed to remove the overburden, while bucket wheel excavators and conveyor belts can be used for coal mining and transporting. Mined coal undergoes crushing and screening, followed by washing stages to remove any present gangue minerals, reduce ash content and improve the overall product quality (Geoscience Australia, 2015a).

The coking coal production processes at the Goonyella Riverside mine include (BMA, 2005):

1. Topsoil removal (for replacement after mining process is complete).
2. Drill and blast, and overburden removal (overburden depths range from 70 to 150 metres).
3. Mine and haul raw coal in required sequence.
4. Process coal to customer specifications (blending, crushing, beneficiation, fines removal).

At the underground Broadmeadow mine, located within the boundaries of the opencut Goonyella Riverside mine leases, the longwall equipment is used to mine coal from blocks developed directly from an opencut highwall. Longwall mining is safer and more efficient than other underground coal mining methods. It involves extraction of large rectangular panels of coal by progressively shaving slices of coal from the longwall face (200-300 meters wide), under the protection of hydraulic roof supports. As a result, large blocks of coal can be totally extracted and the mine roof allowed to collapse behind the working face. The extracted raw coal is transported via conveyor system to the surface for processing at the existing facilities at Goonyella Riverside.

Final products are transported to Hay Point and Dalrymple Bay coal terminals by a modern electric rail system (up to 120 wagons, over 9000 tonnes of coal), to be loaded on vessels of up to 200,000 tonnes capacity.

6.4 Current environmental impacts and risks and mitigation measures

6.4.1 Goonyella Riverside mining area

The large scale opencut coal mining results in significant land disturbance. It changes the local topography and surface water drainage pattern, sometimes also requiring watercourses diversion. Effective management of waste materials (especially if there is a risk of acid mine drainage), minimisation of greenhouse gas emissions, preserving downstream water quality, and ultimately leaving an acceptable and stable post-mining landform with a self-sustaining vegetation cover are the principal objectives for environmental programs at coal mines.

Land use

Historically, land within and surrounding Goonyella Riverside mine has been used for beef cattle grazing. A part of it has been cleared for improved pasture, with buffel grass well established in most soil units. The progressive and final rehabilitation measures at the mine site target providing stable final landforms for native bushland and grazing. However, at the end of mining operations, there will likely be a permanent loss of grazing land as a result of the final void, ramps, and waste rock dumps (rehabilitated but unsuitable for grazing).

The major impacts associated with longwall mining are related to the surface subsidence. Once coal is excavated, the roof strata falls into the void under its own weight, also causing the natural ground surface to subside. The amount of subsidence is mainly driven by the extracted coal seam thickness (typically 2 to 5 m), but also influenced by mine geometry, depth, and geological conditions which usually reduce subsidence at the surface working as a 'bridge'.

The longwall panels are typically 300m wide and separated by chain pillars of approximately 60m wide. The amount of subsidence above a deep mine is about 1 to 2 m, but could be 2 to 3 m for a thick seam mined at shallow depth. The final compaction of the strata and subsidence at the surface may take several years after the operations are finished, but generally occur within 1 to 2 years.

The maximum predicted subsidence at Broadmeadow mine is 2.5 meters, however for thick seam mining within the former channel bed of Isaac River (which was diverted in 1985-87) this figure is higher – up to 4 meters (BMA, 2015). The major long-term risks associated with surface subsidence relate to erosion and potential loss of vegetation and therefore require constant monitoring and response where applicable (e.g. reshaping the channel bed and protecting eroding lower banks) (Lechner et al, 2014).

The construction of waste rock dumps would results in new elevated landforms in the local landscape. Measures to manage erosion on waste rock dumps include re-grading, placement of good quality topsoil, using a hay mulch crimped into the soil, seeding with a cover crop to hold topsoil in place and the installation of drains to control runoff.

Water use

The Goonyella Riverside and Broadmeadow Mine complex is located downstream of a number of other coal mines in the western catchment of the Isaac River, which is a significant tributary of the Fitzroy River. The mine is traversed by a number of watercourses and a diversion has been built on Eureka Creek and Fischer Creek to permanently divert flows around mine workings.

Opencut coal mining usually requires localised dewatering to maintain the operations. At the end of operations and/or upon ceasing dewatering, groundwater discharge would continue filling in the final void. High evaporation rates in the area of Goonyella Riverside mine will likely slow down the recovery of groundwater levels, also leading to deterioration of water quality in the final void over time. However, the impact on the surrounding aquifers is expected to be limited, as the final void would work as a permanent sink, while local aquifers would be replenished by rainfall.

The major water use at the coal handling and preparation plant is for coal washing operations, i.e. removal of impurities such as soil and rock. Water is removed from final product for recirculation. The tailings materials can also be dewatered before disposal and/or water can be harvested from tailings dams, contributing to reducing fresh water offtake. Continual water recirculation, however, can result in elevated levels of salinity affecting the plant performance and maintenance, and thus limiting feasible opportunities for water reuse. One of the major challenges for coal mines in Bowen Basin is establishing an effective management of large storages of 'dirty' water (mainly in tailings dams) to minimise discharges to the local environment, while at the same time allowing for natural drainage and evaporation processes. A compilation of production and water use figures for 21 mines in the Bowen Basin region during the period 2003-2005 showed that ~38 GL/year of fresh water and ~52 GL of worked water was used (Moran et al. 2006).

Waste

The primary waste materials generated by coal mining include waste rock and overburden, coal rejects and tailings. Major environmental impacts from deposited and/or rehabilitated waste dumps include poor quality saline and/or acidic water runoff/seepage, soil erosion, and dust. Sediments exposed to weathering and in this case primarily wetting and drying have a high potential for degradation and break down of the rock fraction. This increases the risk for surface erosion and failure of rehabilitation. The deposition of rock containing spoil either by dragline or as truck and shovel creates inhomogeneities within the dump matrix which may lead to very heterogeneous water flow patterns and concentrated flow (preferential flow) with the risk of immediate transport of saline waters through the dump and discharge at seepage points at the toe of waste dumps. Such seeps may be active over extended periods of time and require management (collection in sumps; pumping etc.).

Rehabilitation

Final mine void(s) can pose a significant risk to wild life and humans, particularly given their size and their impact on the landscape. Similar to other large mine voids, they can and will fill up with water to form pit lakes, which will initiate geochemical and hydrological processes that evolve with time. There can be lateral seepage, depending on the permeability of the void walls, and base seepage from the void. With time pit lakes can become sources of hyper-saline water and affect the local hydrogeology.

Depending on the local geological and hydrogeological context, pits can act as a groundwater sink[26] or be a throughflow cell[27] in groundwater flow. In the latter the pit can temporarily act as groundwater source after major cyclonic rain events. The impact of pit water on the regional hydrology will depend on the surrounding geology and geological stratification, for instance sedimentary strata with higher permeability can allow for regional distribution of contaminated water. If this is expected then long-term monitoring of groundwater flow and quality is necessary to determine if any salinisation and acidification impacts on the local or regional hydrogeology.

Sometimes infill of pits with water is used to prevent the generation of acid mine water, although in arid environments with high evaporation losses (such as the Goonyella Riverside site), the infilling of voids with water may take long times (Johnson and Wright, 2003), and any water loss by evaporation can concentrate the salts contributing to hypersaline water bodies. In such cases, mine voids have to be managed accordingly to prevent access and potential harm to wildlife or humans. Where the pit is part of a larger catchment, extreme (cyclonic) rain events can raise the water table and as such measures need to be put in place to ensure that contaminated waters are not discharged off lease.

At the end of mining the preferred option is to leave an open void as this is usually the most financially attractive option, and also allows for possible future mining. There might also be longer term social benefits, with the development of innovative water treatment approaches for pit lake water and possible commercially viable projects such as tourism, fish farming, tree farming and horticulture, although this is less attractive given the mine site's remote location. The backfilling of final voids with inert waste (overburden) has environmental advantages and typically meets community expectations. However, this strategy can face resistance from the mining companies due to the trade between cost and expected environmental benefits. Nevertheless, in a few recent showcased examples of coal mine rehabilitation in Australia, the decision and the extent of backfilling the voids was primarily driven by the long-term sustainability of the post-mining landform (Mineral Council of Australia, 2018). It also becomes more evidenced and recognised, especially in the case of severely degraded and/or altered landscape, that the development of an alternative post mine land use is the most viable option from both an economic and environmental perspective.

Revegetation of waste dumps have the risk that due to the material properties and the required undulating landform, vegetation is often not supporting the attenuation of erosion to an acceptable degree and is not self-sustaining with the requirement for ongoing maintenance. The success of revegetation is very much dependent on suitable weather and soil moisture conditions at the time of e.g. seeding. Failure of revegetation establishment increases severely the risk of introduction of unwanted species and weeds.

Vegetation communities often have been altered prior to mining by creating grazing country from (Brigalow) woodland. Creating new landscapes after mining require a definition about future land use, e.g. for grazing or native ecosystems. Failures in creating adequate physical environments (type of soil; risk of soil erosion) are often associated with a high risk that rehabilitated sites fail in achieving ecosystem goals. They lack the number of native or exotic woody species that would support limited native and feral fauna species.

Energy use and emissions

The main sources of energy use and GHG emissions in coal mining are associated with the use of fuels to power machinery (mainly diesel), the use of explosives, from land clearing and decay of vegetation, and fugitive (mainly methane) emissions from coal seams. The total CO_2 equivalent emissions have been estimated in the range of 0.06-0.08 tonnes per tonne of coal produced, with major part coming from methane (41 per cent), followed by electricity (31 per cent) and fuels (23 per cent) (BMA, 2009).

[26] When the evaporation rate exceeds the rate of groundwater inflow, the pit will become a groundwater sink.

[27] When groundwater inflow exceeds evaporation, the pit will act as a throughflow cell.

The energy intensity depends on the maturity and depths of mining operations, strongly affecting the volumes of overburden removed per tonne of product and travel distances.

Biodiversity

The current and prospective mining area at Goonyella Riverside is located within the Brigalow Belt bioregion, on relatively flat lands at elevations 250-325m above sea level. It is represented by woodlands, dominated by Eucalyptus or Acacia species, native grasslands, as well as non-remnant grasslands (as pasture) and shrubby regrowth. The habitat in the area is highly impacted by grazing practices and historical tree clearing, and in general is considered of low conservation value. However, within the mine lease boundaries, there are recognised areas of importance to arboreal animals and other native wildlife, i.e. riparian forest and alluvial woodland adjacent to the Isaac River (McLeod and Gatfield, 2013). The latter areas are expected to be maintained as a wildlife corridor.

Health

No major health related impacts to the local region from coal mining at Goonyella Riverside have been reported recently. However, a fatality on-site occurred in 2017 (Caruana, 2019).

The major environmental concern associated with coal mining and coal export terminals relates to dust issues. The latest coal dust study (2013) for Port of Hay concluded that "coal terminals are not a significant contributor to respirable dust related health issues in the local community", and samples taken at community sites recorded no exceedance of National Ambient Air Quality Standards (NQBPC, 2017).

6.5 Current climate impacts and risks

6.5.1 Goonyella Riverside mine

Current weather

The climate of the Bowen Basin is classified as BSh (B = arid, S = steppe, h = hot arid) in the Köppen and Geiger Classification (Kottek et al., 2006). Rainfall is strongly summer dominant with more than three quarters of rainfall precipitating in the period from October to March (BOM, 2015).

Average annual rainfall is only between 32 and 39 per cent of potential evaporation, and there are only an average of between 16 and 20 days per year with rainfall ≥10mm (BOM, 2015).

The representative weather station chosen for the mine site Goonyella Riverside is weather station Wentworth (BOM Id 034015) with a monitoring record dating back to 1962 compared to the closer weather station of Moranbah airport, which records data only since 2012. The station Wentworth is located about 37km south-west of the mine site.

Past weather extremes

The Bowen Basin experienced several severe weather extremes over the last decades. The Isaac Regional Council was facing a prolonged drought between 2002 and 2008 (Sharma et al., 2013). A new prolonged drought is occurring in parts of the Isaac Regional Council since September 2012 (Longpaddock, 2017).

Flooding events had the most devastating impacts on mining in the area. In particular, the 2010-11 floods and the floods caused by Cyclone Debbie in March 2017 harmed mining operations and transportation systems. The Queensland Flood Commission of Inquiry, established by the Queensland Premier in the aftermath of the 2010-11 floods, reported that the flooding affected 85 per cent of Queensland's coal mines, leading to a restricted production or a closure of mines (Queensland Flood Commission of Inquiry, 2012). Large amounts of water entered the mines and flooded open cut mines and underground areas (Queensland Flood Commission of Inquiry, 2012). Many mines had to release excess water from storage facilities and dams (Queensland Flood Commission of Inquiry, 2012). Although environmental damages and contamination was caused by the flooding, the Queensland Flood Commission of Inquiry was "unable to come to a definitive conclusion as to the causes of the ecological damage observed in the marine environments after the floods or the relative contribution of releases from mines" (Queensland Flood Commission of Inquiry, 2012: 357).

The mines needed several months for recovery (Queensland Flood Commission of Inquiry, 2012). In economic terms, the floods caused a loss of AUD$ 2 billion in export earnings[28] (ABARES, 2011).

In March 2017, Cyclone Debbie caused damages to the railway system delivering coal to the ports which led to a significantly reduced rail capacity (BHP Billiton, 2017). The railway operator, Aurizon, reopened the Goonyella coal rail system – as the last of the four Aurizon coal rail systems – almost four weeks after the cyclone hit the region (Aurizon, 2017). Although media reports focused on damaged and interrupted railways, some mines were also impacted by excess water which led to lowering or fully suspending activities at several mines in Bowen Basin, in total accounting for about 15 per cent of global seaborne exports of coking coal (OCE, 2017).

Curtis Pitt, Queensland's Treasurer and Minister for Trade and Investment, estimated the economic losses caused by Cyclone Debbie at AUD$2 billion (Vogler, 2017). The main losses were in coal exports with an estimated value of AUD$1.5 billion (Vogler, 2017).

In the wake of Cyclone Debbie, the Mackey Conservation Group raised concerns over aerial photos that showed polluted water in the Caley Valley Wetland next to the Abbot Point coal terminal, presumably caused by a coal-laden water spill (Chang, 2017). During the flood events caused by Cyclone Debbie, the Queensland Department of Environment and Heritage Protection granted the port a temporary permission to increase the limits for the release of sediment laden water (Department of Environment and Heritage Protection, 2017). After the images of the pollution were published, the Department of Environment and Heritage Protection started investigations (Department of Environment and Heritage Protection, 2017). The results were that Abbot Point released more total suspended solids (TSS) than the permission allowed (806mg/L of TSS instead of 100mg/L; Department of Environment and Heritage Protection, 2017). Nonetheless, the investigation found only non-hazardous trace amounts of coal in the water (Department of Environment and Heritage Protection, 2017).

6.6 Climate change impact assessment[29]

The Goonyella Riverside mine area, the railway connecting the mine to the port (both located in the Isaac region) and Hay Point port (located in the Mackay region) are projected to face a number of climate change impacts in the near future, caused by changes in temperature, precipitation and sea level as well as more frequent and more intense extreme events[30].

Annual average temperatures are expected to increase by 0.5 to 1.4°C by 2030, under a lower and higher emission scenario.[31] By 2070, a lower emission scenario could mean an increase of 1.1 to 2.6°C, whereas a high emission scenario could mean an increase of 1.8 to 3.6°C. The region is expected to face hotter days, as well as a higher frequency of hot days. While the frequency of wildfires is not expected to change much, the fires that do occur are expected to be more extreme.

The overall change in rainfall is unclear; however, downpours are expected to become more intense. The region is also projected to face changes less frequent but more intense tropical cyclones.

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[28] Includes also exports other than coal.

[29]For an overview see Figure 7.

[30]All climate projections for the Isaac and Mackay regions are based on a climate change factsheet published by the Queensland Department of Environment and Heritage Protection (Department of Environment and Heritage Protection, 2016b), except for sea level rise projections which are based on CSIRO's Climate Change in Australia website.

[31]The lower emission scenario uses the RCP4.5 scenario and the high emission scenario uses the RCP8.5 scenario.

Sea levels in Mackay are expected to rise by 0.09m to 0.17m or by 0.09m to 0.18m above present-day levels by 2030 for a lower and a higher emission scenario respectively. By 2090, sea levels are projected to rise by 0.3m to 0.64m under a lower emission scenario or by 0.44m to 0.87m under a higher emission scenario. Sea-level extremes are expected to increase in infrequency, increasing the risk of coastal hazards such as storm floods.

6.6.1 Potential climate impacts on the Goonyella Riverside mine area

There are several climate impacts that might affect the Goonyella Riverside mine area in two major ways.

First, water-related extreme events could impact the mine. Water excess or flooding events caused by extreme downpours or in connection with cyclones could lead to the flooding of both open pit and underground mines. This might jeopardise mining operations and lead to a decreased or interrupted production as well as cause potentially harmful environmental impacts through a discharge of high saline waters. Deposited and/or rehabilitated waste dumps could also be affected by water excess, impacting the environment negatively through physical displacement due to flooding and potential contamination of local river and ecosystems. Changes in severity of weather events, such as heavy rainfall or storms, would have a major impact on the likelihood of success of rehabilitation programs. Past experiences have shown that water excess is particularly harmful to the mine’s operations and environment.

Second, there will be temperature-related impacts. A higher mean temperature means that revegetation could be impeded in the future, e.g. as the germination of seeds could become more difficult. Hotter days and a higher frequency of hot days can result in more heatwaves which would impact the health of the mine’s workers. Alongside the individual risk, the reduced workforce could impact the productivity of the mine. Fires which are likely to be more intense in the future could damage the mining site and its infrastructure, resulting in a decreased or interrupted production of coking coal. Fire might also put the mine workers at risk. Additionally, fire produces smoke which could add to dust and particular matter emissions which occur during mining operations, leading to hazardous levels of air pollution. Also, revegetation could be impeded by fires.

6.6.2 Potential climate impacts on the railway connecting the mine and port

Floodings and landslides that come along with floods are the most relevant direct climate impacts on the railway which connects the mine to the port. They can be caused by heavy rain, heavy wind and storm surges, either related to cyclones or occurring independently. Floodings and landslides that are caused by the extreme weather could cause damages to the railways, leading to decreased or interrupted transportation of coking coal to the port.

6.6.3 Potential climate impacts on Hay Point port

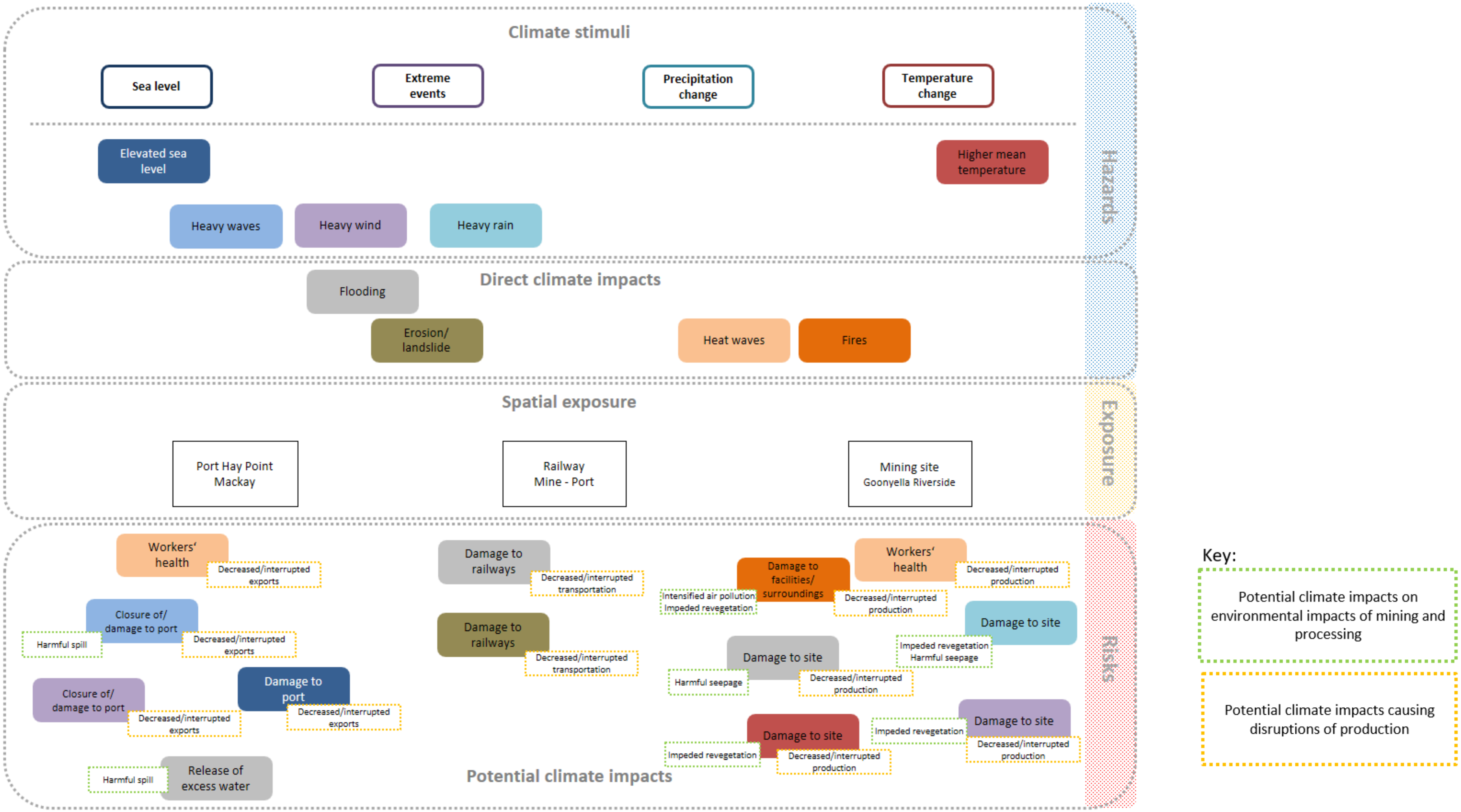
The main potential climate impacts and risks for the Hay Point port could be caused by extreme weather, in particular heavy wind and rain, which alongside cyclones can cause storm surges, leading to the flooding of coastal areas. The risk of coastal flooding is exacerbated by an elevated sea level. Water excess or flooding can cause damages to the ports which might result in decreased or interrupted export and/or an uncontrolled spill of coal-laden water from coal storage facilities into the sea.

To prevent an uncontrolled spill of coal-laden water, port operators usually release water into the sea. As a further precautionary measure, ports are instructed by the port’s authorities to halt operations when there is a cyclone warning. This minimises the risk of damage but leads necessarily to an interruption of exports.

Heatwaves could have a potential impact on the port workers' health. Also, cyclones might put the workers at risk. If the ports workforce is impacted, the ports operations will be also affected, potentially leading to decreased or interrupted exports.

Based on the sea level projections for 2030, sea level rise is not expected to directly impact the port. In contrast, the projected sea levels for 2090, particularly under a higher emission scenario, could harm the ports operations, unless adaptive measures are taken.

Figure 7: Climate impact chain for coking coal



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.

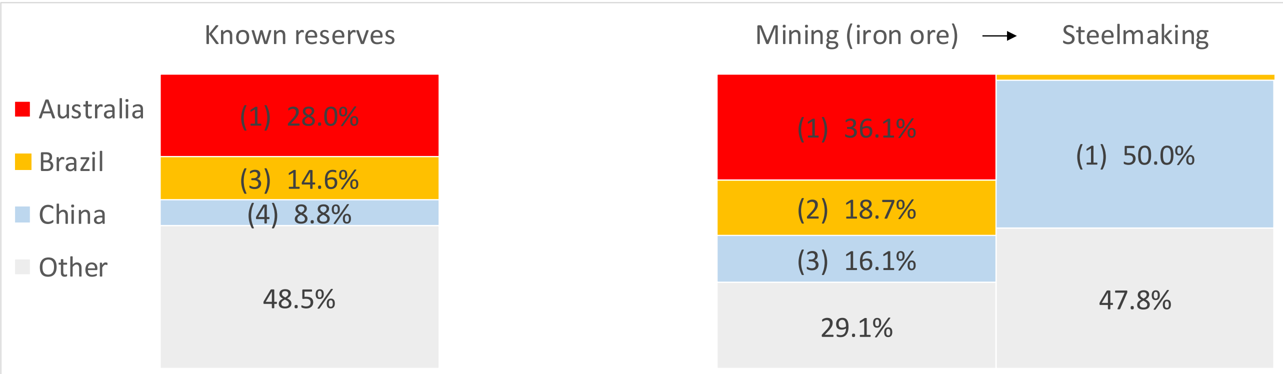
7 Case study iron ore mining

7.1 The global value chain of iron ore and steel

Iron (Fe) is - after aluminium - the second most abundant metallic element in the Earth's crust (5 per cent wt.). There are two principal iron ore minerals: hematite (Fe_2O_3) and magnetite (Fe_3O_4). Pure hematite contains 69.9 per cent iron, is non-magnetic, with colour variations from steel silver to reddish brown. It is the dominant iron ore in the world's steel production, mainly sourced from Australia and Brazil. Magnetite contains 72.4 per cent iron, is generally black in colour and highly magnetic. Due to presence of impurities it is usually more costly to produce iron ore concentrates from this mineral (Geoscience Australia, 2015b).

Over last decade Australia has been the world's largest exporter of iron ore and China the largest importer. Considering production of usable iron ore only (for comparability purpose and due to different reporting system in China), Australia is also the world's largest producer, with estimated 37 per cent or 825 Mt produced in 2016, followed by Brazil with 18 per cent (391 Mt) and China with 16 per cent (353 Mt) (USGS, 2017). Most of Australia's iron ore comes from the Hamersley province of Pilbara in Western Australia – the world's largest known premium quality iron ore reserve base.

Figure 8: Iron ore and steel global value chain and ranking for selected countries (2016)



Note: figures in brackets show the country's global ranking; known reserves are shown for iron content. Data source: USGS, 2017.

Australia's iron ore reserves are the world's largest – 52 Gt (with 23 Gt of iron content) which is 30.6 per cent (28 per cent) of the world's total estimated 170 Gt (82 Gt). Australia is followed by Russia with 14.7 per cent (17.1 per cent), Brazil 13.5 per cent (14.6 per cent) and China 12.4 per cent (8.8 per cent) (USGS, 2017). China's iron ore reserves have substantially lower grades if compared to other countries.

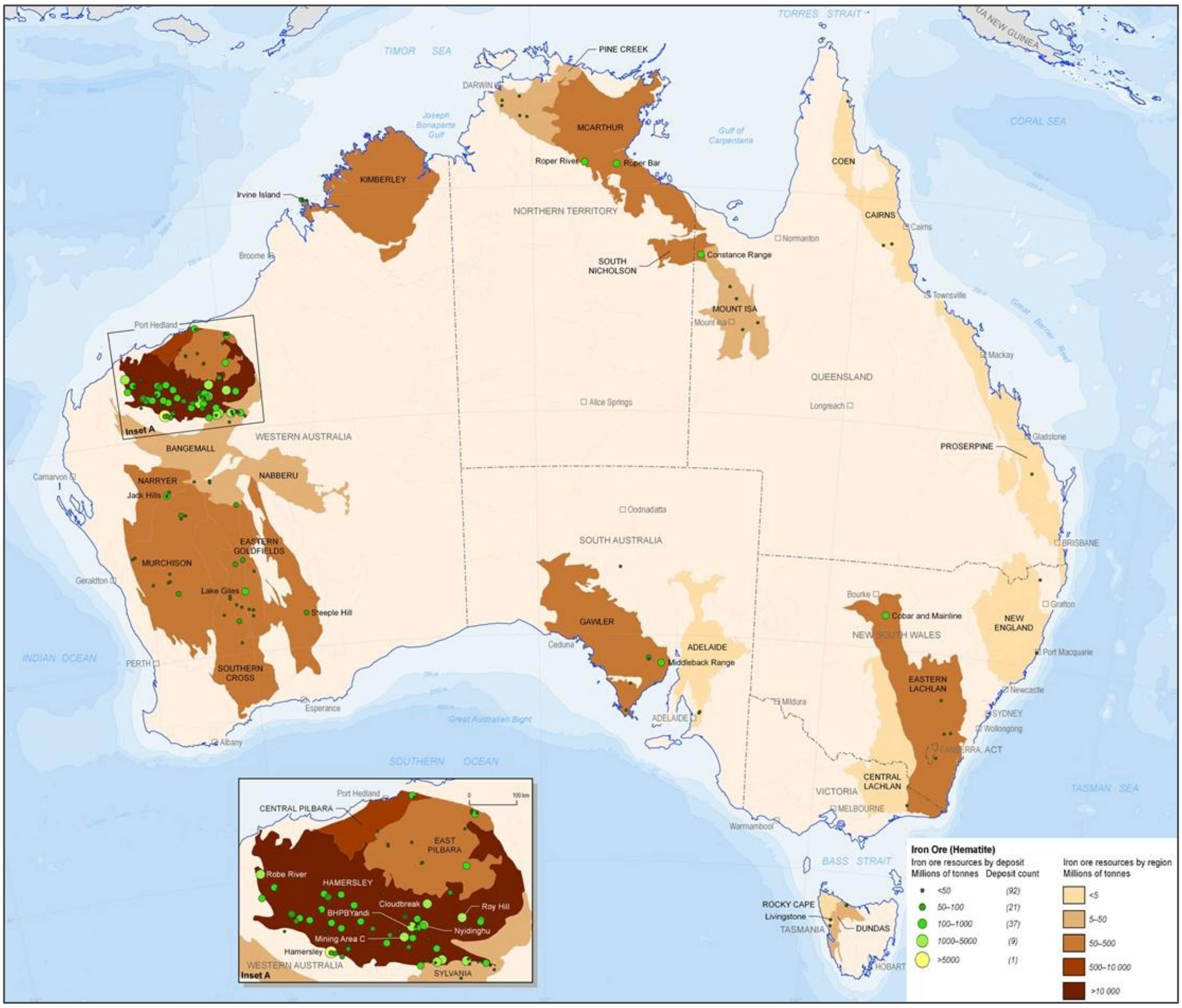
For high quality (hematite) deposits, mined iron ore requires minimal processing and can be directly shipped to steel producers. The conventional steel making process converts iron ore into pig iron (via the blast furnace route) followed by refining in basic oxygen furnace and shaping in rolling mills into steel products. Other important input materials in steel making are iron steel scrap, manganese and coking coal. The latter works both as the chemical reductant and as the energy source for the process. An alternative steelmaking technology, electric arc furnace (EAF) route, is primarily used for smelting scrap metal and consumes significant quantities of electricity as its energy source.

China dominates the world's steel industry with a share of about 50 per cent. A siginficant part of produced steel is consumed domestically, nevertheless China is also the world largest steel exporter. The major end user industries of steel products include building and construction, automotive, and machinery.

7.2 Mount Whaleback iron ore mining area

Australia's current economic demonstrated resources of iron ore are 52 Gt, with about 80 per cent in hematite and 20 per cent in magnetite ores (by iron content), and estimated resource life of 60 years (Geoscience Australia, 2015b). About 91 per cent of known iron ore reserves are in the Hamersley province of Pilbara of Western Australia (WA). WA contributes about 98 per cent to country's current total iron ore production.

Figure 9: Australian In Situ Iron Ore Resources: Hematite.



Source: Geoscience Australia, 2012b (CC BY 4.0).

The Mount Whaleback is a high-grade hematite iron ore deposit operated as an open cut mine, located in the Pilbara Region, about 6km west of the mining town of Newman. It is one of the largest single pit iron ore mines in the world - more than 5km in length, 1.5km in width and almost 0.5km deep. The Mount Whaleback mine is primarily owned by BHP Billiton (85 per cent), which also operates two port facilities at Port Hedland in northern WA and more than 1,300 kilometres of railway to connect the mines with the port. BHP Billiton is the second largest iron ore producer in the region, behind Rio Tinto and followed by Fortescue Metals Group.

Adjacent to Mount Whaleback, there are a number of smaller deposits (orebodies 29, 30 and 35) and satellite mines (Wheelarra and orebodies 18, 23, 24 and 25). Ore from all of these mines is transported to BHP Billiton's 'Newman Hub' at Mount Whaleback to be blended, and then railed to the port and shipped to steel makers in China, Japan, Korea, Taiwan, Europe and Australia (BHP Billiton, 2017b).

7.2.1 Overview of the Mount Whaleback mining area

Most of the region belongs to the Archean–Proterozoic Hamersley sedimentary basin, which comprises the Fortescue Group, the Hamersley Group and the Pinjian and Manganese groups. The underlying geology of the region of Mount Whaleback is Archean granite–greenstone rocks. Erosion and deposition in the Cenozoic formed deep paleochannels, which contain important aquifers and channel iron deposits (CIDs). More recent shallow alluvial deposits coincide with the modern stream network. The regional aquifer system is hosted in Tertiary substrates and the valley-fill sequences are often highly permeable. The flanks of the valley rise into ranges comprising fractured-rock aquifers of low permeability and storage. In places, these basement rocks have more transmissive sections associated with orebodies and form localised aquifers. The extent of these orebody aquifers and their connectivity with larger groundwater flow systems may be enhanced by faulting or erosion or other structural features, and as such can vary widely and is site specific.

Soil profiles in the region are weakly developed because of the hot, arid climate and sparse vegetative cover. Soils in elevated parts of the landscape are skeletal, which enhances runoff during high-intensity rainfall events. In the lower lying alluvial deposition areas alkaline, clay-rich and saline soil profiles have developed.

The vegetation of this region is typically open (tree steppe) and dominated by spinifex grassland with Mulga and occasional eucalypts (Snappy Gum), acacia small trees and shrubs. On the flats downstream of the Mount Whaleback region the low lying alluvial plains typically carry as vegetation a mosaic of spinifex grasslands and Acacia woodlands and shrublands.

For iron ore mining in the Pilbara region, there is a likelihood of encountering small volumes of potentially (net) acid-forming materials. In the case of Mount Whaleback, these materials account for up to 10-15 per cent of overburden and waste rock, requiring special waste management procedures to avoid or minimize potential acid mine drainage (AMD) (Bonstrom et al., 2012).

7.2.2 Overview of transportation systems

The major transport links important for this case study include the railway line from the mining area of Mount Whaleback to the ocean port of Port Hedland (about 500 km); and shipping of iron ore from the port to steel smelters all over the world, primarily to China. The (Mount Newman) railway is privately owned by the mining company, and services one of the heaviest and longest trains in the world.

The major facilities at Port Hedland include the ore transport (rail connections) and ore handling infrastructure (car dumpers, stockyards and conveyor system), as well as marine jetty, wharf and dredged channel to accommodate bulk carriers. The estimated nominal capacity of BHP Billiton's port facilities is about 300 Mt of iron ore per year.

Table 4: Cargo statistics for Port Hedland (WA) in 2016.

Product	Destination	Tonnes	Per cent
Iron ore	China	398,193,541	83.1%
	Republic of Korea	37,701,433	7.9%
	Japan	23,316,829	4.9%
	Australia	3,481,753	0.7%
	Other	16,224,784	3.4%
	Total	**478,918,340**	**100%**

Note: BHP Billiton and Fortescue Metals Group use Port Hedland for iron ore shipping. Source: Pilbara Ports Authority, 2017.

7.3 Extraction and processing technologies

7.3.1 Extraction and processing technologies at Mount Whaleback

The conventional opencut iron ore mining operations, used in the Pilbara region, consist of drilling and blasting of the overburden and ore body, followed by loading into haul trucks by excavators or front-end loaders, and transporting to relevant location around the mine site. Overburden is used as in-fill material within the pit or relocated to the out-of-pit storage area. The ore is hauled to the Ore Handling Plant (OHP) to undergo crushing, screening and mixing, in order to meet the market requirements. The final product outputs are typically in the form of fines or lump. The low grade ore (mainly due to high alumina content) is usually stockpiled, and then further upgraded via washing process, removing gangue minerals based on differences in the minerals density and particle size distribution. Tailings generated by the latter process (mainly consisting of fine iron oxides, alumina, silicates and clay) are stored in the tailings storage facilities (BHP Billiton, 2013).

7.4 Current environmental impacts and risks

7.4.1 Mount Whaleback mining area

Land use

Iron ore mining is characterized by significant land impact including landscape changes. The total BHP Billiton's iron ore mining lease area in Pilbara is more than 10,000 km^2 (or one million hectares), including both existing and perspective future mines (RDAP, 2013).

The country surrounding Mount Whaleback is historically used for extensive grazing. And while the dry climate of Mount Whaleback and poor soils prevent agricultural use of the land, rehabilitated land may be used for grazing purposes.

Water use

Open-pit iron ore mining in Pilbara is undertaken both above and below the water table, thus it requires in-pit and ex-pit mine dewatering (i.e. groundwater abstraction to facilitate dry mining conditions to access ore resources below the water table). Subject to water licences, water drawn from bores and mining pits is reused for mining operations, including dust suppression on roads, and crushing and processing facilities at Mount Whaleback operations. A close proximity of several iron ore mines also allows an exchange of water resources between them. Surplus water can be returned back to local groundwater aquifers, discharged into local creeks (particularly in the wet season), and also supplied to Ophthalmia Dam.

Waste

Overburden and waste rock are mining wastes, which do not contain valuable minerals, and/or their concentration is insufficient for economic recovery. Overburden and waste rock are usually stockpiled in approved storage areas (overburden and waste rock dumps), and/or progressively placed back into the pit void to minimise otherwise required land clearing for storage and to assist in future mine closure. The total amount of overburden and waste rock is estimated to reach more than 4 billion tonnes by the end of mining operations at Mount Whaleback, which is expected post 2030 (Bonstrom et al., 2012).

A small portion (10-15 per cent) of overburden and waste rock at Mount Whaleback are characterised as potentially (net) acid-forming materials. In general, AMD is not considered significant for arid environments and relatively low sulphides content waste, however due to cyclone activities, iron ore mines in Pilbara occasionally experience this problem. In most cases, waste segregation and appropriate cover design for waste dumps to limit net percolation is sufficient (this mainly relies on evaporation to cycle moisture back to the atmosphere).

The iron ore tailings are stored in tailings storage facilities (tailings dams) and will have risks that include potential for acid mine drainage, mobility of heavy metals, seepage into the local ecosystem, unscheduled discharges from extreme weather events. The amount of tailings is significantly smaller than the waste rock and overburden by a factor of 20 to 50 times and typically there is about 0.1 tonne of tailings for every tonne of iron ore produced.

Energy use and emissions

The main sources of energy use and GHG emissions in iron ore mining are associated with the use of fuels to power machinery, the use of explosives and from land clearing and decay of vegetation. The major power use at Mount Whaleback is for diesel powered mine fleet. Processing equipment uses electricity from the Newman gas-fired power station, and the company employs diesel-electric trains for iron ore transportation (BHP Billiton, 2017). Potential strategies to minimize GHG emissions include restricting amount of vegetation to be cleared, progressive rehabilitation of disturbed areas, minimizing haulage distances (per tonne of material), as well as improving the efficiency of mining and processing operations.

Biodiversity

The mine area is situated near the southern boundary of the Fortescue Botanical District of the Pilbara, and is dominated by a tree steppe of *Eucalyptus leucophloia* (Snappy Gum) over *Triodia wiseana* (Spinifex), with *Eucalyptus gamophylla* also widespread (Lyons, 2015).

Rehabilitation

Mine rehabilitation in the Pilbara environment focuses on a number of challenges. To date it is estimated that only 15 per cent of the pre-mine biodiversity has been redeveloped on land rehabilitated from mining. Largest obstacles for successful rehabilitation are physical and biological challenges for this region like high temperatures, unpredictable rainfall, limited topsoil, chemically hostile waste materials and in some cases poorly understood seed ecology, but also high costs.

Pit lakes are formed within the mine void after cessation of dewatering initiating geochemical and hydrological processes that evolve with time. Over time these pit lakes can become sources of hypersaline water and affect the local hydrogeology. Accelerated infill of pits with water is commonly used to prevent the occurrence of negative outcomes like generating acid mine water in the process of infilling of the pit. However, in arid environments with high evaporation losses, the infilling of the void with water may take long times (Johnson and Wright, 2003). In addition, water loss by evaporation will up-concentrate the salts in the pit water and will contribute to the development of hypersaline water bodies. In such case mine pits have to be managed accordingly to prevent access and potential harm to wild life or humans. In situations where the pit is part of a larger catchment, it has to be ensured, that any raising water table triggered by extreme (cyclonic) rain events may not connect into strata with high hydraulic permeability and lead to discharge of contaminated waters.

The salinisation and acidification of pit lakes has the potential to affect local and regional groundwater resources. Dependent on the local geological and hydrogeological situation, pits may function as a groundwater sink or participate in groundwater flow as a throughflow cell. In case the pit is part of a larger catchment, it may temporary even function as groundwater source after major cyclonic rain events. The severity of the impact of pit water to the regional hydrology will be largely decided by the surrounding geology and geological stratification, i.e. existence of fractures or fissures with higher permeability and risk for preferred transport of contaminated water. Only long-term monitoring of groundwater flow and quality in the vicinity of the mine pit will reveal any consequences originating from pit water.

Depending on the geographic location, climatic conditions, overall disturbed area and mine closure plan, the recovery of the groundwater system can take from several decades to hundreds of years. While it is assessed that most vegetation is not groundwater-dependent and impacts to surface water will be minimal, there are still long-term concerns for environmental sustainability of the area. Backfilling above the pre-mining water table is one way to minimize the long-term impacts on groundwater quality, including salinity, within and outside the pit area. It is recognised that several of the Pilbara iron ore mines will require backfilling of the voids as these are hydrogeologically connected to significant groundwater resources.

According to BHP Billiton's Iron Ore Rehabilitation Standard, the intent for rehabilitation in the Pilbara region is aimed at "habitat reconstruction, soil development, and ecosystem establishment (rather than vegetation establishment alone) where this is aligned with the agreed end land use". It is also acknowledged that in most cases of iron ore mining in the Pilbara, mainly due to large scale operations, the opportunities to restore mined land to pre-disturbance conditions are limited, thus the major focus of rehabilitation is in re-integrating the disturbed areas with the surrounding environment to create habitats that are appropriate to the location and can sustain over time (BHP Billiton, 2011).

Soils other than from the low lying plains are usually very shallow, low in nutrients and water holding capacity. The correct timing of seeding and available soil moisture for seed germination is challenged by the erratic occurrence of rainfall. Attempts have been recently made to use criteria of soil functionality to improve success of restoration of disturbed ecosystems. It has been found that next to organic carbon, biological indicators described by microbial diversity and activity are the most sensitive indicators for the selection of soils for revegetation. In further steps it may be required to identify approaches to establish or create soils with required functionality properties.

Major challenges remain for revegetation like failure of traditional revegetation methods (e.g. use of nursery seedlings) but also the fact that certain species only seed once every few years.

BHP Billiton has developed the innovative 'Sowing the Seeds for Success' program which focuses on the use of seed to revegetate land, and to date successfully rehabilitated around 2,500 hectares of land across BHP Billiton sites in the Pilbara (Price, 2015). This represents only a minor part of the total disturbed area, however most mine sites are relatively young and still active.

Health

No major health related impacts from iron ore mining at Mount Whaleback have been reported recently.

The assessment of tailings dam potential failure risks across BHP portfolio in 2019 classified one of the tailings dams at Mount Whaleback as extreme. The structural integrity of the dam was independently verified to meet international safety standards, nevertheless the employees were temporarily relocated from offices in the 'inundation zone' until an additional protection barrier is built (Hastie, 2019).

7.5 Current climate impacts and risks

7.5.1 Mount Whaleback mining area

Current climate

The Pilbara region of WA, where Mount Whaleback mine is located, has an arid climate and experiences regular cyclonic activity in summer (November to March) with rainfalls greater than 100 mm/day. The region is characterised by seasonally low rainfall with high temperatures, high potential evaporation rates and a high daily temperature range. The Köppen-Geiger classification describes the climate as hot, arid climate typical for deserts. The closest operating Bureau of Meteorology (BOM) station to Mount Whaleback operations is at Newman (BOM station number 007176).

Past weather extremes

The Pilbara region is regularly facing weather extremes, in particular cyclones and heat waves. For example, in January 2012, ports had to be closed in Port Hedland because of Cyclone Heidi (The Telegraph, 2012). The severe tropical cyclone Christine hit the region at the end of 2013 and led to a closure of all ports and the coastal rail for several days. In January and February 2014, "adverse weather conditions" had impacts on mines, railways and ports and lowered the production of iron ore (Rio Tinto, 2014). One of these "adverse weather conditions" might have been a severe heat wave (BOM, 2014).

In 2016, two cyclones hit Rio Tinto's mining operation in the Pilbara, decreasing the company's iron ore production (The Courier Mail, 2016). Also the first quarter of 2017 was impacted by cyclone activity. Rio Tinto accounts for its Pilbara iron ore operations: "Production and sales were both impacted by significant weather disruptions, which resulted in heavy flooding across several sites including the rail network, along with the suspension of ship loading on a number of occasions. All operations across the mine and infrastructure network have now recovered and are operating to plan" (Rio Tinto, 2017a).

7.6 Climate change impact assessment[32]

Mount Whaleback, the railway connecting the mine to Port Hedland port, all located in the Pilbara, are expected to face numerous climate change-related impacts in the future.[33]

Temperatures in the region are projected to rise substantially, with annual average temperature projected to increase by 0.6°C to 1.5°C by 2030, both under a lower and higher emission scenario. By 2090, temperatures are estimated to increase by 1.5°C to 3.1°C according to a lower emission scenario and by 3.1°C to 5.6°C according to a higher emission scenario. The intensity and duration of hot spells is expected to increase as well.

Furthermore, evaporation is very likely to increase, although the magnitude of this change is still uncertain. While rainfall in the region is not expected to change drastically by 2090, some projections show a decrease in rainfall in western parts of the Pilbara and an increase in eastern parts. Rainfall intensity is projected to increase, but it is still unknown to what extent. Projections for drought are very uncertain. However, a higher emission scenario suggests an increase in the duration of droughts until the end of the century.

Tropical cyclones are projected to decrease in frequency by as much as 50 per cent by 2100, but are likely to increase in intensity. And while the projected future fire risk in the region is uncertain, the anticipated hotter and drier conditions have the potential to increase the intensity of any fires in the future.

Port Hedland is expected to experience a sea level rise by 0.07m to 0.16m or by 0.08m to 0.17m by 2030 for a lower and a higher emission scenario respectively. By 2090, sea levels are projected to rise by 0.28m to 0.64 m under a lower emission scenario or by 0.4m to 0.84m under a higher emission scenario.

[32] For an overview see Figure 10.

[33] All climate projections for the Pilbara are based on climate change bulletin published by the Western Australia Department of Agriculture and Food (Sudemeyer, 2016), except for sea level rise projections which are based on CSIRO's Climate Change in Australia website. These sources include projections for 2030 and 2090.

7.6.1 Potential climate impacts on the Mount Whaleback mine

The most important projected impacts on the mining site are linked to water-related extreme events, temperature changes and heat extremes.

Water-related extreme events are projected to impact the mine in several ways. During prolonged drought events, water loss by evaporation can lead to the concentration of salts in the pit water, contributing to the development of hypersaline water bodies. This increases the risk of environmental harmful saline seepage. Drought can also lead to water shortages, either in terms of physical availably or due to officially imposed water restrictions. In such cases, the mine is expected to face limited access to water supply, potentially decreasing its productivity.

Water excess or flooding events caused by extreme downpours or in connection with cyclones could lead to the flooding of the mine's large open pit or damage tailings dams. This would jeopardise mining operations and lead to decreased or interrupted production as well as cause potentially harmful environmental impacts, e.g. the drainage of acid or hypersaline water into the local groundwater. A tailings dam failure could have far-reaching environmental and other impacts. Deposited and/or rehabilitated waste dumps are also expected to be affected by water excess, impacting the environment in a similar way. In particular, a combination or sequence of drought and extreme wet weather events would increase the risk of hazardous environmental impacts.

Extreme weather events, such as heavy rainfall or storms and drought, would have a major impact on the likelihood of success of rehabilitation programs, e.g. as they impede revegetation.

Alongside water-related extremes, temperature changes and heat extremes are also expected to impact the mine. A higher mean temperature means that the already difficult revegetation could be further impeded in the future, e.g. the germination of seeds. Hotter days and a higher frequency of hot days can result in more heatwaves which would impact the health of the mine's workers. Alongside the individual risk, the reduced workforce could impact the productivity of the mine. Fires which are likely to be more intense in the future could damage the mining site and its infrastructure, resulting in a decreased or interrupted production of iron ore. Fire might also put the mine workers at risk. Also, revegetation could be impeded by fires.

7.6.2 Potential climate impacts on the railway connecting the mine and port

Water excess and landslides that come along with floods are the most relevant direct climate impacts on the railway which connects the mine to the port. They can be caused by heavy rain, heavy wind and storm surges, either related to cyclones or occurring independently. Floodings and landslides could cause damages to the railways, leading to decreased or interrupted transportation of iron ore to the port.

7.6.3 Potential climate impacts on Port Hedland port

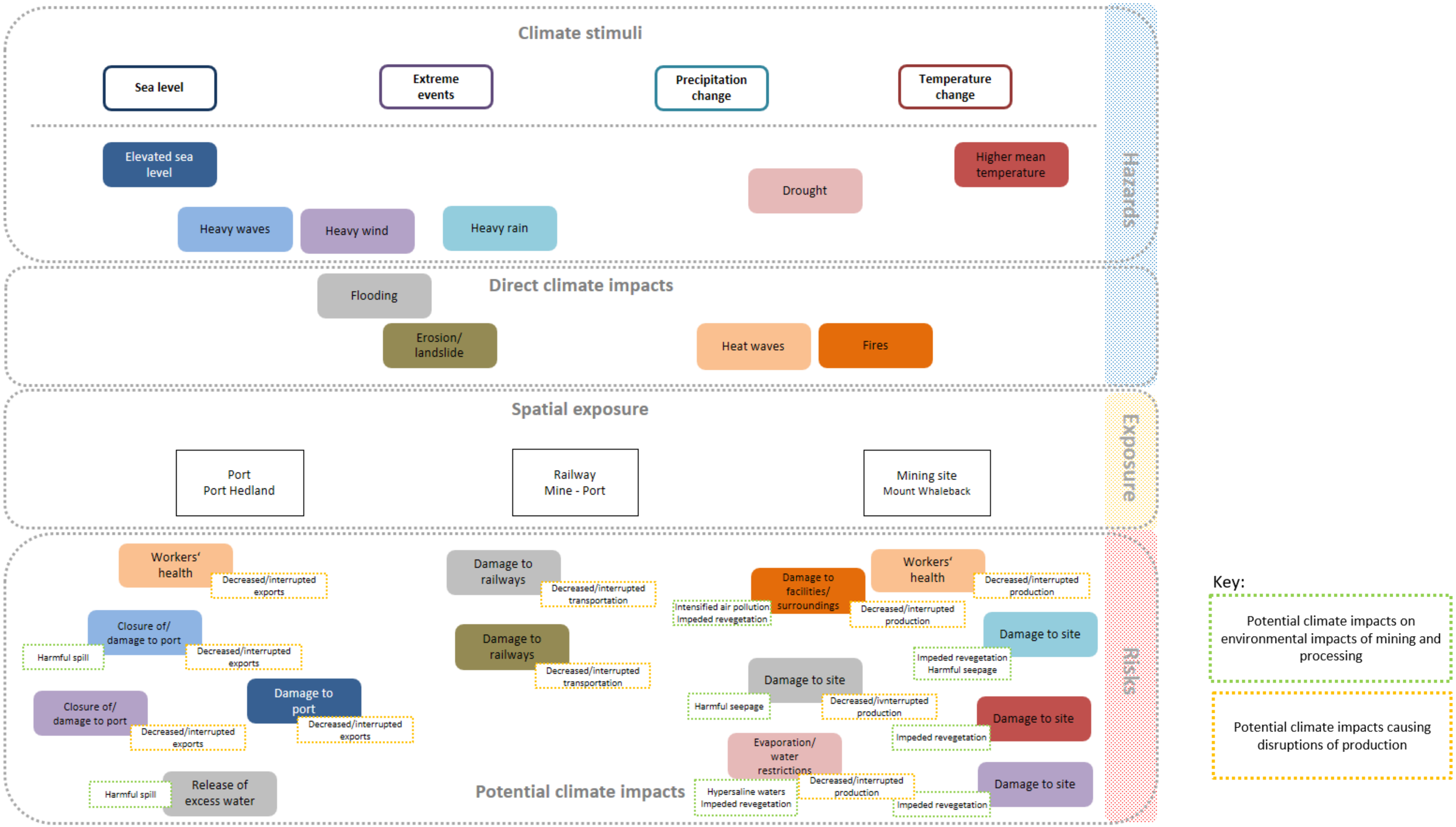
The main potential climate impacts and risks for the Port Hedland port are caused by extreme weather, in particular heavy wind and rain, which alongside cyclones can cause storm surges which lead to the flooding of coastal areas and the port. The risk of coastal flooding is exacerbated by an elevated sea level. Water excess or flooding can cause damages to the port which could result in decreased or interrupted export and/or an uncontrolled spill of sediment-laden water from iron ore storage facilities into the sea. The spillage of sediment-laden water or iron ore from the port facilities would be unlikely to have a significant impact on the marine environment.

To prevent an uncontrolled spill of sediment-laden water, port operators usually release water into the sea. As a further precautionary measure, ports are instructed by the port's authorities to halt operations when there is a cyclone warning. This minimises the risk of damage but leads necessarily to an interruption of exports.

Heatwaves could have a potential impact on the port workers' health. Also, cyclones might put the workers at risk. If the ports workforce is impacted, the ports operations will be also affected, potentially leading to decreased or interrupted exports.

Based on the sea level projections for 2030, sea level rise is not expected to directly impact the port. In contrast, the projected sea levels for 2090, particularly under a higher emission scenario, could harm the ports operations, unless adaptive measures are taken.

Figure 10: Climate change impact chain for iron ore



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.

8 Summary and conclusion

Australia has a high natural climatic variability and often faces weather extremes. The last years saw particularly harmful weather events, such as the 2010-11 Queensland floods and Cyclone Debbie in March 2017. Based on climate projections, the country is expected to experience not only an increase in the mean temperature, but also an increased intensity of several climatic phenomena (in particular more intense tropical cyclones, wet weather extremes, more intense droughts and coastal hazards) in the future. The mining locations and transport infrastructure analysed as part of this case study are all located in regions which are projected to be affected by these climatic changes.

The exact likelihood of extreme weather events and temperature and precipitation changes remain uncertain. However, projections are confident that the severity of extreme weather events will increase and that mean temperatures will rise. Whereas temperature and precipitation changes as well as sea level rise are projected for different emission scenarios and points in time[34], projections for extreme weather events do not refer to emission scenarios and specific points in time, but make more general statements.

Climatic regions and geographic location

In regard to the projected climate impacts, there are important differences and similarities between the climate zones that are covered in this case study: Wet weather extremes are particularly prevalent in the tropics but can also occur in arid regions where extreme rainfall can interact strongly with drought events. Droughts and accompanying water stress is a more important issue in already arid regions.

Another important insight of this case study is that in addition to the importance of climate zones, the geographic location of mining projects and transport infrastructure are essential in shaping risks and climate impacts. If located near to the coast, sites and infrastructure are prone to sea level rise, waves and storms. In addition, sites and infrastructure in the proximity of inland water bodies face an increased risk of flooding in times of rainfall excess – both from wet weather extremes and increased mean precipitation.

Environmental risks

The case study identified the following key environmental risks for bauxite/alumina, coking coal and iron ore production:

Bauxite: The beneficiation of mined bauxite does not entail high environmental risks since no chemicals are used in processing, Therefore, tailings, at this stage, are not anticipated to have negative impacts on the environment in the case of a runoff or leachate. However, refining and smelter processes pose higher risks to the environment. Alumina refineries produce as a residue highly alkaline red mud. However, the environmental risk of an uncontrolled release is lowered at the Gladstone refineries through the neutralisation[35], drying and compacting of red mud. Furthermore, the refining process is very water intensive – the refineries are the largest consumers of fresh water in the area. Yet, they decrease their need of fresh water through the use of secondary treated water. The aluminium smelter does not require as much water but is highly energy intensive. In addition, fluoride emissions occur during the smelting process which can harm the local vegetation and human health in the case of an uncontrolled release.

[34] For Queensland: RCP4.5 and RCP8.5 and 2030, 2070 and 2090. For Western Australia: RCP4.5 and RCP8.5 and 2030, 2070, 2090 and 2100.

[35] During neutralisation the alkalinity is lowered.

Coking coal and iron ore: Saline and/or acid water seepage are environmental risks for both coking coal and iron ore mining pits and mine waste which can pose an environmental risk to surrounding soils and the groundwater. Infill of pits with water can prevent the generation of acid mine water, although this usually takes a long time in the regions where the mines are located, as they characterized by an arid climate. Coal mining additionally causes air pollution. Further, the mining site is traversed by a number of watercourses, which increased the risk of flooding.

All mines use open pit mining and thus have a large land footprint and revegetation is generally difficult to achieve, e.g. due to soil and climatic conditions.

Climate impacts increasing environmental risks

Overall, the impacts of climatic changes are expected to aggravate or add to current environmental risks:

The **impacts of extreme weather events** stand out as the main risk across the resources, mining sites and climatic zones analysed. In particular, more intense wet weather extremes can lead to the flooding of mining areas, increasing the already existing environmental risk of drainage or discharge of hazardous waters, e.g. high saline waters from coal and iron ore mining operations. As the residues from bauxite are not hazardous, the environmental risk is not increased in that case. Yet, for the alumina refineries and smelters, climate change impacts are also expected to increase the environmental risks of their operations, e.g. the uncontrolled release of red mud from the refineries into the sea during extreme rainfall events or the leakage of fluoride emissions from the aluminium smelter caused by damages through a severe cyclone. Smoke from fire can add to the dust and particular matter emissions from coal mining operations, leading to hazardous levels of air pollution. As coal is the only resource whose mining process produces such dust and particular matter emission, this risk does not occur at the mines of other resources.

Furthermore, **a combination or series of extreme events**, for example an extreme wet weather event during a prolonged drought, is estimated to increase the risk of hazardous environmental impacts of mining and processing operations. This is the case for the Mount Whaleback iron ore mine which is projected to face more intense droughts as well as an increased intensity of rainfalls and cyclones. Water loss by evaporation during drought events can lead to the development of hypersaline water bodies. In the case of the Goonyella Riverside coking coal mine, the risk of acid mine drainage is also higher during drought events, as high evaporation losses impede the infill of mine pits with water (which is a measure to prevent acid mine drainage). In both cases, the risk for harmful saline and/or acid drainage will be considerably exacerbated if extreme rainfall occurs at the same time as a drought.

At all mining sites, **rehabilitation** is expected to be impacted by a changing climate, in particular an increased mean temperature and destructive extreme events such as fires and heavy rain. These climate changes make already difficult site rehabilitation more problematic, as they harm revegetation efforts. **Workers health** is estimated to be most impacted by heat waves. This applies also for all mining sites as well as transportation systems.

Security of supply

Extreme wet weather events are also expected to have an impact on the supply security of bauxite, coking coal and iron ore. Flooding and landslides that are caused by extreme weather could cause damages to **railways**, leading to decreased or interrupted transportation of coking coal or iron ore to the ports. This is not applicable for the transport of bauxite from Weipa to the refinery in Gladstone, as it is directly shipped by sea. Due to the proximity of the locations of refineries and smelter, the transport of alumina to the smelter is less likely to be impacted by extreme weather.

Water excess or storm surges could cause damages to **ports** which might result in decreased or interrupted exports, as ports have to halt operations during extreme weather events or face damages. This applies to all three resources. Past extreme wet weather events have already heavily impacted transportation systems, e.g. the 2010-11 floods and Cyclone Debbie in Queensland. Droughts which cause water shortage could affect **mining and processing operations** as water use might be restricted or energy prices rise. This would also impact the security of supply as production might have to be reduced or halted or prices for production would increase.

The specific impacts of sea level rise on ports or mining sites that are near the coast are uncertain for the near future. Yet, at the end of the century **ports** are expected to face substantially elevated sea levels, accompanied by more and more cyclones and other storm events, which will require new protection measures.

Communities

Communities and other industries (e.g. agriculture) in the vicinity of mining operations will also be impacted by more intense weather extremes as well as gradual climate changes. In particular, vulnerable communities (e.g. indigenous communities) will face more pressures, potentially creating new or aggravating already existing conflicts between the local communities and mining companies.

Mining sector governance and adaptation

In general, Australia's mining sector and environmental governance is well functioning. It comprises good environmental management and regulation capacities, as illustrated by the investigations into the port spill from Abbot Point Coal Terminal in the aftermath of Cyclone Debbie. The Government of Australia also acknowledges the country's high vulnerability to climate change impacts. There are challenges in regard to inconsistencies in the overall disaster risk reduction and climate change adaptation policies and lacking coordination between the different government institutions. Yet, there is a range of functioning policies in place, in particular in the field of disaster risk reduction. This is illustrated by the good early warning services, provided by the Bureau of Meteorology.

The analyses have shown that past weather extremes provide insights into the current resilience of mining operations and transportation systems in Australia. Past events have shown that even in the event of an extreme weather incudes disaster Australia has significant capacities for reconstruction on the federal government and state/territory government level. It has also shown that it can learn from past events as exemplified by the establishment of a permanent agency for reconstruction in Queensland.

However, the case study underlines the necessity of mining companies to start adapting to climate impacts. It is also particularly important to take projected climate changes into account when planning new mining projects or expanding existing ones. Australia can build upon its high capacities and advanced technologies in this regard, , e.g. sea water neutralisation of red mud at the Gladstone alumina refineries, the use of recycled water during processing and modern railways.

Some mining companies already consider climate change as threat to their operations and have developed, in addition to technical improvements, adaptation strategies (e.g. BHP Billiton's Climate Resilience Plan for its Western Australia Iron Ore operations and Rio Tinto's Climate Change Sensitivity Framework in Weipa). However, there is no public account on how these strategies are implemented to date. Even though there are some publications and guidelines on climate change adaptation for the Australian minerals industry available (e.g. Mason et al. 2013), it is not clear whether adaptation strategies are applied across the mining industry in Australia.

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