TEXTE
106/2020

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

Case study on PGMs and nickel mining in South Africa

For our Environment

Umwelt Bundesamt

TEXTE 106/2020

Environmental Research of the
Federal Ministry for the
Environment, Nature Conservation
and Nuclear Safety

Project No. (FKZ) 3716 48 324 0
Report No. FB000279/ANH,5,ENG

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

Case study on PGMs and nickel mining in South Africa

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Imprint

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Study completed in:
July 2018

Edited by:
Section III 2.2 Resource Conservation, Material Cycles, Minerals and Metals Industry
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Publication as pdf:
http://www.umweltbundesamt.de/publikationen

ISSN 1862-4804

Dessau-Roßlau, June 2020

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 the Mogalakwena PGMs and nickel mining project and its smelting and refining operations in the Limpopo region, South Africa. The region is characterized by an arid climate and faces wet weather extremes. Mogalakwena is an open-pit mine and has a large land footprint. Mine waste at the site has acid mine drainage potential and requires appropriate treatment. The mine operates in a water deficient area and competes with other water users. Solid waste from the processing plants (including refineries) is stored at the slag dump or reprocessed at the smelter. Main air emissions from the smelter are sulphur dioxide, nitrogen oxides, and particle matter. Smelting at Polokwane has a limited water footprint. Effluents from the refineries include different wastewater streams, stored in several lined dams, with some of the water being recycled.

Climatic changes, especially projected water stress and wet weather extremes, are expected to aggravate current environmental impacts of PGMs and nickel mining and processing in Limpopo. The mining and beneficiation process at Mogalakwena and the refineries at Rustenburg require large amounts of water. In addition, the water-intensive operations at the mining site and the refineries might lose productivity in times when water is scarce and restricted. Heavy rainfall, cyclones and flooding events could wash out contaminated effluents from the mining pits, tailings (mining site), slag dump (smelter) or effluent dams (refineries). The destructive powers of wild fires, heavy rain, flooding, cyclones and heavy winds could interrupt mining operations, smelting, refining and roads, and potentially decrease or interrupt production and transportation of PGMs and nickel. In Limpopo, many bridges, dams and power line crossings may be at risk during times of flooding.

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 betrachtet das Mogalakwena-Bergwerk (Platinmetalle und Nickel) und die dazugehörige Hütte im südafrikanische Limpopo. Die Region hat ein arides Klima und ist von Starkregenereignissen geprägt. Das Bergwerk konkurriert mit anderen Nutzern um knappe Wasserressourcen, während die Schmelze einen geringeren Wasserverbrauch hat. Bei dem Bergwerk handelt es sich um einen Tagebau mit einem großen Landverbrauch. Die Bergbaureststoffe bilden potentiell saure Grubenwässer. Feste Reststoffe aus den Verarbeitungsbetrieben werden auf Halden gelagert oder bei der Verhüttung wiederaufbereitet. Die Hauptluftemissionen bei der Verhüttung sind Schwefeldioxid, Stickoxide und Partikel. Bei der Verhüttung entstehen außerdem verschiedene Abwasserströme, die in mehrere ausgekleidete Dämme geleitet werden. Ein Teil des Wassers wird recycelt.

Es ist wahrscheinlich, dass klimatische Veränderungen, insbesondere steigende Wasserknappheit und häufigere Starkregenfälle, die Umweltauswirkungen bei der Gewinnung und der Weiterverarbeitung von Platinmetallen und Nickel verschärfen werden. Der Abbau und der Umschmelzprozess erfordern

große Mengen an Wasser. Deswegen könnte eine sich verschärfende Wasserknappheit die Produktion einschränken und Nutzungskonflikte verstärken. Starkregen, Wirbelstürme und Überschwemmungen könnten belastete Abwässer auswaschen, die beim Abbau, Umschmelzen oder bei der Verhüttung entstehen. Weiterhin könnten diese Wetterereignisse sowie Waldbrände die Produktion und den Transport von Platinmetallen und Nickel beeinträchtigen. So wurden in Limpopo viele Brücken, Dämme und Stromleitungsübergänge als potentiell durch Hochwasser gefährdet eingestuft.

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List of Abbreviations

Amplats	Anglo American Platinum Ltd
AR4	Fourth Assessment Report of the Intergovernmental Panel on Climate Change
AR5	Fifth Assessment Report of the Intergovernmental Panel on Climate Change
ASM	Artisanal and small-scale mining
BMR	Base metal refinery
BMU	Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety)
CMA	Catchment Management Authority
DEA	Department of Environmental Affairs
DMR	Department of Mineral Resources
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EIA	Environmental Impact Assessment
EMI	Environmental Management Inspectorate
GCM	General Circulation Model
GHG	Greenhouse gas
ILO	International Labour Organisation
LTAS	Long Term Adaptation Scenarios
MCP	Magnetic concentration plant
MPRDA	Mineral and Petroleum Resources Development Act
NAS	National Adaptation Strategy
NEMA	National Environment Management Act
PGM	Platin Group Metal
PMR	Precious metal refiners
R	Rand (South African Currency)
RBMR	Rustenburg Base Metals Refiners
RCP	Representative Concentration Pathways
UBA	Umweltbundesamt (German Federal Environment Agency)
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change

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.

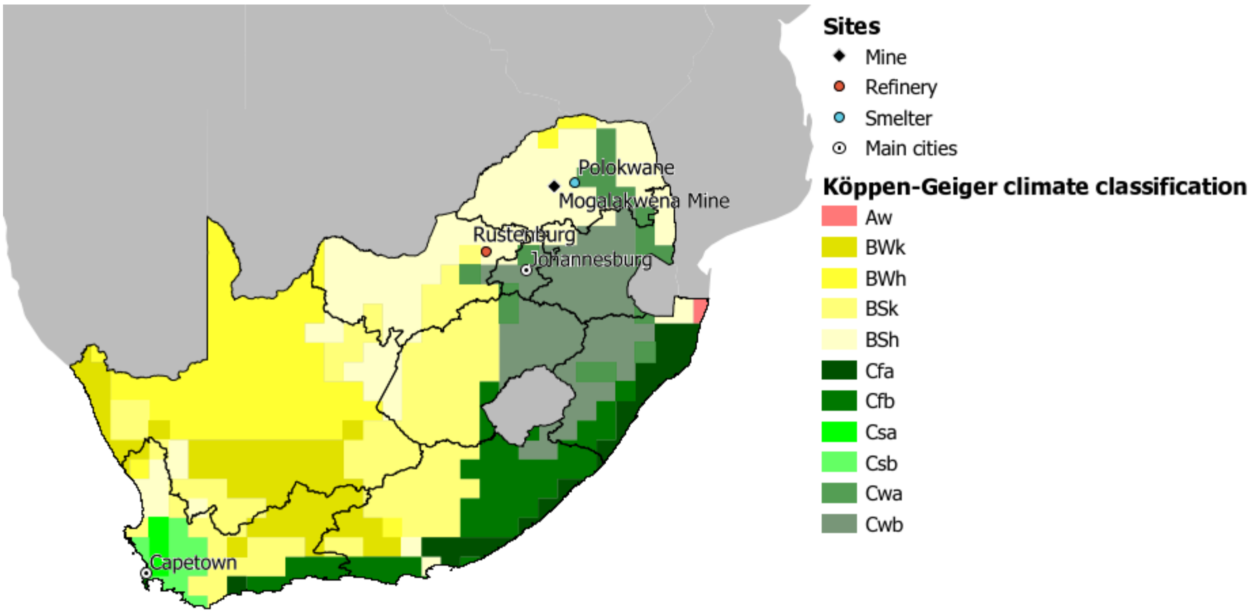
Each case study analysed a chosen mine site and the processing steps (to the extent these take place in the relevant country). The project team evaluated the environmental and supply risks potentially caused by climate stimuli and/or direct climate impacts for each of the mining and processing sites.

1.3 Content and structure of case studies

This study focuses on the following resource and mining site in South Africa (see Figure 1):

- PGMs and nickel: Mogalakwena mine in the Limpopo region (arid to temperate climate)

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



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

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

First, the case studies provide a brief overview of the climatic conditions and projected climatic changes (in the case of this case study, for arid and temperate regions and for South Africa 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 changes

2.1 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). According to the Köppen-Geiger climate classification, this climatic zone has four subtypes: an arid desert climate, either of hotter[1] or cooler[2] 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).

2.2 Temperate regions

Temperate climates are usually associated with mild and moderate mid-latitude climate, lying in between hot tropical and cold climates (Matthews, 2014). According to the Köppen-Geiger climate classification, temperate climates are defined by the "temperature of warmest month [being] greater than or equal to 10°C, and [the] temperature of coldest month [being] less than 18°C but greater than -3°C" (Arnfield, 2016). This classification covers various climates, ranging from "Mediterranean-type climates and humid, subtropical zones to maritime climates influenced by the oceans" (MetOffice, 2012). Temperate climates cover over 13.4% of the global land area (Peel et al., 2007).

Hydrological regimes in mild temperate regions depend on seasonal cycles of rainfall and evaporation (IPCC, 2007). Climate change projections for temperate regions in North and South America show an increased mean annual temperature and no change or an increase in mean annual precipitation. Areas that experience a water deficit are projected to increase: in North America the proportion of water deficit areas increases from 11% to 22%, while South America sees and increase from 28% to 41% (Lauenroth et al., 2004). Climate change projections for Western Europe indicate a decrease in summer runoff and an increase in winter runoff (IPCC, 2007).

2.3 South Africa

South Africa is characterised by a mix of arid and temperate climate zones. The key feature to distinguish the different climate zones of South Africa is the amount and seasonal distribution of rainfall. South Africa is located in the transition zone between subtropical easterly trade winds during the austral summer and westerly trade winds in winter. The precipitation patterns of southern Africa are generally driven by the oceanic currents along the coasts. In the Indian Ocean, the Agulhas Current transports warm water from tropical regions and brings summer rains with the easterlies to Mpumalanga, KwaZulu Natal, Lesotho and the eastern parts of Free State and Eastern Cape (Walker, 1989). The climates in those areas are warm temperate climate types (Köppen-Geiger classification C). At the Atlantic coast, the Benguela Current brings cold upwelling water from the South Atlantic (Walker, 1989). As a consequence, the central parts, the north and the west of South Africa are more arid (Köppen-Geiger classification B). An extensive belt of steppe and desert landscapes ranges from the central and northern regions and reaches up to the Atlantic coast at the Namibian boundary (Kottek et al., 2006; Conradie, 2012). In summer stable subtropical high pressure results in little winds and no rainfall. In winter, the westerlies reach the southern tip of the African continent, but because of

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

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

the cold Atlantic waters, they transport only little moisture to the hinterland and only a limited area around Cape Town receives considerable rainfall from April to September (Walker, 1989).

The weather system is sensitive to changes in the oceanic fluctuation and one major challenge of the contemporary climate is the high variability of rainfall. Due to teleconnections with oceanic oscillation patters, the rainfall is driven by multi-annual cycles of alternating wetter periods and long dry-spells (Fauchereau et al., 2003; Ambrosino et al., 2011).

South Africa has a comparatively dense network of climate stations and long coherent observation series. Several studies have shown a significant rise in temperatures. This warming trend has been 1.5 times higher than the observed global average increase of 0.65° C over the past five decades (Ziervogel et al., 2014). Mean annual temperatures, minimum and maximum temperature have been increasing in almost the entire country (Ziervogel et al., 2014; DEA, 2017a). Heat waves have become more frequent, while fewer cold events were recorded (DEA, 2013). Several studies expect this trend to continue in the future. Ziervogel et al. (2014) project a temperature increase for the end of the century of 1°C to 1.5°C in the coastal regions and around 3°C further inland (RCP4.5). Under the RCP8.5 scenario, it is projected that the warming increases by 3°C at the coast and 6°C in the interior. Studies of the British MetOffice (2011) and DEA (2017a) confirm the projected temperature rise, although they project that the warming will be more pronounced on the coast and to be less inland.

In contrast to temperature, trends in precipitation are harder to determine as they are subject to high variabilities in amount, seasonality and geographical distribution. This means that forecasting precipitation is more difficult because the climate models suffer from high uncertainties. Although the amount of rainfall remained stable for most parts of the country, the number of rain days per year decreased. This indicates a tendency to less, but more intensified rain events and longer dry periods (Ziervogel et al., 2014). In accordance with the observed trend, it is projected that higher precipitation variabilities increase the likelihood of extreme rainfall and long persisting droughts in the future (DEA, 2015; DEA, 2017a; Ziervogel et al., 2014). Additionally, there is a shift in seasonality with decreasing autumn/winter precipitation and increasing summer precipitation.

3 Overview of the mining sector

South Africa has rich natural resource endowments and the mining sector contributes significantly to the country's economy. South Africa has the world's largest reserves of PGMs (91% of global reserves) and manganese (29%). Additionally, South Africa ranks second in reserves of chromium (39%), gold (11%) and of zirconium (19%), and third in world reserves of vanadium (18%) (USGS, 2018b).

The main mining provinces in South Africa are: Northern Cape (lead, zinc, copper and silver), Free State (gold), North West (PGMs), Gauteng (gold), Mpumalanga (coal and PGMs), and Limpopo (coal and PGMs) (Chamber of Mines, 2017).

The mining sector accounted for 7.3% of the country's GDP in 2016. In terms of exports, South Africa's mining industry contributes significantly to foreign exchange earnings. In 2016, a majority of total sales of many minerals stemmed from exports, such as gold (80.2%), PGMs (88.5%), silver (93.1%), iron ore (91.1%), lead concentrate (100%), manganese (95.5%), nickel (81.7%), and zinc (100%) (Chamber of Mines, 2017). The sector also contributes to direct and indirect employment. In 2016, over 457,000 people were directly employed in the mining industry (Chamber of Mines, 2017), and mining-related employees are considered as the top performing earners (in nominal increase terms). In PGM mining, reported earnings are the highest (R172,444), followed by earnings in gold (R116,419) and copper mining (R77,506) (Chamber of Mines, 2017). The sector's contribution to GDP, employment, tax revenues and profit for private companies, however, have been affected by the price volatility during the last years and poses challenges for the sector's further development.

The South African artisanal and small-scale mining (ASM) sector has long been overlooked. With an estimated 10,000-30,000 people participating in ASM activities it employs less people than the large-scale mining (LSM) sector. It is mainly focused on the exploitation of industrial and construction minerals. Despite a formalisation of ASM in 1994, challenges remain in terms of access to mineral rights, capital, information, technologies, and markets, and inadequate skills, knowledge, and institutional support. In the current regulatory setting, entrepreneurs who have the necessary financial resources are favoured, rather than those from poor backgrounds. Against this backdrop, many have consequently decided to remain operating outside the formal framework and illegal mining has been on the increase. Recent estimates speak of up to 30,000 people involved in illegal mining in the decade preceding 2015 (Ledwaba, 2017).

4 Overview of mining sector governance

4.1 Disaster risk management and climate change adaptation

In terms of climate change adaption, South Africa started various legislative efforts with the aim of creating the necessary structures to face the impacts of climate change and make the country more resilient. Before 2001, climate change was considered an environmental problem alone rather than a development challenge. This has changed after South Africa submitted its first National Communication to the UNFCCC. Following this and after the National Climate Change Summit discussions in 2005, South Africa issued its National Climate Change Response White Paper in 2011, which became the first climate change adaptation and mitigation policy in the country (Ziervogel et al., 2014).

With this policy, South Africa recognised its vulnerability to climate change as a water-stressed country, its exposure to droughts and weather variability, and set the objective of strengthening the country's resilience (Government of SA, 2011). The White Paper used a strong sectoral approach and gave priority to certain sectors, such as water, agriculture and forestry, health, biodiversity, and human settlements. Additionally, it identified strategic priorities to ensure a resilient development of the economy. The White Paper has no special focus on the mining sector but draws links to the sector's activities with regard to water and energy.

The White Paper ascertained that adaptation measures have a stronger local context than mitigation responses, and adaptation benefits are more tangible because they are perceived sooner and have a potential for job creation, especially so-called 'green jobs' (Government of SA, 2011). Amongst other things, the White Paper called for the development of Long Term Adaptation Scenarios (LTAS) which should include a regional risk analysis and possible measures for climate resilience on a national and subnational level.

One of the LTAS focused on the Limpopo region and emphasised the risks associated with the potential rise in temperatures (Limpopo Provincial Government, 2016). This would mean that the already water-stressed region could face more episodes of droughts and heat intensity. Therefore, in its Provincial Climate Change Response Strategy 2016 - 2020, the government of Limpopo followed the White Paper and identified priority sectors for which adaptation measure should be adopted: agriculture, livelihoods and settlements, ecosystems (terrestrial and aquatic), water supply, and human health (DEA, 2017b). However, as in the White Paper, this strategy did not identify the mining sector as a priority.

In 2016, a new National Adaptation Strategy (NAS) was drafted and a second draft is out for public comments since October 2017. The strategy intends to adopt a unified, cross-sectoral and economy-wide approach to climate change adaptation (SACBC, 2017). There is a strong focus on coordination between government institutions and all governmental levels, and a holistic approach to climate change. One of the main developments is that more economic sectors have been integrated into the sectoral priority strategies, including the mining sector. The NAS emphasises the need for assessments to design a tailored climate change and resilience strategy for the mining sector and envisages the development of a Climate Change Response Strategy for the Mining Sector by 2020 as well as the development of a Mining Sector Climate Resilience Charter by the Chamber of Mines. Furthermore, the NAS lists as implementation priorities regarding the mining sector a public-private flagship programme for resilience in the mining sector, and the development of an early-warning system for climate related disasters in the mining sector (DEA, 2017b). In addition to finalising the NAS, the Department of Environmental Affairs has developed a draft Climate Change Bill that was published for public comment in June 2018. The draft bill builds on the same approach as the NAS and substantiates the establishment of a national environmentally sustainable development framework by setting implementation timelines (DEA, 2018).

In 2002, South Africa issued the Disaster Management Act from which further regulatory developments followed, such as the creation of the National Disaster Management Centre and the issuance of the National Disaster Management Policy Framework in 2005. South Africa was one of the first African countries to extensively legislate disaster management. It applied a decentralized approach for disaster risk reduction by engaging three government tiers (local, provincial and national) into the process. However, full implementation was hampered by weak institutional structures as well as, according to local stakeholders, by inadequate funding, a lack of understanding of disaster risk management by other stakeholders and insufficient political will (van Niekerk, 2014).

Disaster risk management was also addressed in the 2011 White Paper, which announces a further development of early warning systems with regards to weather, climate and pest infestation events. Furthermore, the White Paper plans to ensure that information reaches potential affected parties in a timely manner, collaborate with neighbour countries to share early warning systems, promote further research, raise awareness and build capacities, and develop mechanisms such as micro-insurances that would help the poor to recover after disasters (Government of SA, 2011).

On the company level, Anglo American has shown efforts to design and implement climate change adaptation strategies. Between 2010 and 2011, the company ranked all of its operations and projects worldwide according to their climate vulnerability. Following these efforts, Anglo American began with low-resolution climate modelling for the most vulnerable regions, including the platinum operations in South Africa (Anglo American, 2016a). The company has participated actively in the policy debate through its membership in the National Business Initiative, the Business Unity South Africa and the Industry Task Team on Climate Change. It is also a founding member of the Centre for Carbon Capture and Storage (Anglo American, 2018d).

4.2 Environmental governance

Since the end of the apartheid regime, South Africa underwent a series of institutional and regulatory reforms to move past this period and to ensure the adoption of a new and more inclusive legal framework. Environmental policy also fell within the reviewed legislations with a special focus on mining activities, which historically had been an economic sector supported by the apartheid regime (Olaleye, 2010).

The post-apartheid constitution of 1996 stipulates "the basic human right to a clean, safe and healthy environment in the context of the protection of the natural resource base and sustainable economic and social development" (OECD, 2013: 38). In 1997, the government issued the White Paper on Environmental Policy for South Africa, establishing main policy objectives derived from a wide consultative process. One year later, the first legal environmental framework of the post-apartheid era was issued, the National Environment Management Act (NEMA), replacing the Environment Conservation Act (which had a mainly declarative character) and 36 additional environmental laws (OECD, 2013). However, the mining sector used to be exempted from some key provisions of the NEMA and the environmental aspects of mining activities were mostly governed by the Mineral and Petroleum Resources Development Act (MPRDA), which was issued in 2002 (OECD, 2013).

In terms of permitting, the authorisation process used to be split across different departments which were supposed to coordinate their activities; yet, in practice this proved to be very challenging (Jeffery, 2018). However, since a 2014 amendment to NEMA, all environmental provisions were removed from the MPRDA and the Department of Environmental Affairs (DEA) became the sole regulating authority. The introduction of an "One Environmental System" was supposed to consolidate the authorisation process. Nevertheless, the integration process, covering water-use licenses and other necessary permissions so far remains split, partially because the Department of Mineral Resources (DMR) did not hand over all environmental authority to the DEA as initially planned (Jeffery, 2018; Mpinga, 2017). The uncertainty concerning environmental regulations therefore still remains, due to which

South Africa dropped in the ranking of the Fraser Institute from place 23 out of 72 countries surveyed in 2009 to 81st out of 104 in 2016 (Jeffery, 2018).

The DEA as national environmental authority has the following functions: ensuring the protection of the environment and the conservation of natural resources; promoting sustainable development and an equitable distribution of benefits from the natural resources; and formulating, coordinating and monitoring the implementation of national environmental policies. It was linked to the tourism sector (Department of Environmental Affairs and Tourism) until 2009. From then on, environmental and water departments are administered together by the Minister of Water and Environmental Affairs. Between 2002 and 2012, the DEA strengthened its capacities, especially in terms of budgetary allocation (from R1.1 billion to R5.2 billion) and human capacities (from 1.000 to 1.400 employees) (OECD, 2013). Other authorities involved in environmental governance are the DMR and the Department of Water and Sanitation (DWS).

At the sub-national level, provincial authorities are in charge of administering environmental laws and have the power to establish determined standards for certain topics. They should also prepare environmental plans that are in line with the municipal Integrated Development Plans. However, at the sub-national governance level the economic disparities among provinces are visible and only those wealthy enough have sufficient human and capital resources. For the majority of provinces, the environmental budget has declined over the years so that it became overly difficult for the local staff to implement the tasks they are faced with (OECD, 2013).

In general, there were many positive developments that came with the introduction of new legislation, for example the introduction of the Environmental Impact Assessment (EIA) in the late 1990s. However, one of the major obstacles for an efficient implementation of EIAs has been the fragmentation of processes and authorities on the three government levels.

Mining companies are required to submit an environmental management plan which also needs to include provisions for closure and remediation to the DMR for approval. In addition, the plan needs to lay down how the company secures funds to guarantee the post-closure site remediation. Nonetheless, the implementation of those practices is confronted with some challenges, such as the lack of adequate remediation plans and the insufficient assessment of required funding. The DMR has already developed strategic plans to address these issues; however, further efforts are still necessary to ensure better compliance (OECD, 2013).

4.3 Water governance

Water scarcity is a key issue in South Africa. In general terms, the water resources are scarce and limited, rainfall is almost half the global average, evaporation is high and there is no large river crossing the country. This situation is aggravated as in several river basins water requirements today often exceed natural availability, mainly due to high irrigation levels previously established under the illusion of water abundancy (Basson, 2011). Similarly, the South African National Water Act of 1956 was designed following examples from water-rich countries.

The new National Water Act that was issued in the post-apartheid era in 1998 was lauded as one of the most advanced water legislations in the world (Schreiner, 2013). This new Act included topics such as the principle of subsidiarity, the establishment of Catchment Management Authorities (CMAs), and the creation of an agency to deal with water resources infrastructure, among others. It also introduced a change away from the historical approach according to which landowners were also the owners of water resources on their lands towards a system in which the Minister of Water and Environmental Affairs is, on behalf of the government, the trustee of all national water resources (OECD, 2013). However, the implementation of this Act, and the reforms contained within, was challenging. In general, the DWAF was overburdened with the number of tasks and pace of reform.

In 2004, the First National Water Resource Strategy was issued. The strategy laid down that water resources management (including water quality) was an exclusive competence of the national government exercised through the oversight of the DWAF. It also established that water supply and sanitation services are in the power of the municipalities. However, coordination between the national and the municipal level in particular between the DWAF and local governments is still missing. This lack of interaction creates a gap between the management of water resource and water services (e.g. creating conflicts between land-use planning tools and the water services delivery) (OECD, 2013).

On the company level, Anglo American recognises that water scarcity can seriously impact its production at Mogalakwena, both from a supply perspective (i.e. not enough water is available) and a social perspective (i.e. the mine water use competes with the residents' water use which can lead to opposition and protest, also see chapter 4.5 on mining-related conflicts) (CDP, 2016; Anglo American, 2016b). The company took measures to respond to water scarcity including the implementation of a long-term bulk water strategy and infrastructure plan, comprising the upgrade of the municipal sewage works (CDP, 2016).

4.4 Indigenous people[3]

Khoe-San is the general denomination for the indigenous groups that live in South Africa, corresponding to 1% of the 50 million people living in South Africa (Jacquelin-Andersen, 2018). The San and Khoekhoe people are the two biggest indigenous communities, which comprise further subgroups. Even though these two groups share languages, geography and culture, they are differentiated based on their livelihoods and occupations, the San being nomads and the Khoekhoe pastoralists (Le Fleur and Jansen, 2013). The San and Khoekhoe peoples in South Africa identify themselves as indigenous peoples, but have not yet obtained constitutional recognition of their indigenous status. The South African Constitution does however recognize the importance of the Khoi, Nama and San languages and some efforts have been undertaken to promote multilingualism and adult literacy as an expression of recognition of the indigenous peoples. Although South Africa voted in favour of the adoption of the UN Declaration on the Rights of Indigenous Peoples, the country has not yet ratified the ILO Convention No. 169 (UN, 2005a; Jacquelin-Andersen, 2018).

Indigenous communities were greatly discriminated against during the apartheid regime. One of the principle examples of the segregation policies was the Natives Land Act of 1913 which remained in force until the end of the regime in the 1990s. Under this legislation, only 13% of the country's land could be owned by natives, leading to the situation that most of the indigenous communities were dispossessed of their lands, first by the Dutch and then the British (Le Fleur and Jansen, 2013).

Under the apartheid regime, indigenous people were classified as "coloured", which brought with it a series of discriminatory treatments and economic and social disadvantages. During this period, Khoisan people that were not registered under other population denominations had the obligation to be registered as "coloured" neglecting their identity as indigenous communities. Regardless of the discriminatory implications of such a term, these communities are still classified under this connotation today (Le Fleur and Jansen, 2013).

Since then, there was a major advancement for indigenous people rights in terms of land ownership with a judicial decision of the Constitutional Court in 2003. In 1920, about 5,000 Khoikhoi people, who comprised the Richtersveld community, were removed from their land due to the beginning of mining activities by Alexkor, a state-owned mining company. The Land Claims Court decided at that time that these people had lost their property rights on the land after the British annexation and that the reason for this was that they were "insufficiently civilized" to have any property rights which led to the

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[3] Two definitions of the term 'indigenous' could apply to the South African context: One "broadly referring to all South Africans of African ancestry, the other referring to specific populations using the UN definition and making specific territorial and cultural claims against the State" (ILO, 1999: 3). This chapter refers to the latter definition.

declaration if this land as terra nullius (i.e. land that belongs to nobody). In 2003, the Constitutional Court ruled upon appeal that the Richtersveld community had rights to those lands and ordered their restitution (UN, 2004). It was a historical decision because it did not only recognize the land rights of the indigenous community, but also their mineral rights, making negotiations between the community, Alexkor and the state possible. The final agreement was endorsed by the Land Claims Court in 2007 (UN, 2012).

Most Khoe-San, however, are confronted with the problem of insecure land tenure (Sapignoli and Hitchcock, 2013). The 1996 post-apartheid land reform policy aimed at enforcing a systematic land restitution, tenure reform and redistribution of land, but disregarded indigenous peoples. In 2017, the Ministry of Rural Development and Land Affairs acknowledged that the Khoe-San were excluded from the restitution process and developed a new policy to accommodate also the Khoe-San. Thus far, it remains unclear how the Department of Rural Development and Land Affairs will implement this policy (Jacquelin-Andersen, 2018).

In terms of mining regulation and activities, there is no specific mentioning of indigenous people's rights. The MPRDA of 2002 emphasises the importance of increasing opportunities for historically disadvantaged South Africans, and under this general categorization includes all communities that were discriminated under the apartheid regime. The MPRDA advocates for the improvement in terms of ownership, management of mining projects, employment quotas and sharing of benefits (Moraka, 2015). Nevertheless, it is still criticised that the DMR is an absent actor which "lacks the capacity, the skills and the political will" to improve the situation in mining towns – not only for indigenous people, but for marginalised communities in general (Dlamini and Mbangula, 2017).

4.5 Mining-related conflicts

In South Africa, mining-related conflicts must be understood against the broader backdrop of colonialization, apartheid and racism. Even though apartheid was officially abolished in 1994, it continues to influence many of today's economic sectors in their organisation and power structure (Rüttinger et al., 2015). The South African mining sector is still dominated by foreign investments (World Bank, 2011). In 2017, a new mining charter was announced, forcing companies to give more ownership to black shareholders (minimum quota of 30 per cent) and more decision-making authority to black board members (minimum 50 per cent) to redress established power structures. However, the first draft charters were heavily disputed, with the mining industry even going to court (Burkhardt, 2018; Njobeni, 2018). As of July 2018, the issue had not been resolved and the finalisation of the charter was further delayed with the third draft charter still being open for public comments before it will be able to enter the law (Gous, 2018).

Most conflicts and violent escalations today occur between the workers and unions on the one side and the mining companies on the other. Both sanctioned and unprotected ("wildcat") strikes and blockades, aiming at a disruption of the mining production, have taken place "virtually every year" at Anglo American's platinum operations (Mattera, 2013). For the period between January 2016 and April 2018 alone, Stoddard (2018) has counted over 400 social unrest incidents in South Africa's east platinum belt, including road blocks, marches and strikes. The motivations behind the protests are diverse.

Mostly, workers protests are over wages, but sometimes also over other labour-related issues such as changes to the medical coverage or an increase in the use of casual and contract labour (Mattera, 2013). In the past, tensions have also arisen over the accident and fatality rate, perceived by worker unions as being too high (Mattera, 2013). Anglo American, who reports injuries and fatalities not in numbers of incidents but as "lost time" (see Anglo American Platinum, 2018a), was forced to respond to public pressure by halting its operations for one week following the deaths of five workers in 2007. Whether safety and working conditions have consequently improved is unclear (Mattera, 2013).

The probably most salient example of a conflict between mining workers and company is the wildcat strike at the Lonmin platinum mine in Marikana in 2012, which caught wide international attention. During the conflict, 43 people died, of which 34 miners were shot by the police (Engels, 2016), and 78 were injured (Rüttinger et al., 2015). As consequence of their strike, workers achieved a dramatic wage raise of 22 per cent (rts, 2012) and therefore served as an inspiration for following strikes in other mines in South Africa and beyond (Rüttinger et al., 2015; Engels, 2016). The longest strike of platinum workers happened in 2014 and lasted over five months when about 70,000 workers demanded higher wages (Africa Leader, 2014). Consequently, global production reduced by 40% and companies lost a combined USD 2.25 billion. Ultimately, wages were increased dramatically, especially those in the lower tiers where annual wages increased by up to 20 per cent over a period of three years (Stoddard, 2014; Africa Leader, 2014).

Conflicts also occur between mining companies and the communities adjacent to mining sites. In most cases, the environmental and social costs related to the mining operations are perceived by local communities as being high, whereas the benefits are low (Ololade and Annegarn, 2013). Surrounding communities suffer from rock blasting, dust and water contamination and other environmental impacts as consequence of the mining, as well as from poor basic services and infrastructure (Pickering and Nyapisi, 2017; News24, 2015). Adding to the people's frustration, unemployment in the area of the platinum belt is close to 80 per cent, according to an estimate of Anglo American Platinum (Stoddard, 2018). In 2015, residents near the Mogalakwena mine engaged in protests to demand jobs, greater benefits from mining and further social and infrastructure development in the area, especially improved water supply and roads (News24, 2015). The community protest led to a reduction of platinum production by 8,600 ounces (Anglo American, 2015).

Another major point of conflict has been the resettlements of several villages as part of mining site expansions, which happened against the will of many locals. Exemplary for such conflicts was the resettlement of the inhabitants of Ga-Pila and Motlhotlo in the vicinity of Angloplat's Mogalakwena mine. 10,000-20,000 were resettled in a newly built town. Whereas according to Terminski (2013) 98% of Ga-Pila residents accepted the offer to move and the relocation was voluntary, others have reported coercion, e.g. by cutting off basic services such as water and electricity (Mattera, 2013). Several other villages in Limpopo province have experienced similar disputes over relocation with some residents taking court action (Parker, 2008; MAC, 2007)

Conflict management is said to have been rather poor. Strikes and protests have been met with violence or dismissal. After a wildcat work stoppage in 1996, for instance, Anglo American fired the entire workforce of 28,000 people (Mattera, 2013). Furthermore, transparency is often lacking, such as in resettlement deals that are often struck with traditional leaders who are paid off and falsely claim to be the sole community representatives in violation of customary laws (Pickering and Nyapis, 2017). Following the protests in 2015, the Department of Mineral Resources established a multi-stakeholder dialogue (Anglo American, 2015).

Finally, women in mining are especially vulnerable and not enough is being done for their protection. A study of platinum mining in the Bojanala District reports that women are sexually harassed and exploited due to them making up small minorities in each shift. Also recruiters employed by Anglo Platinum have been accused of trading jobs for sex. Moreover, women are mostly employed in unskilled and semi-skilled sectors, and generally deployed as supplementary and not as core labour (van Wyk, 2012).

5 Case study: PGMs and nickel mining

5.1 The global value chains of platinum group metals and nickel

As platinum group metals (PGMs) and nickel are mineralogically associated in this case study, summaries of both the PGMs and nickel global value chains are presented in this section.

5.1.1 Overview

Platinum group metals (PGMs) comprise six metals which are platinum (Pt), palladium (Pd), iridium (Ir), osmium (Os), rhodium (Rh) and ruthenium (Ru). PGMs are among the rarest elements in the earth's crust. In nature they commonly occur together (in various ratios) in the form of alloys with one another or other metals (e.g. iron) or bonded to other elements (e.g. sulphur). They are primarily mined from magmatic base metal (poly-metallic) sulphide bearing deposits, either as a dominant product or a by-product of nickel and copper. Such deposits are also the most important source of nickel worldwide. The PGM-dominant deposits are typically associated with dispersed sulphide mineralisation, such as in Bushveld Complex in South Africa and Great Dyke in Zimbabwe. Some nickel-copper sulphide deposits contain comparable amounts of PGMs in the ore, allowing for their feasible extraction as a by-product. The major examples of the latter are Norilsk-Talnakh in Russia and Sudbury in Canada (BGS, 2009).

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

5.1.2 Properties

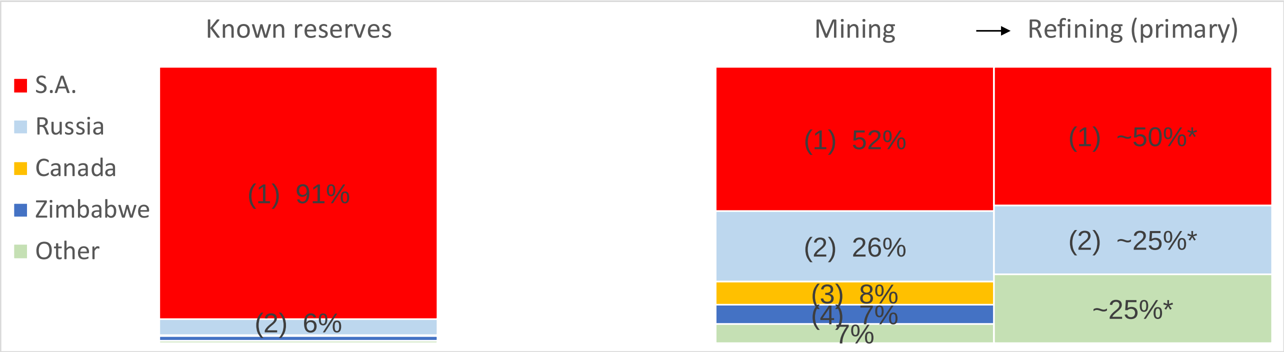
PGMs share similar chemical properties, though physical properties vary, and typically occur and are extracted together from the same mineral deposit, and can partially substitute one for another in some applications (USGS, 2018a). Their properties include resistance to corrosion and oxidation, high-melting points, electrical conductivity and outstanding catalytic activity. Emissions control in motor vehicles is the leading area of PGMs application, followed by jewellery, electrical applications, chemical industries, as well as an investment option (Zientek et al., 2017). Platinum and palladium are the most commercially important and abundant PGMs, accounting for more than 90% of total supply (Matthey, 2018).

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

5.1.3 Global production

Mining of PGMs is heavily dominated by South Africa (52%) and Russia (26%); two other significant primary producers are Canada (8%) and Zimbabwe (7%) (USGS, 2018a). Unlike mining, refining of PGMs is more complex and diversified (including recycling of spent catalysts and other secondary materials), with several developed countries such as Switzerland, UK, USA, Germany, and Japan being also among major players (BGS, 2009).

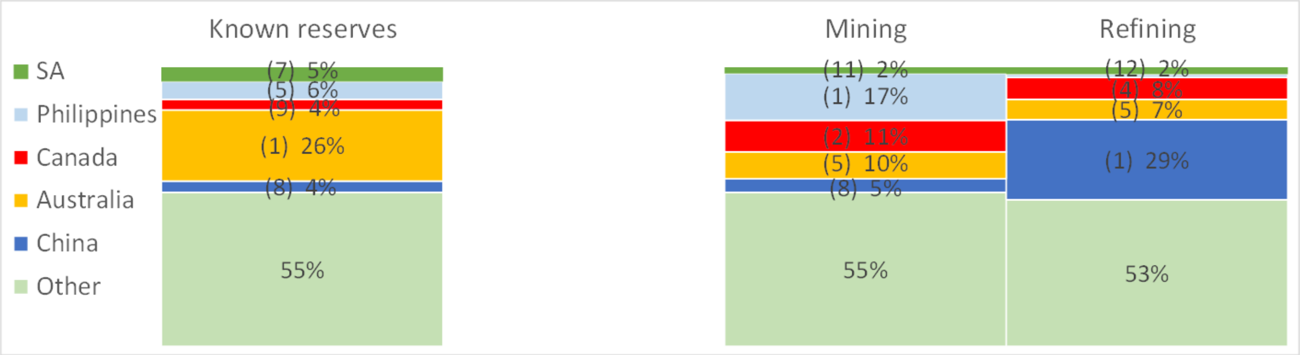
Figure 2: Platinum group metals global value chain and ranking for selected countries (2016)



Note: figures in brackets show the country's global ranking. Data sources: (USGS, 2018a). Note: * authors' estimate as relevant statistics are not available.

Major nickel reserves are located in Australia (26%), followed by Brazil (16%) and Russia (10%). A major nickel mining country is the Philippines (17%), while nickel refining is dominated by China (29%). Canada is the second largest miner and fourth largest refiner, holding about 4% of the world known nickel reserves (NRC, 2017; USGS, 2018a). South Africa's known nickel reserves represent about 5% in the world's total (7th largest), while mining accounts for about 2% of global nickel output (11th largest) (USGS, 2018a).

Figure 3: Nickel global value chain and ranking for selected countries (2016)



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

5.1.4 Markets and End Uses

PGMs are traded in a number of forms, including PGM rich Ni-Cu concentrate from mining operations or matte from smelting pure metals, as well as a variety of compounds, solutions and fabricated products (BGS, 2009). The international trade of nickel is represented by ores, concentrates, intermediate products (such as mattes, sinters, and oxides), ferronickel and unwrought metal (BGS, 2008). A significant part of both PGMs and nickel used in final products can be recycled to supplement primary supply (Nickel Institute, 2018).

More stringent emission standards and increased automobile production in developing countries are expected to support demand for PGMs in the near future (USGS, 2018a). Another potential growth area for PGMs is associated with fuel cell electric vehicles (Matthey, 2018). The global nickel use is dominated by stainless steel (68%), followed by alloys (16%), plating (9%), casting (3%), and batteries (3%) (OCE, 2017). An increasing amount of nickel is used in batteries, particularly lithium-ion batteries for electric vehicles, where nickel is used in the cathode materials. It is forecasted that nickel application in batteries will grow from about 3% to 15-20% in the 10-year time (Roskill, 2018).

5.2 Site specific overview – Mogalakwena mine, South Africa

Mogalakwena is the world's largest open-pit platinum mine. It is located in Limpopo province, South Africa, about 20 km west of Mokopane, within the Bushveld Igneous Complex which hosts about 90% of all known platinum resources in the world (BGS, 2009). The mine and its infrastructure cover an area of about 137 km^2, being operational since 1992 and expected to last at least until 2040. It is owned by Rustenburg Platinum Mines Ltd, a wholly owned subsidiary of Anglo American Platinum Ltd (also known as Amplats) – the leading producer of PGMs, providing the world with around 40% of all newly mined platinum (Anglo American, 2018c).

PGM mineralisation at Mogalakwena predominantly occurs in the relatively thick (30-100 m) Platreef horizon allowing for open cast mining. The Platreef ore body is characterised by lower PGM grades (about two times, 2-3 g/t versus 3-6 g/t) but enriched in base metals such as nickel, copper and cobalt (up to five times), which represent important by-products from Mogalakwena's operations (Anglo American, 2018b). The two other major PGM reefs mined elsewhere in Bushveld Complex are Merensky Reef (with higher PGM grades and platinum ratios), and chromite-rich UG2 Reef (high chromium but lower gold, copper and nickel content).

The infrastructure at the Mogalakwena mine (complex) comprises five open pits (Sandsloot, Zwartfontein, Mogalakwena South, Central, and North), two concentrator plants (North, and South), and two tailings dams. The total measured and indicated resources at Platreef are currently estimated at 1,325 Mt with the grade of 2.26 g/t of 4E (platinum, palladium, rhodium and gold), and inferred resources at 1,140 Mt with the grade of 1.95 g/t of 4E, which under current production rates would allow operations to continue for almost 100 years (Anglo American, 2018b). The data for nickel content in the ore and overall nickel resources for Mogalakwena mine are not disclosed. Taking into account current production rates, Platreef likely contains about 2 Mt of nickel, this is compared to 49 Mt of total nickel reserves in South Africa reported by USGS (2018a).

5.2.1 Overview of transportation systems and routes

The majority of the (PGM-nickel) concentrate produced at the Mogalakwena mine is treated at the Polokwane primary smelter, the largest and closest to the mine site (about 100 km to the east) among all three Anglo American's smelters in South Africa. The green matte from smelting (from all smelters) is transported to the company's facilities in Rustenburg (about 400 km south-west from Polokwane) for processing through a converter and acid plant (with annual capacity of 0.25 Mt of furnace matte), a base metal refinery to extract nickel, copper and cobalt (32.4 kt of nickel), and a precious metal refinery for gold and PGMs recovery (3.5 Moz or 110 t of platinum) (Anglo American Platinum, 2018b). Mogalakwena mine currently contributes to about 50% of nickel and about one third of PGMs output. The final products – pure PGMs, gold, copper, and nickel metals, and cobalt sulphate – are supplied to domestic and international customers. The details on precious metals transportation routes are not disclosed.

5.3 Extraction and processing technologies

5.3.1 Extraction and processing technologies at Mogalakwena

Mining

PGMs deposits are mined either by open-pit or underground methods, or a combinations of both (BGS, 2009). The surface mining is typically cheaper, and involves removing the overburden, digging the ore or blasting with explosives, followed by ore transportation by truck or conveyor belt to the mineral processing plant.

Mogalakwena is an open pit mine which employs a truck and shovel mining method, with operating depths from 45 m to 245 m. The current production capacity is over one million tonnes of ore per month, transported on haul roads by 300-tonne haul trucks (Anglo American Platinum, 2017a).

Beneficiation

After mining, the ore is processed to increase PGMs and other valuable metals content (e.g. from about 2 g/t to 100-500 g/t of PGMs). The beneficiation of PGM-dominant ores includes primary and secondary crushing, followed by fine regrinding (milling) and froth flotation. Magnetic separation can be used to remove pyrrhotite, dense media separation to remove lighter silicate minerals from the denser chromite and PGMs, and the final concentrate has to be dried before smelting (BGS, 2009).

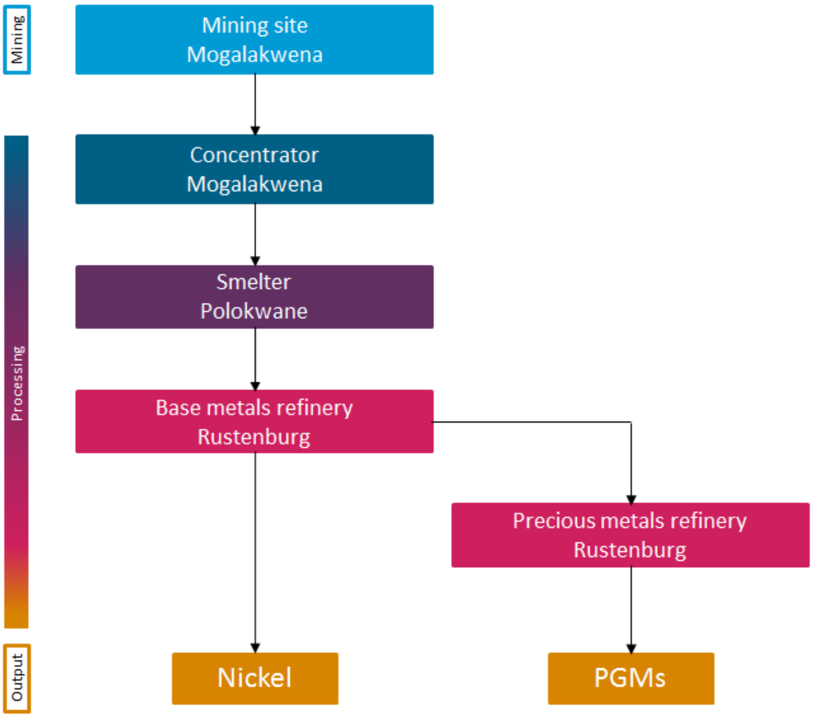
Smelting

In the smelting process, the so-called green matte, rich in PGMs (e.g. about 2000 g/t) and base metal sulphides (including nickel), is initially produced. This is followed by a converting process to oxidise and remove iron and sulphur. The resulting matte is slow cooled to produce a copper-nickel sulphide product containing the PGMs, which is then crushed and the iron sulphide component separated magnetically (BGS, 2009).

Refining

Nickel (and copper and cobalt) are leached out from the converter matte at the base metal refinery for further recovery, while the PGM containing residue is sent directly to the precious metal refinery. The refining is used to separate and produce individual PGMs via a series of hydrometallurgical operations, such as multiple dissolution and precipitation stages, or metal leaching followed by sequential solvent extraction (BGS, 2009). It is a very lengthy and complicated process which differs from company to company.

Figure 4: Overview of mining and processing



Source: own elaboration.

5.4 Environmental impacts and mitigation measures

Anglo American Platinum publishes an annual integrated sustainability report for all PGM operations, without disclosing data for individual mine sites, smelters and refineries. Mogalakwena mine's output (including PGMs, gold, nickel, copper and other minor by-products) roughly represents a quarter in the company's revenue, with significantly stronger economic performance compared to other mines (Anglo American Platinum, 2018b). Due to the large scale of operations at Mogalakwena allowed by the open-pit mining method, it is likely to have a lower environmental footprint per tonne of metal produced.

5.4.1 Mogalakwena mine

Land use

The major land use and disturbance includes open pits, tailings storage facilities, waste-rock dumps, as well as roads and infrastructure. The company aims to perform progressive land rehabilitation, where possible, to agreed (with communities and government regulators) land-use specifications (Anglo American Platinum, 2018b). The area surrounding the mine is mainly used for commercial grazing and agricultural purposes; a few rural settlements are also adjacent to the mine.

Water use

The mine is located in a water deficient area, where there is a growing (and competing) demand for water from agricultural, mining, industrial and domestic use. The expansion of Mogalakwena mine would potentially be hindered by limited water access, as well as on-going drought conditions. The use of alternative water sources such as pit water at the mine site, waste water from other organisations and municipalities (delivered via a pipeline), and connecting to other water dams in the area are all parts of the company's water strategy (Anglo American, 2018a).

In 2016, about 66% of water requirements at all Anglo American Platinum operations were met by recycling and reuse, while new water is primarily withdrawn from ground sources (Anglo American Platinum, 2018b).

Energy use

In general, mining and beneficiation processes account for about 70% of total energy requirements to produce PGMs (IPA, 2015). The major energy use at Mogalakwena mine is associated with the ore beneficiation processes (crushing, grinding and flotation), ore transportation (by haul trucks), and the use of explosives in the open pit. The major electricity supply is from the South African national grid, mainly based on coal fired power generation. The company has long term commitments to reducing energy consumption and investigates opportunities for carbon offsetting (Anglo American Platinum, 2018b). A solar photovoltaic project at Mogalakwena complex is currently under consideration (Anglo American, 2018d).

No details on energy consumption at the mine site has been disclosed to date.

Mine waste

The major waste from mining is in the form of waste rock and tailings. At Mogalakwena, some waste rock dumps are classified as low grade PGM ore, and can be re-mined under favourable economic conditions; waste rock is also used for processing into aggregates for construction and road building (Anglo American Platinum, 2018b).

Due to the presence of sulphides in the ore body (such as pyrrhotite, pyrite, chalcopyrite and pentlandite), there is a potential for acid mine drainage from mine waste (Zientek et al., 2017). Appropriate waste management techniques are required for tailings deposition and storage during the operational stage, and for land rehabilitation at the end of mine life, including revegetation, dust management and water management.

Emissions

No details on emissions (including dust emissions) at the mine site have been disclosed to date.

Biodiversity

The area of the mine site can be characterised as the Makhado Sweet Bushveld vegetation type, with species being limited to small mammals, birds and reptiles due to the disturbed nature of land (Mucina and Rutherford, 2006). The company estimates that the mine has a moderate risk to biodiversity, versus primarily low risk at other locations (Anglo American Platinum, 2018b). This is likely due to the size of operations and open pit mining method (versus underground mining in other locations).

Anglo American has biodiversity action plans incorporated into its environmental management systems, and has developed appropriate frameworks to assist and understand the biodiversity issues, with a particular focus on invasive plant species and conserving important plant species. The invasive plant species are considered to be a key risk to biodiversity (Anglo American Platinum, 2018b).

Rehabilitation

All operations of Anglo American in South Africa are required to update their environmental liability and mine closure assessments annually, including complying with financial provision regulations for closure (Anglo American, 2018d). The operations at Mogalakwena mine are expected to last at least until 2040, and likely to continue for several more decades thereafter. No detailed rehabilitation plans have been announced, however the company progressively moves towards concurrent rehabilitation (where applicable) to reduce the closure liabilities at the end of mine life (Anglo American, 2018d).

Health

The major potential health risks from mining at Mogalakwena relate to noise and inhalable hazards, such as dust on haul roads and from explosives in the pit. However, no health-related impacts have been reported to date.

5.4.2 Polokwane smelter

Land use

The major land use is associated with the processing facilities, ore stockpiles, and slag dump.

Water use

The smelting process has a limited overall water footprint. Being designed as a zero-effluent operation, most water at Polokwane smelter is recovered either in thickeners or via a system of dams (Hundermark et al., 2006). No details on the actual water consumption and effluent discharge are disclosed.

Energy use

The major energy use in PGM smelting process is in the form of electricity, followed by coal and gas; the average energy consumption for Anglo American Platinum smelters in South Africa was estimated at 1.7 MWh per tonne of processed concentrate (Liddell et al., 2011).

Waste

The solid waste from PGM smelting process is silica, magnesium and iron oxides rich slag, which after granulation and dewatering is disposed to a slag dump (Hundermark et al., 2006). The company investigated possible reprocessing and reuse options for this material at the Polokwane smelter, however they have been found uneconomic; the overall volumes are about 60 kt of slag per month (Anglo American Platinum, 2008). No environmental concerns for the slag dump have been reported to date.

Emissions

The air emissions are mainly represented by sulphur dioxide, nitrogen oxides, and particle matter, while direct GHG emissions are likely to be relatively minor due the electricity supply coming from the grid. The overall (direct and indirect) GHG emissions are estimated in the range of 1-1.5 tonnes per tonne of processed concentrate (Liddell et al., 2011). No details on the actual emissions have been reported to date.

Biodiversity

The impact on biodiversity is likely to be minimal due to the relatively small overall land footprint and previous disturbance by industrial activities. A recent independent baseline biodiversity assessment for the proposed SO_2 abatement plant site and road construction at the Polokwane smelter also concluded that there will only be a limited footprint, with no impact on critical biodiversity areas or ecological support areas; although some mitigation measures are recommended (Kimberg, 2017).

Rehabilitation

No plans for site decommission have been announced, and the operations are expected to last into the foreseeable future. The slag dump will require appropriate rehabilitation at the end of operations.

Health

No health-related impacts have been reported to date.

5.4.3 Rustenburg's base metal refinery

Rustenburg base metal refiners (RBMR) complex has an annual capacity of 32.4 kt of nickel, and is the largest nickel producer in South Africa (Anglo American Platinum, 2016). It consists of two metallurgical plants: a magnetic concentration plant (MCP) and a base metal refinery (BMR). At the MCP, the PGM-nickel matte is crushed and milled to undergo magnetic separation. The PGM-bearing magnetic fraction is directly sent to precious metals refinery, while non-magnetic fraction is processed at BMR to recover nickel, copper, cobalt, and sodium sulphate via a series of hydrometallurgical processes (Rustenburg Platinum Mines, 2012).

Land use

The major land use is associated with the processing facilities, water dams and effluents dams, and other supporting infrastructure (Rustenburg Platinum Mines, 2012).

Water use

Process water is obtained from the on-site stormwater dams (with total capacity of over 200,000 m^3), with an additional supply from an external network (primarily from water dams) (Rustenburg Platinum Mines, 2012). There are also several water effluents dams dedicated to different waste streams from the processes which are adequately lined; some of this water is also reused (Rustenburg

Platinum Mines, 2012). No details on the actual water consumption and effluent discharge are disclosed.

Energy use

The major energy use in refining processes is electricity supplied from the national grid. No details on the actual energy consumption are disclosed.

Waste

The solid waste from refining processes (low grade residues) are sent back to one of the smelters for metal recovery (Rustenburg Platinum Mines, 2012).

Emissions

No details on air emissions have been reported to date.

Biodiversity

The impact on biodiversity is likely to be minimal due to the relatively small overall land footprint and previous disturbance by industrial activities.

Rehabilitation

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

Health

No health-related impacts have been reported to date.

5.4.4 Rustenburg's precious metal refinery

Precious metal refiners (PMR) complex has an annual capacity of 3.5 Moz (about 110 t) of refined platinum, and is the largest platinum refinery in the world (Anglo American Platinum, 2016). PMR receives PGM matte from RBMR via road, to process it into high degree purity PGMs and gold according to market requirements, and it is on the top end of the platinum value chain, i.e. it produces the highest 'value add' compared with the rest of the value chain (Rustenburg Platinum Mines, 2012).

Land use

The major land use is associated with the processing facilities, water dams and effluents dams, and other supporting infrastructure (Rustenburg Platinum Mines, 2012).

Water use

Process water is obtained from the on-site stormwater dams as well as from an external water network via existing pipelines. All effluents are handled internally to recover some remaining valuable metals either in the Values Recovery Plant or converted into low grade residues which are returned back to the smelters. The remaining liquors are neutralised and concentrated by evaporation prior to discharge to effluent dams (Rustenburg Platinum Mines, 2012). No details on the actual water consumption and effluent discharge are disclosed.

Energy use

The major energy use in refining processes is electricity supplied from the national grid. No details on the actual energy consumption are disclosed.

Waste

The solid waste from refining processes (low grade residues) are sent back to one of the smelters for metal recovery. Effluent dams store acidic and alkaline effluents (Rustenburg Platinum Mines, 2012).

Emissions

No details on air emissions have been reported to date.

Biodiversity

The impact on biodiversity is likely to be minimal due to the relatively small overall land footprint and previous disturbance by industrial activities.

Rehabilitation

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

Health

No health-related impacts have been reported to date.

5.5 Current climatic impacts and risks

5.5.1 Current climate

The Limpopo province, where Mogalakwena mine is located, is a water scarce area with high average temperatures and high evaporation rates. The nearest large populated area to the mine is Mokopane (30,200 inhabitants in 2011; STATS SA, 2018), about 20 km to the east. The climate at Mokopane is characterised as local steppe climate, classified as BSh[4] by Köppen and Geiger. The average temperature is 19.3 °C, and average annual rainfall is 495 mm, mainly occurring during the summer months from November to March (Climate-Data, 2017). According to Köppen-Geiger, Polokwane (smelter location) is classified as Cwa[5]. This climate type belongs to the mild temperate climates, also described as subtropical climates.

Table 1: Mokopane - monthly mean rainfall

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	94	68	63	33	5	11	1	2	14	42	75	87

Source: Climate-Data, 2017.

5.5.2 Past weather extremes

Drought is a recurring issue in Limpopo (Maponaya and Mpandeli, 2016). In 2015/2016, southern Africa experienced one of its most severe droughts (Archer et al., 2017) and the Limpopo region was declared a drought disaster area (Reuters, 2017; Maponaya and Mpandeli, 2016). Anglo American reports that its Mogalakwena operations were affected by water restrictions (Anglo American Platinum, 2018c).

There are no reports that floods have impacted the Mogalakwena operations to date. However, in 2017, Anglo American's Amandelbult platinum operations, also located in Limpopo, were impacted by "unusually heavy rainfall resulting in flooded opencast pits and affected the feed chutes to the concentrator plants" (Anglo American Platinum, 2017b). Primarily due to the flooding event, Amandelbult's production dropped by 12% for the first quarter of 2017. Limpopo was heavily impacted by flooding in 2014, damaging several roads and houses (Kundu et al., 2014). In 2013, coal mining in Limpopo had to halt for several days due to flooding (News24, 2013).

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[4] BSh: B (arid), S (Steppe), h (hot).

[5] Cwa: C (temperate), w (dry winter), a (hot summer).

Cyclones do occasionally occur in the north of South Africa. In February 2017, tropical cyclone Dineo developed over the South West Indian Ocean and made landfall in Mozambique on 15 February, bringing heavy rain and strong winds (IFRC, 2017; DWA, 2017). It also reached Limpopo several days later, but was downgraded to a tropical storm. Instead of damage, it brought rain which was a relief for farmers and led to a rise of water levels in the region's dams (Phillips, 2017; Infrastructure News, 2017).

5.6 Climate change impact assessment

All data is derived from the DEA report Climate Trends and Scenarios for South Africa (DEA, 2013), unless otherwise stated.

Temperatures are projected to increase significantly in the region where the Mogalakwena operations are located. Projected temperature anomalies are beyond the range of recorded present-day anomalies. Relative to the baseline period (1971-2005), the annual average temperature is projected to increase by 1°C to 3°C under the relatively high emission A2 scenario and by 2°C to 5°C under the high emission scenario RCP8.5 for the period 2040-2060. Further in the future temperature increases are expected to be even higher: projections show an increase by 3°C to 6°C under the A2 scenario and by 4°C to 7°C under the RCP8.5. for the period 2080-2100. Under the lower emission scenario RCP4.5 for the same period, projected temperature increases are lower, reaching 2°C to 3°C.

Under different scenarios, precipitation projections show different patterns. Under the A2 scenario, drying is projected to intensify over time. However, projected precipitation is within the range of present-day anomalies. The RCP8.5 scenario implies no clear drying pattern. Precipitation variability is projected to remain within the range of present-day anomalies. Under the RCP4.5 scenario, precipitation is also projected to be similar to present-day precipitation.

Extreme events are expected to occur more often and/or to become more severe. Several climate models indicate that extreme floods will increase in the Limpopo region (DEA, 2015; Zhu and Ringler, 2012). The Limpopo River Basin is already facing water stress which is projected to worsen in the future[6] (Zhu and Ringler, 2012). Heat waves are expected to occur more frequently and increase in intensity (Limpopo Provincial Government, 2016). Fires, which regularly occur in the area, are expected to increase in frequency (Strydom and Savage, 2016). Projections for heavy winds and cyclones[7] are uncertain (USAID, 2015).

5.6.1 Potential climate impacts on the Mogalakwena mining site

The projected climatic changes and extreme events could impact the Mogalakwena mining operations, in particular through declining water availability and wet weather extremes.

The region where the mine is operating is already water-stressed. Projections indicate that the region might become even drier in the future. Drought can lead to water restrictions, potentially decreasing the mine's productivity. Drought could also mean that there will be less water available for dust control, potentially impacting workers' health unless mitigated by technical solutions. In addition, the already tense relationship with neighbouring communities might deteriorate over competing water use during times of water scarcity. Drought can also have negative impacts on site rehabilitation and the region's biodiversity.

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[6] Projections are based on the downscaled General Circulation Models (GCM) CNRM-CM3 and ECHam5 GCMs, limited to the medium-emission scenario SRES A1b, focusing on 2050 (Zhu and Ringler, 2012).

[7] "South Africa is not generally directly impacted by tropical cyclones, but cyclones that track into the Mozambique channel can occasionally have indirect effects" (MetOffice, 2011: 67). For a recent example, see chapter 5.5.2 on past weather extremes.

After heavy rainfall, cyclone and flooding events, soluble accumulated constituents could be flushed out from the mining pit and tailings (Nordstrom, 2009). The release of contaminated effluent could be potentially harmful to the environment.

Heavy rain, flooding, cyclones, heavy winds and wild fires all have destructive powers that could potentially cause damages to the site, leading to a decreased or interrupted mining production, to hampered revegetation efforts and harmed biodiversity. All these events could also put workers at risks. A study by the DEA (2015) found that flooding might also affect power crossings in the Limpopo region which could also lead to production interruptions.

It is not possible to evaluate the risk for erosion and landslides at the pit and the tailing facilities during rain and flood events, as mass movements depend on a number of factors (e.g. geological and geomorphological conditions, surface texture, surface coverage with vegetation, etc.). However, erosion and landslides could affect the productivity of the mine negatively, disturbing the mining operations, as well as having adverse impacts on rehabilitation efforts and biodiversity. It is not clear what impacts erosion and landslides would have on the pit and tailings, i.e. whether it would have environmentally harmful consequences. Workers might be also put at risk by erosion or landslides.

More frequent and intense heat waves are a serious risk for workers, having health impacts and decreasing the productivity at the mine. Heat waves could also stress flora and fauna, potentially having negative impacts on site rehabilitation and the region's biodiversity.

Site rehabilitation (especially revegetation) and biodiversity in the vicinity of the mine could also be negatively impacted by an increased mean temperature and a decreased mean precipitation.

5.6.2 Potential climate impacts on Polokwane smelter

The smelter does not require much fresh water for processing the ore, therefore drought and water restrictions are not expected to negatively impact the production.

No environmental concerns arising from the slag dump have been reported to date. Therefore, it is difficult to evaluate whether heavy rain, cyclones, flooding, erosion and landslides, leading to slag dump washouts, would pollute the soil and water systems at the smelter. Flooding, however, could potentially interrupt the smelter's production. In addition, flooding-affected power crossings could hamper production at the smelter.

The dispersion and behaviour of sulphur dioxide and other emissions from the smelter are affected by weather conditions, such as wind speed and direction, air temperature and precipitation. In particular, temperature inversion and light or no wind can lead to elevated levels of air emissions (Potvin Air Management Consulting, 2004). It is difficult to evaluate whether climatic changes will lead to an increased frequency of such unfavourable weather conditions. However, if occurring, they would have a negative environmental impact as air pollution potentially increases. Smoke from wild fires could add to the emissions produced at the smelter which combined could potentially lead to elevated levels of air pollution.

Extreme events, such as wild fires, heavy rain, flooding, cyclones, erosion, landslides and heavy winds could damage the refinery, leading to a decreased or interrupted production. However, it is difficult to evaluate whether such an event could lead to the release of additional emissions and what the environmental impact would be.

Revegetation efforts and biodiversity near the site could be negatively impacted by all occurring climate stimuli and direct climate impacts (i.e. increased mean temperatures, decreased mean precipitation, heat waves, droughts, wild fires, heavy rain, flooding, erosion, landslides, and heavy wind). However, impacts on rehabilitation and biodiversity at the smelter are expected to be smaller than at the mining site as only the smelter's slag dump needs to be rehabilitated and its environmental impacts on biodiversity are minor. Most of these impacts, apart from increased mean temperatures, decreased mean precipitation and drought, are also potentially harmful to workers at the smelter.

5.6.3 Potential climate impacts on Rustenburg's base metal refinery

The refining process requires water inputs, mostly supplied from stormwater dams at the site and water dams in the region. Water supply might be curbed during times of drought, potentially reducing the base metal refinery's production.

During heavy rain or cyclone events and if flooding, erosion and landslides occurred, effluents high in sulphates and heavy metals could be released from the dams at the site, potentially contaminating soil and water systems at the site. Flooding-affected power crossings could also hamper production at the base metal refinery.

Extreme events, such as wild fires, heavy rain, flooding, cyclones, erosion, landslides and heavy winds could damage the refinery, leading to a decreased or interrupted production at the base metal refinery.

Revegetation efforts and biodiversity near the site could be negatively impacted by increased mean temperatures, decreased mean precipitation, heat waves, droughts, wild fires, heavy rain, flooding, erosion and landslides, and heavy wind. Similar to the smelter, the area that needs to be rehabilitated at the base metal refinery (i.e. effluent dams) as well as its environmental impacts on biodiversity are smaller, compared to environmental impacts of the mining operations. Therefore, the climate impacts might be smaller, too. Most of these impacts, apart from increased mean temperatures, decreased mean precipitation and drought, are also potentially harmful to workers at the base metal refinery.

It is not possible to evaluate climate impacts on emissions as there is not information on emissions produced at the site available.

5.6.4 Potential climate impacts on Rustenburg's precious metal refinery

There are a number of similarities between the climate impacts on the base metal refinery and the precious metal refinery.

The precious metal refining process also requires water inputs, mostly supplied from stormwater dams at the site and water dams in the region. Water supply might be restricted during times of drought, potentially reducing production at the precious metal refinery.

The effluent dams at the precious metal refinery contain acidic and alkaline effluents which could overflow during a heavy rain or cyclone events and if flooding, erosion and landslides occurred. Such an overflow could potentially contaminate the environment. Flooding-affected power crossings could also hamper production at the precious metal refinery.

As it is expected to be the case at the base metal refinery, extreme events, such as wild fires, heavy rain, flooding, cyclones, erosion, landslides and heavy winds could damage the refinery, leading to a decreased or interrupted production at the precious metal refinery.

Revegetation efforts and biodiversity near the site could be negatively impacted by increased mean temperatures, decreased mean precipitation, heat waves, droughts, wild fires, heavy rain, flooding, erosion and landslides, and heavy wind. At the precious metal refinery climate impacts on rehabilitation and biodiversity are also expected to be smaller than at the mining site. Most of these impacts, apart from increased mean temperatures, decreased mean precipitation and drought, are also potentially harmful to workers at the precious metal refinery.

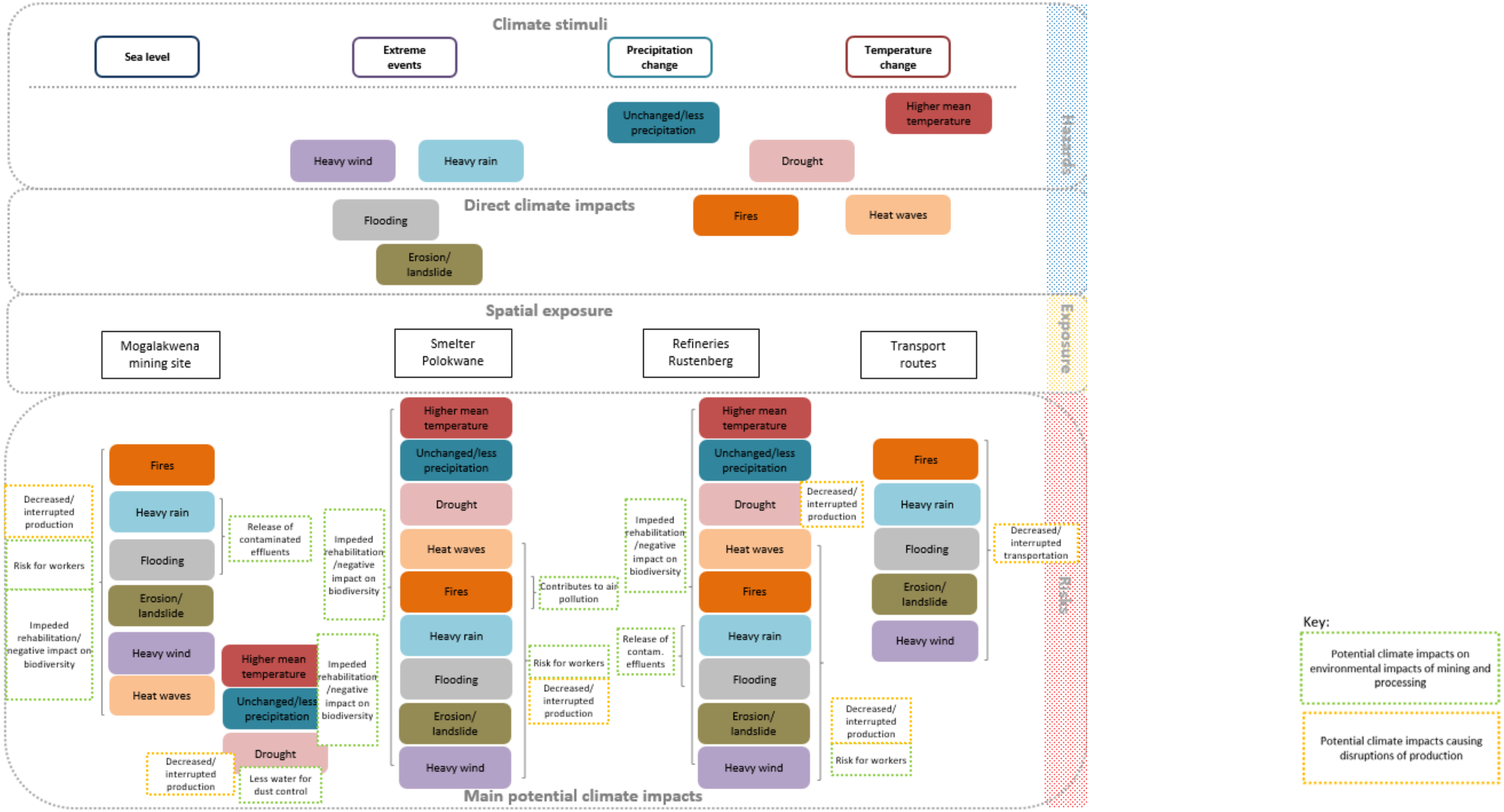
It is not possible to evaluate climate impacts on emissions as information on emissions produced are also missing for the precious metal refinery.

5.6.5 Potential climate impact on transportation

Several climate-related extreme events could interrupt transportation via road from and to the mining site and processing plants.

Heavy rain, flooding, also in the case of a cyclone, erosion, landslides, wind and fire could potentially lead to the disruption of transportation because of damaged or flooded roads. The DEA 2015 study found that most bridges and dams in Limpopo are projected to potentially experience flood risk by the end of the century which could impact transportation in the region.

Figure 5: Climate impact chain for PGMs and nickel



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

6 Summary and conclusions

The Mogalakwena PGMs and nickel mining site and processing plants are located in the Limpopo region which is characterised by arid and temperate climates. The region already faces water stress, causing water restrictions which also affected the Mogalakwena operations. The area does not only experience extreme aridity, but also wet weather extremes. In 2017, Mogalakwena's sister operation Amandelbult was flooded after heavy rainfall which resulted in a reduced PGMs output.

Climate projections indicate a significant temperature rise, while precipitation projections are unclear. They either show no change to present-day precipitation or a decreasing precipitation. Water stress, heat waves, fires and flooding are expected to occur more often and/or to become more intense.

Environmental impacts of mining and processing

The case study outlined several environmental impacts resulting from PGMs and nickel production. These metals are mined, concentrated and smelted jointly until the base metal refinery where nickel is leached out from the converter matte. The PGMs containing residue is further refined at the precious metal refinery. Until that point the environmental impacts are the same. The refining of PGMs is an additional step in the value chain which requires additional water and energy. Furthermore, it uses additional land and produces additional emissions and waste.

Mogalakwena operations employ an open-pit mining method. Land is used for open pits, tailing storage facilities, waste-rock dumps and infrastructure. Part of the waste rock is stored for potential re-mining or used for construction and road building. Mine waste at Mogalakwena has acid mine drainage potential due to the presence of sulphides in the ore body and therefore needs appropriate treatment. The mine operates in a water deficient area and competes with other water users for the scarce resource. Anglo Platinum currently covers 66% of its water demand with recycled and reused water; the remainder is withdrawn from ground sources.

The smelter plant at Polokwane consists of processing facilities, ore stockpiles, and a slag dump. All solid waste from the processing plants (including refineries) is stored at the slag dump or reprocessed at the smelter. Main air emissions from the smelter are sulphur dioxide, nitrogen oxides, and particle matter. Smelting at Polokwane has a limited water footprint.

Both the base metal and the precious metal refineries at Rustenburg have processing facilities, water dams, effluent dams and infrastructure. Both refineries use water from on-site stormwater dams and regional water dams. No details on emissions are disclosed. Effluents from the refineries include different waste water streams, stored in several lined dams, with some of the water being recycled in the processes.

Climactic changes potentially aggravate environmental impacts of mining and processing

Climatic changes, especially projected water stress and wet weather extremes, are expected to aggravate current environmental impacts of PGMs and nickel mining and processing in Limpopo.

The mining and beneficiation process at Mogalakwena and the refineries at Rustenburg require large amounts of water which is already scarce in the region. Furthermore, less water might be available for dust suppression.

At the mining site, the smelter and the refineries, heavy rainfall, cyclones and flooding events could wash out contaminated effluents from the mining pits, tailings (mining site), slag dump (smelter) or effluent dams (refineries). Such wash outs could be potentially harmful to the environment.

The smelter produces sulphur dioxide and other emissions which concentration in the air is generally affected by local weather conditions. Temperature and wind changes could negatively affect the concentration of air emissions. However, these effects are difficult to evaluate. During times of wild fires, smoke could add to the smelter's emissions which combined could potentially lead to high levels of air pollution.

At all sites, rehabilitation and biodiversity could be negatively impacted by slow onset changes, such as increased mean temperatures, decreased mean precipitation and droughts as well as by extreme events, such as heat waves, wild fires, heavy rain, flooding, erosion, landslides, and heavy wind. Extreme events could also put workers at all sites at risk.

Climatic changes negatively impact security of supply

Aggravated water scarcity might lead to water restrictions occurring more often. The water-intensive operations at the mining site and the refineries might lose productivity in times when water is scarce and restricted.

Mining operations, smelting, refining and roads could all be interrupted by the destructive powers of wild fires, heavy rain, flooding, cyclones and heavy winds which could potentially decrease or interrupt production and transportation of PGMs and nickel. In Limpopo, many bridges, dams and power line crossings were found to be at risk during times of flooding.

Community relations might be further strained under climate change

The Mogalakwena mine operates in a populated area which is characterised by high social inequalities. Grievances and protest reoccur as mining communities are dissatisfied with poor basic services and infrastructure in the region. In addition, communities report to suffer from environmental impacts such as noise, air pollution and water contamination caused by mining operations and have experienced resettlements. Therefore, the relationship between the Anglo American and the communities in the neighbourhood is already tense.

During protests in 2015, mining communities demanded improved water supply. Increasing water stress could intensify competition over water between the mine and the communities in the future. Against the background of existing grievances, it will be essential to address water scarcity not only with technical solutions, but also to balance the power inequalities between the company and communities.

Mining sector governance

South African environmental and water governance are in transition since the end of the apartheid regime and the government developed several important policies and regulations to create a more inclusive policy framework. Although new policies and regulation promise improvements, implementation and compliance is often insufficient. The mining sector has a special position in South Africa's environmental governance system as it is mostly administered by the Department of Mineral Resources (DMR) and not by the Department of Environmental Affairs (DEA). Attempts to change this institutional setup have not been fully successful yet.

Climate change adaptation policies in South Africa are advancing since 2001, supporting research on climate adaptation and the development of regional strategies. The draft of the new National Adaptation Strategy (NAS) includes a very positive development for climate change adaptation in the mining sector: It emphasises the need to develop a Climate Change Response Strategy for the Mining Sector by 2020 and encourages the development of a Mining Sector Climate Resilience Charter by the Chamber of Mines. Beyond that, the draft of the NAS states that a public-private flagship programme for mining sector resilience and the development of an early-warning system for climate-related disasters in the mining sector should be implementation priorities. However, it is unclear what the outcome of the drafting process will be and whether the suggested policies will be part of it.

Anglo American has also shown efforts to design and implement climate change adaptation strategies for its operations and projects worldwide and assessed and ranked their climate vulnerability. The company is well aware that its operations in Limpopo are already facing water scarcity and took adaptation measures for its Mogalakwena operations.

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