Gold and climate change
Adaptation and resilience

About World Gold Council

The World Gold Council leverages its broad knowledge and experience to improve understanding of the gold market and underscore gold's value to individuals, investors, society and the world at large.

Collaboration is the cornerstone of the World Gold Council's approach. It is an association whose members are the world's most forward-thinking gold mining companies. With its membership and its many industry partners, the Council seeks to develop Gold's evolving role as a catalyst for advancements that meet societal needs.

It initiates and raises standards, expands access to gold, and supports innovation to a ensure vibrant and sustainable future for the gold market and its many stakeholders. From its offices in Beijing, London, Mumbai, New York, Shanghai, and Singapore, it seeks to deliver positive impacts worldwide.

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About Stantec

Stantec is a global design, engineering, science and project management consultancy. It innovates at the intersection of community, creativity, and client relationships to advance the quality of life in communities across the globe.

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Executive Summary

Climate change is one of the most complex challenges facing the world today. It is a global, multi-dimensional problem requiring consideration of scientific, economic, social, political, and moral questions. It also has substantial impacts that are felt on a local scale, that will likely persist for many generations, and pose significant threats to the lives and livelihoods of many people in many different locations. These risks cannot be completely avoided or mitigated, which means governments, companies, and civil society and community organisations must make plans and take actions to ensure they are better managed.

Closing the gap on our knowledge and understanding of climate risks will therefore be a vital part of ensuring greater sectoral and local resilience in the face of potentially more frequent and severe impacts. This work seeks to contribute to this by extending the World Gold Council's body of research on gold and climate change to consider the physical risk landscape, current gold mining industry approaches to adaptation, and what 'good practice' might look like from an examination of existing plans and practices, and leading guidance and standards.

Gold mining plays a vital part in the economic and social development of many emerging or frontier economies, and many of the nations that host mining operations are also countries that are among the most vulnerable to the disruptive and potentially destructive impacts from climate change and extreme weather events.

An improved understanding of the nature of climate-related risks and physical impacts, and the formulation of better plans to prepare for and adapt to these risks, can therefore result not only in more resilient gold mines, but also more resilient local economies and safer, more stable and prosperous local communities.

There are a wide range of factors that will influence adaptation and resilience to climate change in gold mining. These climate-related risks are typically categorised as ***transitional risk*** factors – associated with the decarbonisation of the global economy, such as policy, legal, and technology interventions, market readiness, and reputation protection – and ***physical risk*** factors, manifested in ***acute impacts*** (severe and short-term) and ***chronic impacts*** (long-term, gradual change). Acute physical climate impacts are typically witnessed in the form of extreme weather and weather-related events, such as tropical storms, wildfires, droughts and flooding, whereas chronic impacts refer to enduring changes and shifts in, for example, average air or land temperatures, sea levels, water acidification, soil quality, and other persistent trends.

Regarding these latter physical risks, this research clearly indicates that the gold mining sector has made substantial progress in understanding the impacts of climate change on mining assets[1] with a range of operators having undertaken detailed climate risk assessments and reported on their adaption plans.

Examining these reports and plans, there are a number of drivers cited by gold mining companies as having shaped their disclosure of climate change risks, but the main driver is to meet financial reporting requirements, such as via the CDP[2] disclosure system. The content of most current climate-related disclosures appears to be primarily guided by the recommendations of the Task Force on Climate-related Financial Disclosures (TCFD).[3]

1 'Assets' here refer to the key structures, equipment and processes, alongside the stakeholder or participant groups, that together comprise a gold mining operation.

2 Formerly the Climate Disclosure Project – www.cdp.net/en

3 www.fsb-tcfd.org/

Current approaches to reporting on physical climate risks tend to focus more on considerations of the vulnerability of a mining operation to specific acute events and setting adaptation measures accordingly to reduce immediate business and financial impacts. For example, the possibility of extreme rainfall causing flooding risk may prompt a redesign of drainage infrastructure to better manage flood events and thereby reduce the risk of operational disruptions and potential mine closure.

Climate change is, however, creating a complex 'ecosystem' of interconnected impacts and interactions between the natural and human environment, and this has implications far greater than the immediate consequences of isolated weather incidents and specific impacts.

The in-combination and cumulative effects of more than one physical climate impact can create a compounding or cascading set of risks which, together, can impose a far greater overall level of risk on mining operations. For example, the risk of flash flooding from extreme rainfall (that is, an *acute* impact) is significantly magnified by long-term dry weather (a *chronic* impact) reducing the ground's ability to absorb water. Assessment of risk therefore needs to address wider in-combination effects – for example, the changing hydrological catchment environment (deforestation, urbanisation, soil erosion etc.) on the risk of flash flooding.

The complex of interconnected climate impacts may also affect vulnerable entities – facilities, stakeholders, and communities – that reside outside of conventional corporate risk assessment boundaries. Whilst these risks may be indirect to a mine site, their magnitude may significantly affect operations. For example, local communities will share climate change conditions with neighbouring mines and acute and chronic impacts may negatively affect employee welfare, social wellbeing and local economy stability, which may then raise challenges for mine sites, even if they have proven to be relatively unaffected by a particular impact or hazard.

The geography of gold mining, with mine sites often located in emerging economies and remote locations with limited and/or fragile infrastructure, means the industry may find itself at the 'front-line' of climate change risks and efforts to manage their potential physical consequences. This, coupled with frequent high levels of dependence of host governments, local authorities, and communities on mining revenues, suggests that gold mine site resilience and responses may be particularly significant to a wide set of stakeholders.

Gold mining, given its often strategic and pivotal role in local economies, may have an opportunity to lead on developing approaches to respond to the complex challenges of climate change. In creating robust and sustainable mining operations in the face of physical climate risks and hazards, the industry may enable greater resilience at and beyond the mine site, reducing the economic and social risks for all stakeholders.

Gold and climate change – context and research to date

To contribute to a clearer, more consistent appreciation of how climate-related risks (and opportunities) might impact the future prospects of the gold industry and its many stakeholders, the World Gold Council has undertaken a programme of research, in collaboration with leading climate analysts and sustainability experts.

Previous works have primarily focused on gold's carbon footprint, its potential decarbonisation pathway,as aligned to key climate targets, and the role of gold as an asset in climate-smart portfolios. This study widens the focus of our analysis to include consideration of physical climate risks in addition to the previous examination of gold's possible impacts and contributions in the context of the global transition to a low carbon economy.

www.gold.org/esg/gold-and-climate-change

Key findings and recommendations

Through a combination of literature research, an examination of company and mine site data, and a regional climate change vulnerability appraisal, this study has identified the major risks and impact drivers of relevance to the gold mining industry and the measures it has implemented to address many of its key vulnerabilities.

Physical climate risks that will likely impact gold mine sites and the specific vulnerabilities of particular site assets and local communities are described below (see, for example, **Table 1**), but it should be noted that cumulative, combined and cascading risks will likely impose further challenges on adaptation planning.

The adaptation measures currently implemented at gold mine sites can be broadly categorised as focused primarily on planning and infrastructure design.

Plans to address climate change vulnerabilities include:

- The use of **meteorological forecasting** to prepare for acute weather impacts
- The use of long-term **environmental monitoring** to inform adaptation plans in response to specific climate impacts
- The development of additional **emergency response procedures**
- The implementation of management procedures for further **inspection and maintenance** of mining assets.

Infrastructure design measures for greater resilience include:

- **Designing resilience** to extreme weather events through the (re-)engineering of tailings, transport infrastructure, water systems and power systems
- **Increasing the capacity** of operational infrastructure such as pumps and power solutions
- Building **emergency health and safety accommodation.**

(A more detailed list of gold mining companies' adaptation responses and measures is presented, below, in **Table 2** in **Section 4 – *Gold mines and climate adaptation strategy.***)

And while gold mining's consideration of **climate impacts on local and host communitie**s is probably given less focus and less widely reported, there is clearly an industry awareness of the need to extend adaptation plans and responses beyond the mine site. Companies reported that they were aware that climate impacts could lead to the following:

- Disruption of livelihoods and increased dependencies
- Increased vulnerability of food provision and food prices, particularly for coastal communities.
- Climate related migration and community tensions
- Increased risk of water pollution and water borne diseases
- Drought-induced competition for water resources between mining operations and host communities, creating tension or civil unrest.
- Wildfire and extreme weather risks to local safety, homes and livelihoods.

This awareness has, in some instances, led to collaborative efforts to introduce greater community resilience. For example, some gold mines are already working with neighbouring communities and villages to develop emergency responses to extreme weather by:

- Developing a command structure and allocating predefined responsibilities and personnel
- Establishing community-based disaster warning equipment and facilities
- Responding to local drought by voluntarily provision of drinking water to the local community.

Looking forward to what the research process and findings might suggest as being beneficial to future industry adaptation and resilience strategies, we propose **seven recommendations, beyond the guidance and measures already in place,** to potentially advance sectoral planning. We hope this might bring the gold mining industry closer together in its responses to physical climate change risks and in collaborating with and supporting its local supply chains and communities.

1. Greater consistency and knowledge sharing in defining methodologies for assessing climate vulnerability and adaptation

This report identifies a broad range of standards, guidance and methodologies available to assess physical climate change vulnerabilities and develop approaches to adaptation.

Whilst the gold mining sector has already made great progress in its understanding of physical climate change risks, there is substantial variation in how and what is being analysed, reported and implemented across companies and sites.

This is, perhaps, not surprising given the great difference in the locations, nature and scale of gold mining operations and companies, reflective of the diversity and dispersal of gold mining operations across the globe.

This study, however, clearly highlights that there are substantial areas of commonality and shared materiality for many gold mines. This suggests that, when seeking to identify vulnerabilities and prospective responses, the learnings and solutions may be more widely applicable than might be immediately obvious than when viewing risks from the perspective of a particular site or location. The indication of shared perspectives across companies and regions might also suggest that a more convergent and systematic approach to assessing levels of vulnerability may be beneficial to many gold mining companies as they strive to build resilience.

As gold mining's understanding of physical climates risks is further developed, its opportunity to share knowledge, identify convergent and consistent methodologies, and define innovative adaptive solutions should grow. This will potentially enhance the sector's ability to evaluate physical risks and reduce its levels of vulnerability.

2. Balance consideration of acute risk with a longer-term view on chronic risks

The majority of guidance and standards – and therefore disclosures – on physical climate change risk focus on the acute catastrophic impacts of extreme weather. This is quite rational considering immediate threats will likely be more obvious and demand a rapid response or plan, but additional consideration of longer-term vulnerabilities may ultimately produce more robust adaptation plans.

As gold mining's understanding of physical Identifying major chronic long-term climate impacts and vulnerabilities to both mine operations and local populations should help in defining more durable solutions and form the basis of a better understanding of in-combination impacts and compound risks.

3. Greater acknowledgement and understanding of combined *compound* risks

When assessing vulnerability, the compound impacts of chronic, long-term climate change trends may have financial consequences comparable to the costs imposed by more obvious or immediate acute risks. For example, the combined effects of warmer average temperatures and greater wind speeds, resulting in increased dust levels, will likely shorten the operational life span of machinery. Other chronic climate factors will also increase vulnerabilities to acute risks. For example, protracted dry ground conditions from a rising long-term average temperature will reduce soil water absorption rates, consequently increasing the risk (and destructive impact) of flash flooding from storm events.

As part of corporate and operational risk assessment processes, evaluating in-combination impacts will enable a better understanding of the overall 'ecosystem' of climate impacts and vulnerabilities.

4. Integrate community risk into local vulnerability appraisals and resilience plans

Climate change may disproportionally affect host and local communities in emerging economies. The devastating impact of extreme weather to communities can consequently impact the local social and economic foundations of all sectors, including mining. While some impacts may clearly be of a scale and severity that no one entity or company can fully manage or mitigate them, an awareness of wider vulnerabilities and community-specific impacts might contribute to more broadly robust adaptation plans. Local communities may host significant numbers of employees and contractors as well as suppliers, reflecting both the often symbiotic relationship that may exist between gold mines and their surrounding communities and their shared or overlapping vulnerabilities.

Local or neighbouring communities, potentially susceptible to climate impacts, should be factored into climate change vulnerability appraisals. Consideration of this wider set of risks might contribute to extending the scope of resilience measures within local societies and economies, thus creating a more generally robust environment which should further support the sustainability of mining operations.

5. Use local and indigenous knowledge of climate change and weather impacts to inform the physical risk assessment process

At a local level, communities frequently have a detailed understanding of the impacts of local adverse weather and long-term climate conditions, which may offer additional insights to – or even be more useful – than the data from regional-level climate models. Local people are often at the forefront of managing the impacts of weather and can therefore be a valuable source of knowledge and acumen.

Taking input from communities and stakeholders at or around mine sites as part of the climate risk assessment process can inform better adaptation planning and the development of potential resilience solutions and responses.

At a national level, countries signed to the Paris Agreement are expected to plan for adaptation as part of the Nationally Determined Contributions (NDCs),[4] with developed nations contributing to the funding of emerging economies' transition plans. An awareness of the national context and adaptation strategies, in addition to more local perspectives, might allow for a more integrated and strategic approach to planning for future resilience.

Understanding the national-level approach to adaptation, alongside local capacity and plans, might lead to a more robust and integrated response to the national, regional and local situation on climate vulnerabilities.

4 The adaptation component is a voluntary element of Nationally Determined Contributions but is becoming an increasingly important part of countries' commitments to the Paris Agreement. As these are voluntary components, countries are not using a standard approach or template to develop their adaptation contributions, which may be barrier to progress.

6. Sharing knowledge and resources with communities and stakeholders

Knowledge and resource sharing, to help shape or bolster wider local resilience measures, might include provision or exchange of:

- Environmental data, such as weather forecasts, flood warnings, etc., to support local economic activity and social planning
- Disaster and emergency management plans
- Extended or co-ordinated infrastructure, such as flood defences
- Back-up power generation or emergency facilities.

More generally, a multi-stakeholder approach to planning and designing for climate change, in consultation and collaboration with local communities and supply chain players (and mindful of the local and national government context), might produce positive sectoral outcomes. It might also help deliver stronger corporate performance on a number of key environmental, social and governance factors.

Approaches and solutions to adapting to climate change risks might be shared or developed in co-ordination with local populations, supply chain participants and stakeholders to facilitate wider resilience.

7. Plan for innovation

There are significant advancements in technology and data analytics – for example, in both the operation of mines and in predicting adverse weather. Such innovations can simplify the process of measuring, reporting and verifying climate change impacts, enhancing preparations and resilience plans, while also speeding up responses and the disclosure of risk management performance.

Digital technology and techniques might be further integrated into the environmental management systems of mining operations to ensure the climate-related aspects of environmental management become a more dynamic and responsive activity, to help mines better manage risk.

Image courtesy of Agnico Eagle.

1: Introduction

> "Human induced climate change, including more frequent and intense extreme events, has caused widespread adverse impacts and related losses and damages to nature and people, beyond natural climate variability. Some development and adaptation efforts have reduced vulnerability. Across sectors and regions, the most vulnerable people and systems are observed to be disproportionately affected. The rise in weather and climate extremes has led to some irreversible impacts as natural and human systems are pushed beyond their ability to adapt."
>
> Climate Change 2022, Impacts, Adaptation and Vulnerability Working Group II, IPCC 6th Assessment Report, February 2022[5]

Climate change is now an enduring fact of life and a significant challenge for the world and all its inhabitants. It will continue to have growing and profound societal and environmental impacts across the globe. More frequent and intense extreme weather events, beyond natural climate variability, have already caused widespread and adverse impacts on nature and people. However, climate change impacts vary substantially across the globe and within regions, affecting human systems and ecosystems in many ways.

The Intergovernmental Panel for Climate Change (IPCC) Sixth Assessment Report (AR6), released in 2021, defines a comprehensive list of the observed and projected impacts and risks from human-induced climate change. A headline statement from AR6 describes how ***"...global warming reaching 1.5°C in the near term will cause the unavoidable increase of multiple climate hazards and presents multiple risks to ecosystems and humans ."***[6]

Recent analysis also indicates that nearly all economic and commercial activity and assets will be at risk from physical climate impact, with research from S&P Global estimating that, within the next three decades, over 90% of the world's largest companies will have at least one asset exposed to climate-related hazards, such as wildfires or floods.[7]

Although climate change will have impacts on nearly all aspects of human life as the century progresses, not everyone will be affected equally and poorer communities, women, children, and indigenous peoples are all projected to be far more vulnerable over the decades to come. Climate-related crop failures, declining soil fertility, and depleting nutrition from staple foods have already caused increased malnutrition in many communities, especially among low-income households, with children and pregnant women particularly vulnerable.

Deaths caused by extreme weather events, such as storms, floods, and droughts, in vulnerable nations over the last decade are estimated to be 15 times higher than those in nations at the low vulnerability end of the spectrum.[8]

The World Gold Council (WGC) recognises that climate hazards may pose a risk to the gold mining sector, with impacts not only on physical mines, but also on wider supply chains and host communities. These risks are likely of direct concern to industry participants, investors, lenders, insurers, and government regulatory bodies. But they are also highly consequential to a wider set of stakeholders, particularly in remote locations and developing economies, that may be, often indirectly, dependent on a robust and stable gold mining industry for the provision of key capacities, infrastructure, and growth and development opportunities.

5 *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change,* edited by H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (2022), Cambridge University Press. www.ipcc.ch/report/sixth-assessment-report-working-group-ii/

6 www.ipcc.ch/report/ar6/wg2/resources/spm-headline-statements/

7 As reported at www.bloomberg.com/news/articles/2022-09-15/s-p-reveals-fallout-from-climate-change-on-asset-values

8 As also reported in www.nytimes.com/2022/02/28/climate/climate-change-ipcc-report.html

Many gold mining companies have demonstrated an awareness of the challenges imposed by potential physical climate impacts and have made significant steps to introduce greater resilience at their sites. These steps will, however, very probably need to accelerate and expand. That is because, across all industries, our collective understanding of climate impacts, at the global, regional, and local level, is developing at a rapid rate. All sectors of the economy and society will need to urgently consider – in a detailed and rigorous manner and in response to current scientific cues – how they can prepare and adapt to reduce their vulnerability to the many hazards of a changing climate.

The gold mining sector, like other industries, will therefore need to build further resilience in the face of physical climate impacts and identify a range of potential adaptation solutions to the complex challenges imposed by a changing climate. Better adaptation planning and implementation across the sector should generate multiple benefits by closing knowledge gaps, supporting collaborative, multi-sectoral solutions to business continuity and operational stability, and addressing challenges faced by host or neighbouring communities. Given gold mining's significant role in many emerging and frontier economies, these solutions may have socio-economic and development implications well beyond mine sites.

The World Bank has recently highlighted the need for climate adaptation strategies that avoid *'measures that are designed for a precise scenario of the future, instead prioritizing interventions that are robust and flexible, and can be adjusted over time as more information becomes available'*.[9]

This paper accepts that premise. It sets out to provide a summary of common climate change vulnerabilities likely to impact gold mining at a regional level, as well as approaches to managing physical climate change risks at the mine site (asset) level, and various potential adaptation and resilience strategies that can be viewed from a risk management and continuous improvement perspective.

The analysis summarised here sits within a wider programme of research produced by the WGC focused on gold's relationship with climate change.[10]

1.1 Climate change risks and physical impacts

Climate change is already affecting the gold mining sector, with companies increasingly witnessing impacts to operations from climate trends and, specifically, more frequent and extreme weather events. Investors and industry stakeholders are looking to ensure companies are managing these risks appropriately, which has already led to many mining companies reporting on the status of their climate risk and adaptation plans as part of their non-financial disclosures.

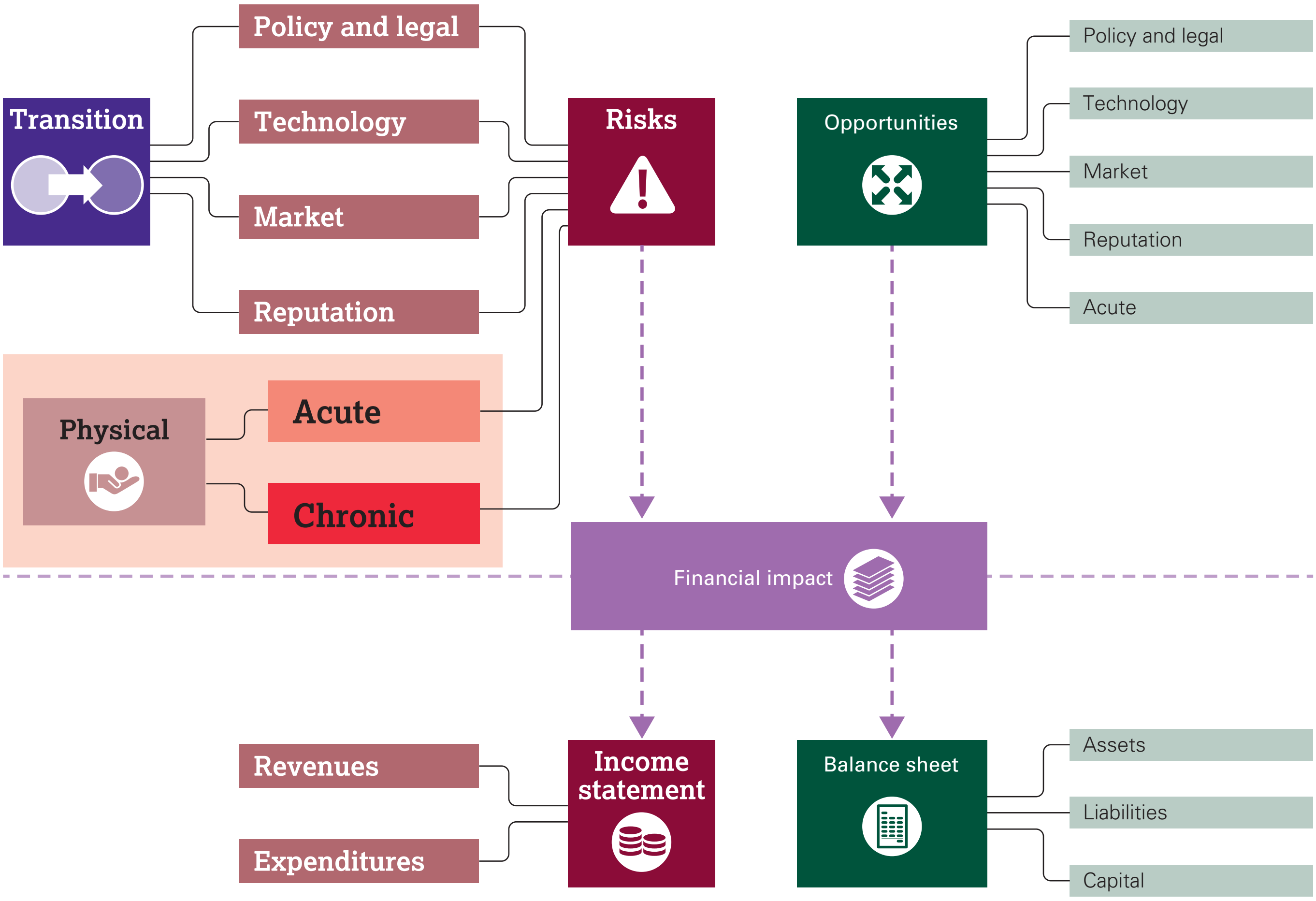
Due to the broad geographical nature of climate change and the very dispersed, diverse locations of gold mining operations, climate change risk management and adaptation reporting needs to respond to a range of drivers, including immediate and acute extreme weather risks, transitionary impacts such as government fiscal policy and regulatory changes, and longer-term impacts on, for example, host communities.

9 *Adaptation Principles—A Guide for Designing Strategies for Climate Change Adaptation and Resilience,* Stephane Hallegatte, Jun Rentschler, Julie Rozenberg (2020), World Bank.

10 See www.gold.org/esg/gold-and-climate-change

For the purposes of corporate reporting, climate change risks are typically categorised into two types: *physical risks* and *transitional risks* as shown in **Figure 1.**[11] Physical risks – potential physical impacts from climate variations – are considered either as ***acute*** (incident- or event- driven) or ***chronic*** (long-term shifts).

Figure 1. Climate-Related Risks, Opportunities and Financial Impact[12]



11 The World Gold Council's research programme on gold and climate change has largely, to date, focused on transitional risks and the implications of the decarbonisation of the world economy for both gold mining and the performance of gold as an asset class. See www.gold.org/esg/gold-and-climate-change

12 Adapted from *Recommendations of the Task Force on Climate-related Financial Disclosures,* (2017), TCFD.

This analysis examines both potential acute and chronic physical risks. As indicated in **Figure 2,** these risks have been considered individually, in terms of how they might cause specific impacts on gold mines, and also *in combination*, acknowledging that acute and chronic impacts can compound risks, amplifying the potential threat of damage to the physical mine assets (buildings, structures etc), processes (water use, energy, filtration, etc.), and local communities that are integral to or co-reside with mining operations.

This complexity of climate change risks and potential impacts is making the development of strategies to adapt to change more difficult. Multiple climate hazards are occurring which trigger multiple climatic and non-climatic interacting impacts. Combined, cumulative and cascading risks are becoming greater and more widespread across all environments, including the regions in which gold mines are located.

There is a growing body of research on the often-overlooked implications of combined and cascading climate impacts.[13] There is also substantial evidence (including that recently published by the IPCC) that these impacts, and the failure to acknowledge their interconnections, are escalating marginalisation, creating maladaptation,[14] and already locking in negative impacts to the detriment of local communities and natural environments.

1.2 Risk assessment methodology

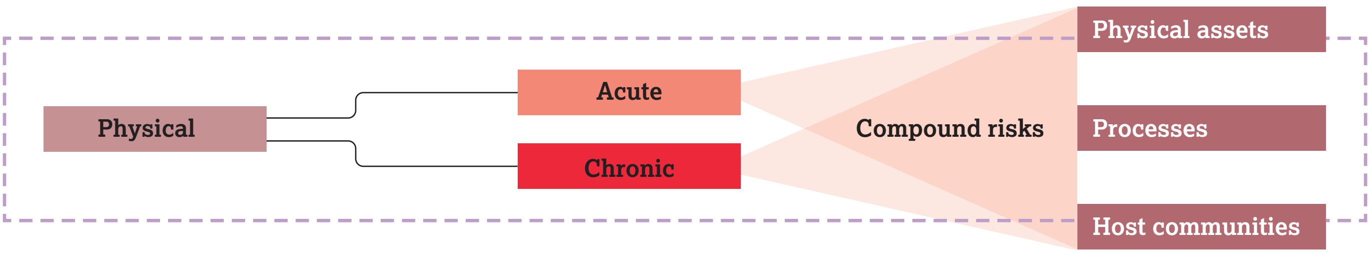
The climate risk methodology that underpins the findings of this report is consistent with the IPCC Risk Framework, ISO 31000 Risk Management and ISO 14090/14091 Adaptation to Climate Change Standards

There are a broad range of established approaches for assessing the risk of climate change of physical assets defined by International Organisation for Standardisation (ISO) assessment methodologies. These methodologies are used to deliver detailed assessments at the site/asset level and are explored further in **Section 5.**

The methodology for assessing climate risk to mining assets follows the IPCC ***climate impact driver*** **(CID)**[15] framework adopted in Chapter 12 of IPCC AR6 Working Group II (WGII).[16] CIDs are physical climate system conditions (e.g. means,[17] events, extremes) that affect a particular element of a society or ecosystem within global climate regions.

The IPCC define eight land-based **climate reference regions:** Africa, Asia, Australasia, Central and South America, Europe, North America, Poles, and Small Islands (Caribbean and Pacific Islands). These are further divided into 45 sub-regions to allow for sub-continental analysis.[18]

Figure 2. Climate-Related Physical Risks



13 See, for example, *Cascading climate change impacts and implications,* Judy Lawrence, Paula Blackett, Nicholas A.Cradock-Henry, *Climate Risk Management,* Volume 29 (2020); *Cascading climate impacts: a new factor in European policy-making,* Mikael Hildén et al., CASCADES Policy Brief ((2020); and *The Cascading Climate Crisis,* Kemp, L., Cambridge Open Engage (2021).

14 *Climate maladaptation* describes a failed adaptation strategy or process through which people become even more vulnerable to climate change, typically through poor planning and a lack of understanding of the drivers of vulnerability. See, for example, *Maladaptation: When Adaptation to Climate Change Goes Very Wrong,* E. Lisa F. Schipper, *One Earth,* Volume 3, Issue 4 (2020); *Adaptation interventions and their effect on vulnerability in developing countries: Help, hindrance or irrelevance?* S. Eriksen et al, *World Development,* Volume 141 (2021); and *The challenges of dynamic vulnerability and how to assess it,* Marleen C.de Ruiter, Anne F.van Loon in *iScience,* Volume 25, Issue 8 (2022).

15 *Annex VI: Climatic Impact-driver and Extreme Indices,* Gutiérrez J.M., R. Ranasinghe, A.C. Ruane, in *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change,* IPCC (2021).

16 *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change,* edited by H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama, (2022), Cambridge University Press.

17 That is, *average weather* conditions.

18 www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Atlas.pdf

Depending on the sub-region or type of asset being affected, the CID could be detrimental, beneficial, neutral or variable in nature. The methodology here, primarily driven by risk management considerations, only considers detrimental CIDs.

Specifically, the intensity and frequency of extreme weather events are based on the **high emission scenario RCP 8.5.**[19] The use of the high emission scenario is applied to identify which CIDs are altered within each climate region.

Terminology used within this paper is summarised in the glossary provided in **Appendix A.**

Full details of the gold mining climate vulnerability and adaption research data and method can be found in **Appendix B.**

1.3 Analysis – framing, scope and structure

While some gold mining companies have made great progress in identifying scenarios and risks that may impact their ability to operate and have mapped out strategies to build greater resilience, there is a strong case to be made for the benefits of a more collective approach to the planning and management of adaptation, not least as an enabler to reduce wider risks to people and nature. These considerations have shaped the focus and scope of this report.

This analysis assesses the climate change information presented within the IPCC's AR6 to appraise how regional direct physical climate changes may impact gold mining across the world. Secondary impacts beyond the boundaries of a mine or mining company (such as possible economic, technological, or legal responses) are not examined, although consideration is given to local populations both in terms of the *host communities,* who may have a stake in and/or offer support to mining activities, and *local communities,* that may be less directly engaged but whose economies and infrastructure may still be influenced by mining activities. Throughout this document, the term local population is used as the collective description for both host communities and local communities, although we are mindful that the relationships will differ, with the latter typically having a less direct interest/stake in a mine site.

This paper seeks to provide an overarching summary of how climate conditions and impacts[20] may affect gold mining sites and their composite assets,[21] infrastructure and processes, as well as the potential implications for the local population in each identified weather region.

At present, there is no consistent industry standard approach and, therefore, to identify current industry status and practices, a representative selection of gold mining sites has been selected and reviewed. Sites were chosen based on their geographical coverage (across the IPCC's seven climate regions and in order to capture variations in production scale, mine type and extraction methods.

A range of publicly available company reports and data submissions have been reviewed, alongside additional data provided by WGC member companies.

Based on this information, the vulnerability of gold mines to climate change is explored in terms of the potential impacts from acute and chronic climate change hazards across global climate regions (**Section 3** and **Section 4**). Specifically, the key features, structures and processes of the gold mining industry (that is, the mine site assets) are evaluated in terms of their vulnerability to various climate change impacts, and the relative severity of each climate hazard, including any geographical differences in weighting. In addition, strategies for gold mining companies and mine managers to better adapt and plan to manage vulnerability are also considered (**Section 5**).

This methodology[22] supplemented by data from within the gold mining sector that is currently used to support climate-related decision making with site-level impacts. This approach provides a framework for examining climate vulnerability and adaptation measures of relevance to gold mining and its stakeholders.

19 RCP 8.5—A scenario of comparatively high greenhouse gas emissions, K. Riahi, S. Rao, V. Krey, C. Cho, V. Chirkov, G. Fischer, G. Kindermann,N. Nakicenovic, P. Rafaj, 2011 International Institute for Applied Systems Analysis (IIASA). While there is some debate over whether the RCP 8.5 climate change scenario represents a "business as usual", a "high emissions" or a "worst-case" scenario, it is typically used to represent the concentrations of atmospheric carbon that would likely be reached if substantial efforts are not made to constrain emissions towards a Net Zero carbon target.

20 More specifically, *climate impact drivers (CIDs)* – physical climate system conditions (e.g. means, events, extremes) that affect a particular element of a society or an ecosystem.

21 *Mining 'assets'* here refer to the structural and infrastructural components and processes that, together and as a whole, define a mine site and its operations.

22 As defined in Chapter 12 of IPCC AR6.

2: Climate impacts and gold mining vulnerabilities

To assess the vulnerability of gold mining infrastructure and assets to climate impacts and hazards, a three-step process was adopted:

Step One: Define the likely assets (e.g. physical structures and processes) of gold mining that may be vulnerable to climate change within a conceptual (archetypal) mine model.

Step Two: Screen which climate impact drivers (CIDs),[23] under a high emission scenario, will affect the identified assets and processes based on geography, relevance of CID, confidence of change occurring and timeframe of occurrence.

Step Three: Appraise comparative risk of CIDs to the conceptual mine for each climate region.

This methodology is described in detail in **Appendix B,** but the key information and data 'building blocks' of the analysis – the identification of gold mining vulnerabilities and regional climactic risks (climate impact drivers) – from which the key findings and conclusions are then drawn, are summarised below.

2.1 Identifying the gold mining assets (infrastructure and processes) at risk

In order to summarise specific aspects of a range of gold mine sites, a ***conceptual model*** for gold mining has been defined, drawing from WGC member companies and mine site data, that represents a holistic view of the process of metal extraction, processing, handling and transportation. The conceptual model has been used to understand the potential vulnerability of climate variables at a wide range of sites and covering the various structures, activities and processes that comprise modern gold mining. The key components of this model and typical gold mine vulnerabilities and impacts are presented in **Figure 3.**

Thel mine model provides a basis on which to evaluate the relevance of each climate impact driver on each part of the mining process or asset (infrastructure or operational component) type and their sub-categories. This enables a detailed comparison of different mine site vulnerabilities to climate change, thus highlighting specific risk points.

23 *Climate impact drivers (CIDs)* – physical climate system conditions (e.g. means, events, extremes) that affect a particular element of a society or an ecosystem.

Figure 3. The 'conceptual' gold mine model (covering both open-pit and underground sites)

PHYSICAL ASSETS

Excavation

Rock excavation equipment, mineral stockpiles, dredging activities, access arrangements to excavation, mine shaft systems, haulage vehicles

TYPICAL VULNERABILITIES

- Physical asset vulnerabilities
- Efficiency of equipment
- Health and safety
- Cost of operations and maintenance activities
- Utility supply disruption

Buildings

Headframe, hoist house, offices

TYPICAL VULNERABILITIES

- Challenges to environmental management and mitigation
- Physical assets vulnerabilities
- Health and safety
- Utility supply disruption

Waste

Tailings, rock, water/effluent

TYPICAL VULNERABILITIES

- Physical assets vulnerabilities
- Facilities with long lifespans such as tailings dams and storage facilities impact beyond the operational lifespan
- Environmental risk for rehabilitation land post operation

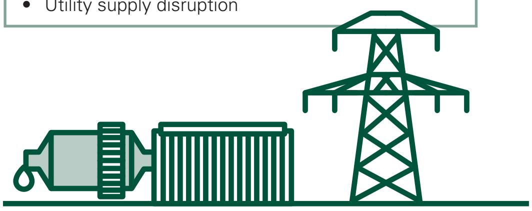
PROCESSES

Mechanical process

Water supply, power infrastructure, communication infrastructure, conveyor systems, mills, crushers flotation tanks, filtration and separation equipment

TYPICAL VULNERABILITIES

- Physical assets vulnerabilities
- Efficiency of equipment
- Cost of operations and maintenance activities
- Health and safety
- Utility supply disruption

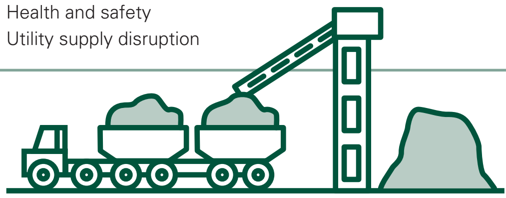


Material handling

Stockpiles, stackers and reclaimer, offsite haulage onshore, offsite haulage offshore

TYPICAL VULNERABILITIES

- Challenges to worker health and safety conditions in supply chain
- Physical assets vulnerabilities
- Access and logistic disruption
- Cost of operations and maintenance activities
- Health and safety
- Utility supply disruption



COMMUNITIES

Community

Health and wellbeing

Labour productivity, morbidity, mortality

TYPICAL VULNERABILITIES

- Damage to community infrastructure
- Food security
- Conflict over natural resources
- Increase diseases

Poverty, livelihoods and sustainable development

Housing stock, farmland, livestock mortality, indigenous traditions, water

TYPICAL VULNERABILITIES

- Financial cost
- Conflict over infrastructure use
- Migration and resource demand
- Loss of traditional activities and lifestyles
- Competing resource consumption

2.2 Identifying relevant climate impact drivers (CIDs)

Seven main types of climate variation are identified and then divided into subcategories to evaluate their potential impact on the mine infrastructure assets defined above (in **Section 2.1**). These climate impact driver hazards are expressed in terms of their duration and characteristics.

The screening of the relevance of each climate impact driver (CID) and their sub-categories focus on their potential impacts on:

- water
- cities, settlements and key infrastructure
- health, well-being and changing structure of communities
- poverty, livelihood and sustainable development.

This screening has been reviewed and benchmarked with WGC member company data and compared with industry wide references and site-specific references (as presented in **Appendix B**). The definitions used for each CID and how they are connected to gold mining are detailed in **Appendix C.**

A summary of the relevance of CIDs as potential hazards to gold mines is presented in **Table 1,** on the following page.

The 'relevance ratings', indicating the level of relevance and strength of connection between a CID and a particular mine site asset and host community (or local population) are described below.

In order to understand the potential vulnerability of gold mines and their local communities to climate hazards across each climate region, a qualitative assessment process has been developed that allows potential vulnerabilities to be 'scored' against the likelihood of the CID hazards occurring. This is described as the ***climate change vulnerability assessment*** and the methodology used to arrive at the impact scores is presented in **Appendix D.**

Specifically, the intensity and frequency of extreme weather events are based on the ***high emission scenario RCP 8.5.***[24] The use of the high emission scenario is applied to identify which CIDs are altered within each climate region.

It should be noted that the gold mining sector and its supply chain will be influenced by CIDs that are geographically specific. The geography of climate change, and local socio-economic and natural environmental variables at each mine location, will influence the magnitude and effect of the CID. Whilst acknowledging that variance, this analysis seeks to identify the common attributes of climate change and mine site vulnerabilities, which should facilitate a wider collective understanding of material risks and impacts, and potential risk management solutions.

No relevance		The mine asset is unlikely to be impacted by CID hazard.
Low relevance	(yellow)	A connection between a CID and asset that is referenced but not prominent within literature review or reference sites where tangible damage could occur but business is not interrupted, and therefore within tolerable limits.
Medium relevance	(orange)	A connection between CID and asset that is known and more prominent and referenced within more than one reference site where damage generates a considerable interruption of process(es). Business objectives would be affected, and additional budgets would be required to adjust operations.
High relevance	(red)	A connection between CID and asset that is well known and referenced by all referenced sites where damage generates a non-tolerable interruption in process(es). Could affect commitments to stakeholder, market and regulators.

24 RCP 8.5—A scenario of comparatively high greenhouse gas emissions, K. Riahi, S. Rao, V. Krey, C. Cho, V. Chirkov, G. Fischer, G. Kindermann,N. Nakicenovic, P. Rafaj, (2011) International Institute for Applied Systems Analysis (IIASA). While there is some debate over whether the RCP 8.5 climate change scenario represents a "business as usual", a "high emissions" or a "worst-case" scenario, it is typically used to represent the concentrations of atmospheric carbon that would likely be reached if substantial efforts are not made to constrain emissions towards a Net Zero carbon target.

Table 1. Relevance of key climate impact drivers (and their respective changes in intensity, frequency, duration, timing and spatial extent) for the conceptual mine model

		Heat and cold				Wet and dry								Wind				Snow and ice						Coastal			Open ocean					Other		
Process/Asset Category	Sub-category	Mean air temperature	Extreme heat	Cold spell	Frost	Mean precipitation	River flood	Heavy precipitation and pluvial flood	Landslide	Aridity	Hydrological drought	Agricultural and ecological drought	Fire weather	Mean wind speed	Severe wind storm	Tropical cyclone	Sand and dust storm	Snow, glacier and ice sheet	Permafrost	Lake, river and sea ice	Heavy snowfall and ice storm	Hail	Snow avalanche	Relative sea level	Coastal flood	Coastal erosion	Mean ocean temperature	Marine heatwave	Ocean acidity	Ocean salinity	Dissolved oxygen	Air pollution weather	Atmospheric CO2	Radiation
Excavation workings	Geology					Low	Low	Medium	Medium										Medium				Medium											
	Rock excavation equipment	Low	Low			Low	Low	Low					Medium		Medium	Medium	Medium				Medium	Medium	Medium											
	Stockpiles					Low	Low	Medium							Medium	Medium	Medium				Medium	Medium	Medium											
	Dredging	Low	Low			Low	Low	Low							Medium	Medium	Medium				Medium	Medium	Medium											
	Access arrangements		Medium		Low	Low	Low	Medium	Medium						Medium	Medium	Medium				Medium	Medium	Medium											
	Mine shaft systems	Low	Low			Low	Low	Low							Medium	Medium	Medium				Medium	Medium	Medium											
	Haulage		Medium		Low	Low	Low	Medium					Medium		Medium	Medium	Medium				Medium	Medium	Medium											
Buildings	Headframe	Low	Low	Low				Low					Medium		Medium	Medium	Medium				Medium	Medium	Medium											
	Hoise House	Low	Low	Low				Low					Medium		Medium	Medium	Medium				Medium	Medium	Medium											
	Offices	Low	Low	Low				Low					Medium		Medium	Medium	Medium				Medium	Medium	Medium											
Mechanical process	Water supply	Low	Medium					High		High	High				Medium	Medium	Medium				Medium	Medium	High											
	Power infrastructure	Low	Medium			Low	Low	High					High		High	High	High				High	High	Medium											
	Communication Infrastructure		Medium			Low	Low	High					High		High	High	High				High	High	Medium											
	Conveyor	Low	Low			Low	Low	Low							Medium	Medium	Medium				Medium	Medium	Medium											
	Mill/Crushers	Low	Low			Low	Low	Low							Medium	Medium	Medium				Medium	Medium	Medium											
	Floatation/Tanks	Low	Low			Low	Low	Low							Medium	Medium	Medium				Medium	Medium	Medium											
	Filteration/Seperation	Low	Low			Low	Low	Low							Medium	Medium	Medium				Medium	Medium	Medium											
Material handling	Stockpiles					Low	Low	Medium							Medium	Medium	Medium				Medium	Medium	Medium											
	Stacker/Reclaimer	Low	Low			Low	Low	Low							Medium	Medium	Medium				Medium	Medium	High											
	Offsite Haulage onshore		Medium		Low	Low	Low	Medium					Medium		High	High	High				High	High	High											
	Offsite Haulage offshore		Medium		Low	Low	Low	Medium					Medium		High	High	High				High	High	Medium											
Waste	Tailings		Low			Low	Low	Medium							Medium	Medium	Medium				Medium	Medium	Medium											
	Rock		Low			Low	Low	Medium							Medium	Medium	Medium				Medium	Medium	Medium											
	Water		Low		Low	Low	Low	Medium		Low	Low				Medium	Medium	Medium				Medium	Medium	Medium											
Host community: health and wellbeing	Labour productivity	Low	High	Low	Low	Low									Medium		Medium				Medium	Medium	Medium									Medium		Medium
	Morbidity	Medium	High			Medium	Medium	Medium		Medium	Medium		Medium				Medium								High							Medium	Medium	Medium
	Mortality	Medium	High			Medium	High	High	High		Medium		High		High	High	Medium				Medium	Medium	Medium									Medium		Medium
Host community: poverty, livelihoods and sustainable development	Housing stock	Low		Low	Low		High	Medium	Medium				High		High	High					Medium			High	High	High								
	Farmland	Low		Low	Medium	Low	High	Medium							Low	Low	High				Medium			Medium	Medium	Medium								
	Livestock mortality	Low	High				High	Medium		High	High	High	Medium		High	High	High				Medium	Medium	Medium	Medium	Medium	Medium								
	Indigenous traditions	Medium		Low		Low			Medium				Medium		Low	Low					Medium	Medium	Medium	High	High	High								
	Water Supply	Medium	Medium	Low	Low	High	High	High		High	High	High	High				Low							Medium										

Not relevant | Low relevance | Medium relevance | High relevance

2.3 Regional climate vulnerability assessment findings

This section presents the results of the climate vulnerability assessment, setting out the key CIDs for each of the climate regions and their potential influence on gold mining operations. (The status of current industry awareness of specific vulnerabilities is detailed in **Section 3,** below.)

Please note that there are significant nuances relating to the physical and social geography within each climate region but, for the purposes of simplicity and data consistency, this assessment reviews variations in CIDs primarily for the 45 sub-regions defined by the IPCC and of relevance to gold mining.[25]

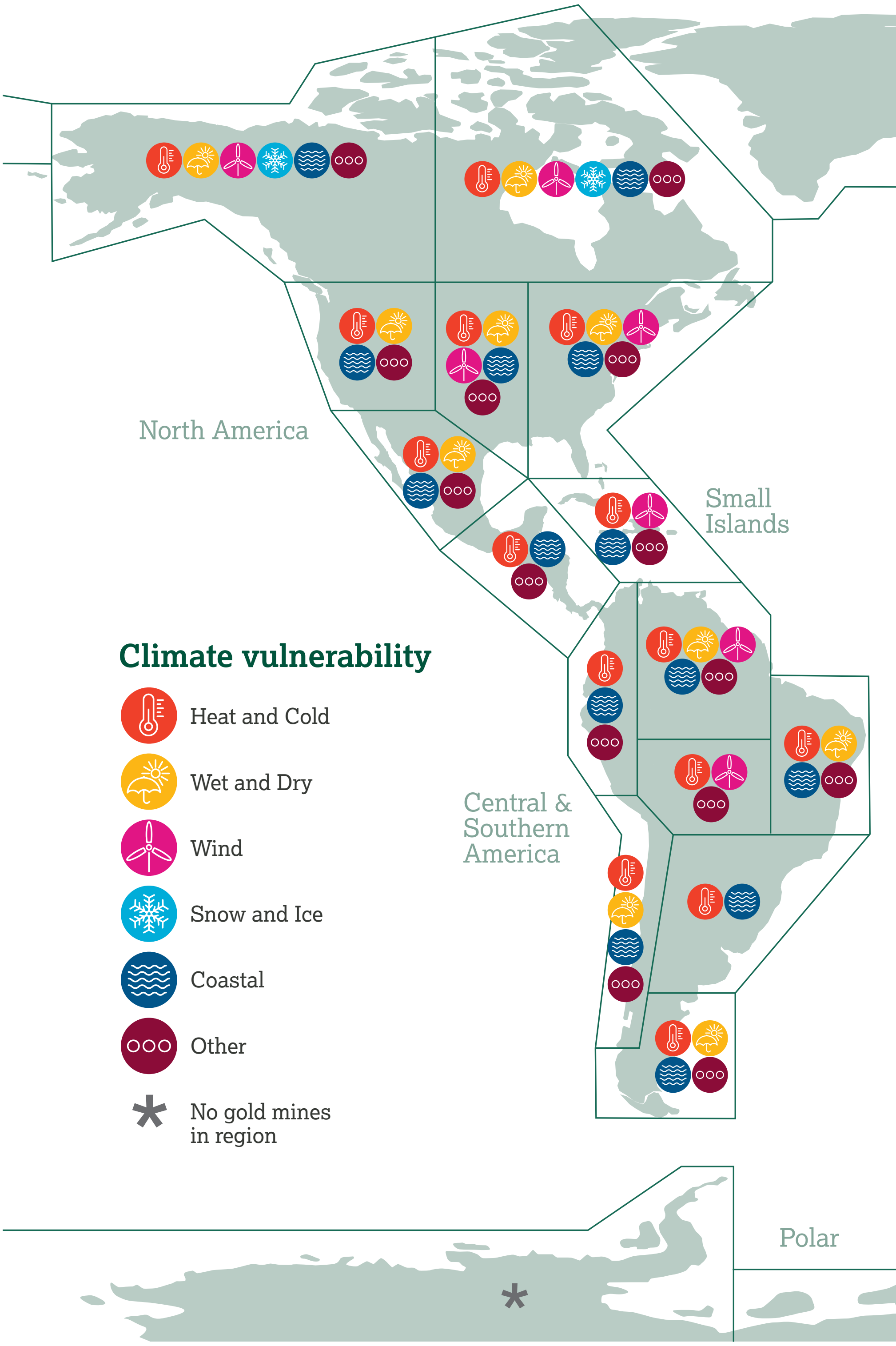
The assessment has established a range of potential acute and chronic potential hazards (as described in **Appendix D**) to gold mining infrastructure, its processes, and local populations.

The qualitative results of the assessment are summarised in **Figure 4.** The results have been presented to show which CIDs have been identified as either acute or chronic hazards to mining activities and host communities within each weather region.

As shown in **Figure 4,** all regions are anticipated to experience **extreme heat** CIDs and increases in mean air temperature.[26]

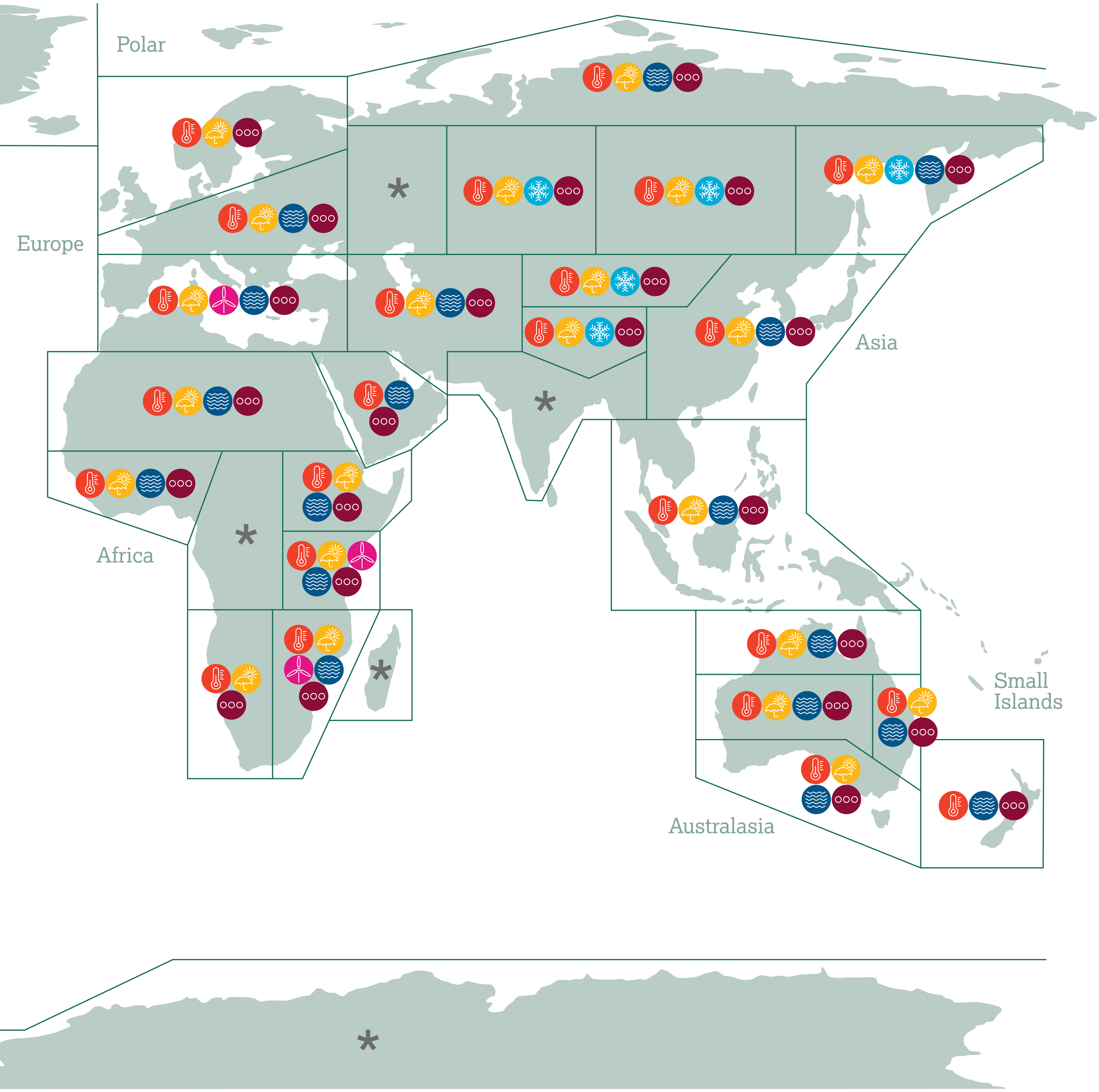
The **increase in mean air temperature** is likely to affect local populations and the process of mining activities over a longer period, presenting more chronic impacts.

Figure 4. Climate vulnerability appraisal of gold mine assets and operations against IPCC Climate Impact Drivers (CIDs)



25 www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Atlas.pdf

26 There is no strict definition of 'extreme heat' – it is a term used to describe periods that are much hotter than usual for the time and place where they occur.


Polar
Europe
Asia
Africa
Small Islands
Australasia

The increasing number of severe extreme heat events is likely to affect all gold mine sites and local populations through acute impacts. The impact on local populations from extreme heat is of note across the world.

Increased chronic and acute **hazards from wind** have been noted across all regions but are more notable in North-Eastern and Western America. Again, these hazards will likely affect all gold mines, operations, and local populations through acute impacts, especially relating to the **frequency** and **severity of storms.**[27]

Across all regions with a coastal geography, coastal CIDs are expected to primarily affect local populations and communities through the economic impacts (on food provision and supply chains, agriculture, etc.) and direct disruptions from **rising sea levels, coastal erosion and flooding,** as it impacts basic physical infrastructure such as housing and transport.

The increase in atmospheric CO_2 at surface has been noted to affect local population morbidity across all regions from the health risks associated with **air pollution and radiation.**

The results of the climate vulnerability assessment presented above shows that there is a complex mix of hazards from CIDs across all regions that will create compound risks to mining operations and local populations.

The vulnerability of local populations to specific CIDs and the combinational effects of acute and chronic hazards is likely to be amplified by **lack of resources and adaptive capacity.**

A more detailed appraisal of each climate region is presented in **Appendix E.**

27 Whilst the science on hurricanes and tropical storms is highly complex, there is growing evidence that climate change has contributed to the increased frequency and intensification (and destructive power) of such storms – see, for example, *Global increase in major tropical cyclone exceedance probability over the past four decades,* James P. Kossin, Kenneth R. Knapp, Timothy L. Olander Christopher S. Velden, PNAS, Vol. 117 (2020).

3: The current status of gold mining and climate vulnerability

Vulnerability to climate impact drivers (CIDs) is, as noted above (in **Section 2.2**), influenced by the temporal nature of an event. Both the mining sector analysis, summarised in **Table 1** (and presented in further detail in **Appendix C**) and the regional vulnerability assessment, above, suggest that acute hazards are generally perceived as representing the most significant and substantial risks to mining assets. This is, however, at least in part, also a reflection of the weighting of impacts within assessment methodologies being skewed towards short-term extreme hazards, for example flooding or extreme temperatures. Although the impacts of long-term chronic hazards may not be as immediately obvious, they are potentially equally as significant, especially where multiple hazards may eventually create greater disruptions through the sum (and interaction) of their parts.

This section sets out the range of specific impacts that potential climate hazards may have on gold mines and their host and local communities. It combines both the data summarising industry vulnerabilities (presented in detail in **Appendix B**) and climate vulnerability assessment across the global weather regions (as identified in **Section 2**).

To assess the status of current industry guidance and considerations of climate vulnerability in the gold mining sector, a review of industry literature and sectoral analysis was undertaken. This was supported by a review of a range of gold mining companies and their adaptation plans across the sub-climate regions.

3.1 Current gold mining reporting of climate vulnerabilities

Our research indicates that there is substantial evidence[28] that gold mining companies are aware of the vulnerability of gold mines to both acute and chronic climate change impacts, although the level and detail of their awareness varies considerably.

The majority of the reported vulnerabilities relate to physical mine site infrastructure and equipment, worker safety and site access, and supply of goods. The local populations around gold mines are also vulnerable to many of the same pressures which will impact the mine site, but their ability to prepare and respond may differ greatly, which may have implications for the relationship between mines and communities.[29] This can also be perceived as presenting opportunities for gold mining to strengthen that relationship, by pro-actively supporting local populations in better managing climate risks through shared plans, infrastructure and resources. This is explored further in **Section 4.**

Within the existing industry literature covering climate vulnerability considerations, the key impacts identified by gold mining companies were:

- **Water management**
- **Ground stability**
- **Landslides or dam failure**
- **Mobility, transportation and access to sites**
- **Disruption to energy infrastructure and supply**
- **Worker health and safety**
- **Efficiency and performance of mining equipment**
- **Closure and post-closure of mine sites**
- **Biodiversity restoration and protection**

28 This 'evidence base' is drawn from both publicly reported industry documents and data provided by WGC Member companies.

29 There are a range of different 'models' of proximity, engagement and interaction that will determine the relationship and interface between mines, employees and communities, and these will have some bearing on the degree to which climate-related impacts are 'shared'.

While less consideration is given in the literature to the potential effects of these impacts on local populations, this is not unexpected given the scope and focus of most risk assessment guidance, which leads to documented plans directed at local communities typically being focused more on 'transition' risks implications. There is some indication from company reports that some gold mining companies are developing a growing recognition and understanding of a range of potential climate impacts on local communities, with those factors listed below having been specifically identified in company risk assessments:

- Poverty and literacy levels impacting resilience
- Impact on food supply
- Increased prevalence of diseases
- Competition for resources
- Wildfire risk
- Loss of home and personal asset
- Loss of community infrastructure including utilities
- Climate induced migration
- Compound risks increase the vulnerabilities of local populations.

Regarding this latter point (and as noted in **Section 2**) there are a complex mix of hazards from CIDs across all regions that will create compound risks to mining operations and local communities. In existing industry guidance, there is only limited guidance on how to assess compound risks. This is an important additional consideration, explored further in **Section 4,** and of significance when defining adaptation plans to address the complexity of climate change.

The following details describe in further detail, key vulnerability factors of potential relevance and challenge to both gold mining assets and their local populations.

3.2 Vulnerability challenges

Mining infrastructure, machinery and operational processes, site access, supply chain continuity, and workforce health and productivity are all vulnerable to climate change impacts. These include acute physical impacts such as extreme weather events as well as chronic physical effects, which occur over the longer term, such as rising mean temperatures.

Reviewing industry reports and documented research, similar impacts were consistently identified by mining companies, and these are summarised below.

Water management has been identified as a critical issue, with decreased water availability affecting mining operations such as ore processing. For example, drought can increase raw water salinity leading to corrosion of processing plant equipment. Water shortages and supply disruption may also impact the wellbeing and livelihoods of local populations, leading to potential competition for water resources and heightened tension between local people and the mine site (as described below).

Too much water is also a risk, with flooding of tailings, pits and water storage facilities presenting a significant threat. On-site water storage and treatment systems may exceed their capacity and flooding may damage above ground buildings and processing equipment and infrastructure.

Flooded mine pits were reported at gold mines in Africa and Australia that would likely require additional maintenance and remedial actions to be undertaken at the facilities. The need to discharge water offsite would impose not only costs but also cause potential environmental permitting challenges for the mines. For example, in Colombia, heavy rainfall caused landslides and damaged drainage infrastructure at a mining asset. The water treatment plant had to operate intermittently, and the environment authorities were notified due to the potential for environmental damage. In this case, an examination of the consequences of the wastewater spill found it had not negatively affected the local ecosystem.

Flooding has also been reported to affect the construction of mines in Africa prior to the installation of pump systems. This resulted in a delay to the project opening.

Gold mining companies have also identified and reported the critical vulnerability challenges associated with potential flood impacts on tailings dams, resulting in possible overtopping and the undermining of slope stability. Challenges to the potential integrity of tailings dams were noted as high and extreme risks at gold mine sites in central Africa and across North America.

Ground stability can also be reduced due to increased precipitation leading to **landslides or dam failure.**

A number of mines in Peru highlighted the risks of increased precipitation inducing landslides (and, specifically, mudslides), suggesting additional or particular security factors may need to be included in the design of storage ponds, walls and embankments. This is particularly important in remote mining locations where ground stability issues can affect roads and supply chains to mining activities.

Various types of extreme acute weather events such as storms, flooding and wildfires induced by longer term climate conditions can have significant impacts on **mobility, transportation and access to sites,** for workers and for the supply of goods and materials. These impacts may be localised to the mine site itself or affecting the wider supply chain and transport network and therefore disruptive to mining operations even if the site is relatively unaffected or resilient to a particular hazard.

Other off-site impacts include **disruption to energy infrastructure and supply.** Power supply is significantly disrupted by thermal capacity both in terms of long-term temperature increases creating excess wear on systems and disruptions from acute adverse weather conditions or events.

In Turkey, wildfires in areas near mine sites have resulted in a lack of vegetation which may increase the risk of landslides and mudslides. In Canada, ice storms are predicted to impact external equipment including electrical infrastructure.

Low reservoir levels or contrastingly rising sea levels can affect hydro-electric power production and extreme weather events including storms and fires can affect power lines or communication-related infrastructure. Such impacts have been reported in the East Asian climate regions for example.

Worker health and safety is affected by the changing climate, with higher mean temperatures – reflected in the number of days exceeding the heat stress index – increasing over time and consequently impacting worker safety, welfare, and productivity, and. Exposure to hot climate diseases such as malaria or yellow fever will also increase if average temperatures rise.

Extreme weather events such as storms and risk from wildfires can also compromise worker and community safety and delay or halt operations and processes. For example, in South Africa a severe storm in 2018 caused the collapse of powerlines supplying a mine, causing a power surge and outage at all shafts in operation. Backup generators were also damaged during the power surge at one shaft, leaving no emergency power supply so that staff were unable to be hoisted to surface until temporary powerlines were installed two days later. Emergency management procedures were in place to manage the situation and ensure the health and safety of staff.

Higher mean temperatures can reduce the **efficiency and performance of mining equipment.** Regions including Turkey, Greece, Brazil, Australia and North America which are at high risk of extreme heat are predicted to experience **more frequent equipment malfunctions.** Rising temperatures will also increase the levels of energy required to cool underground mines and surface buildings and facilities.

In parts of Canada, where cold temperatures are part of 'normal' operations, because frozen ground facilitates access for drilling equipment, rising temperatures pose a different set of challenges. Additional risks arise from freeze-thaw cycles[30] creating more dust which affects process engineering and asset maintenance schedules such as road maintenance.

Climate change is also an important consideration for **closure and post-closure of mine sites** and land restoration programmes. Extreme rainfall events can erode areas that have previously been rehabilitated after closure, and long-term changes in climate can impact the establishment of vegetation and diminish the effectiveness of **biodiversity restoration and protection** efforts.

30 The 'freeze-thaw cycle', also known as *frost weathering* or *cryofracturing,* refers to the process of ice melting and liquid water performing the act of erosion, carrying away tiny rock fragments and causing rock structures to weaken.

3.3 Vulnerability and communities

Local populations and host or neighbouring communities of gold mines are also vulnerable to the impacts of climate change in many different ways, including threats to socio-economic status, health and cultural impacts.

Mining companies often operate in economically, politically and socially challenged parts of the world, where the mining industry provides not only economic opportunity but also contributes to local social capacity and infrastructure. Therefore, negative impacts on the industry and operations can lead to significant consequences for local populations and, particularly, host communities i.e. those with close ties to the mine and the employment and infrastructure associated with it, in addition to sharing the same surrounding environment and natural resources. This can also apply in the context of relatively stable economic and socio-political contexts, where a mining operation might still play a pivotal role at the localised level.

For example, in Greece in 2019, intense rain led to severe flooding in towns where mines were located. Roads were blocked with debris and **community infrastructure** destroyed, rivers burst their banks, and communities **lost homes** and **personal assets.** Fortunately, in this case, mine staff, with suitable resources and expertise to hand, were able to support the local population by managing and diminishing flooding impact and restoring damaged infrastructure following the event.

The impact of **wildfire weather** has also been felt across many gold mining geographies. In the summers of 2021 and 2022 much of North America was devastated by wildfires, after long periods of drought. Some gold mine companies have made public statements on the potential risk of wildfires to their mining assets and to local communities – for example, in the Yukon area of Canada.

Mining companies also require a 'social license to operate'[31] and this could become increasingly hard to maintain in areas where climate change is affecting communities and there is increased **competition for resources** between companies and communities.

Extreme weather events, drought or heavy rainfall can increase vulnerability of **food provision** and drought may lead to competition for water resources between mining operations and host communities, creating tension or even civil unrest.[32]

Research suggests that local climate-related risks and destructive impacts are very likely to amplify **local discord and ignite conflict.**[33] Whilst the contributions to civil unrest are complex and often reflective of local political dynamics and tensions, there are significant examples of impacts of local unrest on the gold mining sector, particularly in emerging economies, that are likely prompted or exacerbated by climate-related factors. For example, in locations where mining operations (across the sector) are reported to be facing increasing civil unrest, such as in Chile, Guinea, Mali, the DRC, and Zimbabwe[34] are countries that are already dealing with acute extreme weather risks, which may potentially compound local discord.

Fundamental to the wellbeing of local populations, the physical impact of climate change on human health will be driven by direct impacts (heat, cold, flooding, storms, radiation, etc.) and indirect, ecosystem-mediated impacts (disease, pollutants).[35] The WHO has described how climate change can affect some of the basic social and environmental determinants of health – clean air, safe drinking water, sufficient food and secure shelter.

Warmer temperatures will also likely result in the further spread of **hot climate diseases,**[36] and increased rainfall and changing water flows can result in the increased incidence of water pollution and water-borne diseases, which can have severe consequences for the health of local people. Higher temperature and rainfall levels may cause the proliferation of mosquito-borne diseases such as malaria in African and South-East Asian regions and dengue fever across Asia Pacific, tick-borne diseases in Europe, East and West Asia, and other far-reaching vector-borne diseases such as haemorrhagic fever and plague.

31 The *'social licence to operate'* refers to the informal acceptance by a community and set of local stakeholders of the legitimacy of a company to operate, typically based on it being recognised as a credible and trusted entity in a particular location and social context.

32 Although this report is restricted to commenting on formal, industrialised gold mining, it may be worth noting that intensive rainfall can have particularly deleterious impacts on artisanal miners in relation, for example, to flooding of underground operations and pit collapses. The lack of resilience and adaptive capacity of the artisanal gold mining sector strongly suggests that artisanal miners are likely highly vulnerable to many physical climate risks.

33 See, for example, *Armed-conflict risks enhanced by climate-related disasters in ethnically fractionalized countries,* Carl-Friedrich Schleussner, Jonathan F. Donges, Reik V. Donner, and Hans Joachim Schellnhuber, *The Proceedings of the National Academy of Sciences (PNAS),* Vol. 113 | No. 33 (2016) and Climate as a risk factor for armed conflict, Mach, K.J., Kraan, C.M., Adger, W.N. et al., *Nature 571* (2019).

34 www.mining-journal.com/politics/news/1379046/dangerous-rise-in-civil-unrest-threatens-global-mining-industry

35 www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap11_FINAL.pdf

36 See also, *Over half of known human pathogenic diseases can be aggravated by climate change,* Mora, C., McKenzie, T., Gaw, I.M. et al, *Nature Climate Change.* vol. 12 (2022).

Where mine workers themselves live in host communities, impacts to community infrastructure may affect worker health, attendance, and productivity.

Heat Stress Index metrics[37] are often cited by mining companies in their documented efforts to define threshold levels and key levels of impact from higher temperatures on a local population's health and safety. In reviewing these documents, it was noted that gold industry assessments from within African, Australian and South American climate regions often referred to high-to-extreme levels of risk from **heat stress.**

Mines often operate in regions where there are indigenous communities and climate change impacts can significantly affect their **culture, traditions and livelihoods.** Negative impacts can include restricted access to – or even destruction of – sacred sites and changes to land, water and ecosystems that can affect, harvesting and access to traditional **food sources,** medicines and, ultimately, challenge an established way of life.

Indigenous communities may also be disproportionately affected by climate change.[38] In addition to the fact that they have often not participated in the industrial activities which have caused climate change, their existing socio-economic challenges and disadvantages often render them particularly vulnerable. Basic infrastructure, such as drainage, shelter, and transport, can be poor within indigenous communities, and the social and economic consequences of destructive extreme weather events can be devastating and enduring.

An example of such combinational effects of climate change, although not specific to gold mining, has been reported in South America, where the ecological degradation caused by extreme and chronic weather conditions was clearly linked with indigenous community displacement.[39] Substantial environmental change that impacts and inhibits indigenous community traditions and prompts community displacement will very likely have implications and consequences for the nature of any relationship between that community and mining operations in either its original or new location.

Poverty, lack of access to technology, minimal communication infrastructure and low literacy levels in some communities may also hamper their ability, without external support, to build resilience to the impacts of climate change.[40]

A current and very stark example of the impact of lack of capacity for communities to adapt to extreme weather is seen in the spring 2022 heatwave in Pakistan – including the Balochistan region of Pakistan where gold mines operate – where temperatures reaching highs of around 50 degrees Celsius, with approximately 90 deaths reported from extreme temperature exposure. This was followed by excessively heavy summer rainfall causing flooding on a devastating scale, with over 1,400 people reported to have died.[41]

Climate change impacts may lead to **migration,** which can have both direct and indirect impacts on community stability and wellbeing. Rising sea levels, for example, may force coastal communities inland, and migrating peoples may also have to seek both new homes and new livelihoods. If mine locations and local or neighbouring communities are perceived as offering prospective accommodation and employment, the swelling and changing population may spark or exacerbates social problems and stretch or overwhelm local community resources.

As with mining assets, the **compound risks** of climate change accelerate the vulnerability of host communities, disruption of livelihoods and increased dependency of those host communities on the mining companies. For example, the **compound impacts** of dry ground and rain causing flash flooding causing devastation in Pakistan.

37 For an overview of these measures, see *Heat stress indices: A review paper,* Mohameed Youssef Beshir, Jerry D. Ramsey, *International Journal of Industrial Ergonomics,* Volume 3, Issue 2, (1988).

38 See, for example, *Leveraging Hazard, Exposure, and Social Vulnerability Data to Assess Flood Risk to Indigenous Communities in Canada,* Liton Chakraborty, Jason Thistlethwaite, Andrea Minano, Daniel Henstra & Daniel Scott in *International Journal of Disaster Risk Science* (2021) and http://nau.edu/stacc2021

39 *Environmental degradation of indigenous protected areas of the Amazon as a slow onset event,* Bowman, K. W., Dale, S. A., Dhanani, S., Nehru, J., & Rabishaw, B. T. (2021). *Current Opinion in Environmental Sustainability,* 50, 260–271. Available online: www.sciencedirect.com/science/article/pii/S1877343521000695

40 There is also evidence that the ability of indigenous peoples to adapt to climate change may be negatively impacted by external forces and imposed changes which disrupt or inhibit traditional resilience strategies – strategies that have previously been ignored or undervalued by parties considering local climate risk mitigation. For more on the adaptive capacities of indigenous peoples see, for example, *Engaging Transformation: Using Seasonal Rounds to Anticipate Climate Change,* Kassam, KA., Ruelle, M., Haag, I. et al., *Human Ecology* 49 (2021).

41 www.theguardian.com/world/2022/sep/17/drought-floods-pakistan-devastation-climate-crisis

4: Gold mines and climate adaptation strategies

As presented above, in **Section 3,** gold mining operations and assets (infrastructure and equipment, etc.) are vulnerable to a wide range of climate impact drivers (CIDs), representing risks that will need managing to protect and sustain the operational stability and commercially viability of mining activities.

As part of the Paris Agreement all signatory countries have been required to establish climate adaption measures within their Nationally Determined Contributions. These adaptation measure set country-specific adaptation measures that define potential vulnerability and how the country intends to manage them.

Article 9 of the Paris Agreement[42] sets the obligation for developed nations to finance emerging economies approaches to adaptation. Details of adaptation approaches within NDCs provide a good reference point to considering both the maturity of a country's approach to adaption and to informing climate adaptation approach for the gold mine operation. Countries that are progressing their adaptation responses are looking to reduce the impact of climate change on their economies and de-risk investment accordingly.

This section sets out the potential approaches that gold mining companies and mine managers can take to address climate change through adapting procedures and assets to become more resilient to climate impacts.

4.1 Impacts and responses

Section 5, below, presents a wide range of standards and approaches to assessing adaption measures which offer a baseline of consideration for the gold mining sector in recognition of and response to CIDs.

However, many measures identified within the current guidance focus mainly on acute hazards from catastrophic weather events resulting in probable mine closure or a direct and immediate disruption to local community wellbeing. As noted elsewhere in this report, the accumulation of chronic hazards across both the mine site and wider community may also eventually impact operations through cascading risks and possible multiple system failures.

A wide range of measures have been reported by the gold mining sector that set out opportunities for adaption to climate change through adaptation planning.

There are a range of interventions currently established by the gold mining sector to adapt to the impact of climate change, primarily focused on extreme weather events. These interventions are based on planning and infrastructure design.

Planning for climate change vulnerabilities include:

- Meteorological forecasting to prepare for acute weather impacts,
- Developing emergency response procedures, and
- Implementing management procedures and protocols for inspection of assets.

Infrastructure design for climate change vulnerabilities include:

- Designing resilience to extreme weather events such as engineering of tailings, transport infrastructure, water systems and power systems;
- Increasing capacity of operational management infrastructure such as pumps and power solutions; and
- Building emergency health and safety accommodation.

A summary of these measures is presented in **Table 2,** (from the sectoral research detailed in **Appendix B**). These measures are a representation of current industry adaption strategies, based on the local and regional responses of the gold mines surveyed in the report.

42 https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/cop_auv_template_4b_new__1.pdf

Table 2. Current gold mine adaption responses to climate impact drivers[43]

Climate Impact Drivers	Adaptation Responses and Measures Reported by gold mining companies
Heat and Cold	• Providing training in identifying health / safety issues including symptoms, hazards and preventative measures associated with heat stress, diseases etc. • Implementing measures to adapt to impacts of heat stress such as working hours, physical shading, cooling infrastructure • Responding to increasing temperatures by protecting equipment with fire suppression systems, headers, rotary sprays and hydrants • Instituting screening, acclimatisation, and safety procedures for high temperature surfaces and underground industrial workers • Implementing early warning systems to limit impacts of extreme weather events such as heatwaves • Modifying existing risk-identification processes to incorporate additional heat-related health risks • Long term weather measure and verification to inform adaptation measure.
Wet and Dry	• Long-term environmental and climate monitoring of flooding, drought etc. to inform adaptation measures • Flood resilient design measures; for example, infrastructure designed to withstand flood events, raised mine entrances to stop surface water ingress to mines or design volume increases for lagoons/ponds, tailing design, culverts and draining infrastructure • Operating practices such as water management to include mine water pumping to manage ground water and surface water flooding • Locating personnel and equipment away from high-risk areas for water build-up to reduce impacts of flooding • Implementation of water cycle strategy to include water conservation and recycling • Understanding water flows and quality to reduce risk associated with uses of water and to support adaptation actions in future • Improvements to transmission system or additions of wind/solar to prevent declines in power quality after flooding • Innovation strategy to implement resource efficiencies • Implementing early warning systems and emergency response to limit impacts of floods and droughts • Lightning protection strategies • Conservation and enhancement of surrounding habitat and forest areas.
Wind	• Long-term environmental and climate monitoring of tropical cyclones, severe wind storm etc. to inform adaptation measures • Increase frequency of maintenance and monitoring to assets sensitive to weather events, i.e. cyclones / storms • Implementing early warning systems to reduce the impact of storm events • Back-up power strategy for loss of power infrastructure • Install CCTV monitoring equipment and back up communication network for site inspection during extreme wind events.

43 Please note this list of measures is not exhaustive, and there are very likely other idiosyncratic and site-specific considerations that may require additional or alternative adaptation measures.

Climate Impact Drivers	Adaptation Responses and Measures Reported by gold mining companies
Snow and Ice	• Long-term environmental and climate monitoring of permafrost, heavy snowfall, hail, snow avalanche etc. to inform adaptation measures • Maintenance practices such as maintenance of permafrost dependent infrastructure • Removal of snow from building structures • Insulate potable (drinking) water supplies • Design building resilience to weight of snow • Safe driving policies for iced infrastructure • Designing pipelines to allow for colder temperatures through installation of thermal insulation, heat tracing and burying pipes underground.
Coastal	• Long-term environmental and climate monitoring of relative sea level, coastal flooding and erosion to inform adaptation measures • Relocate or raising assets and operations outside high-risk areas, including coastal areas • Retain or restore natural buffers in coastal and river environments to increase resilience against erosion, storm surge and other extreme weather events • Insure against unavoidable risks, i.e. from sea level rise or coastal erosion.
Other	• Long-term environmental and climate monitoring of air pollution and radiation to inform adaptation measures • Implementation of control measures to address pollution impact risks.

Adaptation planning and the national context

All nations signed to the Paris Agreement have established sets of climate change adaptation approaches within their nationally determined contributions (NDCs). The maturity of these adaption measures, and financial arrangements for delivering them, may form an important part of (set the context for) planning for adaptation at the mine-site level. In particular, countries that have routes to finance and deliver climate adaption at a national level are looking to reduce risks to their economies and potential investments and this may have implications for local planning.

As the majority of adaptation measures reported by the gold mining sector related to physical mining assets or process engineering, there was a less detailed exploration of how the impacts and conditions prompting these measures might also impact the mine's relationship with – and the resilience of – local populations. While there was an indication that many mining companies are aware of these factors, they may not yet be integrated or systematised within many companies' climate strategies and reporting procedures. This is probably not surprising given the speed and urgency with which the gold mining sector has had to expand its understanding of its potential vulnerabilities, alongside the rapid development of our wider knowledge of the complexity and interconnected nature of many impacts, including those experienced by surrounding communities.

Gold mining companies may therefore find additional value and opportunity in further exploring their possible support of local populations as they seek to adapt to more frequent or severe future climate change impacts. The examples of current industry awareness of this opportunity suggest gold miners are already starting to grasp the benefits of collaboration with local communities to contribute to collective capacity building, knowledge sharing and resource management. This opportunity to offer local communities additional support in planning their adaptive strategies is explored below.

4.2 Supporting local communities in adaptation planning

Engagement with local and host communities can provide an effective means of identifying and delivering climate adaptation actions that promise to be of benefit to a wide set of stakeholders. In addition to provision of more resilient infrastructure, the benefits can include capacity building, shared understanding of challenges and opportunities (both from an industry and community perspective), enhanced social license, economic growth opportunities, and better stewardship of the land. There is also the wider, and potentially very significant, value of this process contributing to the building of further trust between the host community and the mine.

Knowledge transfer between mining companies and host communities can form a crucial part of effective planning. This might include companies providing access to communities to scientific information about climate change to inform local resiliency planning including, for example, preparation for emergency impacts from acute severe weather hazards, or building agricultural resilience via the farming of different crops or livestock breed.

Appropriate guidance, such as the Climate Vulnerability and Capacity Analysis Handbook developed by CARE,[44] can provide a framework for community-based adaptation planning and the expansion of local capacity, particularly for vulnerable communities. Consideration of the social impacts of climate change adaptive planning will require attention being paid to gender and diversity, livelihoods and rights-based approaches.

The **community-based adaptation** approach considers four inter-related strategies:

- Promotion of **climate-resilient livelihood strategies** in combination with income diversification and capacity building for planning and improved risk management;
- **Disaster risk reduction** strategies to reduce the impact of hazards, particularly on vulnerable households and individuals;
- **Capacity development** for local civil society and governmental institutions so that they can provide better support to communities, households, and individuals in their adaptation efforts; and
- **Advocacy and social mobilization** to address some of the underlying causes of vulnerability, such as poor governance, lack of control over resources, or limited access to basic services.

Supplementing such approaches are a range of additional templates, such as the CRiSTAL toolkit, that can be utilised to help engage stakeholders in understanding the material considerations in climate adaptation planning.[45] These are explored further in **Section 5.**

Such approaches can be brought into the environmental and social impact assessment process during site planning and funding. This is an important part of meeting industry environmental and social impact standards and benchmarks such as the Equator Principals.[46]

Image courtesy of Agnico Eagle.

44 www.care.org/wp-content/uploads/2020/05/CC-2009-CARE_CVCAHandbook.pdf

45 www.iisd.org/cristaltool

46 https://equator-principles.com/

5: Established guidance for assessing climate vulnerability and adaption

There are a number of internationally recognised standards that define approaches to assessing climate change vulnerability and developing adaption measures, to assist in implementing resilience strategies and measures for at both mine sites and in support of local populations.

This section provides an overview of these international standards. In developing a climate vulnerability and adaptation study, country-specific guidance may also be available. Examples of such national guidance reference points are also presented.

5.1 Guidance and Standards

There are a broad range of established approaches for assessing the risk of climate change of physical assets. These include International Organisation for Standardisation (ISO) assessment methodologies including:

- *ISO 31000:2018 Risk Management Standard*
- *ISO 14090:2019 Adaptation to climate change – Principles, requirements, and guidelines*
- *ISO 14091:2021 Adaptation to climate change – Guidelines on vulnerability, impacts and risk assessment*
- *ISO 14092:2020 Adaptation to climate change – Requirements and guidance on adaptation planning for local governments and communities.*

In addition to these ISO standards, additional guidance is provided by a range of organisations and institutions. Such guidance has been established based on specific drivers for assessment and disclosure of climate change risk – for example for the purposes of financial reporting, regional government policy, or sectoral governance.

The growing expectation that responsible corporate entities will be able to demonstrate and disclose on their climate change risk strategies, particularly as they relate to business continuity and financial disclosures is reflected in the significant influence of the recommendations of the Task Force on Climate-related Financial Disclosures (TCFD). The TCFD has produced a range of key reference documents to guide how businesses consider their climate impacts and the impacts of climate change on their future financial performance (see, for example, Guidance on Risk Management Integration and Disclosure[47]).

Further guidance is provided by independent initiatives such as that from the European Bank for Reconstruction and Development (EBRD) and the Global Centre for Excellence on Climate Adaptation (GCECA) on *Advancing TCFD Guidance on Physical Climate Risks and Opportunities.*[48] And, from a broader development and policy perspective, the World Bank's *Adaptation Principles: A Guide for Designing Strategies for Climate Change Adaptation and Resilience report*[49] is intended to assist in 'the design, implementation and monitoring of national adaptation strategies'.

Guidance from within – or of particular relevance to – the mining sector is also provided through a range of institutions and associations. These include:

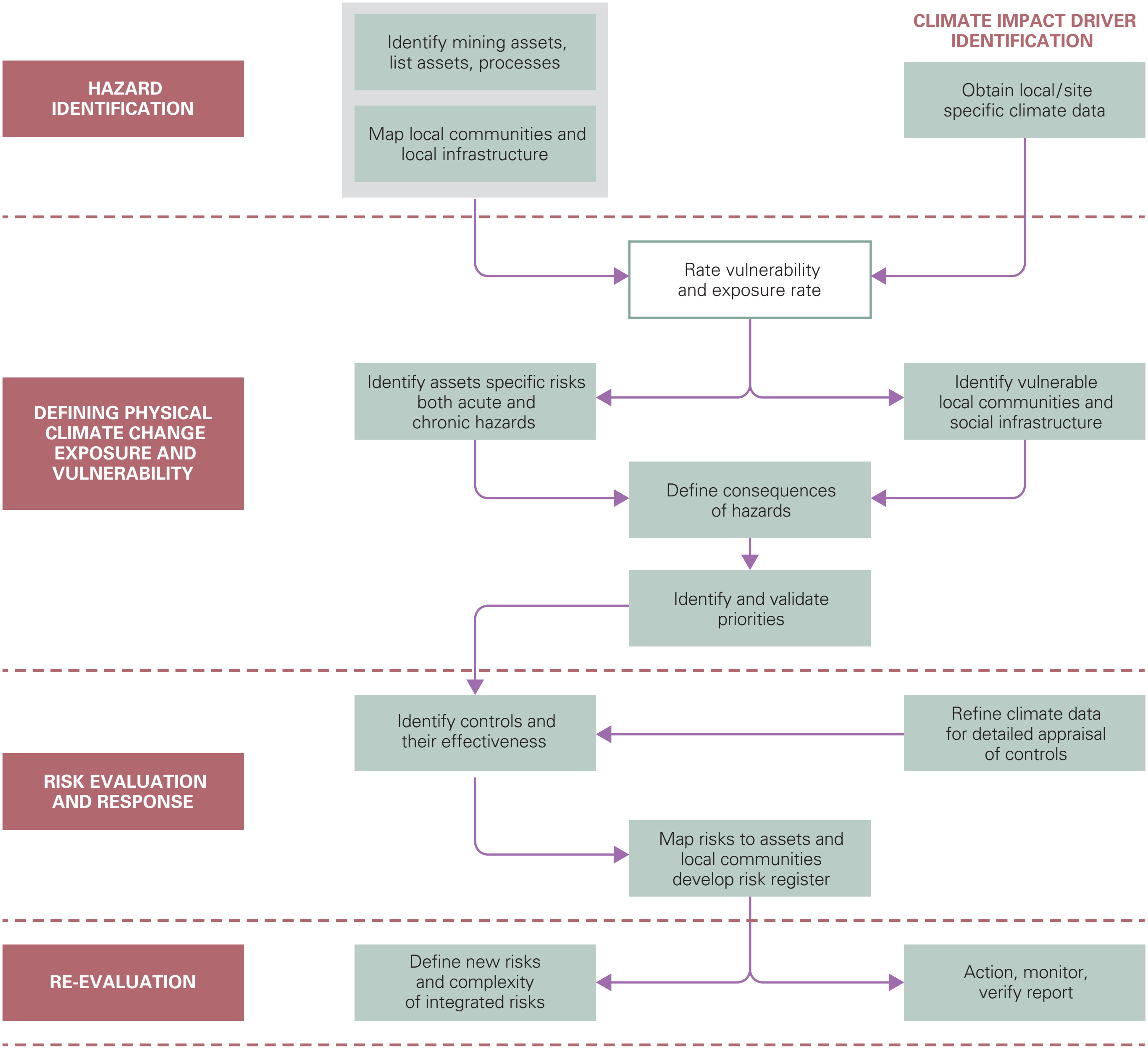
- *Guide on Climate Change Adaptation for the Mining Sector,* Mining Association of Canada[50]
- *Adapting to a Changing Climate,* International Council on Mining and Metals[51]
- *Climate Change Resilience and Adaptation,* Institute of Environmental Management and Assessment.[52]

The development of these parallel sources of guidance, which can be interpreted as representing a shared commitment within the mining sector, is to be welcomed. Nonetheless, the divergences between them may carry the risk of inconsistencies of approach which, in turn, may impede knowledge-sharing and benchmarking. In reviewing gold mining companies' approaches to climate adaption, it was noted that the majority appeared to base their appraisal frameworks on the TCFD guidance, with some also including reference to the ICMM methodology.

The methodologies defined by the ISO standards, when considered together, set a **framework for assessing climate-related hazards and vulnerability.** An overview of the corresponding logical process, as it might apply to gold mines, is illustrated in **Figure 5,** below. Following ISO standards for assessing climate risk hazards would allow climate vulnerability assessments to be integrated within standard company risk management procedures, whilst still being applicable to and aligned with guidance from other reporting frameworks, such as TCFD.

47 https://assets.bbhub.io/company/sites/60/2020/09/2020-TCFD_Guidance-Risk-Management-Integration-and-Disclosure.pdf
48 www.physicalclimaterisk.com/media/EBRD-GCECA_Executive_summary.pdf
49 https://openknowledge.worldbank.org/handle/10986/34780
50 https://mining.ca/wp-content/uploads/2021/10/MAC-Climate-Change-Guide-June-2021.pdf
51 www.icmm.com/website/publications/pdfs/environmental-stewardship/2019/guidance_changing-climate.pdf
52 www.iema.net/resources/reading-room/2020/06/26/iema-eia-guide-to-climate-change-resilience-and-adaptation-2020

Figure 5. Overview of climate change hazard identification and vulnerability assessment at the site/asset level



It is important that climate vulnerability assessments fit within existing business risk processes to ensure they are embedded into core operations and strategic planning. In undertaking vulnerability and adaptation planning for longer-term impacts, environmental management systems and protocols should provide a framework for continued management, measurement, verification and reporting. Reference to established standards (such as the ISO 14001 environmental management system standard and its associated suite of standards) can therefore offer opportunities for closer integration of climate change risk management into 'standard' operational procedures.

This might then allow appropriate reporting against a range of stakeholder needs, including (and beyond) financial or regulatory requirements.

5.2 Established guidance for engaging with local communities

As identified in **Section 4.2,** local populations that host or exit in proximity to gold mines may be particularly vulnerable to the impacts of climate change in ways that, in turn, can affect the operation and reputation of the mine itself. Mining companies should therefore engage and collaborate with these communities to obtain a fuller understanding of local vulnerabilities, which should contribute to the development of more robust adaptation plans.

Host communities can hold significant indigenous knowledge about the local land, water, environment and history, above and beyond data contained within models and records.[53] Local and traditional knowledge, often gathered and transferred though oral history (story-telling) and residing with indigenous/local 'knowledge holders', can form a crucial part of data gathering and help inform a wider understanding of local vulnerabilities that may also impact mine assets and operations. This localised or indigenous knowledge may hold valuable information on local weather conditions, the history of extreme weather events, and significant changes and trends over time. Indigenous people have a long history of adapting to change and can potentially assist mining companies in identifying appropriate adaptation responses and minimising maladaptive responses, particularly when considering how to adapt to the local environment and natural ecosystems of areas.

The geography of local communities is an important consideration in gathering data. Whilst local communities to mining operations may be more easily identified, more remote mining activity, with supply chains stretching over long distances, typically over road, will need to look at engaging with communities from a greater area. For example, landslides in Peru were noted as a high-risk vulnerability to supply chains on road infrastructure. Engaging with whole communities across vulnerable areas would establish a coalition for action in the event of weather impacts.

As presented within **Appendix B** there are a number of tools and guidance documents for engaging with and gathering information from local and host communities. These include the following, that are of particular relevance in this context:

- **The Community-Based Risk Screening Tool – Adaptation and Livelihoods (CRiSTAL)**[54] is a free tool developed in partnership between the International Institute for Sustainable Development, The International Union for Conservation of Nature, the Helvetas Swiss Intercooperation and the Stockholm Environment Institute. It can be used for a variety of projects and aims to help users understand how climate impacts may affect the project area and local livelihoods and identify adjustments which can support climate adaptation and reduce climate risk.
- **CARE's Climate Vulnerability and Capacity Analysis (CVCA) Framework** presents a methodology for undertaking detailed research into and analysis of climate vulnerability of communities. The CVCA Handbook[55] places an emphasis on multi-stakeholder analysis, collaborative learning and dialogue and presents a range of 'enabling factors' which are required at the national, local government and household/individual level for effective community adaptation to take place.

The consideration of climate change impacts on both the host communities and wider local populations is crucial in capturing the likely range of risks on a mining operation, particular those that may not be immediately obvious. To ensure the distribution of the potentially affected population is considered, the geographical and social study area of any climate vulnerability and adaptation analysis should be appropriately scoped.

As noted in **Section 2,** this will require a wide consideration of CIDs that may not impact mining operations directly but will be consequential for the local population. For example, climate-related changes in agricultural practice or food supply can significantly affect local community traditions and community cohesion.

53 https://unfccc.int/news/how-indigenous-peoples-enrich-climate-action

54 www.iisd.org/cristaltool

55 www.care.org/wp-content/uploads/2020/05/CC-2009-CARE_CVCAHandbook.pdf

Image Courtesy IAMGOLD.

Working with local populations is therefore critical in order to create a 'joined-up' multi-stakeholder approach to understanding the complexity of vulnerabilities and in defining mitigation strategies to better manage local climate change impacts. This might include supporting the provision of local infrastructure that improves supply of food, water, energy and other resources for not only the mine site but also the local communities. While this support will undoubtedly impose costs, these need to be balanced against the value of enhancing community relations, avoiding conflict, boosting reputational capital, and cementing social license.

Embedding an awareness of community climate-related vulnerabilities into mine-site plans, coupled with a responsive adaptation strategy, might also provide strong evidence of local performance on a range of wider environmental, social, and governance (ESG) objectives. It is well-documented that contributions to progress on key UN Sustainable Development Goals will require robust adaptation and resilience plans and actions[56] and gold mining may play a pivotal role in catalysing and helping deliver those plans.

56 See, for example: *Targeting climate adaptation to safeguard and advance the Sustainable Development Goals,* Fuldauer, L.I., Thacker, S., Haggis, R.A. et al. *Nature Communications,* vol. 13 (2022).

6: Summary and conclusions

The physical and disruptive impacts of climate change are already being experienced around the world and will continue to affect society and the environment in a growing and very significant way. However, these impacts vary substantially across the globe and within countries, with diverse and complex consequences for human systems, industries, and ecosystems.

Climate risks and hazards may also affect the gold mining sector in multiple ways, including having direct impacts on the operations and integrity of mines, as well as affecting the wider supply chain and the populations that reside in or near gold mining locations. The pivotal role gold mining often plays in many remote and developing economies, in places that may already be very vulnerable to physical climate impacts, makes the industry's awareness of the opportunities for increased resilience, and its corresponding adaptation plans, of particular significance.

This report therefore seeks to provides a summary of climate change hazards likely to impact gold mining at a local and regional level, as well as outlining approaches to managing and adapting to physical climate change risks.

The report's key findings and conclusions are built on the following:

- A summary of the different infrastructure components and **assets that comprise a gold mine site and their likely vulnerabilities** to climate impacts
- An analysis of the level of relevance of particular **climate impacts**[57] **on gold mining processes and assets,** including consideration of local populations and communities.
- A **summary of regional climate risks**, as relevant to gold mine sites and locations
- A survey of **current gold mining adaptation strategies** both at the mine-site and community level
- A survey of **established climate adaptation guidance and standards,** with a summary high-level process map for climate hazard identification and vulnerability assessment.

By narrowing the gaps in the gold industry's knowledge of climate risks, these findings, and the recommendations that emerge from them, seek to contribute to greater sectoral resilience in the face of potentially more frequent and severe impacts, with potential benefits to a wide set of industry stakeholders. In both acknowledging current gold mining approaches to adaptation, and in considering how 'good practice' processes might be derived from an examination of leading guidance and standards, this report seeks to advance gold mining's ability to prepare and respond to a wide range of climate-related hazards. It considers how a more shared and systematic approach, coupled with a wider consideration of local vulnerability at the local community level, might build on current industry progress in identifying relevant risks and defining appropriately robust adaptation plans.

This report highlights seven key recommendations that could support the further resilience of the gold mining sector:

1. **Greater consistency and knowledge sharing in defining methodologies for assessing climate vulnerability and adaptation**
2. **Balance consideration of acute risk with a longer-term view on chronic risks**
3. **Greater acknowledgement and understanding of combined *compound* risks**
4. **Integrate community risk into local vulnerability appraisals and resilience plans**
5. **Use local and indigenous knowledge of climate change and weather impacts to inform the climate risk assessment process**
6. **Sharing knowledge and resources with local communities, and adopting a multi-stakeholder approach to adaptation planning and designing for climate change resilience**
7. **Plan for innovation, using data and technology to produce a more dynamic approach to managing climate-related vulnerabilities and potential physical hazards.**

Taken together, these findings suggest that gold mining, which already plays a significant role in catalysing socio-economic growth and development opportunities in many emerging economies, might also contribute to building greater local resilience to physical climate impacts in host locations. In demonstrating its increased awareness of vulnerabilities and hazards, and their complex interconnections, and in expanding its capacity to adapt to a changing climate, gold mining may find that many of the building blocks to enable its greater future resilience are already in place. To build on these foundations will, however, likely require more systematic planning, wider consultation, and greater collaboration across the gold sector and beyond, involving a broad set of stakeholders, including closer engagement on climate-related risks with local communities. These challenges are not unique to gold mining, but the industry is, perhaps, in a particularly strong position in the implications its responses and progress will have for its many stakeholders, particularly in remote and developing economies.

57 Or, to be precise, climate impact drivers (CIDs).

Appendix A

Glossary, Acronyms and Abbreviations

Adaptation

In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects

Acute Hazard

Short term and severe by nature, for example, a heatwave.

Air pollution

Degradation of air quality with negative effects on human health, the natural or built environment, due to the introduction by natural processes or human activity in the atmosphere of substances (gases, aerosols) which have a direct (primary pollutants) or indirect (secondary pollutants) harmful effect.

Chronic Hazard

Long term, for example changes to mean average temperatures over several years.

Climate

Degradation of air quality with negative effects on human health, the natural or built environment, due to the introduction by natural processes or human activity in the atmosphere of substances (gases, aerosols) which have a direct (primary pollutants) or indirect (secondary pollutants) harmful effect.

Climate change

A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods

Climate Impact Drivers

Climatic impact-drivers (CIDs) are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems. Depending on system tolerance, CIDs and their changes can be detrimental, beneficial, neutral or a mixture of each across interacting system elements and regions.

Hazard

The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.

Impacts

The consequences of realized risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather/climate events), exposure, and vulnerability. Impacts generally refer to effects on lives, livelihoods, health and well-being, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure. Impacts may be referred to as consequences or outcomes and can be adverse or beneficial.

Indigenous knowledge

Indigenous knowledge refers to the understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings. For many Indigenous peoples, Indigenous knowledge informs decision-making about fundamental aspects of life, from day-to-day activities to longer term actions. This knowledge is integral to cultural complexes, which also encompass language, systems of classification, resource use practices, social interactions, values, ritual and spirituality.

Likelihood

The chance of a specific outcome occurring, where this might be estimated probabilistically.

Region

A region is a relatively large-scale land or ocean area characterized by specific geographical and climatological features. The climate of a land-based region is affected by regional and local scale features like topography, land use characteristics and large water bodies, as well as remote influences from other regions, in addition to global climate conditions.

Resilience

The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and/ or transformation.

Risk

The potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards. Hazards, exposure and vulnerability may each be subject to uncertainty in terms of magnitude and likelihood of occurrence.

Vulnerability

The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Acronyms / Abbreviations

AR6
IPCC Sixth Assessment Report

CDP
Carbon Disclosure Project

CID
Climatic Impact-Driver

CO_2
Carbon Dioxide

CRiSTAL
The Community-Based Risk Screening Tool – Adaptation and Livelihoods

CVCA
CARE's Climate Vulnerability and Capacity Analysis

GHG
Greenhouse Gas

IPCC
Intergovernmental Panel on Climate Change

ISO
International Organisation for Standardisation

TCFD
Taskforce on Climate related Financial Disclosures

WGC
World Gold Council

WGII
The IPCC Working Group II

Appendix B

Overview of Gold Mining Sector Climate Vulnerability and Adaptation

To inform the analysis in this report, a desk-based research process was undertaken, reviewing existing approaches to assessing climate change vulnerability and adaptation within the gold mining sector. The following Appendix, describing the findings of that research process, has been set out in two parts:

i. The first is a **review of existing climate change vulnerability and risk reporting** available within the gold mining industry to understand the variety of approaches currently being taken.

ii. The second part of the research process is a **review of the approach to climate change impacts at a range of gold mining sites** operated by World Gold Council (WGC) Member companies **across seven climate regions** (Africa, Asia, Australasia, Central and Southern America, Europe, North America and Small Islands).

   Publicly available company reports such as Climate Change and Sustainability reports and Carbon Disclosure Project (CDP) submissions have been reviewed in the first instance, and further internal risk assessment information was provided by a number of companies in relation to a number of specific sites.

   In addition, a questionnaire was issued to WGC Member companies to capture additional information.

This research focuses predominantly on the physical impacts of climate change on operations and the local populations that gold mines engage with. At this stage 'transitional' risks relating to a shift towards a lower carbon economy, such as regulation, technology, market demand and reputation factors, have not been reviewed.[58]

B.1 Wider Industry Research

This section presents the findings of a review of existing literature and guidance in relation to climate risk assessment within the gold mining industry and more generally.

B.1.1 Task force on climate-related financial disclosures

The Task Force on Climate-Related Financial Disclosures (TCFD) produced its highly influential Recommendations with the purpose of guiding businesses in how to disclose climate-related financial information. The TCFD recognise that organisations of every kind face risks related to climate change, including physical impacts of the changing climate as well as impacts arising from a transition to a lower carbon economy.

The TCFD Recommendations provide a framework for companies considering climate-related risks with the following recommended categories – listed here with examples of the types of risk potentially impacting a business:

- Policy and legal – e.g. enhanced emissions reporting obligations, regulation of products and services
- Technology – e.g. substitution of existing products and services with lower emissions, costs to transition to lower emission technology
- Market – e.g. changes in customer behaviour, increased cost of raw materials
- Reputation – e.g. increased stakeholder concern, changes to customer preferences
- Physical risks – e.g. increased severity of extreme weather events, changes in precipitation patterns, rising mean temperatures and rising sea levels.

While the recommendations offer examples of the types of impacts that should be considered, they do not provide a comprehensive list of climate-related risks, particularly in relation to specific physical impacts. But a recommended strategy for disclosure of risk assessments, as well as guidance on describing risk management processes and mitigation plans are included within a 2021 annex document entitled 'Implementing the Recommendations of the Task Force on Climate-related Financial Disclosures'.[59] The TCFD recommendations encourage organisations to conduct scenario analyses to assess future climate-

58 However, prior to this report, the World Gold Council's climate change research programme has primarily focused on analysing different aspects of transition risks and the move to a decarbonised economy as they might impact the gold supply chain and gold's performance as an investment asset. See www.gold.org/esg/gold-and-climate-change

59 https://assets.bbhub.io/company/sites/60/2021/07/2021-TCFD-Implementing_Guidance.pdf

related risks and recommend considering the '2 degrees or lower' scenario[60] as well as short, medium and long-term effects, but do not provide details on other possible scenarios or what time frames might be considered short, medium or long-term.

B.1.2 Carbon disclosure project

The Carbon Disclosure Project (CDP) administer a system through which companies globally can disclose information related to environmental impacts. They provide an opportunity to report annually on climate change via a questionnaire, including a section on risks and opportunities, with questions based on recommendations from the TCFD. The CDP provide a list of possible climate-related risk drivers, with physical climate impacts broken down into acute physical and chronic physical. The full list of physical drivers considered is presented in **Table A1.** Other risk categories include current regulation, market, emerging regulation, legal, reputation, and technology.

Table A1. Physical climate drivers

Acute physical climate drivers	Chronic physical climate drivers
• Avalanche • Cold wave/frost • Cyclone, hurricane, typhoon • Drought • Flood (coastal, fluvial, pluvial, groundwater) • Glacial lake outburst • Heat wave • Heavy precipitation • Landslide • Storm (including blizzards, dust, and sandstorms) • Subsidence • Tornado • Wildfire	• Changing precipitation patterns and types • Changing temperature (air, water) • Changing wind patterns • Coastal erosion • Heat stress • Ocean acidification • Permafrost thawing • Precipitation variability • Saline intrusion • Sea level rise • Soil degradation/erosion • Solifluction • Temperature variability • Water scarcity

60 That said, the scenarios currently recommended for transition plans and decarbonisation targets are typically moving away from the '2 degrees or lower' scenario towards the more ambitious 1.5 degree scenario.

B.1.3 ICMM

The International Council on Mining & Metals (ICMM) produced a report in 2019 entitled *'Adapting to a Changing Climate: Building Resilience in the Mining and Metals Industry'*.[61] The report looks at how climate change could impact the mining and metals sector and identifies ways for companies to include climate change considerations in their risk management processes. Key themes and challenges relating to climate change identified within the report are:

- Physical impacts of climate change are already being experienced and will be experienced by all companies, in all geographies. Extreme weather events are seen as the most severe risk
- Stakeholder positions on climate resilience are evolving rapidly and companies need to keep up with changing requirements such as legislation and financial regulation
- Water management is a critical issue, with decreased water availability identified as a major concern particularly in areas already facing water stress including South America, North America and Australia. Too much water can also pose a risk, with flooding of tailings, pits and water storage facilities presenting a significant long-term challenge
- Facilities with long lifespans such as tailings dams and storage facilities must continue to be resilient to climate change
- Climate change is an important consideration for closure and post-closure of mine sites. Environmental risks for rehabilitated land will need to be considered far into the future
- The supply chain is vulnerable to climate change impacts in many ways including flooding and storms, snow and ice, and ground instability. Disruption and delay can have significant impact on operations and companies should work to strengthen resilience of their supply chain
- Taking a modular approach to project design can enable flexible asset management and adaptation of systems.
- New and changing technology can support companies with climate resilience such as use of spatial data and simulation as well as remote operations and automation
- A multi-stakeholder approach that includes local populations in discussions around climate change impacts and risks can provide positive outcomes for companies, wider society and the environment.

The ICMM report also identifies nine categories or 'assets' that are likely to be affected by climate change, which are:

- Physical assets
- Efficiency of production processes
- Cost of operations and maintenance activities
- Health and safety
- Workforce and labour productivity
- Ability to supply metals to customers
- Customer demand for certain types of products
- Infrastructure to export products or import materials
- Electric, water or other utilities.

A case study included within this report looks at a community adaptation project undertaken by a mining company for one of their sites. It identifies that the 'CRiSTAL tool' and 'Care International's Climate Vulnerability and Capacity Analysis framework (CVCA)' were used to help communities understand climate change risks and build capacity for adaptation. Summaries of the tool and framework are set out below.

B.1.4 CRiSTAL tool

The *Community-Based Risk Screening Tool – Adaptation and Livelihoods* (CRiSTAL)[62] is a free tool developed in partnership between the International Institute for Sustainable Development, The International Union for Conservation of Nature, the Helvetas Swiss Intercooperation and the Stockholm Environment Institute. It can be used for a variety of projects and aims to help users understand how climate impacts may affect the project area and local livelihoods, and identify adjustments which can support climate adaptation and reduce climate risk. It involves significant community engagement and consultation to understand the local context and impacts.

B.1.5 CVCA framework

CARE is an organisation that delivers global programmes to fight poverty and achieve social justice. It has created a *Climate Vulnerability and Capacity Analysis* (CVCA)[63] tool which can be used to understand climate change vulnerabilities within communities and identify ways to improve their resilience to climate change. CARE's CVCA Handbook presents a methodology for undertaking detailed research into and analysis of the climate vulnerability of communities including a 'Framework for Community-Based Adaptation' which sets out what is needed at a national, local government and individual level for communities to enable effective climate change adaptation.

61 www.icmm.com/en-gb/guidance/environmental-stewardship/2019/adapting-to-a-changing-climate

62 www.iisd.org/cristaltool

63 www.care.org/wp-content/uploads/2020/05/CC-2009-CARE_CVCAHandbook.pdf

B.1.6 BSR

BSR produced a report in 2011 entitled *'Adapting to Climate Change: A Guide for the Mining Industry'*[64] which reviews how companies in the mining industry are reporting on climate change risks and highlights best-practice and guidance in relation to climate change adaptation for companies involved in the mining of a broad range of metals and minerals. This review was undertaken based on 2009 data and is therefore outdated but still provides relevant information and considerations.

The BSR report considers impacts within the following categories:

- Disturbance to mine infrastructure and operations
- Changing access to supply chains and distribution routes
- Challenges to worker health and safety conditions
- Challenges to environmental management and mitigation
- More pressure points with community relations
- Exploration and future growth.

The impacts identified align with those presented by an examination of a range of gold mine sites (across the IPCC climate sub-regions), reviewed for this paper and presented in **Table A2** below.

In relation to local populations, the data summarised in the BSRreport highlights that many gold mining companies operate in politically and socially challenged parts of the world and that mining industry is often key in providing and catalysing economic opportunity in these areas. Negative impacts on the industry can have significant consequences for development of local and communities and adjacent or regional economies. The report also recognises that mining companies, in supporting climate resilience for local communities, can help maintain or enhance their social license to operate. However, this will be more challenging where climate change has exacerbated existing vulnerabilities and increased direct competition between the company and community for resources.

The impacts on communities included within the BSR report are:

- Greater requirement for financial and employee support in response to damaged property and livelihoods as a result of extreme weather events and 'natural disasters'
- Damage to community infrastructure will affect worker health, attendance and productivity where mine workers are living in those communities themselves
- Various changing climate conditions may threaten food security, worsen poverty, and lead to conflict over natural resources
- Warmer temperatures and flooding will further spread diseases, affecting community health
- Local water infrastructure may require improvement to provide sufficient supply both communities and mines and avoid conflict or reputational damage
- Rising sea levels may lead to migration of coastal communities, exacerbating social problems and demand for resources in communities.

The report also provides a set of recommendations for key components that should be included in mining companies' climate adaptation strategies, several of which relate to involving and supporting local populations. The recommendations are to:

- Work with host communities to develop concrete climate adaptation plans
- Integrate climate-compatible development into initiatives for sustainable local benefit from project operations
- Explore how investments in ecosystem services can improve local resilience
- Work with stakeholders to understand their emerging concerns
- Initiate cross-industry collaboration on regional adaptation strategies.

64 www.bsr.org/en/our-insights/report-view/adapting-to-climate-change-a-guide-for-the-mining-industry

B.1.7 Climate change, mining and traditional indigenous knowledge in Australia

An article entitled *'Climate Change, Mining and Traditional Indigenous Knowledge in Australia'* was published in the journal *'Social Inclusion'* in 2016.[65] It reviews the ways in which indigenous communities of Australia are vulnerable to the impacts of climate change, including threats to cultural traditions such as ceremonies, hunting practices, sacred sites, bush tucker and bush medicine. Climate change may lead to restricted access to or destruction of sacred sites and also threaten traditional food supplies.

The article acknowledges that indigenous communities are disproportionately affected by climate change, while not having participated in the industrial and consumer actions which have caused the climate change itself, and often exist in socio-economically challenged and disadvantaged conditions. Infrastructure, such as drainage, shelter, and transport, can be poor within indigenous communities and the social and economic effects following extreme weather events can therefore be particularly devastating.

The article identifies the importance of 'two-way learning' between industry or scientific communities and indigenous people, who may have extensive knowledge of the local environment and historical climate change impacts. It encourages engaging directly and inclusively with these communities, giving them a chance to voice concerns as well as share their knowledge.

B.1.8 Gold mining company and site-specific review

This section provides a summary of the current approaches to assessing climate-related risk taken the a range of gold mines were reviewed as well as any geographical climate considerations that have been identified by the gold mining companies. Physical climate change impacts considered by companies have then been collated, along with perceptions of significance of the impacts, and a long list compiled of potential climate change adaptation measures.

The information contained within this section has been obtained through a review of the selected gold mining companies' public climate change and sustainability reporting as well as some additional information provided by the companies, plus any relevant information obtained through the wider industry research presented above.

B.1.9 Approaches to assessing risk

Through a review of gold mining companies' climate change vulnerability and risk reporting, it is apparent that approaches to assessing risk in relation to climate change vary significantly between the companies reviewed within this study. Companies have made varying levels of progress in terms of undertaking this work, with some having done detailed assessments for a number of years, and others stating in their 2021 reports that this is a priority action for the coming year or is a 'work in progress'.

Many companies are basing any risk assessments on the recommendations of the TCFD and typically those who have already undertaken these risk assessments have done so through various third-party consultancies. The ICMM methodology set out within the 2019 report *'Adapting to a changing climate: building resilience in the mining and metals industry'* has also been used in the preparation of risk assessments.

There is no consistent approach to defining the climate change scenarios, climate drivers, mining assets, time periods, or categories of risk severity used. Time periods selected included 2020 baseline data, 2030, 2050 and 2080 future projections, with scenarios typically based on IPCC Representative Concentration Pathways 8.5, 4.5 and/or 2.6.[66]

65 *Climate Change, Mining and Traditional Indigenous Knowledge in Australia,* Tony Birch, Social Inclusion, Vol. 4 (2016).

66 For a simple introduction to Representative Concentration Pathways (RCPs): www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-guidance---representative-concentration-pathways.pdf; for further details: *The representative concentration pathways: an overview. Climatic Change,* D.P. van Vuuren et al. (2011) – https://link.springer.com/article/10.1007/s10584-011-0148-z

B.1.10 Geographical considerations

This section presents a summary of the climate change projections based on geographical location as identified within the climate change reporting of the gold mining companies risk assessment review included in this study. These have informed the climate vulnerability appraisal by providing more specific sub-regional climate impact definitions.

The projections identified in gold mine risk assessments within each geography are:

- **All regions** are predicted to experience higher temperatures, but severity of impacts will vary based on location with sites near the equator and Australia experiencing more days above the threshold heat index (tolerable threshold for humans)
- **All regions** are also predicted to experience higher intensity storm events
- Projections for **Australia** include increased temperature (extreme heat), reduced rainfall, increased extreme weather events and increased bushfires
- Projections for **South Africa** include increased temperature, increased rainfall variability, decreased annual rainfall, increased frequency and severity of storms, increased water stress and prolonged drought
- Projections for **Ghana** include increased temperature, increased rainfall variability, increased frequency of extreme weather events, increased number of 'very hot' days and sea level rise
- Projections for **Chile** include increased temperature, decreased snow, decreased annual rainfall, increased storm frequency and intensity and increased water stress
- Projections for **Peru** include increased temperature, increased rainfall variability, increased extreme weather events and increased rainfall
- Projections for **Turkey** include increased flooding, drought, wind events and wildfires
- Projections for **Greece** include increased storm intensity, changes in rainfall patterns and amounts, increased temperature, water stress and drought. Flash flooding is identified as a primary physical risk
- Projections for **Canada** include extreme cold, flooding, increased ice storms or black ice, high wind events, increased storm intensities, and warmer winter temperatures
- Some very **localised climate impacts** were predicted, for example for two sites in California, one was viewed as being high risk for wildfires, but another was not, with water stress being the highest risk issue there.

B.1.11 WGC member questionnaire results

A questionnaire was issued to WGC Member companies to capture information that may have been missed in the earlier mine sample. The findings of the questionnaire are summarised below, with responses from mine companies located in the following regions:

- North America;
- Central and South America;
- Africa;
- Asia; and
- Europe.

Existing Climate Risks and Impacts Identified
The majority of responses reported that heavy rainfall events have occurred and caused damage to infrastructure such as drains, ramps, dam stability and roads affecting operations as well as increasing surface run-off causing contamination and requiring an increase in maintenance of stormwater management infrastructure. Heavy rainfall has also delayed the construction of mines prior to the installation of a pump system. Landslides caused by heavy rain damaged drainage systems.

Mines experiencing droughts has led to increased investment in high-performance water management systems to improve water conservation and recycling.

Wildfires have disrupted mine access and caused visibility issues that have slowed down or stopped the operation of mines. The increasing risk from these has led to the monitoring and management of fires in the areas surrounding a mine. Loss and harm to habitat and species that a mine is investing in the protection or enhancement of has also been noted as having the potential affect permitting as the risk of wildfires increases.

Storms have damaged power supply to mines, causing power outages that prevented operations as well putting staff at risk. Increased risk from storms and lightning has led to electrical protection circuits being upgraded.

Cold snaps and heavy snow have caused freezing rain and disrupted mine access due to poor road conditions and safety concerns. These weather events also have the potential to cause pipe freezing.

Existing Measures and Action Plans
In response to the above existing risks, and projected future risks, the following mitigation measures have been implemented across a number of mines:

- Climate Risk Assessments at various stages, either in planning, underway or complete
- Conservation of habitat and forest areas surrounding mines
- Developing designs for increasing drainage capacity and filtered tailings storage facilities that account for increasing precipitation
- Designing pipes to allow for colder temperatures, including thermal insulation, heat tracing and burying pipes underground
- Implementation of emergency procedures, response plans and drills
- Incorporating climate models into site water balance and projections, water storage facility designs and freeboard models
- Enhancing weather and wildfire monitoring and response procedures, including the training staff.

Local and Host Communities
Responses to the questionnaire shows that climate impacts on local and host communities have been considered in some cases, but – quite understandably – this has been less of a priority than the focus on potential impacts on the operation and infrastructure of a mine. The growing awareness of interconnected and cascading risks will likely broaden this focus, particularly as site operational issues can be, in time, by affected by indirect impacts.

For example, gold mine companies have reported that they are aware that local and host communities have been affected by flood damage and drought causing local water shortages. While heavy snow, storms, landslides and wildfires have affected community road access, safety and disruption.

Some mines are already working with neighbouring communities and villages, including through their emergency responses to extreme weather by developing a command structure and allocating predefined responsibilities and personnel, establishing disaster warning equipment and facilities, as well as responding to local drought by voluntarily providing drinking water to the local community.

B.2 Risk assessments summary

Table A2 collates the climate-related risks and impacts identified through the review of company reports and wider industry research, grouped by general climate change category. The risk perception column aims to capture how the severity and likelihood of each impact has been viewed by the mining sites examined in this study. That said, many of the companies did not provide scoring metrics for a specific impact. For those that did, approaches to categorising risk (e.g. low, medium, high) vary and may, therefore, not be directly comparable. Some were considered for specific geographies and others as an overall consideration of climate risk from a corporate perspective.

This suggests that, whilst the majority of companies may be using the TCFD framework (and some reference further guidance, such as the ICMM's proposed methodology), the implementation of assessments are based on methodologies that are not yet shared or consistent. Not surprisingly, company risk assessments often appear to reflect perceptions of climate risks and associated plans and priorities that vary very substantially across organisations.

Table A2. Climate-related risks extrapolated from industry research and company reports

Impact	Risk Perception
Increased precipitation/flooding	
Increased rainfall could flood damage roads, preventing workers from getting to the site or impacting the delivery of essential supplies.	Africa, North America, South America most affected. High to extreme risk. Likelihood 'more likely than not', medium-term, medium impact. Medium risk for Peru.
Flooding of mine pits, maintenance and storage facilities and unpermitted offsite discharges may occur.	Africa and Australia most affected, high to extreme risk based on region.
Extreme rainfall events can erode areas that have been rehabilitated for closure.	Extreme risk in Australia.
Can result in flooding of tailings storage facilities, resulting in "overtopping" of facility or undermining slope stability. Impacts operations and environment.	Africa, North America – high to extreme risk. Short-term, 'very unlikely', medium impact. Medium risk for Australia and South Africa, high risk for Ghana.
Increase in extreme rain events can exceed capacity of on-site treatment systems and potentially result in off-site water quality issues. Can lead to exceeding water treatment facility capacity to store and treat water. Pumping costs may be higher.	All regions, high to extreme risk. High risk for Peru and Ghana, Medium risk for Australia.
Increased precipitation can induce mudslides/landslides and increase the risk of storage pond, wall and/or embankment instability. This can damage site equipment or access to infrastructure.	High risk for Peru.
Floods and debris flows may affect local communities, disrupting livelihoods.	
Abnormal rainfall may damage surface equipment and infrastructure.	Short-term, likely medium-low impact.
Decreased precipitation/drought	
Reductions in water availability for mine operations including ore processing.	Africa, Australia, and North America most affected. High to extreme risk. Medium risk for Chile, Peru and Australia, High risk for Ghana.
Reductions in water quality. Extended drought can increase raw water salinity and corrode processing plant equipment.	Africa, Australia, North America and South America affected – High to extreme risk.
Low reservoir levels at hydro-electric stations	Medium-term, 'about as likely as not', medium impact. Extreme risk for Africa.
Increased tension in communities due to lack of access to safe water	Medium risk for Chile.
Reduced availability of water for fauna	

Impact	Risk Perception
Higher mean temperatures	
Increased warming or increased freeze/thaw cycles can increase dust emissions associated with mines, road maintenance, tailings facilities management and tailings disposal activities.	Australia and North America – moderate to high risk.
The number of days exceeding the heat stress index could increase over time and stay consistently above threshold for longer periods, impacting worker safety. This would increase the need for cooling infrastructure to moderate temperatures and increased costs.	Africa, Australia and South America most affected, high to extreme risk. Medium risk for Chile and Australia, High risk for South Africa and Ghana.
Rising temperatures may put wild animals in distress, especially due to lack of water, increasing their presence at mine sites.	Short-term, 'likely', low impact
Equipment performance and efficiency may be reduced at higher temperatures.	
Warming leads to thawing of permafrost and expansion and eventual rock failure.	North Russia affected. Medium term, 'about as likely as not', medium impact.
Exposure to hot climate diseases and mosquito-transmitted diseases such as malaria, yellow fever and the zika virus increase in areas not previously affected as temperatures rise	Expected to significantly affect Brazil. High risk for Ghana.
Higher temperatures could melt glaciers, impacting on hydropower and interrupting electricity supplies	Medium risk for Peru.
Underground mines have to move deeper as temperatures increase, increasing ventilation requirements	Medium risk for Australia.
Extreme weather events (e.g. storms/cyclones, fires, black ice conditions)	
More frequent extreme weather events could impact site access including worker access and delivery of food, chemicals and materials. This could be in the immediate vicinity of the site or further down the supply chain/transport network.	Australia and South America affected, moderate to high risk. Short-term, unlikely, medium-low impact. Medium risk for Chile, High risk for Peru and Ghana.
Extreme weather events could impact local food production.	
Extreme weather events including storms and fires can affect power lines that provide electricity to mines. Extended power outages may occur and cost of power could increase.	Extreme risk, bushfires likely in Australia. High risk of power outages in North America. Medium risk for South Africa.
Fires can interrupt pumps and fuel supplies and endanger stored explosives.	
Extreme weather events such as storms and lightning can impact worker safety and in turn delay operations where safety would be at risk should activities continue.	Moderate risk for North America. High risk for Peru.
Extreme weather events may damage communications-related infrastructure.	Medium risk for Chile
Other/Multiple Factors	
Long-term changes in climate can impact the ability of vegetation to be established, impacting closure criteria timeframes as well as diminishing plant recovery and biodiversity values of previously reclaimed areas.	Australia and South America affected, high to extreme risk. Medium risk for Peru, Low risk for South Africa.

B.3 Local and Host Communities

Within existing climate vulnerability risk assessments, the majority of the impacts considered focus on physical mine site infrastructure and equipment, worker safety and access, and supply of goods. Less consideration is given to effects on local host communities, which are more often considered within the context of 'transition' risks.

However, that is not to say local community impacts were not acknowledged in some gold mining company climate risk assessments and the following specific risks and potential impacts were noted:

- Multiple climate change impacts could lead to increased vulnerability of host communities, disruption of livelihoods and increased dependency of those host communities on the mining companies
- Poverty and literacy levels may hamper the ability of host communities to build resilience to the impacts of climate change
- Impacts such as heavy rainfall can increase vulnerability of food provision and food prices for coastal communities.
- People may migrate closer to mine locations for jobs, impacting both the communities they move from and to
- Greater spread of water pollution and water borne diseases from increased rainfall and resulting changes in water flow may occur
- Drought may lead to competition for water resources between mining operations and host communities, creating tension or civil unrest
- Extreme weather events may impact opportunities for local food production.
- Wildfire induced through weather poses a risk to local safety and livelihoods.

B.4 Assets

The way in which assets and stakeholders were categorised, and the level of detail into which these were broken down, varied between the gold mine sites reviewed in this assessment. A compiled and summarised list of the different categories of assets and stakeholders predicted to be impacted by climate change is as follows:

- Extraction/Mining equipment
- Processing
- Workforce (health & safety, productivity)
- Transport and access
- Waste management
- Water management (quality, quantity, storage)
- Mine closure
- Energy infrastructure
- Supply chain
- Host communities
- Natural environment.

B.5 Adaptation/Management

Approaches to climate change adaptation and management varies between organisations. This section compiles approaches identified within all the gold mine sites reviewed and their available reporting, split into relevant themes.

B.5.1 Transport/access/supply chain

- Improve current roads and other transport infrastructure, identify alternate routes and define these with key suppliers
- Keep adequate stocks of essential materials to ensure uninterrupted supply, improve storage capacity, and review alternative supplier
- Work with key suppliers to determine their resilience to extreme weather events
- Work with governments to designate strategic and important roads for improvements
- Incorporate climate projections and weather events into care and maintenance plans for sites.

B.5.2 Biodiversity and closure

- Incorporate climate projections and impacts on vegetation into closure management guidance and strategies
- Continue to model rehabilitated sites to determine tolerance
- Investigate use of climate resilient species
- Develop community education, engagement and awareness programmes to raise awareness of impacts on flora and fauna.

B.5.3 Drought/water scarcity

- Identify and prioritise processing and requirements to meet peak demand projections
- Improve water balance modelling to align with future changes and demand
- Undertaken water stress and drought assessments
- Investigate implementation of water saving technologies or improving processes
- Work with stakeholders to manage water as a shared resource.

B.5.4 Dust

- Optimize deposition strategies and develop dust management strategies to account for potential long-term increase of dust emissions due to mean average drier conditions.

B.5.5 Bushfires (Australia) / Wildfires

- Work with stakeholders to ensure forest management plans are maintained
- Work with electrical power companies to maintain lines
- Maintain Fire Management Plans
- Keep firefighting equipment on site and collaborate with local fire brigades
- Implement formal weather forecast and early monitoring systems.

B.5.6 Heavy rainfall and flooding

- Incorporate climate modelling into water balance projections and storage facility designs
- Improve water storage level monitoring and pumping
- Use latest Probable Maximum Flood data to inform design of structures, designing constructing and operating water management and treatment facilities to withstand heavy rainfall
- Implement systems to manage water in accordance with regulatory requirements in emergency situations.

B.5.7 Tailings storage facility overflow/instability

- Optimise existing storage and drainage networks
- Incorporate climate change projections into water balance forecasts, design and planning
- Monitor geotechnical conditions at tailings facilities.

B.5.8 Heat

- Continue to develop chilled underground ventilation and monitoring technology
- Assess working and living areas for appropriate cooling
- Use technology to reduce frequency/duration of worker exposure to extreme heat conditions
- Train works in heat and hydration management and responses to heat stress events.

B.5.9 Land erosion

- Review closure designs and finalize updated rock mulching ratios for closure rehabilitation areas.

B.5.10 Extreme weather/storms

- Review of lightning dissipation technology for site application
- Install wind speed measurement technology at Air Monitoring Stations, continuously monitoring air speed.

B.5.11 Power

- Review backup generator, fuel storage and critical supply capacity and update emergency backup plan accordingly
- Seek to design infrastructure and work with contractors and electricity suppliers to mitigate risks related to weather condition.

B.5.12 Water management

- Evaluate water treatment and capacity based on potential future needs related to climate change impacts
- Enhance monitoring systems
- Implement workforce training for relevant staff
- Evaluate infrastructure to optimise water abstraction and usage
- Update water balance predictions to incorporate climate change projections.

B.6 Summary of gold mining sector data analysis

The information obtained from literature research and analysis of existing gold mining climate vulnerability and adaption reporting has been used to inform the regional climate vulnerability assessment presented in **Section 2** of this report.

The analysis has also established where common practice is occurring within industry, and provide examples of where climate change is impacting the sector and how organisation are responding to those impacts.

Approaches to assessing climate change risk and vulnerability are inconsistent across the industry. Some companies out of those reviewed have not yet undertaken or published results of risk assessments in this area, but all organisations acknowledged the important of this process and are taking action towards producing assessments. For those who have undertaken climate change risk assessments, most were produced by external consultants and in line with TCFD recommendations. Sources of data, scenarios and timeframes chosen, weather effects and categorisation of risk varies significantly between companies.

Climate change impacts will be experienced differently based on geographic location, and companies provided varying levels of detail on how this was considered for each of their sites.

Risks were predominantly viewed from a perspective of financial impact and typically considered impacts on physical infrastructure and assets. Recognition and assessment of impacts of host communities and local environments were included less frequently, although some companies did identify financial and reputational impacts if host communities are negatively affected.

Water management was considered to be one of the most significant risks, both the impacts of too much water from heavy rainfall and flooding, as well as the impacts of too little water and poor water quality.

The impacts of climate change on tailings storage facilities have the potential to cause significant damage to local environments and infrastructure should they overflow or encounter slope failure. This was typically viewed as high severity but low likelihood due to being able to incorporate for climate change within design and management of the structures.

Damage to transport infrastructure due to extreme weather events was commonly identified as having significant impacts in multiple ways, from supply of materials to worker access. Increasing temperatures and more frequent days of extreme heat can affect the efficiency of equipment, productivity and safety of workers, and increase cooling costs.

A broad range of climate change adaptation measures have been identified by companies as part of the risk assessment process.

Appendix C

Climate Impact Drivers

Table C1. Overview of the main climate impact drivers and a short description defined by the IPCC

Climate Impact Driver	Category and description
Heat and Cold	**Mean air temperature** Mean surface air temperature and its diurnal and seasonal cycles.
	Extreme heat Episodic high surface air temperature events potentially exacerbated by humidity.
	Cold spell Episodic cold surface air temperature events potentially exacerbated by wind.
	Frost Freeze and thaw events near the land surface and their seasonality.
Wet and Dry	**Mean precipitation** Mean precipitation and its diurnal and seasonal cycles. Chapters 2, 8 and Atlas.
	River flood Episodic high water levels in streams and rivers driven by basin runoff and the expected seasonal cycle of flooding.
	Heavy precipitation and pluvial flood High rates of precipitation and resulting episodic, localized flooding of streams and flat lands.
	Landslide Ground and atmospheric conditions that lead to geological mass movements, including landslide, mudslide and rockfall.
	Aridity Mean conditions of precipitation and evapotranspiration compared to potential atmospheric and surface water demand, resulting in low mean surface water, low soil moisture and/or low relative humidity.
	Hydrological drought Episodic combination of runoff deficit and evaporative demand that affects surface water or groundwater availability.
	Agricultural and ecological degradation Episodic combination of soil moisture supply deficit and atmospheric demand requirements that challenges the vegetation's ability to meet its water needs for transpiration and growth. Note: 'agricultural' vs. 'ecological' term depends on affected biome.
	Fire weather Weather conditions conducive to triggering and sustaining wildfires, usually based on a set of indicators and combinations of indicators including temperature, soil moisture, humidity and wind. Fire weather does not include the presence or absence of fuel load. Note: distinct from wildfire occurrence and area burned.
Wind	**Mean wind speed** Mean wind speeds and transport patterns and their diurnal and seasonal cycles. Chapters 2 and 12.
	Severe wind storm Episodic severe storms including extratropical cyclone wind storms, thunderstorms, wind gusts, derechos and tornadoes.
	Tropical cyclone Strong, rotating storm originating over tropical oceans accompanied by high winds, rainfall and storm surges.
	Sand and dust storm Storms causing the transport of soil and fine dust particles.

Climate Impact Driver	Category and description
Snow and Ice	**Snow, glacier and ice sheet** Snowpack seasonality and characteristics of glaciers and ice sheets including calving events and meltwater.
	Permafrost Permanently frozen deep soil layers, their ice characteristics, and the characteristics of seasonally frozen soils above.
	Lake, river and sea ice The seasonality and characteristics of ice formations on the ocean and freshwater bodies of water.
	Heavy snowfall and ice storm High snowfall and ice storm events including freezing rain and rain-on-snow conditions.
	Hail Storms producing solid hailstones.
	Snow avalanche Cryospheric mass movements and the conditions of collapsing snowpack.
Coastal	**Relative sea level** The local mean sea surface height relative to the local solid surface.
	Coastal flood Flooding driven by episodic high coastal water levels that result from a combination of relative sea level rise, tides, storm surge and wave setup.
	Coastal erosion Long term or episodic change in shoreline position caused by relative sea level rise, nearshore currents, waves and storm surge.
Open Ocean	**Mean ocean temperature** Mean temperature profile of ocean through the seasons, including heat content at different depths and associated stratification.
	Marine heatwave Episodic extreme ocean temperatures.
	Ocean acidity Profile of ocean water pH levels and accompanying concentrations of carbonate and bicarbonate ions.
	Ocean salinity Profile of ocean salinity and associated seasonal stratification. Note: distinct from salinization of freshwater resources.
	Dissolved oxygen Profile of ocean water dissolved oxygen and episodic low oxygen events.
Other	**Air pollution weather** Atmospheric conditions that increase the likelihood of high particulate matter or ozone concentrations or chemical processes generating air pollutants. Note: distinct from aerosol emissions or air pollution concentrations themselves.
	Atmospheric CO_2 at surface Concentration of atmospheric carbon dioxide (CO_2) at the surface. Note: distinct from overall radiative effect of CO_2 as greenhouse gas.
	Radiation at surface Balance of net shortwave, longwave and ultraviolet radiation at the Earth's surface and their diurnal and seasonal patterns.

Appendix D

Climate Vulnerability Assessment Methodology

D.1 Defining climate change risk

In order to understand the potential vulnerability of gold mining assets to CID hazards across each climate region, a qualitative assessment process has been developed that allows potential vulnerabilities to be 'scored' against the likelihood of the CID hazards occurring. This is described as the climate change vulnerability assessment.

The process allows a qualitative comparison and 'screening' of CIDs in each weather region to establish levels of comparative risk in terms of the acute and chronic nature of different hazards.

A 'rating' is developed for each CID against each asset defined within the conceptual gold mine model.
The climate vulnerability assessment looks at this interaction by assigning each interaction a consequence/severity of impact rating and multiplying the consequence score by the probability of the occurrence and timeframe of the predicted climate impact driver.

The rating/impact score is defined as the product of the three factors as illustrated in the equation:

Rating Score = Relevance and consequence of CID on asset x Confidence (probability) of CID occurring x Timeframe

Each climate hazard/event and (mine site) infrastructure component interaction is assessed to determine if the infrastructure component will be exposed to or interact with the climate hazard.

This considers the vulnerability to climate impact drivers are influence by the temporal nature of the event. These are considered either as long-term chronic hazards or acute hazards that are extreme server short-term.

Those interactions that are deemed to occur are carried forward in the assessment and assigned a consequence /severity of impact score. The higher the consequence/impact score, the greater the effect the climate hazard infrastructure interaction on that asset.

The relevance and consequence of impact rating is a measure of the expected damage and/or associated loss of service associated with the infrastructure component should the climate event occur and interact with the infrastructure. Consequence scores are supplemented by research undertaken within this study and presented in **Appendix B** of this report.

Table D1. Consequence rating of climate hazard

Impact consequence	Impact Score	Description of Impact/Consequence
Not application	0	No impact on assets not relevant.
Low	1	Tangible damage has occurred, but business is not interrupted, and objectives are not affected. Within tolerable limits. Typically defined by chronic hazards that are influenced over a long term.
Medium	2	Damage generates a considerable interruption pf process(es). Business objectives are affected. Add2itional budget would be required for its reparation.
High	3	Damage generates a non-tolerable interruption in process(es). Business objectives are affected. Could affect commitments with clients, market and/or regulator. Reparation could require addition budget and considerable time. Typically defined by acute hazards that are short term and severe by nature.

The confidence of the CID occurring is defined for each weather region. This has been converted to a numerical score, allocated as follows:

- high confidence = 3
- medium confidence = 2
- low confidence = 1.

The Timeframe factor represents when the impact will occur, defined as:

- already occurring = 3
- high probability emerging by 2050 as defined in RCP8.5/SSP5-8.5 = 2
- emerging after 2050 as defined in RCP8.5/SSP5-8.5 = 1.

The scoring mechanism allows a comparative analysis of potential impacts (but does not reflect whether a risk will or will not occur). A higher score presents a set of climate impact drivers that are more likely to be of greater relevance to each infrastructure element within each climate region.

Where a climate impact driver has been identified as not broadly relevant, that hazard has been removed from the model.

The vulnerability rating and potential proportional response is presented in **Table D2** below.

The ratings for the climate parameters were derived from available climate projection information, data, and literature research.

The numerical analysis has been used to represent the relative conceptual vulnerability of mining assets to each CID hazard. This qualitative analysis is presented in **Chapter 3.**

It should be noted that CID hazards are likely to increase in frequency and intensity. This will mean in the future recovery times between events are likely to be reduced, and multiple hazards may happen at once, resulting in compounding risks increasing vulnerabilities.

Compound risks have not been assessed directly. Where multiple hazards have been identified, the potential compound risk has been noted within the assessment.

Table D2. Consequence rating of climate hazard

Vulnerability	Score	Proportional response
Low	1-8	Routine procedures are required to address impacts typified by single chronic hazards being identified.
Medium	8-12	Requires management to assign responsibilities typified by multiple chronic hazards or less severe acute hazards.
High	18-27	Requires Management/Top Management attention typified by complex chronic hazards or severe acute hazards.

Appendix E

Climate Regions Summary

E.1.1 Africa

Africa has a number of different regions that are influenced by different climates, for example the Sahara (deserts), the coastal plains, savannah, rain forests and the African Great Lakes. Climate hazards will therefore vary locally as a result of the different geographies across the continent. However, changes to temperature (discussed above in 3.2.1) and precipitation are anticipated to affect all regions within Africa.

The CIDs of the African region include an increase in heavy precipitation hazards presenting acute impacts to mine sites, operations, and host communities from flooding events. In addition, the seasonal nature of CIDs in the region also requires further consideration – to enable, for example, better management of seasonal flooding and drought impacts.

In the southern African regions, local populations and mining operations are vulnerable to the identified hazards of droughts, aridity and the impacts of wildfires influence by weather.

Asia can be divided into five major geomorphologies: mountains, including the Himalayas and the Ural Mountain ranges; plateaus which are formed of deserts or river and lake systems; plains, steppes, and deserts; freshwater environments; and saltwater environments.

In Asia, wet and dry CIDs relate mainly to heavy precipitation and pluvial flooding events, again presenting acute impacts to mining assets, process and host communities from flooding events. Host communities are anticipated to be affected by all wet and dry CIDs including chronic risks from mean precipitation changes and aridity and acute risks from drought across west central Asia and east Asia.

Fire weather seasons are projected to lengthen and intensify particularly in the northern regions, posing a chronic risk to mining assets and host communities.

It is very likely that cold spells and frost days will decrease in frequency across Asian regions during the century. The decrease in snow and ice cover and melting permafrost poses chronic risk to mining activities, mainly in relation to excavation workings, in areas such as Siberia and far east Russia.

E.1.2 Australasia

In Australasia, wet and dry CIDs pose chronic risks from annual mean precipitation that is projected to increase in central and north-east Australia and in the south and west of New Zealand. Precipitation is projected to decrease in southern and eastern Australia as well as north and east New Zealand, posing a chronic impact from aridity affecting water supply for mines, as well as farmland and livestock mortality.

It has also been identified that host community mortality and mining infrastructure are vulnerable to acute hazards such as fire weather throughout Australia and New Zealand.

E.1.3 Central and South America

South America can be divided into four main geomorphologies: mountains and highlands, river basins, including the Amazon River basin which is the largest watershed in the world, and coastal plains which are extremely dry and include the Atacama Desert, and salt water coastal environments.

Mean precipitation is projected to change in a dipole pattern of oceanic currents across Central and South America with increases in precipitation to the north-east and north-west and decreases in the central north and south. Both mining activities and host communities are vulnerable to the effects of these chronic hazards.

Acute risks from river flooding, particularly in the wetter regions of central South America and the Amazon basin, are increasing and are anticipated to affect mining assets. In contrast, projections also show that the dry season may become longer, increasing acute hazards from aridity and chronic hazards from agricultural and ecological degradation in the same areas (central South America and the Amazon region), and across most of South America affecting host communities.

Weather that increases the potential for wildfires poses an acute hazard to infrastructure and local community mortality.

E.1.4 Europe

Europe can be divided into four main geomorphologies, western Uplands consisting of marshlands, lakes and fjords, North European Plain which is generally low lying and supports many rivers, Central Uplands which is heavily wooded and Alpine Mountains which include the Alps and Pyrenees Mountain ranges.

In Europe, wet and dry CIDs generally present both acute and chronic hazards on mining assets. Mechanical processes are expected to be vulnerable to increased fire weather hazards, heavy precipitation and pluvial flooding by causing, for example, damage to water supply, power and communication infrastructure. River flooding is projected to increase in central and western Europe, also posing an acute hazard where mining activities are reliant on either river systems or within the geography of flood risk.

An increase in aridity across Europe poses chronic hazards to wider communities and some elements of the mining process that are dependent on water supply. Local community access to water supplies in the Mediterranean is also anticipated to be vulnerable to chronic hazards from increasing frequency of ecological degradation and hydrological droughts.

E.1.5 North America

North America can be divided into the mountainous west which comprises the Rockies and temperate rain forests, the Great Plains toward the centre of the continent, comprising of grassland and prairie regions, the Canadian Shield which is formed of lakes and tundra and the varied eastern region which includes Appalachian Mountains and the Atlantic coastal plain.

Changes in North American wet and dry CIDs are largely increasing in precipitation to the north-east (more wet) and decreasing in the south-west (more dry), although heavy precipitation increases are widespread and aridity, agricultural and ecological degradation, and wildfire induced through weather are increasing across North America, particularly in summer.

Tropical cyclones, severe wind and dust storms in North America are shifting towards more extreme characteristics, showing heightened intensity rather than increased frequency, although specific regional patterns are still uncertain. These pose acute hazards to all mining assets including communication infrastructure, transport routes and local community mortality and housing stock.

To the north of the region, permafrost thawing is expected to extend geographically as well as in depth, posing chronic hazards to mining assets in relation to geology.

E.1.6 Small Islands

Small Islands of the Caribbean and Pacific are less likely to experience the same impacts from hot CIDs as other global regions that is noted in **Section 2,** however temperatures are still projected to increase and pose chronic hazards to host communities.

Rainfall trends vary spatially across the small islands, however it is anticipated that all mining activities and host communities will experience acute hazards from heavy precipitation and pluvial flooding, depending on the season.

There is an acute hazard from landslides due to heavy rainfall and tropical cyclones, however the evidence is too limited to determine if such hazards in these geographies will increase due to climate change.

Projections indicate that small islands will generally face fewer but more intense tropical cyclones although there is substantial variability across small island regions.

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