Climate Change Impacts on Mining Value Chain: A Systematic Literature Review

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Abstract Mining is becoming increasingly vulnerable to the effects of climate change (CC). The consequences of changing weather patterns, such as extreme weather events that can damage equipment, infrastructure, mining facilities, and operation interruption, are the source of the vulnerability. The new demand initiated by governments and international agreements put extra pressure on mining industries to update their policies to reduce greenhouse gas (GHG) emissions and adapt to CC, such as carbon pricing systems, renewable energy, and sustainable development. Most mining and exploration industries focus on reducing mining's impact and climate mitigation on CC rather than adapting to extreme weather events. Therefore, it is important to study and investigate the impacts of CC on the mining sector. This paper aims to study the challenges and strategies for adapting and mitigating CC impacts on mining using a systematic literature review (SLR). These results showed that most of the proposed models and strategies in the mining field are in the conceptual phase, and fewer are practical models.

Keywords Climate change · Adaptation · Mitigation · Mining

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U. Kumar et al. (eds.), *International Congress and Workshop on Industrial AI and eMaintenance 2023*, Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-3-031-39619-9_9

1 Introduction

The mining and metal sector contributes 4–7% of greenhouse gas (GHG) emissions globally, which can be exacerbated by increased mineral production (increasing by more than 450% by 2050) [1]. On the other hand, mining operations are vulnerable to the effects of CC. CC means variability that lasts long, generally for decades or longer [2]. For example, temperature variations, extreme precipitation, harsh weather, and storms pose various vulnerabilities to mining infrastructure and activities. The interaction between extreme climatic events and mining infrastructure can create vulnerabilities that may lead to risks and uncertainty that must be addressed long-term [3]. Therefore, there is a need to increase awareness, which helps stakeholders, practitioners, and regulators better understand the negative impact of mining activity (e.g., Carbon footprint) and the impacts of climate change on the mining sector to plan proactive measures to reduce the uncertainty. In addition, CC has significant implications for mining and regional and national economies. On the other hand, Fig. 1 shows that the CC response/ET is one of the main priorities for the mining sector in 2022 and 2023.

However, there is a lack of enough knowledge about how CC may affect important industrial processes, raising concerns about mining firms' capacity to maintain profitable operations.

Thus, the aim of this paper is to study the challenges and strategies (and models) for CC impacts on the mining sector using Systematic Literature Review (SLR). In this regard, the mainstream of the paper is considered to be the two main climate-resilient actions, namely climate adaptation and mitigation. Figure 2 illustrates these actions as follows:

- Climate adaptation: This entails planning for an uncertain future and taking action to lessen the effects of climatic changes [5]. Climate adaptation changes how we

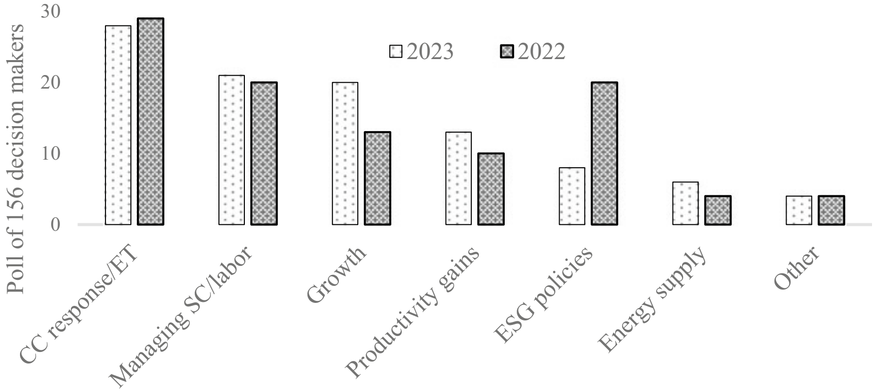

Fig. 1 The main priority for the mining sector (adapted from [4]), (ESG: Environmental, Social, and Governance, ET: Energy transition, SC: supply chains)

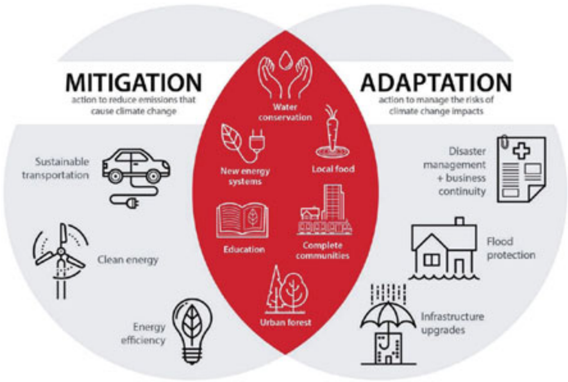

Fig. 2 Climate mitigation and adaptation [5]

live, work, and behave to lessen our vulnerability to the unavoidable effects of CC caused by past and ongoing greenhouse GHG emissions [6]. ISO 2019 defined CC adaptation as adjusting to the current and projected climate and its effects [7].

- Climate mitigation: Lowering GHG emissions through improving energy management (such as efficiency and conservation), implementing renewable energy projects, and promoting a low-carbon economy [5].

Companies, governments, and local communities will be impacted by the economic and environmental effects of climate change's effects on the mining industry. The mining industry may benefit from sustainable practices that minimize impact on the environment and local populations and open up new potential for development and innovation with the right adaptation and mitigation strategies. Thus, the review includes how CC impacts in Mining Operations (CCIMO) are perceived and which strategies/approaches have been used for CC adaptation and mitigation in the mining sector. The rest of the paper is organized as follows: The steps of the SLR approach are detailed in Sect. 2. As elucidated in Sects. 3 and 4, the utilization of SLR for CCIMO has been comprehensively explained. Section 5 is a discussion and conclusions.

2 SLR Methodology for CCIMO

Figure 3 shows the methodology for SLR in this paper. The methodology is divided into three phases: Planning, conducting, and Reporting the review [7]. In phase 1, the research questions must be defined, and keywords must be specifically set to locate scientific papers in designated databases. The data extraction strategy determines how data items are obtained. Phase 2 involves reviewing the scientific database to find potential documents and research. Primary studies are chosen based on inclusion and exclusion criteria. The, required data to meet research objectives extraction and

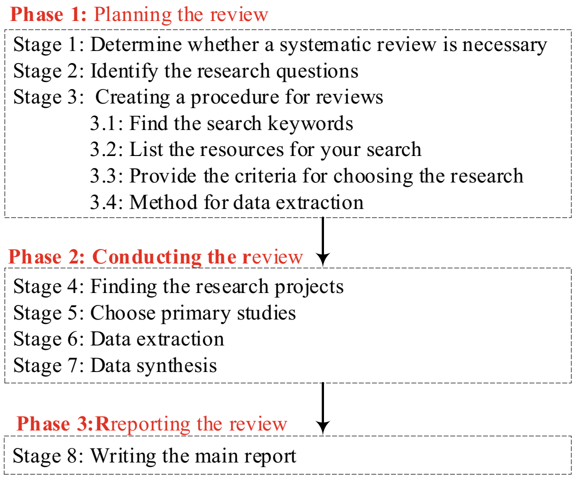

Fig. 3 SLR process phases [7]

synthesis [7]. The outcomes of the earlier phases should be published after the review process during phase 3.

Since the necessity of the review was discussed, the following research questions are defined to meet the aim of the study:

- RQ1: *How is CC perceived in the mining value chain? and what are the impacts (or challenges as risks and opportunities) of CC in the mining industry?*

The mining value chain includes firms, service providers, utility and infrastructure providers, local and/or state government organizations, and community groups.

- RQ2: *What approaches and strategies have the mining industry used to combat CC impacts, and how have climate adaptation and mitigation strategies been addressed?*

Making the right decisions in the face of existing challenges requires specialized, comprehensive, and multifaceted approaches arranged from the macro to the micro level. Thus, the models and methodologies offered for this purpose should be recognized before planning and decision-making. Then, appropriate strategies and decisions can be adopted based on the output of these approaches.

Based on the addressed research questions, search string terms are considered with Boolean operators (AND, OR) as: “climate change” OR “climate adaptation” OR “climate immigration” AND “mining” OR “mining operation”. Several research databases, such as The Multidisciplinary Digital Publishing Institute (MDPI), SpringerLink, Taylor & Francis, Wiley Online, WEB of Science, etc., have been used. In the next stage, the criteria for choosing the search were provided as follows:

- The included document should be prepared in English.
- Included studies need to be turned into a research paper and published.

- Unrelated research should be discarded based on title, keyword, abstract, and conclusion.
- The complete version of duplicated publications was included in the review process.
- The articles of the last two decades were examined based on the search statistics obtained from the Web of Science (WOS) and Scopus.
- Finally, data extraction and synthesis forms were used to gather data to answer study questions. The following is a list of the items on the data extraction form:
  - Research topic;
  - Publication date;
  - Presented definitions for CC and CC challenges for the mining sector;
  - Type and explanation of the concepts determine the CCIMO;
  - Type and description of the strategies used for CCIMO.

After that, the search was done using search sources and the search string starting in 2000. Primary studies were 42 related studies of all one. The results of reviewed articles explain the two main research questions, which will be discussed in Sects. 3 and 4.

3 Answer to RQ1: Impacts

The term “Climate Change” is used in the mining value chain to describe the long-term alterations in the planet’s climate brought on by human activities such as the combustion of fossil fuels, deforestation, and industrial operations. These actions raise GHG emissions, which trap heat in the planet’s atmosphere and negatively affect the ecosystem, including temperature increases, altered precipitation patterns, and sea level rise. In 2006, Irarrázabal identified CC’s significant impacts in the mining sector based on different scenarios. He showed that companies of all sizes must be essentially created comprehensive strategies to reduce GHG emissions. Such strategies should encompass large and established firms and smaller and newer organizations that may lack the resources for costly initiatives [6]. The mine production stage (from pre-mine planning through planning and development, production, post-production and closure, and post-mining) is most at risk from climate change [8]. Figure 4 explored the effects of significant weather events and climatic variations on a general mining process. These effects could be impacted directly or indirectly as follows [6, 8]:

- Primary (or direct) impacts: Physical effects such as flooding, erosion, landslides, debris flows, overflowing waste ponds, and threats to human life, property, revenue, and the environment are the majority of the direct effects.

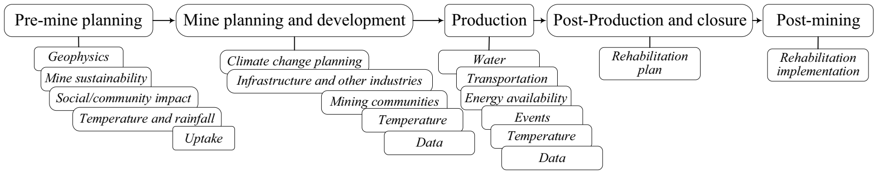

Fig. 4 Potential impacts of climate and extreme weather on mining practices [9]

- Secondary (indirect or 'knock-on') impacts: For instance, Mining access to land and labor can be affected by changes in population and resources. Local labor force shortages can result from a lack of water, electricity, dust, isolation, and tropical diseases. Mining operations, labor, transportation, communication, building infrastructure, and mine decommissioning are all projected.

These effects might favor or negatively influence future mining operations, equipment, assurance, economic stability, and health and safety conditions inside and around the mine. Thus, the effective elements of CC in the mining sector can be delineated through the following perspectives:

- The processing operations: Because mining is frequently a "heavily water-dependent" sector, rising water scarcity is a major concern [10].
- The site geography (condition of the property): There is a chance that steep slopes in permafrost overburden exposed for a long time will damage the stability of open-pit mine walls [11]. Permafrost thaw is a problem in all northern locations, especially when containment buildings have not been built to endure the faster melting expected by CC or to allow for long-term maintenance [12].
- Challenges to environmental management: For instance, risks associated with extreme rainfall and/or tailings dam collapse include polluted water flow into nearby communities, associated remedial costs, increased environmental responsibility, effects on community health and safety, and a large potential for reputational harm can be considered as some of the managerial challenges that need to be considered. Flooding and intense precipitation also run the risk of exposing sinkholes and causing or escalating acid rock drainage, all of which might have negative effects on water supplies [13].
- Dryer conditions could decrease water intake capacity and expose tailings to subaerial weathering, underscoring the urgent need for new technologies to combat the effects of CC. This is due to the limited amount of climate modeling data and continued reliance on permafrost in the design of retention facilities [14].
- It is essential that the planning for new mines and the closure and reclamation of existing ones consider the possible repercussions of CC as its effects become increasingly obvious [14].
- Increasing sea levels by more precipitation, altering storm patterns, and temperature changes in some places will be made possible or hindered access to distribution and supply chains (Transportation services to ports for export) [15].

- Changes in temperature, precipitation, and wind may all directly affect mines. For example, strong winds can damage electrical lines and high temperatures can lead to heat exhaustion in workers, and low precipitation can restrict water availability. These climatic factors also affect the intensity and frequency of natural hazards such as forest fires, avalanches, flooding, landslides, drought, and landslides [15].
- Surface mining and CC are potential threats to Environmental systems. For instance, mining and CC's effects harm delicate ecosystems like wetlands [16].
- The Arctic Climate Impact Assessment (ACIA) highlights the potential impacts of permafrost thawing on transportation, infrastructure, and economic development [11, 15].
- CC significantly impacts the water management infrastructure, waste containment systems, and hydrological, hydrogeological, and geochemical conditions influencing water flow and contaminant levels at mining sites. These changes can increase the risk of acid rock drainage and metal leaching, posing serious environmental threats [17].
- Lack of guidance and misunderstanding about how to respond among employees; conflicting emergency response guidelines; a lack of contingency plans for worst-case scenarios; poor communication within and across organizations and departments; and limited awareness of sensitivity to climatic stresses are some of the issues that need to be addressed [13].
- The mining industry faces mounting pressure to explore strategies to reduce its carbon footprint, including integrating renewable energy sources, owing to heightened scrutiny of the sector's greenhouse gas emissions and advancements in climate discourse [18].
- The life cycle costs associated with CC consequences: This is an important concern due to the long-lasting environmental consequences following mining activities and in the lifespan of mines. It may take hundreds of years, especially for large-scale mines, which disturb the physical balance of the land in the mining area and produce all kinds of waste (or Tailings) [19].
- The uncertain and long-term nature of the effects of climate change can create doubt among miners regarding their investment horizons [19].
- Large-scale mining operations, which are often significant sources of pollution, may be subject to more climate change-related regulations. As a result, investors may want to avoid investing in these mines.
- The mining industry risks being negatively affected by CC legislation that may be created without sufficient participation and awareness from all stakeholders involved in the mining chain [15].
- Managerial challenges, including cost management, organizational cultural attitudes to learning and change, and inflexible company policies and government regulations, can hinder adaptation and mitigation efforts [19].
- Effective land management strategies (Post-mining land use) that address the impacts of CC are crucial for successful mine reclamation operations [40].
- CC will multiply the mining supply chain risks by increasing the complexity of systems, particularly in newly industrialized and developed nations [18].

4 Answer to RQ2: Model/Approaches and Strategies

Mitigation and adaptation are essential and complementary strategies for the mining industry to coexist with the impacts of CC as they work together to reduce climate-related risks [41]. To effectively implement these strategies, design makers require practical approaches and models that can be put into action. Hereof, Table 1 provides the CC impact management methods and models chronologically, highlighting risk management and vulnerability assessment. As a summary of these models, it is evident that while mines must employ a two-pronged approach to addressing the issues posed by climate change, only 20% of the evaluated methods integrate adaptation and mitigation strategies. Also, the study of the currently used techniques demonstrates that most use an analytical mode. Even though these analytical techniques focus on particular CC effects, a holistic strategy has not yet been offered.

Entering into appropriate strategies against the effects identified by these models first requires identifying their main components. The key components of CC strategies are highlighted as [15]:

- Include climate-sustainable development in local and operational efforts.
- Develop practical measures for coping with the effects of CC with the host communities.
- Examine how enhancing local resilience through investments in ecosystem services.
- Consult with stakeholders to comprehend their recent worries.
- Launch industry-wide cooperation on regional adaption plans.

In these regards, climatic adaptations and mitigation strategies in the mining sector conducted by different researchers as follow:

Climate Mitigation Strategies:

- Accurate research and identification of CC-prone mining locations [19].
- Mines should be encouraged to use renewable energy through legislation, tax rebates, etc. [1].
- Some mitigation measures could be implemented at the operational level [1]:
  - Fuel switching (Hybrid diesel, out of diesel)
  - Energy efficiency (Lighting, motors, pumps, conveyors)
  - Renewable energy (Procurement, PPAs, on-site)
  - Battery storage (Energy storage, electric vehicles)
  - Artificial Intelligence (Analytics, machine learning)
  - Digitization (Data processing, interfaces)
  - Low-carbon electricity (Renewables, CCS, SMRs)
  - Ore processing improvements (Bulk processing efficiency)
  - Hydrogen fuel cells (Electricity, machinery)
  - Other (RD&D, grade engineering)

Table 1 Approaches for adaptation and mitigation in the mining sector

Researcher	Main approach, contributions	Category	Researcher	Main approach, contributions	Category
Auld and Maclver, 2006	"No regrets" and "adaptation learning" (conceptual) [20]	AD	Chavalala, 2016	Mixed-method (analytical) [21]	AD
Pearce et al., 2011	Vulnerability-based (conceptual) [22]	AD	Odell et al., 2018	Nature-society relationships (conceptual) [23]	AD&MI
Riaza et al., 2007	Hyperspectral imaging (analytical) [24]	AD&MI	Hotton et al., 2018	Capillary barrier effects (analytical) [25]	MI
Garnaut, 2008	Vulnerability-based (conceptual) [9]	AD	Kosmol, 2019	Vulnerability based on Notre Dame Global Adaptation Country Index (analytical) [26]	AD
Pearce et al., 2009	Two-stage vulnerability-based (conceptual) [13]	AD	Nunfam et al., 2019	Contemporaneous mixed methods based on risk (analytical) [27]	AD
Rayne et al., 2009	Risk of water quality (conceptual-analytical) [28]	MI	Mavrommatis et al., 2019	Regional CC risks (analytical) [29]	AD
Pearce et al., 2009	General circulation models (conceptual) [13]	MI	Mavrommatis and Damigos, 2020	Bottom-up survey-based (analytical) [30]	AD&MI
Ford et al., 2011	Questionnaire for threats that CC (analytical) [31]	AD	Sun et al., 2020	Integrated climate risk index (CRI) based on return on total assets (analytical) [32]	AD
Mason et al., 2013	Risk-based (conceptual) [33]	AD	MAC, 2021	Adaptation measures (conceptual) [3]	AD
Loechel et al., 2013	Questionnaire for attitudes and actions about CC adaptation (analytical) [34]	AD	Bresson et al., 2022	Risks and vulnerabilities (analytical) [35]	AD

(continued)

Table 1 (continued)

Researcher	Main approach, contributions	Category	Researcher	Main approach, contributions	Category
Anawar, 2013	Acid mine drainage (AMD) (analytical) [36]	AD	Xie and van Zyl, 2022	Revised the mine reclamation design (conceptual) [37]	AD&MI
Baisley et al., 2016	Risk-based (analytical) [38]	MI	Ngoma et al., 2023	The endogenous latent factors and exogenous latent variables in the partial least squares structural equation modeling technique (analytical) [39]	AD&MI
Rüttinger and Sharma, 2016	Risk by iModeler and vulnerability (analytical) [18]	AD			

AD: Adaptation, MD: Mitigation, AD&MI: Adaptation-mitigation

Climate Adaptations Strategies:

- Information and communication technology (ICT) innovation adoption as part of adaption measures may lessen the susceptibility and exposure of the mining sector to CC catastrophe risks [42].
- Improved operational safety and resilience under projected future climate conditions through better planning, design, building, and maintenance [19].
- Mining contracts must consider CC concerns (national adaptation plans and climate adaptation guidelines), especially for areas highly vulnerable to the effects of CC [1].
- The mining plan's tailings dam design must adhere to the most recent international safety requirements, and ongoing maintenance and clean-up procedures must be followed [1].
- Applied engineering solutions can play a critical role in achieving climate resilience, which refers to the ability of communities and systems to withstand and recover from the impacts of CC [19].
- At the operational level, several adaptation activities could be carried out [1]:
  - Special pumps must be set up at the mine site to remove the water.
  - Mines open early if winters are short and close early if winters are long
  - Autonomous operations (Drilling, loading, haulage)
  - Fugitive emissions reduction (Ventilation Air Methane, CH_4 capture, and use)
  - Electrification (Mine processes, transport)
  - Tailings management (Emissions capture and mineral carbonation)
  - Water management (Treatment technologies)

Jointly for Adaptation and Mitigation Strategies:

- Governments could mandate that mining corporations account for all direct, indirect, and induced impacts on forests at every step of operations to limit forest conversion [1].
- Governments should stipulate clearly when granting mining firms access to water [1].
- At the project's start, closure plans incorporating climatic risks should be offered and submitted along with the environmental and social impact assessment.
- Use educational initiatives to raise knowledge of and capacity to address urgent threats, particularly in isolated communities, like rising flooding, bushfires, and diseases from mosquitoes [19].
- Impacts that have been identified cascading down, up, and across the supply chain (e.g., a higher frequency of intense rain events (in summer) may cause more transportation disruptions on the roads), which would reduce mining productivity at this time of year and have an impact on jobs and communities (Transport → mining → human resources → community)) [19].

5 Discussion and Conclusion

This article streamlines the actions performed on climate mitigation and climate adaptation in the mining sector to address climate change challenges. The various climate mitigation and adaptation approaches and strategies are presented based on this streamlining. The review discovered that risks and uncertainties associated with the CC must be considered to make informed decisions. Once these risks have been identified, examining how each element or mineral may behave under the given circumstances is essential. On the other hand, CC can have a long-term/gradual impact on mines operation, requiring comprehensive planning to tackle CC challenges.

The first research question explored the impacts of CC on mining activities. The challenges for mitigation and adaptation actions include low-level awareness of climate change impacts in mining, a lack of technical knowledge, high capital costs, and existing rules and regulations, necessitating a multidimensional approach to education and cultural advancement, encompassing political, legal, and practical aspects.

The second research question explored the current CC impacts and associated assessment methods. This section divided the survey into analytical and conceptual approaches. Our survey on climate adaptation and mitigation revealed a critical need for long-term planning in the mining industry. In addition, our analyses show most mining and exploration industries focus on reducing mining's impact and climate mitigation action rather than adapting to extreme future weather events. Therefore, there is a need to emphasize more on climate adaptation action to fulfill the future demand and smooth transition toward sustainable mining development.

According to the literature review done in mining engineering, the knowledge base in this area is relatively new, emphasizing bringing attention to current problems rather than providing practical solutions. This issue is also evident in the development of proposed models, which lean more toward raising awareness of concerns than toward useable solutions. While strategy and macro-level decisions are crucial for combating CC, operational planning is becoming increasingly vital to support them. As a result, managers and decision-makers must concentrate on creating specific plans and initiatives that can successfully handle the risks posed by CC. Most of today's mines have a short lifespan, and CC mitigation and adaptation actions are not considered while designing and operating mining activities. These mines need to adapt to shifting climatic circumstances from an operational perspective and consider mitigation concerns for the foreseeable future. Investigations showed that one of the most important tools for implementing mitigation and adaptation programs is increasing awareness of different phases of mining activities and their associated value chain. In this regard, the mining industry still requires extensive research to develop practical and operational approaches to overcoming the challenges.

References

1. Mebratu-Tsegaye T, Toledano P, Dietrich Brauch M, Greenberg M (2021) Five years after the adoption of the Paris Agreement, are climate change considerations reflected in mining contracts?
2. Geneva S (2013) Intergovernmental panel on climate change, 2014. Working group I contribution to the IPCC fifth assessment report. Climate change, vol 8
3. MAC (2021) Guide on climate change adaptation for the mining sector. The Mining Association of Canada. Accessed 17 Mar 2023
4. Campbell R et al (2023) Mining & metals 2023: lifting the fog of uncertainty. White & Case LLP. Accessed 11 Mar 2023
5. Climate resilience strategy—mitigation & adaptation action plans. Official web site of The City of Calgary, Calgary, 18–00577050, 2018
6. Irarrázabal R (2006) Mining and climate change: towards a strategy for the industry. J Energy Nat Resour Law 24(3):403–422
7. Kitchenham B, Charters S (2007) Guidelines for performing systematic literature reviews in software engineering. Technical report EBSE-2007-01, Keele University and University of Durham
8. Hodgkinson J et al (2010) Climate adaptation in the Australian mining and exploration industries
9. Garnaut R (2008) The Garnaut climate change review. Cambridge, Cambridge
10. Dontala SP et al (2015) Environmental aspects and impacts its mitigation measures of corporate coal mining. Procedia Earth Planet Sci 11:2–7
11. Instanes A (2006) Impacts of a changing climate on infrastructure: buildings, support systems, and industrial facilities. Presented at the 2006 IEEE EIC climate change conference. IEEE, pp 1–4
12. Prowse TD, Furgal C (2009) Northern Canada in a changing climate: major findings and conclusions. Ambio 38(5):290–292
13. Pearce T et al (2009) Climate change and Canadian mining: opportunities for adaptation
14. Smith M (2013) Assessing climate change risks and opportunities for investors—mining and minerals processing sector. Australian National University, Canberra
15. Nelson J, Schuchard R (2011) Adapting to climate change: a guide for the mining industry. Business for Social Responsibility, vol 10

16. Phillips J (2016) Climate change and surface mining: a review of environment-human interactions & their spatial dynamics. Appl Geogr 74:95–108
17. Nordstrom DK (2009) Acid rock drainage and climate change. J Geochem Explor 100(2–3):97–104
18. Rüttinger L, Sharma V (2016) Climate change and mining: a foreign policy perspective
19. Loechel B et al (2013) Climate adaption in regional mining values chains: a case-study of the Goldfields-Esperance Region, Western Australia. CSIRO
20. Auld H, Maclver D (2006) Changing weather patterns, uncertainty and infrastructure risks: emerging adaptation requirements. Presented at the 2006 IEEE EIC climate change conference. IEEE, pp 1–10
21. Chavalala B (2016) An assessment of South Africa's coal mining sector response to climate change adaptation demands. Thesis, University of South Africa, South Africa. Accessed 20 Mar 2023
22. Pearce TD et al (2011) Climate change and mining in Canada. Mitig Adapt Strat Glob Change 16:347–368
23. Odell SD et al (2018) Mining and climate change: a review and framework for analysis. Extr Ind Soc 5(1):201–214
24. Riaza A et al (2007) Pyrite mine wastes hyperspectral monitoring as a tool to detect climate change. Presented at the 10th international symposium on physical measurements and signatures in remote sensing, ISPMSRS07. WG, pp 12–14
25. Hotton G et al (2018) Assessment of CCBE performance with climate change: case study of the Lorraine mine site. Presented at the proceedings tailings and mine waste
26. Kosmol J (2019) Climate change impacts on mining and raw material supply chains. German Environment Agency. www.umweltbundesamt.de/en
27. Nunfam VF et al (2019) Climate change and occupational heat stress risks and adaptation strategies of mining workers: perspectives of supervisors and other stakeholders in Ghana. Environ Res 169:147–155
28. Rayne S et al (2009) Analytical framework for a risk-based estimation of climate change effects on mine site runoff water quality. Mine Water Environ 28:124–135
29. Mavrommatis E et al (2019) Towards a comprehensive framework for climate change multi-risk assessment in the mining industry. Infrastructures 4(3):38
30. Mavrommatis E, Damigos D (2020) Impacts of climate change on the Greek mining industry: perceptions and attitudes among mining industry practitioners operating in the Cyclades. Euro-Mediterr J Environ Integr 5(2):28
31. Ford JD et al (2011) Canary in a coal mine: perceptions of climate change risks and response options among Canadian mine operations. Clim Change 109:399–415
32. Sun Y et al (2020) The impacts of climate change risks on financial performance of mining industry: evidence from listed companies in China. Resour Policy 69:101828
33. Mason LM et al (2013) Adapting to climate risks and extreme weather: a guide for mining and minerals industry professionals. National Climate Change Adaptation Research Facility
34. Loechel B et al (2013) Climate change adaptation in Australian mining communities: comparing mining company and local government views and activities. Clim Change 119:465–477
35. Bresson É et al (2022) Climate change risks and vulnerabilities during mining exploration, operations, and reclamation: a regional approach for the mining sector in Québec, Canada. CIM J 13(2):77–96
36. Anawar HM (2013) Impact of climate change on acid mine drainage generation and contaminant transport in water ecosystems of semi-arid and arid mining areas. Phys Chem Earth, Parts A/B/C 58:13–21
37. Xie L, van Zyl D (2022) How should mine reclamation design effectively respond to climate change? A mini review opinion. J Geosci Environ Prot 10(12):117–125
38. Baisley A et al (2016) Climate change and mine closure—a practical framework for addressing risk. In: Proceedings IMWA, pp 35–42

39. Ngoma RGTM et al (2023) The impact of the mining equipment, technological trends, and natural resource demand on climate change in Congo. Sustainability 15(2):1691
40. Cottrell L, Stowe C (2021) Climate change and extreme weather: how can mine action programs adapt to our changing environment? J Conv Weapons Destr 25(2):6
41. OECD Publishing (2009) Integrating climate change adaptation into development co-operation: policy guidance. Organisation for Economic Co-operation and Development
42. Aleke BI, Nhamo G (2016) Information and communication technology and climate change adaptation: evidence from selected mining companies in South Africa. Jàmbá: J Disaster Risk Stud 8(3):1–9