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Original article

Climate risk perception, management, and adaptation in the Nordic mining sector

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ABSTRACT

Climate change can affect the mining sector in various ways. Physical impacts can be a threat to mines and personnel, transport infrastructure and supply chains, while the low-carbon transition may entail transition risks stemming from e.g., the need to respond to mitigation and adaptation policies, as well as opportunities in the form of increased metal and mineral demand. However, there is little knowledge of how mining companies perceive, manage, and respond to risks related to climate change. To address this knowledge gap, we examined annual and sustainability reports from 2019 for active metal mines in Finland, Sweden, and Norway. Through a structuring qualitative content analysis, we analysed the mining companies' self-reported experience of and expectations for climate change impacts and risks, as well as adaptation and management activities taken or planned. Our findings indicate that physical impacts of climate change are not perceived as a major risk. In contrast, mitigation activities and reactions to climate policies play an important role, at least for some of the companies. Hence, the mining sector would benefit from more stringent risk reporting regulations and distinctive guidelines, as well as more research on the direct and indirect climate change impacts.

1. Introduction

Climate, especially a changing one, is a critical factor for mining. Changing climatic conditions can directly affect operations at mining and mineral processing sites, but they can also have effects on related infrastructure, the surrounding environment, pre-mining and post-mining activities, and value chains in the mining sector (Pearce et al., 2011; Phillips, 2016; Sairinen et al., 2017; Odell et al., 2018).

A changing climate with higher temperatures and hydrological changes can be a threat to mine personnel, mines, tailing dams and restored former mining areas (Pearce et al., 2011; Baisley et al., 2016; Odell et al., 2018; Nunfam et al., 2019). Leakages and heavy rain can lead to the release of mining and mineral processing water into the environment with negative consequences for the water quality in the surroundings and causing degradation of the environment (Pearce et al., 2011; Sharma and Franks, 2013; Sairinen et al., 2017). Higher temperatures and increased precipitation can also negatively impact the relevant transport infrastructure and built infrastructure at the mining site (Pearce et al., 2011). These physical impacts can lead to higher transportation costs, additional remediation costs, and eventually the bankruptcy of mining companies (Pearce et al., 2011; Franks et al., 2014; Phillips, 2016; Sairinen et al., 2017).

In addition to direct climate change impacts, mining companies are exposed to changes in the political economy context they are operating in. Climate change can trigger changes in legal settings, policies, market conditions, and investors' and civil society's attitudes towards mining activities (Odell et al., 2018; Gustafsson et al., 2022). From a private sector's perspective, these changes can be described as transition risks.

Transition risks can be defined as risks related to the transition to a low-carbon society, including policy risks stemming from the need to respond to mitigation and adaptation policies, legal or liability risks from, for example, insufficient risk disclosures, market risks following changes in the demand for and supply of certain metals and minerals, technology risks related to the emergence of low-carbon technologies that may change the competitiveness of companies, and reputational risks from a shift in perceptions among customers or communities of what constitutes sustainable industries (Clapp et al., 2017; TCFD, 2017; Gjesdal and Kristiansen, 2019). For instance, there is considerable policy

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pressure to reduce greenhouse gas emissions from mining operations, which can be very energy intensive (Lee et al., 2020). This may incur increased costs, negatively affecting the competitiveness of companies and the potential for job creation (Peñasco et al., 2021). The low-carbon transition can also provide opportunities for the mining sector; a shift towards renewable energy production (e.g., wind and solar) and the use of low-carbon technologies (such as electric vehicles) will significantly increase the demand for many metals (e.g., aluminium, copper, lithium, cobalt, nickel and rare earth elements) (World Bank, 2020; International Energy Agency, 2021). At the same time, the increased extraction of metals and minerals will put pressure on the mining industry to improve environmental, social and governance (ESG) reporting procedures and increase its transparency (Lee et al., 2020). In short, the mining sector will experience physical risks from exposure to climate change impacts, as well as a range of transition risks and opportunities related to the building of a low-carbon society.

Adaptation is a process of adjustment to the changing climate and its effects (Schipper et al., 2014), and in the private sector, this is often considered in terms of risk management, i.e., to reduce direct climate risks and other related risks or consequences on operational or business activities (Averchenkova et al., 2016). Even though the need for adaptation to climate change within the mining sector has been recognised on a general level (ICMM, 2013; IISD, 2014) and frameworks for the assessments of climate change impacts and adaptation are available (ICMM, 2013; Mavrommatis et al., 2019), explicit climate risk management or adaptation measures have been rare or at least not publicly reported (Baboukardos et al., 2021). For many representatives of the mining sector, climate change has been a minor issue, and mining sites and operations have been planned with the assumption of a static climate, as studies from Canada, Australia, and Greece show (Ford et al., 2010; Pearce et al., 2011; Loechel et al., 2013; Mavrommatis and Damigos, 2020). Although research has identified climate change as a relevant topic for the mining sector, companies do not appear to have shown any deeper interest in the consequences of or adaptation to a changing climate, except for the forecasted increases in raw material demand by manufacturing industries related to the move towards a low-carbon society.

Odell et al. (2018) identified only 28 peer-reviewed articles addressing climate change and mining predominantly in North America and Australia. Literature is available that could benefit the mining sector's climate change adaptation, although not explicitly focusing on it. In particular, mine tailings, water management and mine closures have been well researched (Lottermoser, 2007; Edraki et al., 2014; Kossoff et al., 2014; Gao et al., 2017; Savolainen et al., 2019; Hancock, 2021). For example, heavy precipitation is reported to be the most common factor in tailings dam failure in Europe and worldwide (Rico et al., 2008).

In the Nordic countries, the combination of a pronounced change in climate, the regional importance of mining, and the increasing demand for metals and minerals in the low-carbon transition create a need for more detailed knowledge beyond the general recognition that the mining sector and raw material supply are vulnerable to climate change and would benefit from adaptation measures. In particular, there is little knowledge of how mining companies perceive the impacts of rising temperatures and changing precipitation patterns on mining (including the different stages of exploration, development, operation and closure), or of the potential economic, social and environmental consequences. Moreover, the companies' views on the transition towards a low-carbon society are not well reported.

To address this knowledge gap, our study asked how the Nordic metal mining industry perceives and is responding to climate change-related impacts. To answer this question, we analysed the self-reported climate change impacts, actions and adaptation activities in annual and sustainability reports by mining companies in the three Nordic countries that have metal mines, i.e., Finland, Norway and Sweden.

2. Physical impacts of climate change and transition risks for mining in Northern Europe

Climate change is expected to be more pronounced in Northern Europe compared to other European areas, with a substantial increase in temperatures and precipitation. The duration of thermal winters is expected to shorten by more than a month and thermal summers to lengthen by almost a month by mid-century, assuming 2-degree warming (Ruosteenoja et al., 2020). The Interactive Atlas of the 6th IPCC Assessment Report indicates that warming in Northern Europe could be in the range of 1.9–4.3 °C (5th and 95th percentile), with a median of 2.8 °C by the end of the century if global warming remains within 2 °C compared to pre-industrial values (Gutiérrez et al., 2021; https://interactive-atlas.ipcc.ch/). Precipitation could increase by 7% (2.1–11.3%) for the same period. The increase in temperatures and precipitation is expected to be more pronounced in winter than in the other seasons of the year. Higher temperatures and precipitation can increasingly strain infrastructure, possibly leading to dam failures and an increased discharge of mining and mineral processing water into the environment (Rico et al., 2008; Pearce et al., 2011; Phillips, 2016).

The transition towards a low-carbon society will essentially include fundamental changes in how we produce, use and store energy. Such a major technological change that affects the entire society and industry will also lead to the emergence of new and rapidly increasing demands for a very large range of mineral-based raw materials (Bobba et al., 2020; Hund et al., 2021). Recycling will increase and cover part of the future raw material demands of society, but much larger volumes of mineral-based raw materials are likely to be needed than what can possibly be accessed through recycling. Hence, mining will remain the primary source of necessary metals and minerals, while competition between industrial sectors for all raw materials will increase (Hund et al., 2021; IEA, 2021). Resources in the Nordic countries have the potential to cover a part of this increase in demand (Eilu et al., 2021). However, if not sufficiently prepared for, a rapid increase in metal and mineral utilization could leave the mining industry struggling to keep up with rising demand, causing price spikes and even the depletion of the currently known reserves by 2050 (Lee et al., 2020; Junne et al., 2020).

At the same time, the mining sector is an important regional economic pillar. This is mainly seen in regions where other industries do not provide significant employment, including the Nordic countries, and especially Finland and Sweden (Eurostat, 2021). In addition, mining technology is a significant employer and forms a major share of the local economy in, for example, Finland, Sweden, Germany and France (Löf et al., 2017; Hokkanen et al., 2020). Moreover, the European Commission has highlighted the importance of mining in Europe, and it has strategic interest in supporting the mining industry, as it aims at reducing the EU's dependency on imports of ores and metals, as well as recognising the need to reduce the environmental, social, and health impacts of mining (EIP Raw Materials, 2013; Blengini et al., 2020; Bobba et al., 2020; European Commission, 2020; Sidorenko et al., 2020).

Transition risks related to climate policy, emission reduction demands and ESG reporting cannot be neglected. Switching from fossil fuels to renewables as a measure to reduce emissions from mining operations raises new questions about the security of energy supply (Scholten et al., 2020). Political enforcement tools for reducing emissions include the emission trading scheme of the European Union (2003/87/EC), which applies to most industrial mining installations due to their size, while special treatment related to the risk of carbon leakage has been relatively widely applied in the mining sector thus far. The current list of sectors at risk of carbon leakage for the period 2021–2030 includes the mining of iron ores and other non-ferrous iron ores (2019/708/EU).

Legal requirements for the mining sector regarding adaptation to climate change in Europe derive from at least three different areas of legislation (climate, environmental impact assessment (EIA) and corporate social responsibility (CSR)). Based on the requirements of the

Paris agreement, the European Climate Law and the national Climate Laws (LOV-2017–06–16–60; FOR-2017–06–21–854; FINLEX 609/2015; 2021/1119/EU), Sweden, Finland and Norway report on their adaptation and mitigation actions to the European Commission. Additionally, public and private sectors in Sweden and Finland are obliged to follow the EU directive on EIA, updated in 2014, and the respective national EIA laws (2011/92/EU; 2014/52/EU; SFS 2020:694; FINLEX 252/2017; FOR-2017–06–21–854), and in Norway, the EIA regulation (FOR-2017–06–21–854) requires new mining projects to assess the vulnerability of the project to climate change impacts at different stages. The non-financial reporting directive in the EU and the European Economic Area (EEA) countries (incl. Norway) applies to large, listed companies (>500 employees) (2014/95/EU). The impact of non-financial reporting on the behavior of European companies is widely assessed to be low (Monciardini et al., 2020), and the climate laws (EU and national) have so far not led to the regulation of adaptation measures by private companies. The new climate laws (EU and national) and the EU taxonomy (for sustainable activities) are expected to enhance the adaptation reporting of the private sector.

In addition to the EU non-financial reporting directive, EIA legislation and national CSR legislation, the private sector's own CSR policies set requirements for climate risk and risk management reporting. Transparency with regards to climate risk exposure reporting, which has thus far been voluntary, can contribute to the legitimacy of mining activities and is valued by long-term investors (Pellegrino and Lodhia, 2012; Flammer et al., 2021). The standards and recommendations provided by the Global Reporting Initiative (GRI), the Task Force on Climate-related Financial Disclosures (TCFD) and the Carbon Disclosure Project (CDP) are widely used.

The GRI standards provide guidance on what types of information about economic, social and environmental impacts shall be disclosed. The GRI framework also offers specific guidelines on how to report climate-related risks and opportunities, including physical and regulatory risks or opportunities, potential financial consequences and risk management methods (Global Reporting Initiative, 2020, especially standard GRI 201–2). Analysis according to the TCFD recommendations includes exposure to both physical risks and transition risks, and covers the themes of governance, strategy, risk management, and metrics and targets (TCFD, 2020). The aspects covered by reporting according to the CDP include laws and regulations, technology and reputational risks, as well as acute physical and chronic physical risks related to climate change (CDP, 2020).

3. Materials and methods

We selected Nordic metal mines in operation in 2019, which narrowed the scope to mines in Sweden, Finland and Norway. The case selection was based on information provided by the Fennoscandian Ore Deposit Database (FODD) (Eilu et al., 2019) and the information was cross-checked with national sources and personal communications. The definition of metal mines coincides in all three countries and provided a clear-cut dataset. However, the definitions for industrial minerals and building materials and the differentiation between quarrying and mining vary between countries. Small-scale artisan mining differs substantially from industrial mining and has different reporting requirements. Therefore, we focused on the companies and metal mines listed in Table 1.

This study was based on the analysis of annual and sustainability reports for the (economic) year 2019 of the mining companies that operate and own the selected mines. To the best of our knowledge, these documents are the single most informative publicly available documents—apart from environmental impact assessment (EIA) reports—providing information on the private companies' experience of and expectations for climate-related risks and on their actions to tackle these risks. However, there were no EIA reports according to the updated national EIA legislation (including climate-related impacts) for the Nordic metal mines in operation in 2019. The purpose of the public annual report is to inform shareholders of the company's financial condition and operations over the previous year, often including detailed descriptions of the mine site activities, including possible risks and losses (Stanton and Stanton, 2002).

Annual and sustainability reports of mining companies were used as material to gain a dual perspective on the adaptation needs and activities. All but one of the companies in the scope of this study were legally bound to provide at least the annual report. Half of the companies also provided the sustainability report or similar, e.g., an environmental report, as part of the non-financial reporting (2014/95/EU).

We considered adaptation as measures taken or planned by a mining

Table 1
Companies with active metal mines in Finland, Norway and Sweden in 2020, and documents analysed from each company.

Company	Listed / not listed	Analysed documents	No. of mines*	Main commodities	Annual revenue 2019 (million €)**
Agnico Eagle Mines Ltd	Toronto and New York	Annual Report 2019, Sustainability Report 2019	1	Gold	2228
Boliden AB	Stockholm	Annual & Sustainability Report 2019	8	Zinc, Copper, Nickel, Gold, Silver, Lead, Cobalt, Platinum, Palladium	4779
Dragon Mining Ltd	Hong Kong	Annual Report 2019	3	Gold	33
First Quantum Minerals Ltd	Toronto	Annual Report 2019, Environment, Safety & Social Data Report 2019	1	Copper, Zinc	3631
Kaunis Iron AB	Unlisted, Swedish	Annual Report 2019, Environmental Report 2019	1	Iron ore	156
Kronos Worldwide Ltd	Unlisted, USA	Annual Report 2019	1	Titanium	1546
LKAB	Unlisted, Swedish	Annual & Sustainability Report 2019	4	Iron ore	2991
Lovisagruvan AB	Nordnet	Annual Report 2019	1	Zinc, Lead, Silver	5
Lundin Mining Corporation	Toronto and Stockholm	Annual Information Form 2019, Sustainability Report 2019	1	Zinc, Lead, Copper	1699
Mandalay Resources Corporation	Toronto	Annual Information Form 2019	1	Gold	96
Outokumpu Oyj	Helsinki	Annual Report 2019	1	Chrome	5717
Rana Gruber As	Unlisted, Norwegian	No reports available for 2019	1	Iron ore	110
Sotkamo Silver AB	Helsinki and Stockholm	Annual Report 2019	1	Silver, Zinc	19
Terrafame Oy	Unlisted, Finnish	Sustainability Review 2019, Financial Review 2019	1	Nickel, Zinc, Cobalt, Copper	310

* Includes only mines in the Nordic countries. A map of mines is provided in Fig. 1.
** Revenue is for the whole company. The figures are converted to € using exchange rates of 31 December 2019.

company in response to the direct physical impacts on mining activities from climatic stressors (e.g., extreme weather events) and indirect impacts (Groundstroem and Juhola, 2019) on the different stages of the mining activities (pre-mining, mining, post-mining) (Tolvanen et al., 2019). The typologies of adaptation measures are multiple and we focused on the timing (reactive or anticipatory) with respect to the climate-related risk/impact and the trigger of the adaptation measures (experienced/anticipated climate impact or transition risk) (Tompkins et al., 2010; Holman et al., 2019) as the defining features of adaptation types. Mitigation measures and responses to transition risks (related to climate policies, regulations, reputation and markets) that affect the business activities were considered as own categories (Gasbarro et al.,

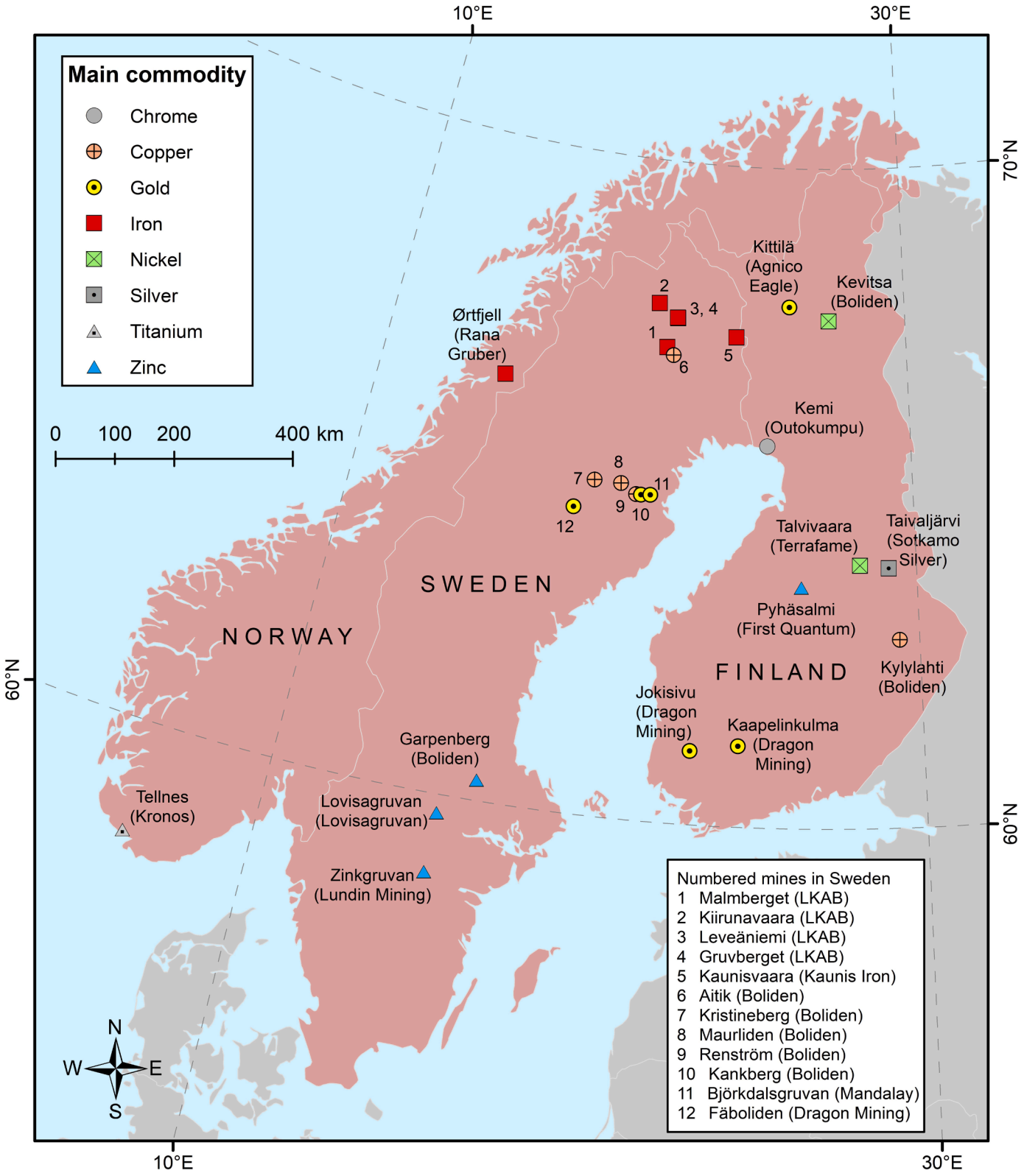

Fig. 1. Metal mines in Finland, Norway and Sweden active in 2020.

2017).

We assessed the types of climate impacts addressed in the documents and the types and level of adaptation measures reported using a structuring qualitative content analysis of climate and weather references in the documents (Mayring, 2014, 95–103). Three coders (authors 1.–3.) independently identified the references based on automated and manual searches. Search terms were developed collaboratively on the basis of, firstly, preliminary test coding performed independently (a single document coded by all) and comparatively assessed with *Atlas.ti* inter-coder agreement analysis, and secondly, iteratively along the course of the first round of searches in all documents. All coded sections referring to the same activity were merged to avoid double counting of individual activities. This was necessary because some individual activities were mentioned up to ten times in a single report. A coding cookbook provided a detailed description for each coded category and examples of the application of the codes (see supplementary material).

4. Results

Many of the companies that operate metal mines in the Nordic countries are internationally active. This means that reported activities cannot always be attributed to the Nordic countries. Many of the reported activities either on a general level affect operations in all countries or they are specifically targeted at mines and production plants outside the Nordic countries. Activities could be attributed to the Nordic countries if the company was exclusively or predominantly active in the Nordic countries (Boliden, Dragon Mining, Kaunis Iron, LKAB, Sotkamo Silver, Terrafame) or if the activity was specifically targeted at a mine or other facility in the Nordic countries. Only Boliden, LKAB and Terrafame reported a noteworthy number of activities. Other internationally active companies with more than three reported individual activities were Agnico Eagle, Lundin Mining and Outokumpu (Fig. 2).

Of all reported activities, 56% were targeted at the Nordic countries. The majority of these activities were reported by Boliden, LKAB and Terrafame. These activities predominantly focused on mitigation and responding to transition risks (Fig. 2), whereas adaptation to climate change directly was found to be more prominent outside the Nordic countries (Fig. 3).

4.1. Adaptation to climate impacts

The companies that were included in our analysis only reported a few past climate and weather impacts in the Nordic countries. All the reported impacts were related to snow melt in the spring and higher than average precipitation. These events led to flooding of infrastructure and a higher amount of water in the mining facilities. For example, a higher amount of cleaned process water from the leach pads had to be released, which resulted in exceeding the sulphate quota for discharged water.

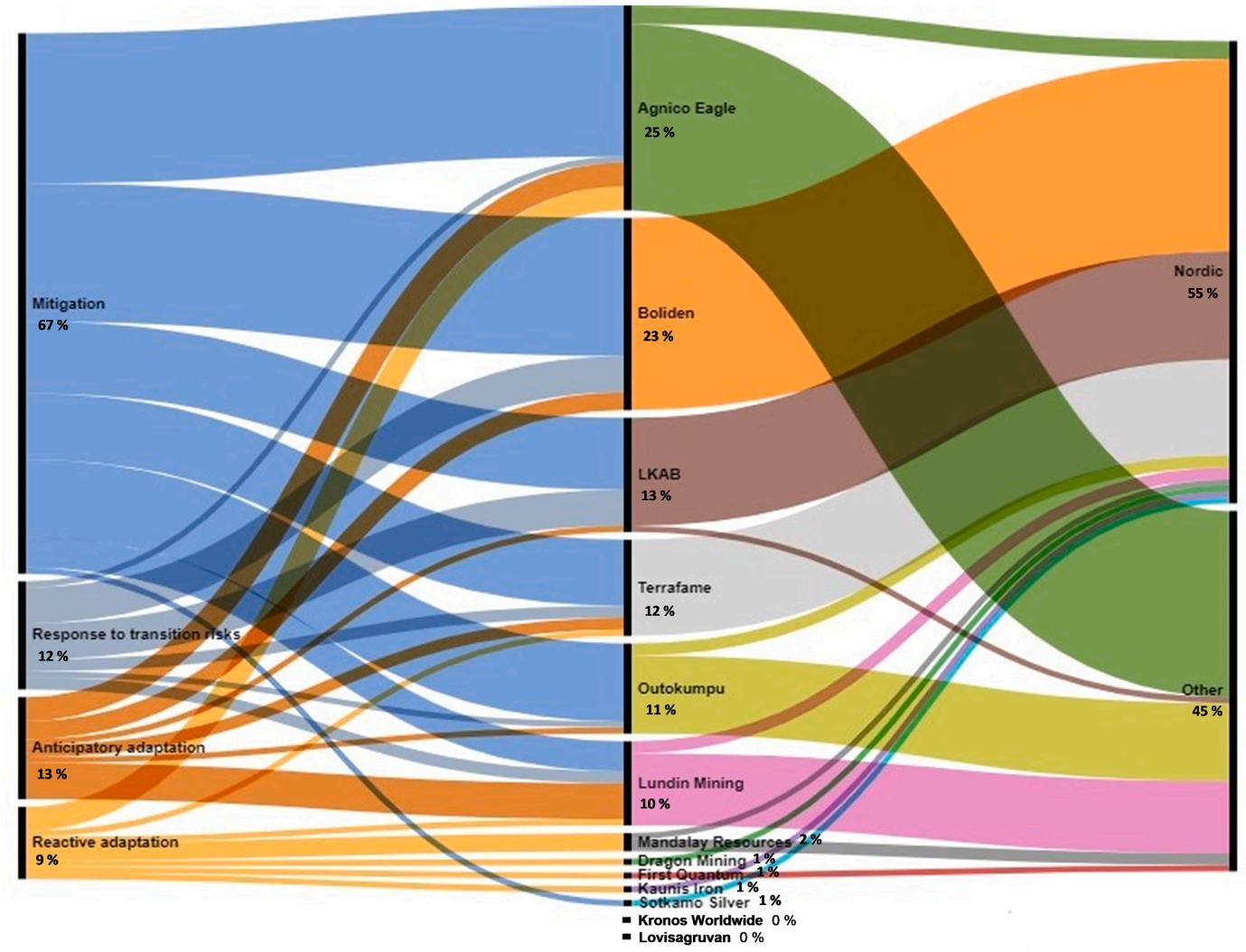

Fig. 2. Climate-related activities of companies with mining activities in the Nordic countries. The columns of the diagram show, from left to right, the type of activity, company and geographic location of the activities (Nordic countries; other countries/not specified).

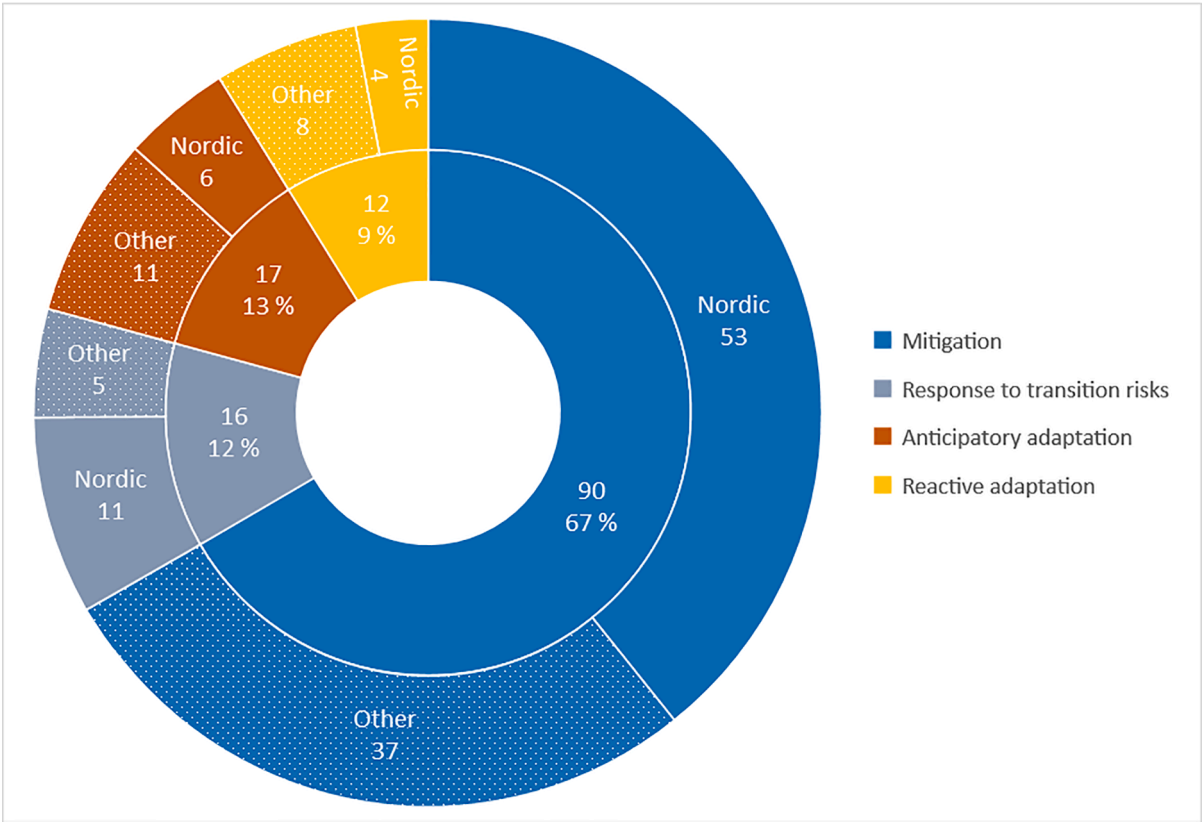

Fig. 3. Geographic distribution of climate-related activities: The inner circle shows the percentage and total number of activities for each type of activity. The outer circle shows the total number of each type of activity either targeted at the Nordic countries or targeted at other countries/not being specified.

Potential future climate change risks were not reported.

Without identified direct climate (change) risks, it is not surprising that few anticipatory or reactive adaptation activities were reported (see Fig. 2). Only 22% (29 activities) of all reported individual activities fell into these categories, whereas all other measures were mitigation activities or responses to transition risks (other than mitigation). These numbers decreased even further when considering only the Nordic countries. Only one-third of the reported activities were specifically targeted at the Nordic countries (6 anticipatory adaptation, 4 reactive adaptation; see Fig. 3).

The reported reactive adaptation measures include compliance with environmental permits and legal requirements, also under exceptional weather conditions (e.g., a higher than usual amount of precipitation), and stricter future standards. Compliance with water discharge permits can be achieved by aiming at reduced water discharge, by renewing permits or by asking for more flexible permits. In addition, some mining companies reported that they support local communities, as well as disaster risk reduction and management activities.

Anticipatory adaptation was reported to be part of some risk assessments that include climate change parameters. Risk assessments have been conducted at the strategic level, as well as at mining sites. The assessments included direct physical impacts on mining activities (e.g., caused by changing precipitation patterns, sea level changes or extreme events), but also transition risks and business opportunities related to climate change. However, the results of site-specific assessments of direct physical risks are not part of annual or sustainability reports, whereas risks and opportunities at the strategic level—as far as they are addressed—are part of specific climate change strategies.

4.2. Response to a changing climate policy context

Compared to risks related to physical climate change impacts, the companies identified far more transition risks and opportunities, such as the general expectation to reduce greenhouse gas emissions, changing regulations and requirements, and changing market conditions.

Roughly half (7 out of 13) of the companies (Fig. 4) and most individual activities (Fig. 2) were found to address climate change mitigation. As the most basic activity, the companies reported their greenhouse gas emissions and—if required—participated in the European emission trading system. Some of the reports referred to climate-related strategic planning, to the 2-degree target of the Paris Agreement, and set clear emission reduction goals. Activities that help to reduce emissions include the use of renewable sources for electricity generation, reducing fossil fuel dependency by switching to electric vehicles or biofuels, increased energy efficiency in mine operations and ore processing, or the recovery and use of excess heat. Other activities that should support the reduction of emissions are the issuing of a green bond (LKAB) and a specific mitigation and adaptation toolkit (Lundin Mining). This means some of the reported activities are legally required, while other activities and pledges are voluntary mitigation activities.

Several companies were found to react to current or anticipated changes to the business environment caused by the low-carbon transition, either by taking advantage of opportunities or by trying to mitigate risks (response to transition risks). Boliden, Terrafame, LKAB and Lundin Mining highlighted in their reports that they provide metals and minerals for climate change mitigation and adaptation activities. This also includes the processing of minerals in a battery chemicals plant (Terrafame) or asphalt mixed with magnetite and heated by microwaves instead of fossil fuels (LKAB). Emission trading is seen as either an opportunity or a risk that has been accounted for. On the one hand, Boliden noted that it has created income by selling unused emission certificates and receiving subsidies for energy efficiency improvements. On the other hand, LKAB reported the possible need to buy emission allowances, and Lundin Mining, Boliden and Outokumpu reported emission

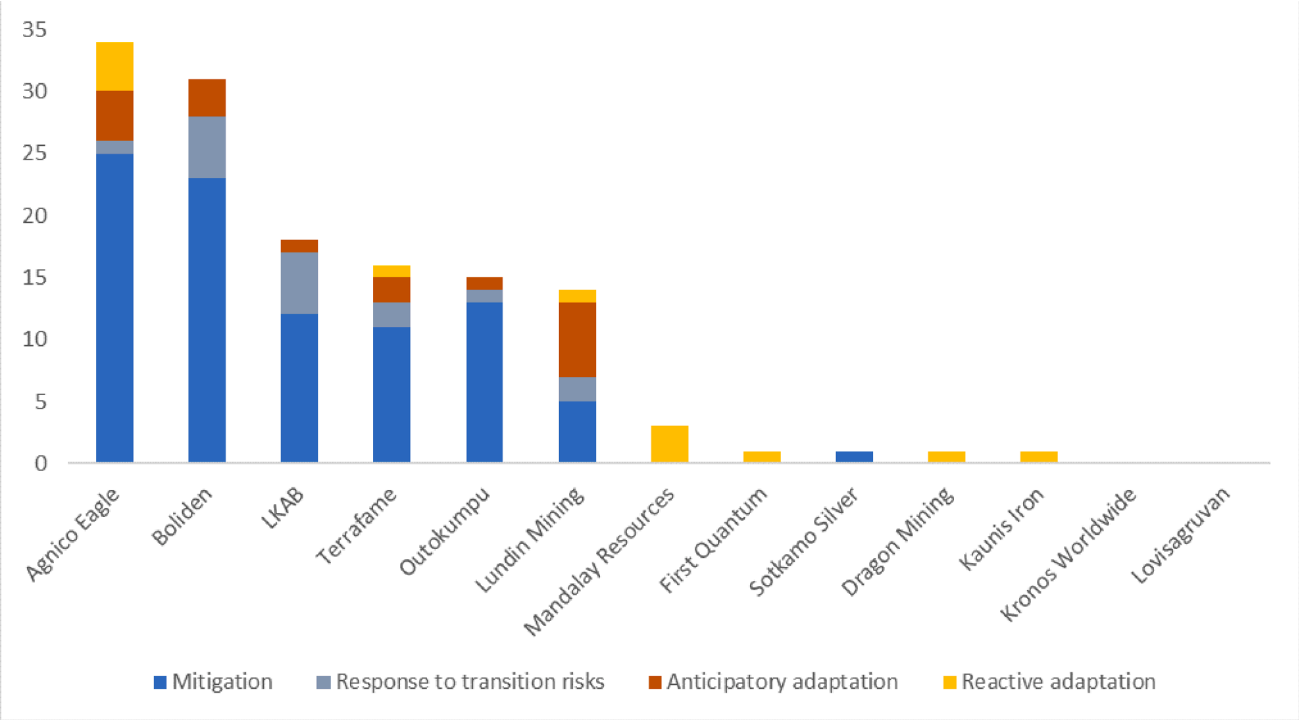

Fig. 4. The number and types of reported activities by company.

trading as a potential source of additional costs or economic disadvantage compared to companies outside Europe.

This type of reporting is often conducted in accordance with TCFD, CDP or GRI guidelines. Seven of the 13 analysed companies referred to at least one of the three guidelines. These seven companies include the first six companies reporting the highest number of activities and, as an outlier, First Quantum Minerals, which referred to CDP and GRI but only reported one activity.

5. Discussion

Our analysis highlights that the mining sector is currently portraying a restricted climate risk perception. This may expose the industry itself as well as the related production chains, communities and environment at risk in the future due to insufficient preparation. The scope of our analysis was limited to the year 2019 self-reporting documents of the metal mining companies that operate in the Nordic countries. This resulted in identification of activities also outside the Nordic region that, while broadening the understanding of the industry perceptions, could not be fully incorporated to the analysis of the Nordic-specific responses. The scope of this study ruled out private (not publicly available) reports as well as public EIA reports that in future might provide new information on the climate risk management and adaptation measures in the Nordic region. Future studies should, furthermore, incorporate longitudinal approach to analyse the unfolding of the measures identified in this study.

Our results suggest that metal mining companies in the Nordic countries do not perceive the physical impacts of climate change as a major risk, while it is also possible that they refrain from publicly communicating their full understanding of the impacts and their planned responses. In their annual and sustainability reporting in 2019, the companies only listed some past climate or weather impacts related to snow melt and the amount of precipitation. The potential future direct or indirect physical impacts on the mines themselves or the surrounding infrastructure (e.g., transportation or energy supply) were not addressed in the reports. These impacts might be part of mine-specific assessments or separate climate reports, but they are not considered relevant for annual or sustainability reports. This may be as much due to the lack of sufficient skills and resources for sound climate risk assessments and adaptation planning in corporations as it is due to the lack of regulation (Goldstein et al., 2019), or the lack of pressure exerted by investors (Gustafsson et al., 2022).

In contrast, mitigation activities and reactions to climate policies appear to play an important role—at least for some of the companies. Several of the companies reported their greenhouse gas emissions and emission reduction activities. In some cases, the companies' reporting extends beyond the legal requirements, and their ESG commitment is also expressed using reporting standards and guidelines provided by TCFD, CDP and GRI. However, as voluntary reporting also offers opportunities for green-washing, it is yet unclear how far reporting practices relate to an actual transition (Zharfpeykan, 2021). Some companies also highlighted their role in providing the necessary raw materials for the transition towards a low-carbon society. On the one hand, these kinds of statements can be regarded as promotion of companies' products. On the other hand, it can also be considered that the companies react to or anticipate changes in legislation and market conditions and in this way tackle the transition risks related to climate change. Nevertheless, roughly half of the analysed companies appear to be unaware of climate change as either a risk or an opportunity, and only reported sporadic climate change-related activities. These companies perceive neither physical climate change impacts nor transition risks or opportunities as affecting their operations.

Adaptation measures to reduce risks and vulnerability related to climate change, as well as to seize climate change-related opportunities, are increasingly being reported in some of the key primary production sectors in Europe, namely agriculture and forestry (e.g., Sousa-Silva et al., 2018; EEA, 2019a), as well as in the energy sector (EEA, 2019b). In the Nordic countries, the agriculture and forestry sectors, in particular, are taking active steps to adapt, but in the absence of public regulation, the adaptation measures in these sectors mainly demonstrate a business-as-usual approach to adaptation and involve maladaptive outcomes (Keskitalo et al., 2016; Andersson and Keskitalo, 2018; Wiréhn, 2018; Neset et al., 2019). Within the energy sector, the focus has mainly been on climate change mitigation and the decarbonization

of the energy system, while climate risks and adaptation have received much less attention (Norden, 2011; Groundstroem and Juhola, 2019). Based on our results, the Nordic metal mining sector adaptation efforts do not differ significantly from the other primary production sectors.

Changes in the legal framework of the EU can potentially affect the climate risk management of the mining sector in the Nordic countries. The updated national EIA legislation, including the assessment of climate change impacts, has so far guided only a small number of projects related to metal mining in the Nordic Countries (e.g., lithium mining under preparation by Keliber and the Sakatti project by Anglo American to mine nickel, copper and cobalt). The decreasing cap for greenhouse gas emission allowances in the emission trading scheme of the EU, puts continuous pressure on mining companies to reduce their emissions, but it has little impact on climate change adaptation. The EU Taxonomy Regulation (2020/852/EU) already provides a set of evaluation criteria to assess the sustainability of economic activities and can play an important role in guiding investments towards sustainable activities. The EU specified the criteria for climate change mitigation and adaptation for several sectors (Commission Delegate Act 2021/2139/EU), but it does not yet directly address the mining of metal minerals. It is still too early to state how extensively the new legislation has influenced the recognition of climate change impacts in the Nordic mining sector. The expected as well as unexpected impacts of these regulatory changes should be observed closely.

6. Conclusions

In this study, we set out to analyse the climate change adaptation activities of companies that mine metal ores in the Nordic countries. Our rationale was that the combination of more pronounced climate change at northern latitudes and the economic importance of mining in some of the Nordic regions could entail environmental, social and economic consequences.

Although studies by Pearce et al. (2011), Franks et al. (2014), Sairinen et al. (2017) and Bleischwitz (2020) indicate that a failure to account for climate change and extreme weather events can have severe, expensive and far-reaching consequences, many companies do not seem to be prepared for these impacts. Based on our findings, we recommend that companies should address potential climate change impacts more thoroughly. On the other hand, we recommend that the reporting of risk assessments and adaptation measures by mining companies should be regulated by public authorities, as it is unlikely that large corporations would voluntarily report such risk information that is potentially damaging to their business.

Climate change adaptation in the mining sector has hitherto received little research attention (Odell et al., 2018). Considering the increasing demand for metals and minerals necessary for a transition to low carbon energy generation, transfer and use, and the EU's aim to reduce dependency on the import of ores and metals, the mining sector will need support from research. Only with a better understanding of the direct and indirect physical impacts of climate change and of the challenges related to the transition towards a low carbon society, will the mining sector be able to tackle the related ESG challenges and exploit the opportunities related to the transition.

Laws and regulations

Swedish EIA law: https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/miljobedomningsforordning-2017966_sfs-2017–966

Finnish EIA law: https://www.finlex.fi/fi/laki/alkup/2017/20170252

Finnish EIA decree: https://www.finlex.fi/fi/laki/alkup/2017/20170277

Finnish Climate law: https://www.finlex.fi/fi/laki/alkup/2015/20150609

European Climate Law: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32021R1119

The European Environmental Impact Assessment (EIA) directive (2011/92/EU): https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32014L0052

Amendment of The European Environmental Impact Assessment Directive (2011/92/EU): 2014/52/EU: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32014L0052

European regulation on the establishment of a framework to facilitate sustainable investment (2020/852/EU): https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32020R0852

EU Taxonomy Regulation (2020/852/EU): https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32020R0852

Commission Delegated Regulation (2021/2139/EU) supplementing Regulation (EU) 2020/852 establishing the technical screening criteria for determining the conditions under which an economic activity qualifies as contributing substantially to climate change mitigation or climate change adaptation and for determining whether that economic activity causes no significant harm to any of the other environmental objectives: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R2139&from=EN

Norwegian Regulations on impact assessments: https://www.regjeringen.no/en/dokumenter/regulations-on-impact-assessments/id2573435/; https://lovdata.no/dokument/SF/forskrift/2017–06–21–854

Norwegian Act relating to Norway's climate targets (Climate Change Act), LOV-2017–06–16–60: https://lovdata.no/dokument/NLE/lov/2017–06–16–60

Norwegian Forskrift om konsekvensutredninger FOR-2017–06–21–854: https://lovdata.no/dokument/SF/forskrift/2017–06–21–854?q=Forskrift%20om%20konsekvensutredninger

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.exis.2022.101092.

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