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Original article

Social-ecological-technological systems consequences of mining: An analytical framework for more holistic impact assessments

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ABSTRACT

Understanding the impacts of extractive industries on sustainable development requires analyzing them as part of dynamic social-ecological-technological systems. Building on insights from studies of social-ecological systems and socio-technical systems, as well as fieldwork on the impacts of mining in the Nordic Arctic, this article presents an analytical framework for co-production of knowledge about the role of industrial or infrastructure projects for regional development. We use this framework to analyze Swedish mining policy, assessment guidelines, and environmental impact assessments for three mining projects in Arctic Sweden. We conclude that Swedish mining policy and guidelines for impact assessments neglect key aspects of social-ecological-technological systems, including the impacts of climate change, and treat many social aspects of sustainable development in a cursory manner. We suggest that more systematic analysis of the dynamics of social-ecological-technological systems would facilitate more transparent decision making and help identify the potential role of proposed mining projects in pathways towards sustainable development in northern regions.

1. Introduction

The transition to fossil-free energy systems is expected to increase the demand for metals (European Commission, 2020). In the Nordic Arctic, these expectations follow on a recent “mining renaissance” as policy changes opened the region to international actors (Bay-Larsen et al., 2018; Koivurova and Petrétei, 2014). While political and industry rhetoric emphasizes the role of mineral resources for a green transition, the relationship between mining and sustainability is complex and contested, and some scholars argue that extraction of non-renewable resources can never be sustainable (e.g. Anshelm and Haikola, 2018). Moreover, mines can have negative environmental impacts decades after they have closed (for Arctic examples, see Avango, 2020; Avango and Rosqvist, 2021; Fischer et al., 2020; Keeling and Sandlos, 2017; Sandlos and Keeling, 2013, 2016). Another local and regional sustainability concern is the economic vulnerabilities created by dependence on raw materials markets with their boom-and-bust cycles and when resources are depleted (Huskey et al., 2014).

The mining industry has developed sustainability agendas, codes of conduct, and processes for ensuring social license to operate (Corder, 2017; Global Reporting Initiative, 2011; Kulig et al., 2010). Proposals for new mining ventures in the Nordic Arctic have nevertheless led to protests, drawn-out permit processes, and social tensions (Bay-Larsen et al., 2018; Beland Lindahl et al., 2018; Koivurova et al., 2015; Zachrisson and Beland Lindahl, 2019). Indeed, the mining industry faces increasing public mistrust (Littleboy et al., 2019), leading to conclusions that the “current ‘mining system’ is flawed and that it needs to be fixed” (Tost et al., 2020). A specific concern is the lack of attention to cumulative and non-linear effects (Uhlmann et al., 2014). At the heart of these discussions are often conflicts over land-use, different perspectives on sustainability, and lack of trust in current decision processes.

The aim of this article is to present an analytical framework for more holistic understanding of the potential social-ecological-technological systems impacts of mining. We use this to scrutinize how current Swedish policy and assessment guidelines treat social and environmental impacts of mining, but the framework as such is relevant as a generic tool for co-producing knowledge about the potential consequences of new industrial projects and infrastructure development on regional development. It speaks to a demand for more holistic environmental impact assessments for mining ventures in the Arctic (Karvinen and Rantakallio, 2019) and would complement approaches that use the Sustainable Development Goals (SDGs) (United Nations, 2015).

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The practice of environmental impact assessments (EIAs) of new industrial ventures stems from the 1970s and has since the 1980s been complemented by strategic environmental assessments (SEAs) to guide spatial planning (Fischer and González, 2015). The wide-spread use of SEAs has also inspired scrutiny of their underlying assumptions, including how sustainability and the decision-making contexts are represented (Pope et al., 2017). While useful for reflecting on assessment practices, the dynamic interactions across social, ecological, and technological contexts remain obscured behind broad notions of sustainability. Furthermore, Cashmore et al. (2020) suggest that discussions about making SEAs more effective are often steeped in an old model of science speaking truth to power instead of facilitating co-production of knowledge.

In Arctic sustainability research, co-production of knowledge across different knowledge traditions is becoming a normative goal (Petrov et al., 2016; Sköld and Liggett, 2019), but in practice it is challenging, especially in decision processes with high stakes (Larsen and Nilsson, 2017). In impact assessments, different notions of sustainability remain a core concern (Pope et al., 2017), where Arctic research highlights the many conflicting ways in which it can be framed (Fondahl and Wilson, 2017; Gad and Strandsbjerg, 2019). The SDGs could provide a platform for assessing potential contributions of specific projects to sustainable development, but their global focus and politically negotiated format make them less useful for open-ended co-production of knowledge about the dynamics of a region. Instead of using experts to judge how a proposed industrial project contributes to the SDGs, we believe that a heuristic tool based on a social-ecological-technological systems perspective can provide insights into the mechanisms of interactions across SDGs and facilitate analyses of *how* proposed projects might lead to path dependencies for a region or potential for change over time. The analytical framework we present can thus be seen as a potential tool for co-production of knowledge in impact assessment processes.

2. Systems perspectives on ecology, society, and technology

In ecology, systems perspectives with attention to the impact of human activities on resilience have developed into studies of social-ecological systems, including attention to system transformations (Berkes et al., 2003; Folke, 2006). With the birth of Earth system science in the 1980s, the scope of these ideas widened from local ecosystems to global change and the interactions between human activities and large-scale bio-geophysical processes (Steffen et al., 2002). While Earth system science and resilience thinking highlighted that social and ecological processes were linked, the analyses of social and political dynamics, including the role of agency, lagged behind (Adger, 2000; Carson and Sommerkorn, 2017; Duit, 2015; Gillard, 2016). Ahlborg et al. (2019) furthermore call for attention to the role of technologies, specifically their mediating function between humans and ecosystems, and propose the term socio-technical-ecological systems. Smith and Stirling (2010) also emphasize that technologies, including the exploitation of mineral resources, affect relations between users and the ecosystem. With an emphasis on sustainable socio-technical transitions, they furthermore highlight the need to analyze how institutions coordinate investments in infrastructure and production technology. The interplay between societal processes and technology has also been in focus in studies of Large Technological Systems (LTS) as socio-technical systems (Hecht, 2004; Hughes, 1987). Studies of LTS pay attention to the actors and the institutional frameworks that affect their expectations and their ability to influence the system.

Our interest in exploring systems thinking for analyzing the impacts of mining in the Nordic Arctic comes from observations of legacies of historic mining and of current multiple pressures of industrial activities on northern landscapes. Rapid changes in climate now combine with an industrial boom, adding to the need for analyzing mining as part of large-scale systems with social features related to global processes (such a climate politics, financial and raw material markets, and the use and eventual discarding of products), transnational infrastructures, national economic interests, and policies for regional development. Systems approaches also facilitate analyzing change over time, including issues of resilience and path dependencies on the one hand and system transformations on the other, where proposed projects are placed into the context of other environmental and social changes. While our analytical framework is inspired by resilience thinking and studies of large-scale socio-technical systems, it also builds on empirical research in the Nordic Arctic, including site visits and interviews related to abandoned, active, and planned mines, and scenario exercises with local and regional stakeholders to identify locally relevant drivers of sustainable development (Avango and Rosqvist, 2021; Nilsson, 2020; Nilsson et al., 2017).

In the following section, we present our proposed framework and illustrate it with results from an analysis of Swedish mining policy, guidance documents, and EIA documents for three mining projects. The specific purpose of this analysis was to identify what is and what is not in focus in the current regulatory process.

3. Mining in Arctic Sweden from a social-ecological-technological systems perspective

3.1. Background

The current context of mining in Arctic Sweden started developing in the 1880s with the construction of a large-scale socio-technical system with infrastructures and institutions that have supported further mining (Avango et al., 2019; Hansson, 1998). Given its implication over the past century for ecosystems and people, including population patterns, identities, and activities, it is relevant to describe impacts in relation to the broader notion of social-ecological-technological systems change. At present, several new mines are proposed, at the same time as tensions between mining and other activities are increasing, including land use conflicts between reindeer herding and mining (Beland Lindahl et al., 2018; Lawrence and Larsen, 2019; Zachrisson and Beland Lindahl, 2019). Mining activities in Sweden require permissions according to several legal frameworks, where the most important are the Mineral Law (SFS, 1991), which regulates extraction and guides rights to access to the minerals, and the Environmental Code (SFS, 1998), which regulates the mining activities in relation to its overarching goal of ensuring a healthy and good environment. The relationship between these frameworks is subject to discussions about *when* the formal assessment of potential environmental impacts of a proposed project should be made (Miljöbalksprojektet, 2017). Praxis, so far, has been that companies submit their EIAs when they seek concession for production, but they can also provide a preliminary assessment to support communication with stakeholders. The EIAs are generally produced by consultancies that work for the mining companies. Sweden's decision process for mining permits has been extensively criticized, for example for its lack of attention to indigenous rights (Larsen and Raitio, 2019; Raitio et al., 2020) and for being slow and unpredictable (Myndigheten för tillväxtanalys, 2016; SveMin, 2021). In March 2021, the government announced a review of the current legal context to ensure supply of critical metals and minerals, due in October 2022 (Swedish government, 2021). This review will be conducted at a time when Arctic Sweden faces large investments in fossil-free steel production and factories for producing batteries for electrical vehicles, both of which will increase demand for electricity and qualified employees. For Arctic Sweden, the implications of this shift may become as profound as the historic development of the mining-energy-transport system.

The empirical foundation for our analysis, with documents related to policy, regulation, and EIAs, is summarized in Table 1. The EIAs relate to three different permission processes. One is an application for production concession at Kallak Norra (Hifab, 2013 revised 2014), which is situated west of the town Jokkmokk and close to the Natura 2000 and UNESCO World Heritage site Laponia. Prospecting activities here have

Table 1
Swedish policy and assessment documents included in the analysis.

Policy and guidance documents
Guideline for assessment of mining in Sweden (SGU, 2014)
Sweden's minerals strategy (Government of Sweden, 2013)
Report about the relationship between the Swedish mineral law and the environmental legislation (Miljöbalksprojektet, 2017)
Swedish parliamentary committee statement on mineral politics (Näringsutskottet, 2018)
EIA documents
Environmental impact assessment for Kallak Norra, prepared for Jokkmokk Iron Mines (Hifab, 2013)
Report from Kaunis Iron in preparation for application of environmental permit for mining in Kaunisvaara (Kaunis Iron, 2018)
Environmental impact assessment for Tapuli, Palotieva och Sahavaara Kaunisvaara submitted by Kaunis Iron (Kaunis Iron AB and Golder Associates, 2019)
Social impact analysis of the Kaunivaara mine, including, sustainability analysis (Bäckblom, 2019a), socioeconomic analysis (Bäckblom and Nordlund, 2019), and analysis of Agenda 2030 (Bäckblom, 2019b)
Environmental impact assessment for the Laver mine, submitted by Boliden AB (Lindeström and Eriksson, 2014)

led to protests from Sami reindeer herders, critical residents, and environmental activists (Harnesk et al., 2018). The case has moved all the way up to the Swedish government for a final decision and to the UNESCO for assessment of impacts on Laponia, but as of August 2021 no decision about permission has been made. The second set of documents relate to expanding the mining activities in Kaunisvaara near the town Pajala (Bäckblom, 2019a, 2019b; Kaunis Iron, 2018; Kaunis Iron AB and Golder Associates, 2019). The Kaunisvaara mine opened in 2012, but the original owner went bankrupt at the end of 2014 and the operation was taken over by new owners, now wishing to expand the mining activities. Research about expectations and the legitimacy of mining conducted before the bankruptcy showed that local actors supported the mining operations, mainly based on expectations of new jobs and a better local economy (Poelzer and Ejdemo, 2018). A workshop conducted after the bankruptcy but before the new company took over confirms a vison with high hopes for mining but also concern for vulnerabilities to shifting market demand (Nilsson et al., 2015). The third case relates to a proposal from the company Boliden to open a copper mine at Laver near the town Älvsbyn, where research conducted together with the local Sami community has highlighted the conflicts between mining and reindeer herding (Lawrence and Larsen, 2019).

The documents were coded based on an initial version of our analytical framework focusing on the components of social-ecological-technological systems, using Atlas Ti™ software. This analysis was used for refining our framework and for providing the examples presented below. Further details of the analysis are available as Supplementary material.

While the context and specific documents included in our study relate to mining in Arctic Sweden, we believe that our analytical framework could be equally useful for studying other contexts where proposed industrial activities may lead to social-ecological-technological systems changes that need to be assessed in ways that facilitate learning across disciplines and knowledge traditions.

3.2. System components and their expression in Swedish mining policies and assessments

Based on the foundation presented above, we have identified eight generic components that need attention in describing mining in Arctic Sweden as part of a social-ecological-technological system. They are: (1) abiotic environment; (2) biodiversity and ecosystems (3) technical artefacts; (4) institutions; (5) markets; (6) knowledge; (7) social networks and demography; and (8) actors and agency.

We furthermore highlight the links between these components. In addition to the physical links, such as the bio-geochemical cycles, we include the influence of norms and norm-making as these are central for agency. We furthermore propose attention to services and constraints. The term services is inspired by the emphasis on ecosystem services in studies of biodiversity, where it refers to the many and varied benefits to humans provided by the natural environment from healthy ecosystems (Millennium Ecosystem Assessment, 2005). Keeping in mind that the value of services for society is always negotiated (Avango et al., 2013; Ernstson and Sörlin, 2013; Sommerkorn and Nilsson, 2015), we find the notion useful for highlighting the role of different types of processes for society, e.g., abiotic services, technical services, institutional services, etc. As a mirror to the notion of services, we direct attention to the constraints created by various structures.

Components in social-ecological-technological systems are closely linked to each other and can often be perceived as nested. The distinction is thus analytical, and our selection based on features that have emerged as particularly relevant in our research on resource extraction in northern regions or from the literature. In a context of co-production of knowledge or in the mapping of a particular system, other priorities and issues are likely to emerge.

3.2.1. Abiotic environment

This component captures processes that shape landscapes and Earth as a planet, such as those related to bedrock and soil, the hydrological cycle, and the atmosphere. Bio-geochemical cycles are increasingly perturbed by human activities and thus serve as a link between the abiotic environment and ecosystems but also to social and technical features (Jacobson et al., 2000). The abiotic environment provides a range of services, including minerals used in a variety of technical artefacts. The constraints created by the abiotic environment include natural processes and landscapes that limit human activities but also abiotic features that are affected by human activities, such as the load of pollutants in water and air and the concentration of greenhouse gasses in the atmosphere.

In the Swedish mining policy documents, the abiotic environment is mainly visible in a focus on the bedrock of Sweden and its interface with technical artefacts, knowledge, and market demand. The bedrock is framed as a valuable abiotic service of both national and international interest. In guidance documents, the importance of waste and chemicals management is also visible.

The EIA documents discuss the quality of the bedrock as it relates to the economic and technical potential for mining, water and its movements in the landscape, and how proposed mining activities will affect landforms. Specific assessments of impacts on water and air quality are often included, following environmental guidelines and the EU Water Directive. Similarly, discussions about noise relate to environmental guidelines. The coupling of mining and the climate is limited to assessments of emissions of greenhouse gasses.

3.2.2. Biodiversity and ecosystems

The convention on biodiversity defines biodiversity as “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part” (United Nations, 1992, Art. 2). Ecosystems can thus be treated as part of biodiversity but highlighted here to include attention to the biotopes of which plants, animals, fungi, and microbes are part. As mentioned earlier, the value of biodiversity and ecosystems to society has been extensively elaborated in the notion of ecosystems services, including specific attention to the economic value of Arctic biodiversity (CAFF, 2013, 2015). Ecosystem constraints feature mainly in discussions about loss of biodiversity but are broadly relevant for all activities that depend on ecosystem processes.

In Swedish decision processes related to mining, biodiversity and ecosystems are visible both at the overarching level and in detailed regulations. For example, Sweden's mineral strategy includes statements that mining should be carried out “with respects for the environment and people's health.” In parliamentary committee documents, environmental considerations are mentioned as one of several potentially conflicting interests and in discussions of the legal situation regarding mining in national parks and other protected areas. Nature protection is also listed as a key national interest to be granted special attention in spatial planning, along with a range of other key national interests (SFS, 1998). Our overall impression from Swedish policy documents is that environmental concerns are treated as a constraint, where Swedish and EU environmental law related to the protection of species and biotopes serve as an obstacle in the decision process of approving new mining activities.

In the EIA documents, biodiversity and ecosystems appear in descriptions of impacts on protected species and especially valuable biotopes, such as wetlands. Potential impacts on the ecological status of lakes are also mentioned. Other aspects of biodiversity, such as role of fungi and microbes in ecosystem processes or genetic diversity, were not mentioned in the documents studied. In terms of ecosystem services, the interaction between mining activities and ecosystems receive attention in relation to impacts on forestry, reindeer grazing, hunting, fishing, and access for berry and mushroom picking and for outdoor recreation.

3.2.3. Technical artefacts

While studies of technology often focus on the links between technical artefacts and the actors and institutions that enable them (Feenberg, 2005; Hughes, 1987, 2004), we here specifically refer to things built by humans (the technical artifacts). Technical artefacts related to mining thus encompass the hardware in machinery and infrastructure that is used for turning geological features into material and products. As a complement to the inclusion of the load of pollution in the component abiotic environment, we also direct attention to waste and emissions created by production processes.

The Swedish policy documents highlight that minerals and metals build modern society and that access to metals is a precondition for producing modern energy and environmental technologies, thus emphasizing a service provided by a combination of the abiotic environment and technical artefacts. They also discuss the need for infrastructure services to support the Swedish mining and minerals industry. Some attention is placed on metal-containing products as a resource for recycling, and the Environmental Code includes demands to economize the use of resources and limit the amount of waste. Technical artefacts are rarely framed as a constraint.

The EIA documents include extensive descriptions of the activities and outcomes of the proposed mining operations, such as waste handling, energy use, and the expected production of ore. Transport infrastructure, including needs for improvements, and earlier mining developments that provide regional railroad infrastructure are mentioned. The EIAs highlight society's need for metals for "critical innovations and for well-functioning lives." The built environment is highlighted in relation to the need for housing but also in assessments of the potential impacts on cultural heritage sites, where cultural heritage is considered a key national interest.

3.2.4. Institutions

Institutions encompass "the sets of rules, decision-making procedures, and programs that define social practices, assign roles to the participants in those practices, and guide interactions among the occupants of individual roles" (Young, 2002, p. 5). A broad definition of institutions also includes common discourses, informal understanding of appropriate behavior, and routine activities that are embedded in culture. By highlighting institutions, we aim to capture the decision-making structures, regulatory frameworks, and political norms, along with rules articulated in sector-based networks and organizations. These all provide services in the form of predictability about the rules of the game but also path dependencies and power relations that can be perceived as constraints, not least in relation to change (Keskitalo, 2019).

The Swedish policy and guidance documents are expressions of the institutional framework for decisions about mining, including the Mineral Law and the Environmental Code, but also the roles of the various government bodies, such as the Mining Inspectorate and the County Administrative Boards. EU institutions are also visible, including the EU Species and Habitat Directive, the EU Raw Material Directive, and the EU Court. In both the guidance documents and in the EIAs, specific norms are apparent, such as the goals of the Environmental Code "to support sustainable development that ensures current and future generations a healthy and good environment" and to ensure effective use of raw material and energy. The Mineral Law's overarching goal to ensure the supply of essential metals and minerals, as well as the right to apply for prospecting and extraction licenses irrespective of property rights to land is also included. In the EIAs, institutions are visible in that certain norms have guided the assessment texts, e.g., environmental quality guidelines and duties to consult specific stakeholders.

While the legal and political framework provides institutional services and constraints, it does not resolve conflicts between goals. For example, key national interests include both ensuring supply of valuable minerals and protecting the environment, Sami reindeer herding, and cultural heritage, which often come in conflict with mining activities. In practice, the assumption is that conflicts are to be resolved in the environmental court decisions that conclude the EIA permit process, or eventually by the government. The newly initiated review of the Swedish mining strategy and the fact that several current mining applications are waiting for decision by the government show how the institutions are currently in the midst of a renegotiation of the rules of the game where older norms and expectation are challenged and where various actors try to reframe the institutional context.

3.2.5. Markets

An important link between the production of technical artefacts and users is the distribution networks and markets, which represent the user side of socio-technical systems (Geels, 2004). For mining, raw materials markets play a central role but also markets for products containing metals and labor markets. Investment capital and thus the capital market is also critical. The systems component that we call markets encompasses financial flows and transactions, such as investments, payment of dividends, buying and selling of materials and goods, and the buying and selling of labor and competence. It also includes the distribution of monetary wealth, where lack of financial capital can be a major constraint and access to it an important asset. Market services are also needed to supply labor to new industrial ventures. As noted by Geels (2004), markets are constructed by a variety of laws and rules, perceptions, and expectations, along with user preferences and practices. They thus link to several social structures and to agency.

In the Swedish policy documents, the market component appears as descriptions of increasing demand for mineral resources and the economic value of the ore, a trope that also appears in the EIA documents. Another trope is the mining industry as a contributor to Sweden's economic welfare and economic growth, accompanied by attention to the need for investment capital and certainty in the decision process, thus linking the market discussion to the institutional context. The labor market is also mentioned, especially in relation to mining providing new jobs in a region with high unemployment and that this would generate tax income. It can be noted that the job market has changed since these documents were written, with calls now being made to the government to provide incentives for people to move north to the new jobs (Lindberg, 2021). Regarding market services and constraints, the documents feature expectations that the overarching political framework should support the needs of industry, especially by creating a favorable environment for investments. Some of the EIA documents feature assumptions that conflicts of interest can be resolved by compensation payment, and thus a reliance on a market service.

3.2.6. Knowledge

Knowledge and agency are closely intertwined, where the social processes that structure knowledge play a key role in shaping the relationship between society, technology and the environment (Jasanoff, 2004). Knowledge that is deemed credible can also influence how people define problems, their impacts, and potential solutions, though knowledge is rarely the only factor (Mitchell et al., 2006). In the knowledge component, we include theoretical knowledge, knowledge built into various practices, and indigenous or local knowledge, but also the social structures that shape knowledge such as formal and informal education and knowledge production, including research and assessment processes. While knowledge can rest with individuals, e.g. skilled personnel and well-informed consumers, it can also be embedded in institutionalized routines and rules.

In the policy and guidance documents, knowledge services and constraints come forth when the documents express the need for access to a competent workforce, along with calls for making relevant educations more attractive and for supporting regional higher education opportunities. The need for research and education are mentioned but not prominent in the EIA documents. Here, knowledge appears mainly as reliance on professional knowhow, both in relation to mining-specific issues and in assessing environmental impacts. Examples of the latter are reliance of environmental quality guidelines and references to earlier expert assessments of impacts on cultural heritage and protected species. While the mining-related knowledge services are often based in the industry's professional networks, the environmental expertise seems to rest with consultants or rely on institutionalized norms. Local and indigenous knowledge is only briefly mentioned as a part of the motivation for consultation processes in preparing an EIA.

3.2.7. Social networks and demography

The importance of social networks for the functioning of social-ecological systems has received attention in studies of resilience (e.g. Hahn et al., 2008) and has also been highlighted in studies of dynamics in socio-technical systems (Geels and Kemp, 2007). They represent agency at a structural level where a social network can enhance individual agency. This component thus highlights both closer circles of relations (family, friends, neighbors etc.) and more extended informal networks and civil society organizations. Included here are also demographic structures, with attention to settlement patterns, in- and out-migration, and population structure in relation to age and gender. Our own empirical work and other studies of social impacts of resource extraction point to demography as a central concern for sustainability in the Arctic, with close connections to shifts in demand for human capital following boom and bust cycles in resource markets (Jungsberg et al., 2018). It has been suggested to be a key issue in social impact assessments for large-scale industrial projects in the north (Suopajärvi and Jungsberg, 2016).

In the analyzed documents, social networks and demography are not a prominent theme, except for brief mentions of making it attractive to live in rural areas and as background for discussing job opportunities. Other examples from the EIAs are mentions of a historic ideal society built to support mining, an ambition to support a local business network, and that mining can impact Sami communities. In general, social networks, such as civil society, along with family, friends, and neighbors, appear absent from EIA assessments and mining policy and guidance.

3.2.8. Actors and agency

As pointed out by Ahlborg et al. (2019), power and agency are central features of social-technical ecological systems in that they shape and mold all other aspects of the system, which in turn can enhance or limit power and agency. The relationship between structure and agency is a recurring theme in political science (McAnulla, 2002), and, as mentioned earlier, a central critique of systems approaches based on resilience thinking has been their lack of attention to agency. With this component of the framework, we highlight the actors, including individuals, organizations, and businesses, that might affect the system by their decisions and actions. Examples are how actors shape the institutional context by taking part in formal and informal political negotiations, knowledge via education and research, and markets via their purchasing and investment powers. The structural services and constraints are thus negotiated by actors. Meanwhile, the degree of actual agency by specific actors is circumscribed by a range of structural constraints.

In the documents we have studied, some types of actors are more visible than others. The movers in the policy documents are sector interests, including mining companies, a major sector organization, and government agencies. Members of parliament serve as visible drivers of change. Individuals and their life choices, consumers, and media are not visible. In the EIA documents, companies and their consultants are obviously visible, but also government agencies, reindeer herding communities with which companies have a duty to consult, forest owners, tourists, hunters, fishers, and local property owners. Outside the circle of stakeholders potentially impacted by a specific mine, there is a mention of consumers as needing the metals and the importance of opinion-shaping to reduce the risk of misunderstanding and conflict. Overall, the impression from the documents is that agency lies with the mining sector and government agencies at the national level rather than with those who live in the vicinity of mining activities (unless they are part of the workforce, in which case the proposed mine is framed as a job opportunity).

4. Summary and discussion

In this article, we have proposed a social-ecological-technological systems approach to analyze the potential impacts of industrial projects, with a specific focus on providing an analytical framework for understanding the role of mining for the environment and social dynamics of Arctic Sweden.

Application of the framework to documents related to mining in Sweden reveals a context of strong institutions that favor mining but also constraints, primarily related to nature protection. Expectations of growing global demand appear as the main driver of change to this current framework. In Sweden, EIAs mainly have a local focus on the land where mining is planned (SGU, 2014, p. 16), while the analysis shows how the national political discourse emphasizes national interests and that the brakes in the system come from EU legislation on protection of nature. Except for general statements about new job opportunities, this creates a setting where impacts on the regional dynamics are left out of the analysis.

Social-ecological-technological systems operate simultaneously across multiple loci (Smith and Stirling, 2010) and the choice of focal scale always privileges some perspectives (Reid et al., 2006). Reid et al. (2006) highlight that explicit cross-scale analyses could improve the legitimacy of impact assessment processes. Complementing the local focus of current impact assessment processes with thorough analyses of cross-scale linkages to regional, national, and global dynamics would thus be an important step in improving the knowledge about the role of mining in the Nordic Arctic and elsewhere, where our analytical framework can provide a starting point.

Attention to processes at various temporal scales is equally relevant. While assessment of potential environmental legacies is part of the current regulatory framework, other legacies are not as obvious, including how large-scale infrastructures for transport and energy can create path dependencies as they facilitate the establishment of new mines (Avango et al., 2019) and become part of the cumulative impacts and multiple pressures on other uses of land (Fohringer et al., 2021). Moreover, mines create individual and collective memories integrated into identities and expectations about the future (Avango, 2018; Fischer et al., 2020). Such memories and identities are relevant both for those who benefit from mining activities and for those whose interests have not been prioritized.

Temporal scale is also relevant for assessing how climate change will affect mining and the landscape in which it takes place. A review of the literature on mining and sustainable development highlights impacts of climate change as a knowledge gap in (Tolvanen et al., 2019), and in the EIAs, the impacts of climate change were not visible at all. This suggests an underlying assumption that climate change will not affect mining operations and their eventual environmental or social impacts even in a decadal perspective. Given the current and projected changes in temperature and precipitation in this region (AMAP, 2017), they thus miss the cumulative impacts of mining and climate change.

Today, the SDGs play an increasing role in the political discourse, and Tost et al. suggest that the SDGs should be considered for creating better processes for impact assessment. One of the assessment processes in our study included an explicit analysis of the implication for the SDGs but based on the judgement of the authors rather than on iterative rounds of consultation for developing convergence around how to define and monitor valued regional assets, which Uhlmann et al., 191) suggest as necessary. Noteworthy is also that many social aspects of sustainable development highlighted in the SDGs are poorly covered in the current Swedish assessment process.

The material we have analyzed lacks attention to the dynamics of systems change, including the potential for regime shifts. For example, one of the EIAs assumes that most activities would be back to a pre-mining situation after mining closure and proper remediation and reclamation measures. It fails to mention how lack of land access for other activities, new infrastructures, new expectations, along with other changes in socioeconomic structures and climate make it more likely that a new local system will emerge. To understand whether such a shift could provide a pathway for achieving the SDGs would require analyses of how different parts of the social-ecological-technological system interact and how different drivers of change might push the system in different directions, with or without a mine. In participatory processes focusing on creating sustainable local futures, we believe that our analytical framework complements the SDGs and could facilitate a process of co-producing knowledge where system dynamics become visible. Such participatory processes will also be useful for further developing the proposed framework.

CRediT authorship contribution statement

Annika E. Nilsson: Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing. **Dag Avango:** Conceptualization, Writing – review & editing. **Gunhild Rosqvist:** Conceptualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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