Production of critical minerals and metals: Empirical investigation of sustainability aspects

Johanna Askros
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Production of critical minerals and metals: Empirical investigation of sustainability aspects

JOHANNA ASKROS


**Abstract:** The threat of global climate change has brought on the need for a transition towards renewable energy sources and electrification, thereby creating a significantly increased demand for energy minerals and metals. Despite being on a path towards an energy system with net-zero emissions, the European Union (EU) is currently highly dependent on the import of these minerals and metals from outside of the Union. In addition to constituting a supply risk, the sourcing of energy minerals and metals form outside of the EU also leads to the displacement of the impacts that mining has on the environment, society, and the economy in places where pre-existing environmental and social vulnerabilities often enhance these damages. This study sets out to explore how the mining industry of the EU could contribute to the sustainable supply of energy minerals and metals, considering the current state of the industry and the interactions of different associated environmental, social, and economic sustainability aspects on different spatial scales. It is empirically explored from the perspective of the potential mining of battery minerals and metals in Sweden. Media articles on the subject are reviewed and stakeholders of such a potential mining sector are interviewed. Both sets of data are analysed using the frameworks of systems theory and environmental justice, as well as theories on the resistance to and acceptance of mining. The analyses of the empirical findings suggest that there are some unavoidable trade-offs associated with mining, where the global need to mine is put against local concerns. It is concluded that while there is potential for the EU mining sector to produce energy minerals and metals more sustainably than is currently the case, some environmental, social, and economic damages cannot be avoided. To enable the energy transition, there is a need to make trade-offs between different aspects of sustainability. However, there is a lack of guidelines for how these trade-offs, which often involve more than one spatial scale, should be made. Ultimately, the sustainability contributions of a EU energy mineral and metals mining sector is dependent on how sustainable mining is defined and which spatial boundaries are applied. To deal with the limitations of the sustainability concept, it is proposed that the question is also approached from a perspective of justice.

**Keywords:** Energy transition, environmental justice, sustainable development, sustainable mining, systems thinking

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Production of critical minerals and metals: Empirical investigation of sustainability aspects

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Summary: The threat of global climate change has brought on the need for a transition towards renewable energy sources and electrification. This is creating a significantly increased demand for minerals and metals used in energy and electrification technologies. This study sets out to explore how the EU mining industry could contribute to the sustainable supply of these so-called energy minerals and metals. Despite being on a path towards a decarbonised energy system, the EU is currently highly dependent on the import of these minerals and metals from outside of the Union. The mining of energy minerals and metals is associated with impacts on the environment, society, and the economy that contributes both towards and away from an overall more sustainable future. Due to the EU import of energy minerals and metals, these impacts are currently being displaced outside of the Union in countries where pre-existing environmental and social vulnerabilities often enhance the negative effects of mining. To understand how the current state of the EU mining industry and the interactions of different environmental, social, and economic sustainability aspects on different spatial scales affect the ability of the EU to sustainably supply energy minerals and metals, the potential mining of minerals and metals for batteries is explored in a Swedish context. To do so, a systemic approach to mining is applied in combination with theories on justice and the acceptance of and resistance to mining. A review of the subject in Swedish media articles and interviews with central actors of a potential battery minerals and metals mining sector suggest that there are some conflicts between different sustainability aspects that cannot be avoided, as the global need to mine is put against local environmental, social, and economic issues. Whether the mining of battery minerals and metals in Sweden could be sustainable is therefore dependent on the subjective acceptance or non-acceptance of the global benefits of mining being allowed to outweigh the local burdens that the mining creates. From the empirical findings, it is concluded that while there is potential for the EU mining sector to produce energy minerals and metals more sustainably than is currently the case, some environmental, social, and economic damages cannot be avoided. To enable the energy transition, there is a need to make trade-offs between different aspects of sustainability. However, there is a lack of guidelines for how these trade-offs, which often involve more than one spatial scale, should be made. Ultimately, the sustainability contributions of a EU energy mineral and metals mining sector is dependent on how sustainable mining is defined and which spatial boundaries are applied. To deal with the limitations of the sustainability concept, it is proposed that the question is also approached from a perspective of justice.

Keywords: Energy transition, environmental justice, sustainable development, sustainable mining, systems thinking

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1 Introduction

In a pursuit to reduce the extent of climate change, the legally binding Paris Agreement was adopted by most countries in 2015 (United Nations Climate Change, n.d.). The agreement stipulates a goal to limit global warming to 1.5°C or, at most, to well below 2°C above the pre-industrial global average temperature (United Nations / Framework Convention on Climate Change, 2015, p. 3). In 2022, the global average temperature was approximately 1.15°C above pre-industrial times and the greenhouse gas (GHG) emissions driving the warming continued to increase (World Meteorological Organization, 2022). Of the close to 50 billion tonnes of GHG emitted by humans each year, about three quarters of the emissions are produced by the energy sector (Climate Watch, 2022). A shift from fossil fuels to renewable energy sources and electrification of society has therefore been proposed as necessary steps in reducing GHG emissions and mitigating further warming (e.g., European Union: European Commission, 2019; Intergovernmental Panel on Climate Change, 2022; United Nations Environment Programme, 2022).

The International Energy Agency (IEA) (2017, p. 283) propose that roughly 70 percent of the energy produced in 2060 will have to come from renewable energy sources, if the target of keeping the global average temperature below 2°C is to be met. Similarly, the Intergovernmental Panel on Climate Change (2022, p. 688) assumes that between 55 and 68 percent of the energy produced in 2050 needs to be renewable or low in carbon dioxide emission if the same global warming temperature limit is to be met. If the temperature increase is to be kept below 1.5°C, the share of renewable and low-carbon energy production is predicted to have to make up between 74 and 82 percent of total energy production (ibid.). In 2021, only 13.5 percent of the energy produced globally came from renewable sources (although the share of renewable energy varied significantly between countries) (Our World in Data, n.d.). This suggests a need for a large-scale increase in renewable energy production, as well as in the necessary technologies behind it.

Conventional technologies such as solar power, wind power, energy storage batteries, and battery powered electric vehicles are expected to increase substantially with the transition towards renewable energy and electrification (Watari et al., 2019, p. 227; International Energy Agency, 2023b). The influx of new technologies such as low emission hydrogen, hydrocarbon, and fuel cells also have the potential to contribute significantly (World Bank Group, 2020). However, while an energy transition has the potential to put an end to the use of fossil fuels in the energy sector, it does come with the increased use of another set of non-renewable resources (Vidal et al., 2013). Renewable energy technologies require larger quantities of a greater number of raw materials than non-renewable energy technologies (World Bank Group, 2020, p. 93; International Energy Agency, 2023b, p. 52), thereby essentially increasing the raw materials demand per unit of produced energy (Vidal et al., 2013; Frenzel et al., 2017). This increases the need to mine so-called energy minerals and metals, many of which have been attributed a criticality status due to their economic importance and associated supply risks (World Bank Group, 2017; European Commission, 2020a; International Energy Agency, 2023b).

However, while the energy minerals and metals contribute to reducing GHG emissions by enabling the use of fossil-free energy sources, mining of these raw materials is associated with a complex set of impacts contributing both positively and negatively towards the sustainability of the environment, society, and the economy (Columbia Center on Sustainable Investment et al., 2016; Mancini et al., 2019; Responsible Mining Foundation & The Columbia Center on Sustainable Investment, 2020). Providing clean energy and combating climate change are only two of 17 Sustainable Development Goals (SDGs) put forward by the United Nations (UN) and recognised by its member states (United Nations, n.d.). Mining comes with both opportunities and risks related to each of the SDGs (Responsible Mining Foundation & The Columbia Center on Sustainable Investment, 2020). These trade-offs between SDGs must be accounted for to promote sustainability (Mancini et al., 2019), including the sustainable production of raw materials for the energy transition.

With the aim of reaching net-zero emissions of GHGs in the European Union (EU) by 2050, the European Green Deal was launched in 2019 (European Union: European Commission, 2019). The EU aspires to have a sustainable supply of raw materials (European Union: European Commission, 2008). However, the increased awareness of social and environmental impacts of the mining of energy minerals and metals in
producing countries threatens to disrupt the energy transition. At present, most of the minerals and metals required for the implementation of the EU energy transition are sourced from outside of the Union (European Commission, 2023a, pp. 27–28), often from countries with high environmental, social, and governance risk factors (Lébre et al., 2020). Because the necessary raw materials are imported to the Union, many of the negative impacts of the mining take place beyond the borders of the EU (Sovacool et al., 2019) where the social and environmental vulnerabilities in the producing countries enhance the damage that the displaced impacts create (Lébre et al., 2020; Owen et al., 2020). If measures are not taken to improve the social and environmental conditions in the raw material producing countries or if mines are not successfully established in locations with strict regulations, the increased scrutiny of suppliers could hinder the demand for minerals and metals from being met (Lébre et al., 2020; International Energy Agency, 2021, p. 12).

As part of the Strategic Dialogue on Sustainable Raw Materials for Europe, the EU made it clear that it has a responsibility as a consumer of minerals and metals to not transfer the environmental or social impacts of mining to non-EU countries (Farooki et al., 2018). Instead, the EU should act as a role model by showcasing best practice standard in a strengthened domestic mining sector (Farooki et al., 2018, p. 11; Schüler et al., 2018, pp. 8-9). This does not mean that the EU can, will, or should cease to source minerals and metals from supplying countries with extensive negative impacts of mining. Firstly, a completely domestic supply of energy raw material would not be possible, as the EU is a net-importer of most raw materials deemed critical for the energy transition (European Union: European Commission, 2020b, pp. 3-4; Mateus & Martins, 2021, p. 246). Secondly, the purpose of strengthening the domestic mining sector is not to eradicate the need for minerals and metals from outside of the Union, but to create leverage and credibility when putting expectations of sustainable mining standards on these countries (Schüler et al., 2018, p. 8). Thirdly, taking the market away from a mining area prone to negative social and environmental impacts does not solve the issues and can create additional problems by removing the positive impacts (Tsurukawa et al., 2011; Manhart et al., 2017, pp. 7-8).

Succeeding in strengthening the EU mining sector could both positively affect the domestic supply for energy minerals and metals (Reguiero & Alonso-Jimenez, 2021) and contribute to making the mining of these materials more sustainable (Thies et al., 2019; da Silva Lima et al., 2022). However, to understand the extent of this contribution, all aspects of sustainability – environmental, social, and economic –, including the impacts that have been displaced, require attention. Thus far, both the trade-offs between sustainability aspects (Lébre et al., 2020) and the injustices associated with the displacement of the impacts of mining (Sovacool et al., 2019; Heffron, 2020) have received limited attention in the literature on the production of energy minerals and metals. The aim of this study is therefore to identify potential sustainability aspects associated with the mining of energy minerals and metals in a EU context, to explore the trade-offs between them, to put them in perspective to the sustainability aspects of the current supply chain, and to assess the merit of a EU supply from a sustainability point of view. As a result, the following research scope arises:

How would the EU mining industry contribute to the sustainable supply of energy minerals and metals in the coming decades, considering the current state of the industry and the interactions of different associated environmental, social, and economic sustainability aspects on different spatial scales?

Four sub-questions are in need of examination to provide an answer to the research scope:

1. What is the current state of the EU mining industry?
2. What does a sustainable supply of energy minerals and metals entail?
3. How are the interactions and possible goal conflicts between sustainability aspects perceived by stakeholders of a EU energy mineral and metals mining sector?
4. How would a potential EU production of energy minerals and metals affect the sustainability on different spatial scales, including beyond the borders of the EU?
2. Overview of critical materials

Energy production and electrification are dependent on certain technologies, such as power plants to generate energy and batteries to store electricity. The technologies behind energy production and electrification require minerals, metals, and other geological raw materials, which creates an increased dependency on these resources (Vidal et al., 2013; World Bank Group, 2017; Watari et al., 2019; Hodkinson & Smith, 2021). With the new dependency on minerals and metals to sustain the energy transition and electrification, the supply potential of and demand for these materials have gained increased awareness (World Bank Group, 2017, p. 7) and resulted in assessments of the criticality of these and other raw materials (e.g., Schulz et al., 2017; European Union: European Commission, 2020b). The following sections explain the concept of criticality and introduces the EU application of it, including in relation to the energy transition technologies. This section therefore provides a contextual background to the focus on critical minerals and metals for the energy transition. The chapter is concluded by an overview of the criticality of battery minerals and metals, which is presented to introduce the empirical focus of the study.

2.1 Criticality

The increased attention paid to the supply security of minerals and metals, especially in relation to the demand from the transitioning energy sector, has made the concept of criticality gain traction in recent years (Graedel & Reck, 2016; Frenzel et al., 2017). Criticality lacks an agreed upon definition but is often assessed on similar grounds (Frenzel et al., 2017). Most commonly, the degree of criticality is assessed two-dimensionally based on the (economic) importance of the mineral or metal and the supply risks associated with it (ibid.). In terms of supply risks, most assessments consider the concentration of producing countries and companies (ibid., p. 3), especially in the context of countries with poor governance (Graedel et al., 2012). The criticality concept is therefore closely related to geopolitics1. In addition to the dimensions of economic importance and supply risks, some criticality assessments also include a third dimension related to the environmental implications of the extraction of the material (Erdmann & Graedel, 2011; Graedel et al., 2015). Others (e.g., the EU) account for environmental implications when determining the supply risk (European Commission, 2020b). Regardless of how the criticality assessment is carried out, criticality should be regarded as a gradual concept rather than a binary one: a resource can be more or less critical, but not simply critical or non-critical (Graedel & Nuss, 2014; Hayes & McCullough, 2018).

Related to the non-binary state of criticality is the variability in degree of criticality. Criticality is a dynamic concept in need of periodical re-evaluations (Erdmann & Graedel, 2011; Graedel & Reck, 2016; Fretzel et al., 2017) due to variability in context and over time. The specific context in which a criticality assessment is carried out makes the concept subjective (Hayes & McCullough, 2018). The purpose of conducting a criticality assessment and the entity behind it will therefore influence whether criticality is perceived or not, resulting in different minerals and metals being deemed critical in different assessments (Frenzel et al., 2017; Schulz et al., 2017; Hayes & McCullough, 2018). On a temporal scale, the dynamic characteristic of the criticality concept stems from the variability in what is considered important and scarce (Hayes & McCullough, 2018). Building on Zimmermann’s (1951, in De Gregori, 1987, p. 1241) argument that something becomes a resource through a perceived need rather than that it is a resource in and of itself, criticality can be directly linked to the current and fluctuating resource demand and the subsequent value ascribed to the resource in question. In other words, the development of new technologies and the abandonment of old ones will impact what is considered important or not (Graedel & Reck, 2016; Hayes & McCullough, 2018). The opening and closing of new mines and changes in the geopolitical context of the supply chain will further impact the associated supply risks (Graedel & Reck, 2016).

1 The dominating role of China, especially, is highlighted as a risk factor for several minerals and metals in the EU criticality assessment (European Commission, 2020b). For example, between 2005 and 2011, China produced 97 percent of the world’s supply of rare earth elements (Shen et al., 2020). Although China’s market share is closer to 70 percent today (Shen et al., 2020; U.S. Geological Survey, 2023), between 98 and 99 percent of the EU supply of rare earth elements is still provided by China (European Union: European Commission, 2020b).
2.2 The EUs Critical Raw Materials List

In 2011, the EU compiled a list of 14 minerals, metals, and metal groups that were considered to be of higher criticality than other materials (European Commission, 2010). The purpose of the European Critical Raw Materials (CRMs) List is to identify raw materials that are essential for the competitiveness of the EU economy, to evaluate their supply security, and create incentives for a domestic primary and secondary production of these raw materials (European Commission, 2020b). It is part of the EU Raw Materials Initiative from 2008 (European Commission, 2010), which in turn is a strategy intended to secure a sustainable supply of raw materials from outside of and within the Union, as well as through a reduced consumption of primary raw materials (European Union: European Commission, 2008). Due to changes in supply and demand, the CRMs list has been re-evaluated every three years (European Union: European Commission, 2020b). The current and previous CRMs and the edition(s) of the List in which they were entered or got excluded are shown in Table 1.

Table 1. Materials included in each of the EUs CRMs Lists, where REEs = rare earth elements (used before the distinction was made between HREEs and LREEs in 2014); HREEs = heavy rare earth elements; LREEs = light rare earth elements; and PGMs = platinum group metals (European Commission, 2010; 2014; 2017b; 2023a; European Union: European Commission, 2020b).

<table>
<thead>
<tr>
<th></th>
<th>Antimony</th>
<th>Arsenic</th>
<th>Baryte</th>
<th>Bauxite</th>
<th>Beryllium</th>
<th>Bisith</th>
<th>Borates</th>
<th>Chromium</th>
<th>Cobalt</th>
<th>Cooking coal</th>
<th>Copper</th>
<th>Feldspar</th>
<th>Flourspar</th>
<th>Gallium</th>
<th>Germanium</th>
<th>Graphite</th>
<th>Hafnium</th>
<th>Holmium</th>
<th>PGMs</th>
<th>Subtotal</th>
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<td>34</td>
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</tbody>
</table>

Like most other criticality assessments (Frenzel et al., 2017), the EU list of CRMs is compiled based on two factors: economic importance and supply risk (European Union: European Commission, 2020b). All raw materials considered in the assessment is attributed a value for each of the factors and if both values reach or transgress the decided threshold for criticality, the material is considered critical (European Commission,
The economic importance of a material is evaluated through its end-use applications and added value (ibid.), thereby focusing on the demand for the materials up for consideration. To assess the supply risk of a material, the risk of disruption in the EU supply is evaluated based on production concentration, governance performance, and trade aspects in supplying countries (European Commission, 2017a). The assessment framework acknowledges both secondary supply (i.e., recycling) and substitution, in addition to primary production, when determining the supply risk of a material (ibid.). The supply risk assessment also takes into consideration the environmental aspects (European Union: European Commission, 2020b), but it is no longer treated as a stand-alone factor.

The criticality matrix from the 2020 re-evaluation of the list is displayed in Figure 1, showing the economic importance and the supply risk of the raw materials up for consideration. It provides an idea of how dynamic the criticality concept is: a relatively small change in economic importance or supply risk in either direction could change the status of many critical or non-critical raw materials. This has been the case for arsenic, feldspar, helium, and manganese, which were added to the 2023 list, as well as indium, which was removed from the list in the 2023 edition. Copper and nickel were also added to the 2023 edition, although not because they met the requirements to be deemed critical. Instead, they were added due to their status as strategic raw materials (SRMs).

Figure 1. Economic importance and supply risk of raw materials considered in the 2020 re-evaluation of the European CRMs list (European Commission, 2020b, p. 29).

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2 The supply risk is estimated on the so-called “bottleneck” stage (i.e., the extraction or processing stage (European Commission, 2017a, p. 3). To account for differences in global supply and EU sourced (domestic) supply, proportions are ascribed based on the EU’s import reliance on the raw materials (ibid.).

3 The first EU report on CRMs included calculations on associated environmental risks (European Commission, 2010; Erdmann & Graedel, 2011), using the Environmental Performance Index (EPI) (European Commission, 2014). However, the calculations were never included in the criticality matrix (European Commission, 2010; Erdmann & Graedel, 2011) and the use of the EPI was abandoned as the first revision was conducted (European Commission, 2014).

4 All SRMs are automatically included in the CRMs List (European Union: European Commission, 2023, p. 2).
In addition to updating the CRMs List in 2023, the EU also provided a list of SRMs. The SRMs List consists of 17 raw materials and raw material groups\(^5\), including copper and nickel, that are considered to be “of high strategic importance” for the Union based on their use in technologies necessary for the green transition, the digital transition, and defence purposes (European Union: European Commission, 2023, p. 2). Characteristics of the SRMs are a gap between the global supply and expected demand, as well as a difficulty to scale up the production to a sufficient level (ibid.). To alleviate this gap between supply and demand, the EU has made goals for the production of these materials, including 10 percent of the extraction of the annual EU demand taking place domestically by 2030 (ibid., p. 17).

2.3 The case of battery minerals and metals

The demand for CRMs for all energy technologies is expected to increase with the energy transition (International Energy Agency, 2021). A more substantial increase in demand is however expected for minerals and metals for one technology in particular: lithium batteries (ibid.). Lithium batteries are rechargeable batteries used for both energy storage and electrical vehicles. Although lithium batteries may vary in their composition, the most common and effective chemical composition of the cathode consist of either lithium and cobalt (for energy storage) or lithium, nickel, manganese, and cobalt (for electric vehicles) (Clean Energy Institute, n.d.). In addition, graphite constitutes the most common anode material (Asenbauer et al., 2020). These five minerals and metals – cobalt, graphite, lithium, manganese, and nickel – are therefore commonly referred to as the (lithium) battery minerals and metals. Because of the substantial increase in the demand for battery minerals and metals, even compared to other energy minerals and metals, they constitute the empirical focus of the study. The following sections provide an overview of the current demand projections in relation to the potential supply through increased mining, and the potential for other sources of battery minerals and metals to alleviate the need to mine.

2.3.1 A supply-demand gap?

Although an increase in demand for battery minerals and metals is established (e.g., World Bank Group, 2020; International Energy Agency, 2021; European Commission, 2023), the extent of it remains an open question. The World Bank Group (2020) anticipate a roughly 500 percent increase in the demand for cobalt, graphite, and lithium and a doubling in the demand for nickel by 2050. However, these estimates are made in comparison to the production in 2018, not the demand (ibid.). The European Commission (2023) and the IEA (International Energy Agency, 2021) have instead produced forecasts for the increase in demand for these materials and for manganese in 2040, compared to the demand in 2020\(^6\). These estimates are displayed in Figure 2. The IEA has made two different estimates, based on alternative pathways for the future (International Energy Agency, 2021), where the lower of the two estimates is based on current policies and plans and the higher estimate assumes that sufficient actions are taken to meet the goals of the Paris Agreement (International Energy Agency, n.d.). Regardless of which prediction comes closest to the reality of the future demand, they all imply the need for a substantial increase in battery mineral and metals production.

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\(^5\) The SRMs are bismuth, borates, cobalt, copper, gallium, germanium, graphite, HREEs, lithium, LREEs, magnesium, manganese, nickel, PGMs, silicon metal, titanium, and tungsten.

\(^6\) The European Commission bases its forecast on a report by the European Commission’s Joint Research Centre (European Commission, 2023b), where the demand for 2020 is itself a forecast (Huisman et al., 2020). Whether the 2020 demand referenced by the IEA is also forecasted is not clear. Further, while the European Commission (2023) only forecast the demand for batteries (i.e., excluding all other applications), the IEA has included both the battery-related and energy technology-related demand when forecasting the demand for nickel (International Energy Agency, 2022c). The forecast for cobalt (International Energy Agency, 2022a) and lithium (International Energy Agency, 2022b) seemingly only include the battery-related demand and no information is available regarding the forecast for graphite and manganese.
Figure 2. Projected increase in global demand for cobalt, graphite, lithium, manganese, and nickel in 2040 compared to demand in 2020 (International Energy Agency, 2021; European Commission, 2023b).

The increased demand for minerals and metals critical to the energy transition and electrification has resulted in concerns regarding future availability of these materials (Watari et al., 2019, p. 92). Studies conducted in the late 2010s suggest that several materials could be at risk of depletion, including cobalt, lithium (Månberger & Stenqvist, 2018; Valero et al., 2018; Watari et al., 2018), manganese (Valero et al., 2018), and nickel (Valero et al., 2018; Watari et al., 2018). However, the apparent discrepancy between demand and potential supply in these articles is not necessarily a geological issue. According to Mudd and colleagues (2017), materials mined as by-products (which is often the case for critical metals) are far from always reported as reserves or resources in the first place, due to mining companies primarily being interested in the more profitable materials. The growth of known mineral resources in the last few years and the potential for resources to become reserves in the future have further been highlighted by Mudd and Jowitt (2018) as contraindications to depletion.

The distinction between a mineral resource and a mineral reserve is fundamentally economic. A resource is a concentration of minerals or metals of economic value and a reasonable extraction probability, while a reserve refers to a part of a resource that could be profitably mined during current conditions (Canadian Institute of Mining, 2014). What is presently considered a mineral resource could therefore become a reserve in the future, provided, for example, that technologies improve, or further exploration is conducted (Mudd & Jowitt, 2018, p. 230). An increase in demand and a rise in mineral and metal prices could also make the mining of lower-grade resources profitable enough to re-define them as reserves (Achzet & Helbig, 2013, p. 440; Vikström et al., 2013, p. 253). Worth noting, however, is that an increase in mineral and metal prices could also have a reversed effect on demand and create unwanted volatility on the raw material market (International Energy Agency, 2021).

Since the publication of the articles arguing for caution or optimism (e.g., Mudd & Jowitt, 2018; Månberger & Stenqvist, 2018; Valero et al., 2018; Watari et al., 2018), a change in conditions and a growth in mineral reserves and resources has indeed taken place. The estimates for global reserves and resources used by Månberger and Stenqvist (2018) were taken from a U.S. Geological Survey summary of mineral commodities in 2017. Watari with colleagues (2018) further used the same report from two years prior. As is shown in Table 2, the known reserves and, in some cases, resources for cobalt, lithium, manganese, and nickel have increased substantially between 2017 and 2022. The same is true for graphite.
Table 2. Comparison between global reserves and resources of cobalt, graphite, lithium, manganese, and nickel (kilotons) in 2017 and 2022 and increase in reserves and resources (%) since 2017 (U.S. Geological Survey, 2018; 2023).

<table>
<thead>
<tr>
<th></th>
<th>2017</th>
<th></th>
<th>2022</th>
<th></th>
<th>Increase since 2017</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Reserves (kt)</td>
<td>Resources (kt)</td>
<td>Reserves (kt)</td>
<td>Resources (kt)</td>
<td>Reserves (%)</td>
</tr>
<tr>
<td>Cobalt</td>
<td>7 100</td>
<td>25 000</td>
<td>8 300</td>
<td>25 000</td>
<td>17</td>
</tr>
<tr>
<td>Graphite</td>
<td>270</td>
<td>&gt; 800 000</td>
<td>330 000</td>
<td>&gt; 800 000</td>
<td>122</td>
</tr>
<tr>
<td>Lithium</td>
<td>16 000</td>
<td>53 000</td>
<td>26 000</td>
<td>98 000</td>
<td>63</td>
</tr>
<tr>
<td>Manganese</td>
<td>680</td>
<td>NA</td>
<td>1 700</td>
<td>NA</td>
<td>150</td>
</tr>
<tr>
<td>Nickel</td>
<td>74 000</td>
<td>&gt; 130 000</td>
<td>100 000</td>
<td>&gt; 300 000</td>
<td>35</td>
</tr>
</tbody>
</table>

The growth in mineral reserves and resources suggest that depletion may not be as likely as was previously thought. However, supply constraints could still affect the ability to meet the demand for minerals and metals for the energy transition and electrification. It takes time—often over a decade—to get a new mine operational (Kushnir & Sandén, 2012, p. 101), which could create a supply deficit if demand were to rise too quickly. Additionally, the fact that cobalt, for example, is often mined as a by-product of nickel or copper makes it more susceptible to market volatilities (Nassar et al., 2015; van den Brink et al., 2020). Primary production (i.e., mining) of battery minerals and metals may therefore not be enough to secure the supply of battery minerals and metals.

2.3.2 Options to primary production

In addition to primary production, minerals and metals can also be produced through secondary production. One such option is recycling of end-of-life products (e.g., used batteries). Another option is to re-mine tailings (i.e., old mine waste). It is sometimes also possible to substitute one material for another, thereby decreasing the need to produce that material (but increasing the need to produce the substitute material). This section provides an overview of the potential to decrease the primary production of battery minerals and metals through recycling and substitution and the viability of such solutions.

The ability to recycle raw materials contained in products in their end-of-life stage reduces the need for increased extraction of new raw materials (United Nations Environment Programme, 2011, p. 10). In relation to the materials required for a fossil free future, recycling is often highlighted as an important aspect of mitigating supply constrains (whether due to depletion or insufficient primary production rates) (Watari et al., 2018; Alessia et al., 2021). Measures are therefore being taken by the EU, for example, to establish a circular economy for these materials (e.g., European Commission, 2018; European Union: European Commission, 2020a). However, the degree to which different materials are being recycled varies substantially, with iron, base metals, and precious metals being recycled to a larger extent than other metals (International Energy Agency, 2021, p. 35). The recycling rates for the battery metals are presented in Figure 3.

Of the battery metals, lithium stands out in terms of recycling. Most sources agree that the recycling rate of lithium is insignificant, at around or below one percent (e.g., United Nations Environment Programme, 2011; Valero et al., 2018; International Energy Agency, 2023a). The low recycling rate of lithium is mainly attributed to economic reasons; it is more profitable to focus on recycling the more valuable metals in lithium batteries (e.g., cobalt and nickel) (Kushnir & Sandén, 2012; Vikström et al., 2013; Wang et al., 2014; Swain, 2017). Whether this will change in the future is unclear (Kushnir & Sandén, 2012; Vikström et al., 2013). The increase in lithium batteries is expected to provide a major opportunity in terms of recycling (Sun et al., 2017). Nevertheless, the development of lithium batteries containing less expensive metals than the ones usually recycled could decrease the economic incentive to recycle lithium (Kushnir & Sandén, 2012; Wang et al., 2014).

Recycling, although possibly an important supply source in the future, should be regarded as a long-term solution to the supply constraints of battery metals and other raw materials necessary for the energy transition and electrification (Miedema & Moll, 2013; Månberger & Stenqvist, 2018). It will not be possible to meet the rapidly increasing demand for these materials solely through secondary production, as the supply of recyclable waste will not be sufficiently large during the first few decades of the transition (Miedema & Moll, 2013). An increased primary production will therefore nevertheless be required to fully meet the future demand for these materials (Miedema & Moll, 2013; Alves Dias et al., 2018; Månberger & Stenqvist, 2018; European Commission, 2020a; International Energy Agency, 2022d).

The discarded waste from previous mining operations could provide a profitable option to the virgin ground commonly mined for critical minerals and metals, as the ore grade (i.e., the concentration of the targeted material(s) in the mined ore) of mine tailings can be as high as or higher than the ore grade of the material being mined in primary production (Dold, 2020). For example, Araya and colleagues (2020) concluded that the Chilean copper mine tailings show substantial economic potential, and the Swedish iron mining company Luossavaara-Kiirunavaara Aktiebolag (LKAB) is planning to re-mine its old tailings for rare earth elements (Luossavaara-Kiirunavaara Aktiebolag, 2018; n.d.). In addition to increasing the supply of highly demanded minerals and metals, the re-mining of tailings would also increase the circularity of such raw materials, reduce the amount of waste, and reduce the environmental impacts of mining (e.g., energy and water use) (European Commission, 2018; Sarker et al., 2022). However, the re-mining of tailings is also associated with technical, economic, and environmental challenges (e.g., resource intensive extraction processes) (Sarker et al., 2022).

Substitution has been proposed as a complement to recycling, to reduce the need for primary production of critical minerals and metals (European Commission, 2018). Substitution could either target single elements (element substitution) or entire technologies (technology substitution) (Månberger & Stenqvist, 2018, p. 239). With element substitution, the properties and functionalities (e.g., emission spectrum, conductivity, electronic structure, and magnetocaloric effect) should be the same for the substitute element (Sverdrup et
However, this is generally not the case with materials used in fossil free technologies (Sverdrup et al., 2017). If substitution is possible, it is further primarily between elements that are part of the same group in the periodic table and which are therefore also commonly found and mined in the same deposits (Graedel & Erdmann, 2012, p. 328). Such a substitute would not do much to alleviate scarcity (ibid.). In comparison, technology substitution could successfully be applied to most energy and electrification technologies (Månberger & Stenqvist, 2018).

One technology that could be difficult to substitute in its entirety is, however, the lithium battery, due to the lack of viable alternative technologies (Swain, 2017, p. 389; Månberger & Stenqvist, 2018). Options to lithium batteries (e.g., Zink-air batteries) are under development, but it is uncertain when or if these technologies could enter the market (World Bank Group, 2020, pp. 66–67). Although not normally the case, element substitution could be a better option for reducing the demand for lithium battery materials. Indeed, cobalt is already being substituted by copper or iron in some batteries (Turcheniuk et al., 2018; Watari et al., 2018; Sun et al., 2019; U. S. Geological Survey, 2023, p. 61) and graphite has been proposed as exchangeable, although with lithium as its substitute (World Bank Group, 2020, p. 67). When substituting elements or technologies, materials with secure supply should be used (Sun et al., 2019), which makes lithium unsuitable in the short term due to its current criticality status⁷.

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⁷ In the long term, lithium could become a more suitable substitute, provided that the primary and secondary production of lithium increases adequately.
3 Overview of sustainable mining

Some have recognised sustainability (e.g., Peterson, 2009; Murphy, 2012; Blok et al., 2015) and sustainable mining (e.g., Everingham, 2007, p. 93; Endl, 2017) as wicked problems. A wicked problem (compared to a “tame” or “normal” problem) is characterised by a number of difficulties. Rittel and Webber (1973) argue that it lacks a definitive problem formulation, that the problem is explained differently by different stakeholders, that it is unique, and that it is a symptom of another problem. Further, a wicked problem lacks a given number of solutions and the solutions can only be better or worse (compared to true or false) (ibid.). Once a solution has been adopted, it will generate multiple and large-scale consequences, be difficult to reverse, and lack a stopping rule (i.e., it will not be possible to know when the problem is solved) (ibid.).

The following sections address the issues related to the complexity of sustainability and sustainable mining highlighted through the attributed wickedness of these concepts. Firstly, the issue of defining sustainable mining is explained. The differences in how the sustainability of mining is perceived are then related to a systems perspective on sustainability. The systems perspective also helps highlight the importance of spatial scales when defining and solving issues of sustainability. Through the lens of environmental justice and theories on the resistance to and acceptance of mining, the perceptions of mining on a local scale are explored. Together, these concepts are combined into an analytical framework presented in section 4.2.1. Finally, an overview of the literature on sustainability aspects associated with the mining of battery minerals and metals are presented as an illustrative case connected to the empirical focus of the study.

3.1 Defining and understanding sustainable mining

If defined in accordance with one of the most influential definitions of sustainable development – the so-called Brundtland definition – (Jeswiet & Szekeres, 2014), a sustainable action would have to “[meet] the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987, p. 54). This definition, if taken literally, translates into any use of non-renewable resources being inherently unsustainable (Peterson, 2009, p. 78). Since minerals and metals cannot be considered renewable over a timescale relevant to humanity, it follows by such a logic that mining cannot be considered a sustainable activity (Worrall et al., 2009, p. 1427). Sustainable mining, from such a perspective, is nothing more than an oxymoron.

Contrary to this view, some argue that mining can in fact be sustainable (Allan, 1995) and that minerals and metals can be considered “renewed” (Jowitt et al., 2020) if the rate of discovery of new mineral resources and reserves exceeds the rate of extraction. According to others, it is not the mining itself that is either sustainable or unsustainable, but rather the mining practices that are employed. For example, Laurence (2011) argues that safe, efficient, and economically robust mining operations that considers environmental management and community engagement are sustainable. Finally, a new perspective is emerging, where it is the minerals and metals that constitutes the focal point of sustainable mining (Gorman & Dzombak, 2018). Such a framework expands the analytical boundaries to account for every step from extraction to circular re-entry into the system, thereby allowing for a larger number of variables to be considered when determining the sustainability of mining (ibid.).

As is shown above, it is safe to say that there is a lack of consensus on what constitutes sustainable mining and whether sustainable mining is at all possible. However, regardless of how sustainability is defined and understood, sustainability is generally considered to consist of three overarching aspects (also referred to as e.g., pillars, dimensions, perspectives, or components): environmental sustainability, social sustainability, and economic sustainability (Purvis et al., 2019). The conceptualisation of the division of environmental, social, and economic sustainability into three pillars is not straightforward (ibid.). Purvis and colleagues (2019) argue that while some scholars approach the sustainability pillars as different but interlinked systems, others consider them mere perspectives. Cowell and colleagues (1999) propose that underlying assumptions on the relative importance of environmental, social, and economic goals inform to what degree primary extractive industries are considered sustainable. They thereby argue that the differences in interpretations of the sustainability of mining is based on the perceived acceptability of trade-offs (ibid.). The idea of trade-
offs between different sustainability goals is linked by Purvis and colleagues (2019) to a systems perspective on the sustainability pillars.

3.2 A systems perspective on sustainability

Meadows (2009, p. 188) define a system as “[a] set of elements or parts that is coherently organized and interconnected in a pattern or structure that produces a characteristic set of behaviors”. The behaviours of the system constitute changes in its structure or environment (Ackoff, 1971), such as changes in the sustainability of a system. The system structure within which the change occurs is made up of the system’s boundaries, its interconnected parts, and the processes that unfold within it (Meadows, 2009, p. 89; Leach et al., 2010, p. 43). Applying a systems perspective to a behaviour such as sustainability thereby allows for a holistic examination of it, accounting for all aspects of the system and the relationships between them.

When assessing the sustainability of a system, it is necessary to establish its boundaries and measuring its quality (Dong & Hauschild, 2017). The system boundaries are essential to understand the world in terms of systems as they define the system and differentiate it from other systems (Meadows, 2009, p. 97; Dong & Hauschild, 2017) by constituting the context within which processes towards or away from sustainability take place (Bell & Morse, 2008, p. 14). Particular weight is commonly placed on the spatial and temporal system boundaries (e.g., Dong & Hauschild, 2017). The quality of a system further refers to whether it is improving or deteriorating (Bell & Morse, 2008, p.13). In the case of the sustainability of a system, the question is therefore whether it is becoming more or less sustainable. The quality of a system, in general, and the sustainability of a system, in particular, are fundamentally subjective questions based on value judgements (Bell & Morse, 2008, p. 12). This is also what Cowell and colleagues (1999) suggest when discussing the impact of underlying assumptions of acceptable trade-offs on the perception of sustainability. Essentially, it comes down to the type of sustainability that should be aspired – a question that has its roots in the debate on strong and weak sustainability (Bell & Morse, 2008, pp. 12–13).

Strong and weak sustainability constitute mutually exclusive perspectives, where only the weak sustainability perspective accepts trade-offs (Bell & Morse, 2008, pp. 13–14). According to Cabeza Gutés (1996, p. 156), “the concept of weak sustainability is just a direct application of the Hartwick-Solow rule”. The Hartwick-Solow rule (also the Hartwick rule) refers to what Solow (1986, p. 148) argues to be a “better-than-average rule of thumb” for the sustainability of non-renewable resource economies: revenues of non-renewable resources should be invested into man-made capital (e.g., infrastructure, machines) to compensate for the loss of natural capital (e.g., mineral resources, ecosystem services) (Hartwick, 1977). With the Hartwick-Solow rule, no differentiation is made between man-made and natural capital, which is what sets weak sustainability apart from strong sustainability (Cabeza Gutés, 1996). Proponents of strong sustainability do not consider natural capital to be substitutable or equal to man-made capital (ibid., p. 147). Rather, the man-made capital is limited by the access to natural capital (Ayres et al., 1998, p. 4). Conde (2017) argues that the academic literature on extractive industries is primarily characterised by weak sustainability, where mining projects are supported if better environmental protection and compensation is offered.

The differentiation between strong and weak sustainability has also been described in terms directly related to systems theory through the application of system hierarchies. Systems often do not simply exist by themselves: they are made up of subsystems, which, in turn, are made of up subsystems of their own (Simon, 1962; Meadows, 2009, p. 82). The intention is for the goals of the subsystems to build up to a set of goals for the system, but so-called suboptimisation can occur if the goals of a subsystem become dominating at the expense of the system as a whole (Meadows, 2009, p. 85). The layers of subsystems are referred to as hierarchies and Simon (1962) identifies the hierarchies of systems as a central component in their complexity. According to the principles put forward by Allen (2019), higher-level hierarchies operate more slowly than lower-level hierarchies and provide constraints and context to the lower-level hierarchies. Lower-level hierarchies also influence higher-level ones, creating a mutual interaction between different levels of hierarchy (Wu, 2013). When a higher-level system is made up of lower-level systems, the hierarchy is nested (Allen, 2019).

Sustainability and its pillars are commonly depicted in either one of three representations: (1) the environmental, social, and economic pillars as intersecting circles with sustainability in the middle; (2) the...
economic pillar being encapsulated by the social pillar, which is, in turn, encapsulated by the environmental pillar; or (3) the environmental, social, and economic pillars as literal pillars carrying the notion of sustainability (Purvis et al., 2019). The intersecting circles conceptualise sustainability as a product of the interactions between the environmental, social, and economic sub-systems (Barbier, 1987, p. 104), where the sub-systems are not nested in relation to each other (Giddings et al., 2002). In such a conceptualisation, it is the trade-offs between sub-system goals that achieve sustainability (Barbier, 1987, p. 104). This conceptualisation corresponds to weak sustainability (Giddings et al., 2002). The representation of sustainability as encapsulated circles, in contrast, conceptualises how the environmental, social, and economic sub-systems are nested (Fisher et al., 2007, p. 622). It implies an occurrence of dependency between the sub-systems and constraints from the higher hierarchies (ibid.). Due to the constraints imposed by the environment, this conceptualisation corresponds to strong sustainability (Giddings et al., 2002). Figure 4 show the visual representations of the non-nested or weak and nested or strong approaches to sustainability.

![Figure 4. The visual representations of sustainability as non-nested (left) and nested (right) sub-systems.](image)

### 3.3 The role of justice in sustainable mining

Murphy (2012, p. 3) refers to sustainability as a systemic issue where danger is often displaced as a consequence of what are supposed to be risk reducing measures. The displacement of danger occurs when actors choose not to pursue actions themselves due to the perceived negative consequences, but either continue to use the products generated by the actions when performed elsewhere or substitute them with things that generate other negative impacts (ibid.). The displacement can therefore either be spatial (from one geographical area to another) or material (from one set of impacts to another). The spatial displacement of danger described by Murphy (2012) could be interpreted as an example of distributive injustice. Distributive justice has traditionally been the main concern within the field of environmental justice and focuses on the geographical distribution of benefits and burdens (Schlosberg, 2007, p. 13; McCauley & Heffron, 2018). In recent years, the field of environmental justice has expanded beyond distributive justice, to also encompass aspects regarding inclusiveness and participation in decision making (i.e., procedural or participatory justice) and accurate recognition of and respect for everyone (i.e., recognition justice) (Schlosberg, 2007; McCauley & Heffron, 2018, p. 5). The introduction of new aspects of justice to the environmental justice framework is not intended to replace distributive justice, but to complement it (Schlosberg, 2007, p. 40). For example, Sovacool and Dwokin (2015) argue that distributive justice and procedural justice are interconnected, as a redistribution of benefits and burdens is only effective if done in an empowering fashion. Schlosberg (2007, p. 14) further identifies recognition as a basis for distributive justice.

As the demand for minerals and metals for the transition to a low-carbon society is increasing, the role of justice is beginning to gain more interest in the academic literature (Rodríguez-Labajos & Öskaynak, 2017, p. 245). The just transition and energy justice frameworks, especially, are being applied, both to the energy transition (e.g., McCauley & Heffron, 2018; Sovacool et al., 2019) and to questions of raw materials sourcing (e.g., Heffron, 2020; Bainton et al., 2021). According to Sovacool and Dwokin (2015), an energy-just world
is characterised by an equitable distribution of benefits and burdens related to the production and consumption of energy, and a fair treatment of stakeholders in the energy decision-making process. The just transition framework builds on and overlaps with the environmental, energy, and climate justice frameworks (Heffron & McCauley, 2018; McCauley & Heffron, 2018) and McCauley and Heffron (2018, p. 2) define a just transition as “a fair and equitable process of moving towards a post-carbon society”.

3.4 Resistance to and acceptance of mining

Resistance to mining has been approached by scholars from different perspectives. The Not in My Backyard (NIMBY) phenomenon has been applied by some to the opposition to mines in the EU and elsewhere (e.g., Bloodworth et al., 2009; Badera, 2014; Uji et al., 2023), as well as to other land-use conflicts (Burningham, 2000, p. 56). The concept of NIMBY refers to “the resistance of inhabitants towards the realization of [an] investment which is to serve not only local purposes” (Badera, 2014, p. 30). At first glance, the NIMBY phenomenon appears straightforward: while locals can appreciate the benefits of the investment in principle, the preference is for it to be realised somewhere else than in their community. However, the phenomenon has become increasingly problematised in the last couple of decades. Burningham (2000) argue that the attribution of NIMBYism creates, rather than solves, conflicts of land-use and Hermansson (2007) highlights the seemingly arbitrary criteria used to ascribe NIMBYism to opponents of different risks. It has been proposed that the NIMBY phenomenon is more complex than a selfish want to avoid the negative consequences of an investment (van der Horst, 2007; Hermansson, 2007), that the concept is in need of further research (van der Horst, 2007; Schively, 2007), and that it should not be applied by researchers at all (Burningham, 2000; Wolsink, 2006).

Beland Lindahl and colleagues (2015; 2018) propose that place-based perceptions are considered when evaluating the resistance to mining. Place-based perceptions do not represent the NIMBY phenomenon, but rather protective actions informed by the attachment to and identity of a place, combined with the understanding of what sustainable development entails in the specific context (Devine-Wright, 2009). The perception of place is value-driven and rooted in culture (Horlings, 2015). Although it has been linked to local resistance (e.g., Devine-Wright, 2009; Beland Lindahl et al., 2015; 2018), the spatial boundary of place attachment is vague (Brown & Perkins, 1992, p. 284). Attachment to a place builds up over time through shared behavioural, affective, and cognitive experiences (ibid.), not through being physically present in a particular setting. Often, the attachment to a place is only made explicit following a change of (Brown & Perkins, 1992, p. 283) or threat to (Devine-Wright, 2009, p. 429) it. On a local level, the place-based perception approach could contribute to sustainable development, if a co-creative approach of participation is employed (Horlings, 2015).

In terms of local acceptance, the concept of social license to operate (SLO) has become popular in recent years (Gehman et al., 2017, p. 293), especially in relation to mining (Moffat et al., 2016, p. 477). Raufflet and colleagues (2013, p. 2223) define a SLO as the legitimacy or acceptance perceived by local stakeholders for a company or industry operating in an area. Essentially, it is understood to mean that if a company is granted a SLO, it is also granted access to the environmental, financial, and human resources needed for its operation (Owen & Kemp, 2013, p. 31). The SLO thereby goes beyond the legal minimum standard of behaviour needed for regulatory approval, to create a trusting and mutually beneficial relationship between the company and the local community (Moffat et al., 2016, p. 482).

The sustainability of a mining operation receives plenty of attention during the decision on whether a company should be granted a SLO or not (Prno & Slocombe, 2012; Prno, 2013). According to Prno and Slocombe (2012, p. 348), the belief that the benefits of a mining project must outweigh the negative impacts is a prerequisite for a SLO to at all be considered. The connection is further strong between sustainability and the SLO from a company perspective, as companies tend to adapt their sustainability practices to their

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9 Similar concepts to NIMBY are NIMTOO (Not In My Term Of Office), LULUs (Locally Undesired Land Uses), and BANANA (Build Absolutely Nothing Anywhere Near Anyone) (Gerrard, 1994).
SLO and vice versa (Bice, 2014). This implies two things. Firstly, a SLO can act as an incentive for a company to employ more sustainable mining practices, as its access to mine in an area may otherwise be threatened. Secondly, as is highlighted by Prno (2013, p. 586) and implied by Bice (2014), the understanding of what is considered sustainable by a company is impacted by what the local community defines as sustainable.

A critique made against the concept of SLO is the way that it is understood and used by companies. Owen and Kemp (2013, p. 31) argue that the SLO is often used to mask the divergence in expectations between companies and local communities, rather than to understand the differences. Similarly, Parsons and colleagues (2014) propose that the SLO has been conceptualised, for example, to marginalise dissent, rather than to engage with it through sincere dialogue. For the SLO to be a successful concept in terms of minimising conflicts and assure widespread acceptance, quality communication, relationship building, and trust between mining companies and local communities have been identified as some of the most important factors (Prno, 2013; Moffat & Zhang, 2014; Moffat et al., 2016). However, for these attributes to emerge, different expectations and values (e.g., of what sustainable mining is) must be acknowledged (Prno, 2013).

3.5 The case of battery minerals and metals

The relationship between mining and sustainable development is an emerging topic within the literature on battery minerals and metals extraction (Agusdinata et al., 2022). Thies and colleagues (2019) argue that much of the attention has been focused on the environmental sustainability aspects, leaving the social and economic aspects, as well as the trade-offs and synergies between them, less researched. Similar claims have been made about a tendency to overlook the positive aspects when assessing (social) sustainability, in favour of focusing on negative ones (Di Cesare et al., 2018; Mancini & Sala, 2018; da Silva Lima et al., 2022). In a report by the European Commission’s Joint Research Centre, Mancini and colleagues (2019) touch upon both subjects by highlighting the twofold role of raw materials in achieving the SDGs and suggesting that trade-offs and synergies should be actively analysed. Providing a more nuanced understanding of the sustainability of mining energy minerals and metals, including the trade-offs between the positive and negative aspects of sustainability, is precisely what this study sets out to do through an empirical examination of battery mineral and metals mining. To anchor this contribution to the current body of literature on the sustainability of mineral and metals extraction, an overview of the main sustainability aspects of mining battery minerals and metals is therefore provided.

Out of the battery minerals and metals, the largest risk for negative impacts appears to be associated with cobalt (e.g., Lébre et al., 2020; Mancini et al., 2020; Agusdinata et al., 2022, p. 8). In a study on environmental, social, and governance risk contexts, Lébre and colleagues (2020) conclude that cobalt mining is predominantly associated with risks that are social and governance related. Despite the claim made by Thies and colleagues (2019), social sustainability aspects of cobalt mining have also attracted plenty of attention, not least because of the association between cobalt mining and child labour (Kalantzakos, 2020). Around 70 percent of the world’s supply of cobalt is produced by the Democratic Republic of Congo (DRC), which also hosts a substantial amount of the world’s cobalt reserves (U. S. Geological Survey, 2023). About 20 percent of the DRC’s supply of cobalt is produced in the artisanal and small-scale cobalt mining industry10 (United Nations Conference on Trade and Development, 2020, p. 46), were children as young as six (although more commonly between 15 and 17) are employed (Gaffar et al., 2021). In 2017, it was estimated that close to 13 percent of the labour force in artisanal cobalt mines was made up of children (Faber et al., 2017) and a more recent study suggests that this figure could be increasing (Gaffar et al., 2021). The employment of children is fundamentally attributed to poor economic conditions and a lack of alternative jobs (Faber et al., 2017; Gaffar et al., 2021). The general working conditions in the artisanal mining industry are poor, with workers being exploited and put in danger of accidents and other hazards (Tsurukawa et al., 2011; Sovacool, 2019; da Silva Lima, 2022). Corruption, violence, and the displacement of people are reported to be common in the artisanal mining communities (Sovacool, 2019).

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10 Artisanal and small-scale mining is a more simplified, less capital intense, and more labour intense form of mining (Organization for Economic Co-operation and Development, 2019, p. 13). It can be formalised but does not have to be (ibid.).
In addition to the social impacts of cobalt mining, the environment also suffers. A notable impact is the exacerbation of global warming through fossil fuel-based electricity (Farjana et al., 2018). The issue of GHG emissions is not isolated to the mining of cobalt – all mining operations are currently utilizing fossil fuels to some extent (e.g., for transportation and processing) (Allanore & Gribkoff, 2020). As Mancini and colleagues (2019) point out, the emissions created by the sourcing of raw materials used in fossil free energy technologies that contribute to fight climate change showcase the dualism of the relationship between raw materials and sustainability. Other significant environmental impacts are pollution (subsequently affecting people’s health), and water contamination (Sovacool, 2019; da Silva Lima et al., 2022). Finally, van den Brink and colleagues (2020) emphasise the generally low scores obtained by cobalt mining countries on the EPI and connects it to the issue of trade-offs between different goals: while limited environmental regulations are negative from an environmental point of view, such a situation could technically benefit supply security.11

Despite the many negative impacts that cobalt mining currently has on the mining communities, it also contributes with some positive aspects. In a study on the contributions and risks of the cobalt supply chain for lithium batteries in relation to the SDGs, cobalt mining is credited with the ability to contribute to alleviate poverty (SDG 1), increase employment, business opportunities, and economic growth (SDG 8), and incentivise the development of infrastructure (SDG 9) (da Silva Lima et al., 2022). Similar conclusions have been drawn by others, in combination with warnings about the loss of these effects if countries would cease to buy cobalt from artisanal mines in the DRC (e.g., Sovacool, 2019; Tsurukawa et al., 2011).

Following cobalt (and platinum), manganese is the raw material associated with the highest total environmental, social, and governance risks according to Lébre and colleagues (2020, Supplementary information, p. 12). Manganese mining in Southern China has polluted the Heishui River, exposing local ecosystems and upstream drinking water to heavy metals such as manganese, zinc, copper, and lead (Huang et al., 2016). The mining of manganese in China and Brazil (as well as Gabon, although indirectly) has further been associated with armed violence (Downey et al., 2010) and Mancini and colleagues (2020, p. 27) highlight the risk for internal conflict in South Africa, the world’s largest manganese producer.

In addition to manganese being mined conventionally, it also has the potential to be mined from the sea (Sparenberg, 2019; Toro et al., 2020). The submarine deposits of manganese and several other metals (e.g., cobalt and nickel) are estimated to be larger than the underground deposits (Toro et al., 2020). Deep-sea mining could therefore become an important source of raw materials in the future, not least for countries with limited underground resources (Motoori et al., 2018). The mining of manganese nodules12 from the ocean floors has been discussed back and forth since the 1960s and its potential as a resource is once again being considered (Sparenberg, 2019). By sourcing raw materials such as manganese from the ocean floor, the environmental and social stress caused by land-based mines could be reduced (Levin et al., 2020). However, deep-sea mining is also expected to disturb the lifeforms in the ocean, thereby negatively impact the local biodiversity (van Dover et al., 2017; Sparenberg, 2019). Critics further argue that the effects of deep-sea mining are poorly understood, as the oceans are largely unexplored (e.g., Boetius & Haeckel, 2018).

Lithium can be extracted either from brines (salt lakes), using evaporation techniques, or from ore minerals (Flexer et al., 2018). Some (e.g., Flexer et al., 2018) argue that brine extraction is less environmentally damaging than ore extraction, while others (e.g., Agusdinata et al., 2018) argue for the opposite. Overall, less is known about the environmental impacts associated with brine extraction (Wanger, 2011; Izquierdo et al., 2015; Agusdinata et al., 2018), but it has been suggested that it could have severe impacts on freshwater quality (through contamination) and quantity (through groundwater depletion) (Wanger, 2011; Izquierdo et al., 2015; Flexer et al., 2018; Kaunda, 2020). From a social perspective, such impacts have already been reported due to the contamination and depletion of freshwater also impacting the local communities (e.g., Romero et al., 2012; Kaunda, 2020; United Nations Conference on Trade and Development, 2020). Significant issues of lithium ore mining mirror those of other metals being mined from hard rock, including

11 Achzet and Helbig (2013, p. 440) argue that reserves are not only defined by the economic conditions, but also by political ones such as environmental regulations.

12 Manganese nodules are concentrations of manganese, iron oxide, and other elements (e.g., cobalt) which have been formed around a core material (e.g., a shell or a tooth) (Turner, 2019, p. 509).
a high energy consumption and the creation of a large amount of waste\textsuperscript{13} (Wanger, 2011). Mancini and colleagues (2020) further identify a high risk of water related environmental impacts in Australian hard rock lithium mining\textsuperscript{14}.

Similar to manganese and lithium, nickel can be mined from different sources. Nickel can be produced from sulphide ores or laterite ores, with the mining of laterite ores having become more common over time (Mudd, 2010). The type of nickel ore being mined determines the environmental impacts of the mining and the extent of the impacts (Mudd, 2009).\textsuperscript{15} The mining of laterite ore is more energy intense than the mining of sulphide ores, thereby producing more GHG emissions (ibid.). However, the use of sulphide ore is associated with the production of sulphur dioxide (SO\textsubscript{2}) in the refining stage (Kelly et al., 2020). The emission of SO\textsubscript{2} can create acid rain if emitted into the atmosphere (ibid.), which negatively affects soils, plants, trees, crops, and, indirectly, the health of humans and other animals (Singh & Agrawal, 2008). Available technologies allow for the capture and transformation of the emitted SO\textsubscript{2}, resulting in the emissions generally being a relatively small issue (Kelly et al., 2020). However, the application of SO\textsubscript{2}-capturing technologies differs between regions: in Russia, where such technologies are not commonly applied, the SO\textsubscript{2}-emissions are significantly larger than in other regions (e.g., Canada and China) (ibid.).

Finally, graphite mining is primarily associated with pollution in the form of dust and small particles (e.g., United Nations Conference on Trade and Development, 2020; Pell et al., 2021). The dust is created through the use of explosives to expose the graphite (United Nations Conference on Trade and Development, 2020). The dust can contaminate the environment and threaten the health of people working in the mines or living in proximity to them (ibid.). In terms of the social aspects of mining graphite, the European Commission’s Joint Research Centre has further raised concerns regarding both potential current and future risks (Mancini et al., 2020). Most notably, the working conditions in China and the use of child labour in Mozambique are highlighted as potential issues (ibid., pp. 35, 75).\textsuperscript{16}

\textsuperscript{13} Although the use of lithium mining waste as a commodity has received limited attention (Lemougna et al., 2019, p. 333), it does have some potential. For example, Lemougna and colleagues (2019) have shown that the quartz and feldspar rich tailings commonly associated with lithium ore mining could be used to produce low-temperature ceramics.

\textsuperscript{14} In 2022, 47 percent of the world’s supply of lithium was produced from ores in Australia, 30 percent from brines in Chile, and 15 percent from a combination of ores and brines in China (Grosjean et al., 2012; U. S. Geological Survey, 2023).

\textsuperscript{15} In addition to the type of nickel ore being mined, the extent of the negative environmental impacts is further dependent on the nickel ore grade: the lower the ore grade, the more extensive the environmental impacts are for the same amount of nickel (Eckelman, 2010, p 263). This is the case for all minerals and metals (International Energy Agency, 2021, p. 12). With a declining ore grade, more material must be moved (Eckelman, 2010, p. 263), thereby increasing the demand for energy, the emission of GHGs, and the creation of mine waste.

\textsuperscript{16} In 2022, 65 percent of the world’s supply of natural graphite was produced in China and 13 percent in Mozambique (U. S. Geological Survey, 2023).
4 Methods

Following the application of a systemic perspective on the sustainability of the production of minerals and metals for the energy transition, some system boundaries were created to define and refine the scope of this study. Firstly, the empirical portion of this study is focused on the mining of battery minerals and metals. While the energy transition will require an increase in the mining of several minerals and metals during the next few decades, the demand for battery minerals and metals (i.e., cobalt, graphite, lithium, nickel, and manganese) is expected to increase more than the demand for many other raw materials (International Energy Agency, 2021).

Secondly, to refine the scope of the research further, a narrower geographical boundary was established. Rather than to collect and analyse data from all EU member states, focus was directed towards Sweden. Focusing the study on Sweden was motivated by three reasons. Firstly, the geological conditions in Sweden make it likely that the minerals and metals necessary for lithium batteries could be mined in the country (Eilu et al., 2021; Jonsson et al., 2023). Secondly, the mining sector in Sweden plays a vital role for the economy, both on the local and national level (Copenhagen Economics, 2021). Thirdly, the Swedish government is currently working towards improving the social, political, and legal conditions related to the mining of minerals and metals required for a green transition (e.g., SOU 2022:56). The prospect of a future Swedish mining sector for battery minerals and metals was therefore considered favourable.

A two-step approach of both quantitative and qualitative nature was used to collect and analyse the data necessary to meet the scope of the study. A literature search was conducted to collect data from news articles, debate articles, opinion pieces, and other similar written sources to describe which sustainability aspects are being discussed in Swedish media and how they are being discussed. The results from the literature review provided the basis for a set of semi-structured interviews. The semi-structured interviews were conducted to collect data from organisations with an interest in the potential development of a Swedish mining sector for battery minerals and metals. The interviews were used to probe deeper into the discoveries from the literature review by exploring connections between the sustainability aspects and trade-offs related to the perceived need to contribute to the mining of minerals and metals for the EU energy transition. The interviews were also used to explore themes that did not emerge in the literature review in terms of the understanding of sustainability and sustainable mining.

The following sections explain (1) how the empirical data was gathered through a literature search and interviews with stakeholders to the potential battery mineral and metals mining sector in Sweden; (2) how the collected data was analysed with the help of an analytical framework and quantitative content analysis and thematic analysis, respectively; and (3) which measures have been taken to ensure the quality and ethical integrity of the study.

4.1 Data collection

The collection of quantitative data through a literature search and the collection of qualitative data through semi-structured interviews are described in the sections below.

4.1.1 Literature search

The literature search was conducted using Mediearkivet (The Media Archive). Mediearkivet is the largest Nordic digital media database, containing roughly 100 million editorial articles and selected web pages (e.g., from authorities and municipalities) (Retriever, n.d.). A search of the database was made using the mandatory term “mine*” in combination with the optional terms “battery metals”, “cobalt”, “graphite”, “lithium”, “nickel”, and “manganese”. The search was confined to editorial articles and web page entries published in Sweden during the last year (01/03/2022 to 28/02/2023). In total, 1 601 articles and other media features appeared, including news articles, debate articles, opinions, press releases, television features, and radio features. Articles containing information about or opinions on the possible extraction of any of the battery metals in Sweden were selected. No television or radio features were selected. Any duplicates were sorted out once the search was complete. Based on the search criteria, 61 articles were deemed relevant for the review.
4.1.2 Semi-structured interviews

The interviews were conducted with representatives of stakeholders of a potential Swedish mining sector for battery minerals and metals. The organisations with a stake in such a potential mining sector were identified through the application of an adapted version of Freeman’s (2010) definition of stakeholder. In an organisational setting, Freeman (2010, p. 46) define a stakeholder as “any group or individual who can affect or is affected by the achievement of the organization’s objectives”. For the purposes of this study, which applies a systems perspective to the sustainable mining of battery minerals and metals, stakeholders were understood to be those who can affect or are affected by the system’s behaviours. This definition resulted in the following types of organisations being considered stakeholders: (1) mining companies and mining associations; (2) battery producers; (3) governmental agencies with connections to the mining industry or the energy transition; (4) local communities; and (5) environmental and other interest organisations promoting values which are potentially in conflict with mining. Table 3 contains the stakeholders selected for the study, as well as a motivation for the selections.17

Table 3. Stakeholders interviewed for the study, including a motivation for why each stakeholder was interviewed.

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Type</th>
<th>Motivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boliden AB</td>
<td>Mining company</td>
<td>A mining and smelting company with operations in Sweden, Finland, Norway, and Ireland. Currently mining nickel and cobalt in Finland and conducting exploration for nickel in Sweden.</td>
</tr>
<tr>
<td>Talga AB</td>
<td>Mining company</td>
<td>A graphite battery anode producing and graphite mining company which was granted an environmental permit to mine Sweden in April of 2023.</td>
</tr>
<tr>
<td>Svemin AB</td>
<td>Mining association</td>
<td>The Swedish Association of Mines, Mineral and Metal Producers, representing mining, exploration, and technology companies.</td>
</tr>
<tr>
<td>Northvolt AB</td>
<td>Battery producer</td>
<td>Currently the only battery producing company with an operational gigafactory in Sweden and the first European owned company to produce a battery cell in a European facility.</td>
</tr>
<tr>
<td>Geological Survey of Sweden (SGU)</td>
<td>Governmental agency</td>
<td>The agency concerned with questions about the Swedish bedrock, soil, and groundwater, including the sustainable use of these resources.</td>
</tr>
<tr>
<td>The Mining Inspectorate of Sweden</td>
<td>Governmental agency</td>
<td>An independent part of SGU that handles exploration permits, exploitation concessions, and mine inspections.</td>
</tr>
</tbody>
</table>

The selection of a first set of potential representatives from the organisations showcased in Table 3 was made using a combination of purposive sampling and convenience sampling. Provided that statistical generalisation is not intended, purposive sampling can be useful as it focuses on identifying respondents suitable to provide data required to answer the research question (Robson & McCartan, 2016, p. 281). Convenience sampling is less suitable as a sampling method due to its primary concern being easy access to respondents (ibid., pp. 280–281) and it was therefore only used to initiate first contact with the organisations. Once contact had been established, it was possible to use the representatives from the convenience sampling to identify more suitable interview respondents within the organisations. The ten respondents that were ultimately selected to represent

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17 In addition to the organisations presented in Table 4, a mining company with plans to develop a nickel deposit, a Sami village affected by a planned graphite mine, a governmental agency with responsibility for environmental permitting, and a government initiative towards becoming fossil free were also contacted. However, time constraints on their part made it impossible to schedule interviews with representatives of these organisations.
the surveyed organisations, as well as an eleventh respondent identified during the interview with the respondent from the SSNC, are presented in Table 4.

Table 4. Respondents, including the stakeholder they represent.

<table>
<thead>
<tr>
<th>Respondent</th>
<th>Stakeholder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manager of Social Sustainability</td>
<td>Boliden AB</td>
</tr>
<tr>
<td>Environment and Community Manager</td>
<td>Talga AB</td>
</tr>
<tr>
<td>Director Climate and Energy</td>
<td>Svermin AB</td>
</tr>
<tr>
<td>Director Research &amp; Innovation</td>
<td>Svermin AB</td>
</tr>
<tr>
<td>Director of Legal Affairs</td>
<td>Svermin AB</td>
</tr>
<tr>
<td>Senior Manager Green Batteries</td>
<td>Northvolt AB</td>
</tr>
<tr>
<td>State Geologist 1</td>
<td>SGU</td>
</tr>
<tr>
<td>State Geologist 2</td>
<td>SGU</td>
</tr>
<tr>
<td>Deputy Chief Mining Inspector</td>
<td>The Mining Inspectorate of Sweden</td>
</tr>
<tr>
<td>Vice Chairman and Director of Mining Questions</td>
<td>Svermin AB</td>
</tr>
<tr>
<td>Freelance Journalist</td>
<td>SSNC Norrbotten</td>
</tr>
</tbody>
</table>

Once the respondents had been selected, semi-structured interviews were conducted with each of them. The semi-structured approach allows for comparable, yet tailored interviews where the interviewer can be more flexible in their questions and the respondents can be more flexible in their responses (Robson & McCartan, 2016, pp. 284-285; Bell et al., 2019, p. 436). The respondents that were interviewed represent organisations with different stakes in the mining sector and work with different aspects of mining, minerals and metals, and sustainability. Their capacity to contribute with insights therefore varied with the different questions. By using a semi-structured approach to interviewing, it was possible to adapt each interview to the context of the respondent while still covering the same general areas of questions in all interviews. The five areas covered in each interview were (1) background questions about the respondent; (2) questions about the pre-conditions of mining battery minerals and metals in Sweden; (3) questions about the concept of sustainability; (4) questions about sustainability aspects of mining battery minerals and metals in Sweden; and (5) questions about the trade-offs and acceptability of trade-offs between sustainability aspects of mining battery minerals and metals in Sweden. The interview guide can be found in Appendix A.

The interviews were either conducted in person or online (using Zoom or Microsoft Teams), depending on the respondents’ locations. Conducting interviews digitally is generally associated with some drawbacks, compared to conducting in-person interviews (e.g., technological issues and a higher likelihood of respondents not showing up) (Bell et al., 2019, p. 453). However, Bell and colleagues (2019, p. 451) argue that digital communication technologies have become common enough to justify online interviews. Online interviews further allow for a greater flexibility and convenience, as well as being more time and cost effective than in-person interviews (ibid., p. 453). With permission from the respondents, each interview was recorded and transcribed with Microsoft Office’s transcription tool. Transcribing interviews enables a more accurate and thorough analysis of the collected data (Bell et al., 2019, p. 445). After the transcripts had been analysed, the data extracts that were in consideration of being used as direct quotes in the results section were sent to the respondents for them to go over and approve. As most of the interviews were conducted in Swedish, the translations of the potential quotes were also sent to the respondents for approval.

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18 The Freelance Journalist has experience with questions related to mining, minerals and metals, and the energy transition, including as an author of three books on the subject. The Vice Chairman and Director of Mining Questions at SSNC suggested interviewing the Freelance Journalist to get a more nuanced picture of the sustainability aspects on mining battery minerals and metals in Sweden considering that most interviews were with proponents of a strong Swedish mining sector.
4.2 Data analysis

The sections below introduce the analytical framework applied to the media articles and interview transcripts and the quantitative and qualitative processes of analysing the data through this framework.

4.2.1 Analytical framework

The scope of the study was to determine the potential EU contribution towards or away from a sustainable supply of energy minerals and metals in the coming decades, considering the interactions of different associated environmental, social, and economic trade-offs on different spatial scales. To meet this scope, an analytical framework based on the concepts of wicked problems, sustainability, systems thinking, environmental justice, and the resistance to and acceptance of mining (see section 3.1–3.4) was developed for the analysis of the results. A visual representation of the analytical framework is provided in Figure 5.

![Visualisation of the analytical framework.](image)

Based on the literature, the sustainability of mining is a subjectively interpreted question which can be formulated and approached in a multitude of ways. A systems perspective contributed towards highlighting these differences in interpretation and provide a nuanced answer. From a systems perspective, the way in which sustainability is understood (i.e., the perceived interaction between the environmental, social, and economic sub-systems) has implications for which, if any, trade-offs between sustainability aspects can be accepted. It is the acceptance or non-acceptance of trade-offs that determine whether mining can be considered sustainable or not. Determining the perceived acceptance of trade-offs therefore constituted a first step of the analysis.

The way in which the environmental, social, and economic sub-systems interact with each other is dependent on the hierarchy of them. When a nested conceptualisation of sustainability is applied, the environmental sub-system imposes absolute limits on the social sub-system and the social sub-system imposes absolute limits on the economic sub-system. The constraints on lower-level systems make certain trade-offs impossible (i.e., unacceptable). With a non-nested conceptualisation of sustainability, no such constraints are imposed on the sub-systems because they operate on the same hierarchical level. On the contrary, trade-offs between the goals of the different sub-systems are encouraged.

However, the interconnectedness of the environmental, social, and economic sub-systems is not enough to understand the degree to which mining is improving or deteriorating the sustainability of a system, especially considering the added complexity of the system encompassing different spatial scales. While climate change and the need for mitigation through an energy transition and electrification is a global concern, mining is a
local activity. Questions about justice and local acceptance were therefore also present and needed to be dealt with.

The negative impacts of mining that take place in proximity to the mine needs to be balanced with positive impacts, to create acceptance and a SLO. It requires that the rights of the local people are recognised and respected and that the local communities are allowed to take part in decision-making processes. Although the acceptance of mining primarily occurs on a local level, the effects of mining or not mining can transfer impacts beyond the geographical boundaries of the local system. Whether aspects of sustainability beyond the local system are recognised or not when trade-offs are considered contributes to different perceptions of sustainability.

### 4.2.2 Analysis of the media articles

Content analysis can be either quantitative or qualitative in nature, depending on if it is focused on quantifying manifest content or interpreting latent content (Drisko & Maschi, 2015, pp. 3-5). The content analysis performed on the data collected from the literature search was quantitative, as it only sought to identify the occurrence of certain themes (i.e., sustainability aspects and trade-offs). Quantitative content analysis can either focus on the existence of concepts (e.g., the percentage of texts which treat a concept) or the frequency of them (e.g., the percentage of each text that treats a concept) (Drisko & Maschi, 2015, p. 27).

As the purpose of the literature review was to identify which sustainability aspects are present in the media and how they are being discussed, the articles were coded based on existence rather than frequency. The analysis was performed on a thematic level from a set of predetermined categories related to the mentioning of sustainability aspects and trade-offs.

When the purpose of the content analysis is to provide an overview, broad categories are appropriate (Drisko & Maschi, 2015, p. 45). Limited distinctions were therefore made between different types of sustainability aspects and trade-offs (e.g., no regard was taken to whether perceived environmental sustainability aspects were concerned with biodiversity, water quality, air quality, etc.). One distinction was however made: the spatial scope of each discussed sustainability aspect was noted. Because the spatial scope is central to the definition of the system(s) (e.g., Meadows, 2009, p. 97; Dong & Hauschild, 2017), the (un)just distribution of sustainability impacts (e.g., McCauley & Heffron, 2018, p. 4), and the acceptance of trade-offs between sustainability aspects (e.g., Cowell et al., 1999), not taking it into account would have severely limited the ability to make inferences from the reviewed articles. This resulted in three overarching categories of codes being applied, containing 12 codes in total. Table 5 showcase the codes used for the analysis, the category of codes they belong to, and their operational definitions. A more detailed explanation of the codes, including their theoretical connections, theoretical definitions, and the rules used for each code can be found in Appendix B.
Table 5. Overview of the codes used to analyse the media articles and their operational definitions.

<table>
<thead>
<tr>
<th>Code</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sustainability aspects</strong></td>
<td><strong>Sustainability impacts of mining battery minerals and metals in Sweden.</strong></td>
</tr>
<tr>
<td>Positive environmental sustainability aspects</td>
<td>Impacts of mining battery minerals and metals in Sweden that would contribute towards an increased environmental sustainability.</td>
</tr>
<tr>
<td>Positive social sustainability aspects</td>
<td>Impacts of mining battery minerals and metals in Sweden that would contribute towards an increased social sustainability.</td>
</tr>
<tr>
<td>Positive economic sustainability aspects</td>
<td>Impacts of mining battery minerals and metals in Sweden that would contribute towards an increased economic sustainability.</td>
</tr>
<tr>
<td>Negative environmental sustainability aspects</td>
<td>Impacts of mining battery minerals and metals in Sweden that would contribute towards a decreased environmental sustainability.</td>
</tr>
<tr>
<td>Negative social sustainability aspects</td>
<td>Impacts of mining battery minerals and metals in Sweden that would contribute towards a decreased social sustainability.</td>
</tr>
<tr>
<td>Negative economic sustainability aspects</td>
<td>Impacts of mining battery minerals and metals in Sweden that would contribute towards a decreased economic sustainability.</td>
</tr>
<tr>
<td><strong>Trade-offs</strong></td>
<td><strong>Conflicts between different sustainability aspects of the mining battery minerals and metals in Sweden.</strong></td>
</tr>
<tr>
<td>Acknowledged trade-offs</td>
<td>References to compromises between the sustainability aspects of the mining of battery minerals and metals in Sweden.</td>
</tr>
<tr>
<td>Acceptable trade-offs</td>
<td>Positive sustainability aspects of mining battery minerals and metals in Sweden outweigh negative aspects.</td>
</tr>
<tr>
<td>Unacceptable trade-offs</td>
<td>Negative sustainability aspects of mining battery minerals and metals in Sweden outweigh positive aspects of mining.</td>
</tr>
<tr>
<td><strong>Spatial scales</strong></td>
<td><strong>The spatial boundaries within which the sustainability impacts of mining battery minerals and metals occur.</strong></td>
</tr>
<tr>
<td>Local scale</td>
<td>Environmental, social, and/or economic sustainability impacts occur in proximity to the potential mine site (e.g., in a municipality).</td>
</tr>
<tr>
<td>National scale</td>
<td>Environmental, social, and/or economic sustainability impacts occur on a national level (e.g., in Sweden).</td>
</tr>
<tr>
<td>Global scale</td>
<td>Environmental, social, and/or economic sustainability impacts occur on a global level (i.e., all over the world).</td>
</tr>
</tbody>
</table>

4.2.3 Analysis of the interview transcripts

From the point of view of the conceptual framework applied to this study, sustainability is a subjectively interpreted concept based on underlying and unarticulated assumptions (e.g., Cowell et al., 1999; Bell & Morse, 2008, p. 12). This understanding of the sustainability concept informed the choice of analytical method for the interview data: rather than to continue with content analysis (albeit qualitative in this case), a thematic approach was taken. Compared to qualitative content analysis, thematic analysis emphasises the context in which contents are created (Vaismoradi et al., 2013). This facilitated the exploration of the subjective assumptions. Because thematic analysis integrates both manifest and latent contents (Vaismoradi
et al., 2013) the approach further helped capture the assumptions which were not articulated by the respondents.

As is generally the case with qualitative analysis (Yin, 2010, p. 177), the thematic approach follows the steps of compiling, disassembling, reassembling, and interpreting the data (as well as concluding the analysis by relating the interpretations to the research question) (Castleberry & Nolen, 2004). The analysis was initiated through the compilation of the interview data, including the transcribing of the recorded interviews and the removal of extracts unrelated to the scope of the study. The transcribed interviews were then disassembled into data extracts (e.g., sentences and thoughts) through inductive coding and re-coding. When no new codes emerged during the re-readings of the interview transcripts, the codes were reassembled into a first set of themes and sub-themes. The themes and sub-themes were examined in relation to the coded data extracts and adjusted (e.g., divided into multiple themes or combined into one theme) in cases were discrepancies between the themes and the data extracts were identified. The themes were then interpreted through the patterns that were identified between them. An overview of the final set of codes, sub-themes, and themes as well as a thorough explanation of the codes (including definitions, theoretical connection, and examples) can be found in Appendix C.

4.3 Quality assurance

The quality of this study was considered in terms of the reliability and validity of the quantitative analysis, the trustworthiness of the qualitative analysis, and the ethics of the study. The following sections describe these considerations and how they have impacted the quality of the study.

4.3.1 Reliability and validity

The best measure of reliability, especially when conducting a quantitative content analysis, is accuracy (Potter & Levine-Donnerstein, 1999, p. 271; Krippendorff, 2004a, p. 216). Accuracy is concerned with how well the analysis yields what it is supposed to yield (i.e., whether accurate codes are used) (Krippendorff, 2004a, pp. 215–216). However, it is rarely feasible to measure the accuracy of a content analysis (Potter & Levine-Donnerstein, 1999, p. 271; Krippendorff, 2004a, p. 2016). Instead, reproducibility is often used to determine reliability (ibid.). Reproducibility is concerned with inter-coder agreement (i.e., the consistency in coding between different individuals) (Krippendorff, 2004a, p. 215). Testing the reproducibility of a content analysis is done by having two or more coders code the same part(s) of the collected data, thereby allowing for direct comparisons between the coders’ work (Potter & Levine-Donnerstein, 1999, p. 273). However, because the coding of articles was conducted by a single individual, it has not been possible to account for the reproducibility of the coding either.

A third aspect of reliability is stability, which is concerned with intra-observer disagreements in the analysis (i.e., the consistency in coding over time) (Krippendorff, 2004a, p. 215). It is not a strong enough indicator of reliability by itself, but it can give an idea on whether the analysis is reliably conducted or not (ibid.). Because neither the accuracy nor the reproducibility of the conducted content analysis could be measured, the stability of the analysis constitutes the only measure of reliability. Stability is measured by recoding the analysed texts, preferably after some time has passed since they were first coded (Krippendorff, 2004a, p. 215). The articles were therefore recoded ten days after the initial coding was performed. Using a random number generator, 15 of the 61 articles were chosen for recoding19. Each of the articles chosen for recoding were gone through using the same code book that was used for the articles in the first place. Once the articles had been recoded, the initial coding of the articles and the recoding of the articles were compared to determine whether they had been coded the same way or not. The reliability was then calculated using Krippendorff’s alpha, which provided a value of 0.909 (roughly 91 percent). Krippendorff (2004b) argue that a value of alpha at or above 0.800 should be the goal, thereby suggesting high reliability in terms of the stability of the analysis. Appendix D contains a step-by-step description of the calculation of alpha.

19 Each number referred to an article based on when the article had been published. The earliest article (published 9 March 2022) constituted article number one and the most recent article (published 26 February 2023) constituted article number 61.
When conducting a quantitative content analysis, the validity of the analysis is mainly concerned with the degree of consistency of the coding compared to the standard (Potter & Levine-Donnerstein, 1999). The standard is the accurate set of codes that should be applied (ibid.), making validity and accuracy the same. Because quantitative content analysis is applied to manifest content, the standard is objective (i.e., it is possible to identify all themes that should be coded, provided that the text is carefully analysed) (Potter & Levine-Donnerstein, 1999). However, as is noted above, accuracy is difficult to measure properly.

### 4.3.2 Trustworthiness

The overarching concept of trustworthiness includes the credibility, dependability, transferability, and confirmability of the research. Credibility is concerned with how well the views of the respondents are being represented by the researcher (Nowell et al., 2017). A transparent analytical process enables others to scrutinise and trust it (Castleberry & Nolen, 2018), which has been the goal of this method section and the related appendices (A and C). The choice of participants has also been given careful consideration. A variety of respondents with different experiences is beneficial to achieve a broad understanding of the research scope (Graneheim & Lundman, 2004, p. 109). While it was not possible to achieve an entirely balanced selection of organisations and respondents due to time constraints on the part of some key stakeholders, interviews were conducted with respondents representing all but one of the identified groups of stakeholders (i.e., local communities). Further, to reduce the risk of misrepresenting the respondents (Bell et al., 2019, p. 363), they were provided with an opportunity to go through both the original and the translated extracts that constituted potential quotes for the results section.

Dependability concerns the consistency in gathering and analysing the data (Graneheim & Lundman, 2004, p. 110), thereby constituting a prerequisite for repeatability (Castleberry & Nolen, 2018). In terms of collecting the data, the interview guide included in Appendix A was used as a starting point for all interviews. This ensured that all key areas identified prior to the interviews were covered with all respondents. Regarding the analysis of the transcripts, it was done throughout a continuous process which allowed for the identification of new extracts and recoding of old extracts based on findings in the different transcripts. Additionally, all documents created during the process of analysis (including transcripts, different drafts of the code book, and different drafts of analysed extracts) were saved. An audit trail, making it possible to follow which decisions had been made and how they impacted the findings (Nowell et al., 2017, p. 3), was thereby constructed.

The transferability of the study refers to the ability to generalise the results (Nowell et al., 2017, p. 3). The choice of Sweden as a spatial boundary for the study limits the generalisability of the results. Although all EU member states share some characteristics (e.g., certain policies and legislative frameworks), they simultaneously operate in individual political, institutional, social, cultural, and other contexts. Any generalisations of the findings should be done with the specific context of Sweden in mind. This is alleviated by providing so-called thick descriptions of the context within which the study is conducted, the respondents, and the methods employed to collect and analyse the data (Graneheim & Lundman, 2004, p. 110; Nowell et al., 2017, p. 3; Castleberry & Nolen, 2018; Bell et al., 2019, p. 365). Both the empirical background (section 5.1) and the results from the literature review (section 5.2) provide a contextual setting to the findings from the interviews. Steps have therefore been taken to highlight aspects of importance specific to Sweden. With that said, it is not the role of the researcher to judge the transferability of the study (Graneheim & Lundman, 2004, p. 110).

Achieving confirmability is concerned with limiting the effect that the researcher’s biases have on the results and instead allowing them to be informed by the data (Castleberry & Nolen, 2018). Some degree of interpretations is inevitable when a researcher collects, analyses, and translates data (Patton & Appelbaum, 2003; Graneheim & Lundman, 2004, p. 106; Bell et al., 2019, p. 365, 450). However, one way of limiting these interpretations is to involve the respondents through member checking (Graneheim & Lundman, 2004, p. 110), as allowing respondents to check through interview extracts help guard against researcher bias (Robson & McCartan, 2016, p. 172). Further, by combining the presentation of empirical findings with the analysis, an increased transparency of the impacts of the author’s assessments and valuations can be achieved (Emerson et al., 2011). The analysis of the empirical material is therefore presented in combination with the empirical findings in the results section.
4.3.3 Ethical considerations

Measures were taken to assure that all interview respondents were able to make an informed decision about their participation and that they were aware that they could withdraw from the study at any point before, during, or after their interview. Verbal consent to record the interviews and transcribe the recordings automatically through Microsoft Office’s digital transcription tool was gathered before the start of the interviews. Measures were also taken to protect the identity of the respondents to an extent that they were comfortable with. Anonymity is, in practice, almost impossible to ensure (Walford, 2005) and was therefore not offered as an option. However, the respondents were free to decide with which title they were to be referred to throughout the report, thereby making it possible for the respondents to influence how easy or difficult it would be to identify them.
5 Results

In this section, an empirical background is provided, and the quantitative and qualitative results are presented based on the analytical framework.

5.1 Empirical background

The empirical background provides an overview of the Swedish mining industry at present, focusing on the institutional and geological potential for mining battery minerals and metals, the potential for social acceptance of such mining, and the challenges associated with it.

5.1.1 Experience of mining and geological potential

The practice of mining in Sweden dates back over a thousand years (Geological Survey of Sweden, 2020b) and an industrial mining sector has been present since the 13th century (Bindler, 2011). Historically, most mining operations have been conducted on a smaller scale (Geological Survey of Sweden, 2023b). However, the small-scale mines previously present throughout the country have been replaced by a smaller number of large-scale and high productivity mines. Since the year 1900, the number of active mines in Sweden have been reduced from approximately 240 to 12 (Geological Survey of Sweden, 2023a). Despite this reduction, the yearly output is increasing (ibid.). All 12 mines still in operation today produce metals (Mining Inspectorate of Sweden, 2021) and are mostly located in three distinct areas of the country (Geological Survey of Sweden, 2020b). Figure 6 shows the spatial distribution of active mines, with Aitik, Kaunisvaara, Kiirunavaara, Malmberget, and Leveäniemi in the Norrbotten region, Björkdalsgruvan, Kankbergsgruvan, Kristineberg, and Renström in or in proximity to the Skellefte field, and Garpenberg, Lovisagruvan, and Zinkgruvan in the Bergslagen region. The metal(s) produced by each of these mines are shown in Table 6.
Table 6. Overview of active mines in Sweden, including produced metals, location, and owning companies (Mining Inspectorate of Sweden, 2021).

<table>
<thead>
<tr>
<th>Mine</th>
<th>Metal(s)</th>
<th>Location</th>
<th>Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaunisvaara</td>
<td>Iron</td>
<td>Norrbotten</td>
<td>Kaunis Iron AB</td>
</tr>
<tr>
<td>Kiirunavaara</td>
<td>Iron</td>
<td>Norrbotten</td>
<td>LKAB</td>
</tr>
<tr>
<td>Leveäniemi</td>
<td>Iron</td>
<td>Norrbotten</td>
<td>LKAB</td>
</tr>
<tr>
<td>Malmberget</td>
<td>Iron</td>
<td>Norrbotten</td>
<td>LKAB</td>
</tr>
<tr>
<td>Björkdalsgruvan</td>
<td>Gold, Copper, Silver</td>
<td>The Skellefte field</td>
<td>Björkdalsgruvan AB</td>
</tr>
<tr>
<td>Aitik</td>
<td>Gold, Copper, Silver</td>
<td>Norrbotten</td>
<td>Boliden Mineral AB</td>
</tr>
<tr>
<td>Garpenberg</td>
<td>Lead, Gold, Copper, Silver, Zinc</td>
<td>Bergslagen</td>
<td>Boliden Mineral AB</td>
</tr>
<tr>
<td>Kankbergsgruvan</td>
<td>Lead, Gold, Copper, Silver, Zinc</td>
<td>The Skellefte field</td>
<td>Boliden Mineral AB</td>
</tr>
<tr>
<td>Kristineberg</td>
<td>Lead, Gold, Copper, Silver, Zinc</td>
<td>The Skellefte field</td>
<td>Boliden Mineral AB</td>
</tr>
<tr>
<td>Renström</td>
<td>Lead, Gold, Copper, Silver, Zinc</td>
<td>The Skellefte field</td>
<td>Boliden Mineral AB</td>
</tr>
<tr>
<td>Zinkgruvan</td>
<td>Lead, Copper, Silver Zinc</td>
<td>Bergslagen</td>
<td>Zinkgruvan Mining AB</td>
</tr>
<tr>
<td>Lovisagruvan</td>
<td>Lead, Silver, Zinc</td>
<td>Bergslagen</td>
<td>Lovisagruvan AB</td>
</tr>
</tbody>
</table>

As can be seen in Figure 7 and 8, known deposits of cobalt, graphite, lithium, and nickel are present throughout the country. With the potential to mine manganese in Sweden, knowledge is limited due to a lack of exploration (Martinsson & Wanhainen, 2022). Although no mining operations are currently ongoing (Table 6), all five raw materials have historically been mined at various scales (Martinsson & Wanhainen, 2022). For example, cobalt was mined from the mid-18th century up until right before the start of the 20th century and industrial-scale graphite production took place in Kringelgruvan between 1996 and 2001 (ibid.). Beyond the known resources, the prospect of finding additional deposits through further exploration is deemed to be good (Jonsson et al., 2023) following the limited geological knowledge about battery minerals and metals in the Swedish bedrock (Jonsson et al., 2023; Martinsson & Wanhainen, 2022). The potential to find additional deposits of cobalt and lithium is highlighted by Jonsson and colleagues (2023) as particularly promising.
Figure 7. Known graphite, cobalt, and lithium deposits in Sweden, including size of the deposits in tonnes (adapted from Geological Survey of Sweden, 2021).

Figure 8. Known nickel reserves in Sweden, including size of the deposits in tonnes (adapted from © Lantmäteriet, Geological Survey of Sweden; data from Hallberg & Reginiussen, 2018).
Significant graphite deposits are located in two areas of Sweden. The Nunasvaara and Niska deposits (owned by Talga AB) are found in the Vittangi area in Norrbotten and the Kringeltjärn-Woxna deposit (including the closed Kringelgruvan and three additional deposits owned by Woxna Graphite AB) is found in Gävleborg County in central Sweden (Jonsson et al., 2023). It has been suggested that the ore-grade of the Nunasvaara deposit is the highest in the world (ibid.), although the interview respondent from Talga claimed that this is no longer the case following the discovery of a deposit with an even higher ore-grade. Future mines are planned in both areas, with the development of the Nunasvaara South deposit having come the furthest. In April of 2023 the Swedish Land and Environment Court granted Talga the necessary environmental permit for the planned mine (Sveriges Domstolar, 2023). Talga has also applied for exploitation concessions for three additional deposits (Nunasvaara North, Niska North, and Niska South) in the Vittangi area, although these permits likely will not be granted without additional permits being secured first (Länsstyrelsen Norrbotten, 2023). In terms of the Kringeltjärn-Woxna deposit, the preliminary economic assessment has resulted in the suggestion that further studies, including a feasibility study, are undertaken (Zenito, 2021).

A significant cobalt-bearing nickel deposit under exploration is the Rönnbäcken deposit in Västerbotten. The Rönnbäcken deposit (owned by BlueLake Mineral AB) is claimed to be one of Europe’s largest undeveloped nickel deposits (BlueLake Mineral, n.d.). A favourable preliminary economic assessment of the deposit was conducted in 2022, in which it was concluded that the company would be moving forward with a feasibility study and an environmental and social impact assessment (SKR Consulting, 2022). Work on the assessments is expected to be initiated during 2023, provided that adequate financing can be secured (BlueLake Mineral, 2023). In addition to the Rönnbäcken deposit, the Kiskamavaara deposit in Norrbotten could also provide a source of cobalt. The Kiskamavaara deposit (owned by Talga AB) is a cobalt-bearing copper deposit which is significantly smaller than the Rönnbäcken deposit in terms of tonnage, but with a higher ore-grade (Martinsson & Wanhainen, 2022). Other projects in early stages of exploration include the hunt for manganese nodules in the Bothnian Bay (SVT Nyheter Västerbotten, 2022), nickel in the Norrbotten region (P4 Norrbotten, 2022), and lithium in Bergby (in central Sweden, close to the Bergslagen region) (United Lithium, n.d.).

5.1.2 Potential for social acceptance of mining

Zachrisson and Beland Lindahl (2019) argue that the acceptance of, awareness of, and trust for the mining industry in the EU is lower than in many other regions of the world. A 2022 study conducted by SGU suggests that this is not necessarily the case in Sweden. According to the study, 62 percent of Swedes believe that the mining industry should be given the opportunity to develop (Geological Survey of Sweden & Novus, 2022), compared to 52 percent in 2019 (Geological Survey of Sweden, 2023b). Further, 68 percent believe that the mining industry is an important source of new jobs and 73 percent believe that it is important for the economy (Geological Survey of Sweden & Novus, 2022). This is likely to be the case, considering the documented contributions of the current Swedish mining sector. It supports three percent of the annual Gross Domestic Product (GDP) and eight percent of the exports (Copenhagen Economics, 2021). Close to 93 percent of the iron produced in the EU comes from Sweden and the Swedish mining sector contributes with approximately a third of EU’s lead and zinc production (ibid.). In addition to contributing to the state economy and the EU supply of raw materials, the mining sector also benefits the local communities through employment and subsequent tax revenues. In 2021, close to 7 400 people were employed in the Swedish metal mining industry (Geological Survey of Sweden, 2022) and the mining companies constitute the largest private employer in almost all municipalities in which they operate (Ekonomifakta, 2023; Regionfakta, 2023c). In the Norrbotten and Västerbotten (including the Skellefte field) regions, 5 percent of the jobs and 20 percent of the regional GDP are attributed to the mining sector (Copenhagen Economics, 2021).

While recognition of the benefits of the Swedish mining industry does not necessarily translate into social acceptance on a local level, the explicit acceptance of living in proximity to a mine likely does. According to

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20 LKAB is a state-owned company and therefore does not count as a private employer. However, the LKAB Group is the largest employer in Kiruna and the mining company itself is the second largest employer (only surpassed by the municipality) (Regionfakta, 2023b). LKAB is further the second largest employer in Gällivare, where Boliden Mineral AB is the largest private employer (Regionfakta, 2023a). The only municipality in which an existing mine is not a major employer is Lindesberg, where the small-scale Lovisagruvan is located (Ekonomifakta, 2023).
the survey, 49 percent of the respondents would accept an active mine in their vicinity (Geological Survey of Sweden & Novus, 2022). In addition, the survey also suggests that some trade-offs on the local level are acceptable, provided that the mining contributes to the global undertaking of mitigating climate change. Despite 70 percent of the respondents claiming that the mining industry is in conflict with the environment, 44 percent are of the opinion that the mining industry will be important to reduce negative environmental impacts (Geological Survey of Sweden & Novus, 2022). The connection between Swedish mining and climate change mitigation is also highlighted by SGU in the article accompanying the survey, as SGU, at least partially, attributes the positive perception of mining in Sweden to the increased awareness of the need for minerals and metals for the green transition (Geological Survey of Sweden, 2023b).

5.1.3 Challenges to mining in Sweden

The potential to mine minerals and metals necessary for the green transition and for other strategic applications has become a hot topic in Sweden. For example, in October of 2022, the Ministry of Enterprise and Innovation published an official report on the secure supply of so-called innovation-critical minerals and metals, including minerals and metals critical for the green transition (SOU 2022:56). Calls for research programs and centres focusing on the secure and sustainable supply of these raw materials are further being put out (e.g., Mistra, 2023; Swedish Foundation for Strategic Research, 2023), indicating that it is a subject that is gaining interest in academia as well. However, some challenges will need to be addressed to ensure full potential.

A first challenge that needs to be addressed is the permitting processes related to mining. The purpose of the government report on innovation-critical minerals and metals was to provide suggestions on the permitting processes in terms of (1) how to better take into consideration and weigh the local environmental impacts and the local and global contributions of mining operations; (2) how to better distribute the value of the mining industry throughout the whole country; and (3) how to give minerals and metals necessary for the green transition a strengthened position in relation to land and water use (SOU 2022:56). The report resulted in suggestions targeting five challenges: (1) information about and benefits from mining should be shared to increase the social acceptance; (2) information should be made more accessible to enable exploration; (3) the demands for being granted an exploitation permit should be made clearer to increase the investment attractiveness; (4) more coordination and local planning should be employed when prioritising between societal interests; and (5) a long-term initiative to balance exploitation and environmental interests should be employed to make mining easier (ibid.).

A second challenge that needs to be addressed is the lack of willingness to invest in the Swedish mining sector, which was also highlighted in the government report. From an investor point of view, the Fraser Institute Annual Survey of Mining Companies provides an understanding of the perception of the Swedish mining industry and puts it in a global context. The survey consists of three indexes: the Policy Perception Index which rates the governance policies of jurisdictions, the Best Practice Mineral Potential Index which rates the geological attractiveness of jurisdictions, and the Investment Attractiveness Index which is based on the two former indexes (Yunis & Aliakbari, 2022). The survey data is collected by having managers and executives from global exploration, mining, and consulting companies score mining jurisdictions between 0 and 100 in relation to different questions concerning their governance policies and geological potential (ibid.). Based on the scores, the indexes ranking the jurisdictions are calculated (ibid.). The ranking of the Swedish mining sector between 2017 and 2021 is shown in Figure 9. The ranking of the policy perception has overall experienced a negative trend during the past five years, although a small improvement occurred between 2020 and 2021 (from 20th to 19th place). The rankings corresponding to investment attractiveness and mineral potential have fluctuated during the same period, with only the mineral potential reaching its best ranking in 2021.

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21 Only 10 percent of the respondents are of the opinion that the mining industry is not important for the reduction of environmental impacts, as 16 percent believe that it is neither important nor unimportant and 31 percent state that they do not know (Geological Survey of Sweden & Novus, 2022).

22 The Policy Perception Index is attributed 40 percent of the weight of the Investment Attractiveness Index, while the Best Practice Mineral Potential Index is attributed 60 percent of the weight (Yunis & Aliakbari, 2022).
In addition to the main survey, the Fraser Institute has conducted a sub-survey on some jurisdictions, focusing on the timeline and transparency experienced by mining companies when applying for necessary permits (Yunis & Aliakbari, 2022). This is particularly relevant to the perception of the Swedish mining industry considering the critique against the permitting processes. According to the survey, the wait time is low in Sweden compared to other surveyed jurisdictions, although it is indicated by the respondents that the wait time has either not changed in the past ten years or it has increased (Yunis & Aliakbari, 2022). Further, 40 percent of the respondents perceive the level of transparency in the permitting process as a strong deterrent to exploration investments (although the remaining 60 percent of respondents either perceive it as encouraging or not deterring for investments) (ibid.).

A third challenge, which was not explicitly addressed in the suggestions in the government report published by the Ministry of Enterprise and Innovation, is the conflict between the Sami people and the mining industry. The Sami people is an indigenous group of people. Their traditional land is called Sápmi, which constitutes parts of Sweden, Norway, Finland, and Russia. As an indigenous people, the Sami people have certain nationally and internationally governed rights to engage in their cultural heritage on their traditional land (e.g., Rennäringslag, SFS 1971:437; United Nations General Assembly, 2007). Especially the Sami people’s ability to engage in reindeer herding has conflicted with recent mining initiatives, including Talga’s proposed graphite mine in Vittangi (SVT Nyheter, 2023). Both mining and reindeer herding can constitute national interests in Sweden, meaning that they are to be prioritised over other uses of land (Geological Survey of Sweden, 2020a). However, no clear internal prioritisation between national interests exists other than for military interests (3:10 Miljöbalk, SFS 1998:808).

The UN has repeatedly criticised the Swedish government for not adequately considering the indigenous rights of the Sami people (e.g., United Nations Human Rights Council, 2016; United Nations Committee on the Elimination of Racial Discrimination, 2020). In April of 2023 the United Nations Permanent Forum on Indigenous Issues further concluded that actions to mitigate the climate crisis – including resource extraction – must be done in a way that respects indigenous rights, for example by requiring free, prior, and informed consent (The United Nations Permanent Forum on Indigenous Issues, 2023). The demand for such recognition and participation is intended to achieve a less unjust distribution of negative sustainability impacts (ibid.). However, it could result in it becoming difficult to establish mining projects in the mineral and metals rich Norrbotten region and Skellefte field.

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23 In accordance with the United Nations Declaration on the Rights of Indigenous Peoples, free, prior, and informed consent is a right pertaining in relation to actions that may affect them or their land (Food and Agriculture Organization of the United Nations, n.d.). It means that the community in question is able to voluntarily provide a collective decision on an action that they are affected by in advance of the action being taken and based on accurate and adequate information (ibid.).
5.2 Highlights from the media

The analysis of the reviewed media articles provided insights into the close connection between sustainability and the mining of battery minerals and metals, highlighted the need to make trade-offs between different sustainability aspects, and showed that the sustainability aspects transgress spatial scales. Each of these themes are explored in the sections below.

5.2.1 Sustainability is central to battery mineral and metals mining

All but two of the reviewed articles mention sustainability aspects in some capacity. Considering that no version of the word sustainability was used to conduct the literature search, it highlights a profound connection between the mining of battery minerals and metals and the concept of sustainability.

The occurrence of positive and negative environmental, social, and economic sustainability aspects is illustrated in Figure 10. Environmental sustainability aspects are mentioned in the largest number of articles (84 percent), followed by economic sustainability aspects (75 percent), and social sustainability aspects (69 percent). Both environmental and social sustainability aspects are more often referred to as negative (54 percent and 48 percent, respectively) than positive (48 percent and 30 percent, respectively). The economic sustainability aspects are instead more often considered to be positive (54 percent) than negative (41 percent).

Figure 10. Percentage of articles mentioning sustainability aspects.

Figure 10 also shows the percentage of articles that mention both positive and negative environmental, social, or economic sustainability aspects. Positive and negative environmental sustainability aspects co-occur in 21 percent of the articles. Almost as many articles (18 percent) include both positive and negative economic sustainability aspects, while only 8 percent of the articles bring up both positive and negative social sustainability aspects. No article mentions positive and negative sustainability aspects related to all three sustainability pillars. However, 54 percent of the articles include either positive or negative sustainability aspects related to all three sustainability pillars. This suggests that while the idea of sustainability being dependent on all three aspects is common, a fully systemic perspective on the sustainability of battery mineral and metals mining is not being employed by those who approach the subject in the media.

It is more common for articles that mention positive environmental and social aspects to also bring up negative environmental and social aspects (45 percent and 28 percent, respectively) than the other way around (39 percent and 17 percent, respectively). This is a consequence of negative environmental and social sustainability aspects occurring more often in the articles than positive environmental and social sustainability aspects. Following the same logic, it is more common for articles mentioning negative economic sustainability aspects to also include positive economic sustainability aspects (44 percent) than the other way around (33 percent). This is illustrated in Figure 11.
Figure 11. Percentage of articles mentioning negative environmental, social, and economic sustainability aspects that also bring up positive environmental, social, and economic sustainability aspects and the percentage of articles mentioning positive environmental, social, and economic sustainability aspects that also bring up negative environmental, social, and economic sustainability aspects.

5.2.2 The need for trade-offs is well-known

Figure 12 illustrates the occurrence of trade-offs between sustainability aspects in relation to the mining of battery minerals and metals in Sweden. Trade-offs are acknowledged in 71 percent of the articles, thereby highlighting the complex nature of the question of battery minerals and metals mining. In 26 percent of those articles, the trade-offs between sustainability aspects are not weighed against each other (i.e., no opinion on the perceived acceptability of the trade-offs is provided). The trade-offs are perceived to be acceptable in 54 percent of the total number of articles, indicating a weak or non-nested perspective on sustainability. In 48 percent of the articles, the trade-offs are not perceived to be acceptable. Further, 26 percent of the articles present different perceptions on the acceptability of the trade-offs (i.e., both the perception that the trade-offs are acceptable and unacceptable are featured)\(^\text{24}\), which again brings attention to the complexity and differences in understandings.

Figure 12. Percentage of articles mentioning trade-offs.

It is more common that articles only include the perception that trade-offs are acceptable (52 percent) than that articles only include the perception that trade-offs are unacceptable (45 percent). It is therefore more common for the acceptability of trade-offs to be brought up in articles that also include perceptions of unacceptability (55 percent). In comparison, the unacceptability of trade-offs is only featured in 49 percent

\(^{24}\) This is the case in articles where stakeholders of opposite opinions (e.g., representatives of mining companies and indigenous communities) are interviewed.
of the articles that also include the acceptability of trade-offs. However, the difference is small in both cases, as can also be seen in Figure 13.

Figure 13. Percentage of articles featuring either the perception that the trade-offs are acceptable or unacceptable, the percentage of articles featuring trade-offs as acceptable in articles featuring the perception that trade-offs are unacceptable, and the percentage of articles featuring trade-offs as unacceptable in articles featuring the perception that trade-offs are acceptable.

5.2.3 Sustainability aspects and trade-offs transgress spatial scales

There is a difference in at which spatial scales sustainability aspects are recognised in the articles, depending on which sustainability pillar they are related to and whether they are positive or negative. As can be seen in Figure 14, the negative environmental sustainability aspects are predominantly recognised on a local level (94 percent of the articles), while the positive environmental sustainability aspects are more often related to the global level (83 percent of the articles). This discrepancy between where positive and negative aspects of environmental sustainability are experienced suggest a conflict between local and global interests and a possible sense of unjust exploitation: while everyone benefits from the results of the mining, only a few bears the cost of the production.

Figure 14. Percentage of articles mentioning negative and positive environmental sustainability aspects on different spatial scales.

A similar picture as for the environmental sustainability aspects emerges in terms of the social sustainability aspects: while the negative aspects are predominantly related to the local level (93 percent of the articles), the positive aspects are primarily recognised on the national level (83 percent of the articles) (Figure 15).
Figure 15. Percentage of articles mentioning negative and positive social sustainability aspects on different spatial scales.

With the economic sustainability aspects, the positive and negative aspects are less unevenly distributed on different spatial scales (Figure 16). While negative sustainability aspects are mainly found on the local level (100 percent of the articles), positive economic sustainability aspects are recognised on both the local (59 percent of the articles) and national (94 percent of the articles) levels. While a displacement of the economic benefits of battery minerals and metals mining are still expected, it is less prominent than the displacement of environmental and social benefits.

Figure 16. Percentage of articles mentioning negative and positive economic sustainability aspects on different spatial scales.

Because the positive and negative sustainability aspects of mining battery minerals and metals in Sweden are present at different spatial scales, the trade-offs between sustainability aspects also transgress the spatial boundaries of the systems.

5.3 A stakeholder perspective

The analysis of the interviews resulted in three main themes and a total of eight sub-themes which constitute the headlines for the sections below.

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25 The significant percentage of both positive local and national economic sustainability aspects of mining battery minerals and metals in Sweden is due to the jobs created from such an industry: the jobs would have a positive effect on the people living in the communities close to potential mines as well as on the Swedish economy and labour market.
5.3.1 A multifaceted (lack of) understanding of sustainability

_Sustainability_ can either mean anything or nothing, resulting in a multitude of different and more or less agreed-upon interpretations of what sustainable mining entails. Although all three pillars of sustainability – the environment, society, and the economy – are necessary, they are not perceived by all as equally important. Below, the three sub-themes _sustainable mining is an ambiguous concept, equally important pillars, and the environment sets the limit_ are presented, highlighting the discrepancy in the understanding of sustainability and what it entails for the sustainable mining of battery minerals and metals in Sweden.

**Sustainable mining is an ambiguous concept**

During the analysis, an issue of defining sustainability and sustainable mining emerged. Considering that there is a lack of consensus on the definition of sustainability and sustainable mining in the academic literature, this is not surprising. However, several respondents went as far as to suggested that the sustainability concept has lost its meaning and that it is used in a way that does not translate into actions. For example, the Vice Chairman and Director of Mining Questions at SSNC called sustainability a “PR-word” and explained that:

> You can say that all questions today are about sustainability. [...] So everyone is just talking about sustainability and does not know what sustainability actually is. [...] Everything becomes sustainable nowadays. And not least the mining industry – incredibly sustainable and green.

What the respondent wants to convey by this is clearly not an actual sentiment of the Swedish mining industry being sustainable, but rather that sustainability is a misunderstood and mistreated concept. The multitude of interpretations of it results in it not conveying any real information or being backed up by actions. An example of the latter was further provided by one of the State Geologists (1) at SGU.

> Swedish authorities need to work long-term and practically with sustainability questions. Today there is a lot of talk and little action. We work little or not at all with sustainability.

While discussions on sustainability are part of everyday life, it is more so a box to tick than a tool for change. This was further highlighted by respondents in terms of the difficulty of measuring and reporting sustainability. All the different methods, models, standards, and requirements that can be applied result in it being a rather overwhelming task that ends up saying little about the actual quality of the system within which the mining takes place.

**Equally important pillars**

When asked about the relative importance of the environmental, social, and economic sustainability aspects, several respondents were genuinely confused about the question. The Director of Legal Affairs at Svemin, for example, said:

> I mean, I do not see that we would value the different pillars of sustainability differently, they are integrated pillars that are all necessary for a long-term sustainable mining.

Similarly, the Environment and Community Manager at Talga responded to the question as if it was the obvious – and only – way in which sustainability could be comprehended.

> Yeah, they are three pillars. If any of those pillars fall, the operation will cease, right? We absolutely need all three. Having long term environmental harm – there is no way that it is going to be economically sustainable. Nor if you do not have a social licence. So, if any of those fail, all three fails.

What the respondents conveyed with the above statements was interpreted as all three aspects of sustainability affecting each other, but without any of them constituting more of a limiting factor than the others. Such a perspective would fit that of weak sustainability, as it means all three pillars of sustainability would need to be considered for a mining operation to be sustainable. This interconnectedness became especially apparent in the analysis through the way in which respondents spoke about the importance of economic sustainability. For example, the Senior Manager for Green Batteries at Northvolt explained:

> Well, if an actor can produce [minerals or metals] in a sustainable way and with low CO2-footprint in Sweden that would be very positive. But it also has to be economically sustainable [...] Metal prices are
very cyclical. It has to be sustainable when the prices are lower as well. […] It is neither good for the environment nor for anyone else if a mine is started and is then bankrupted because the metal prices drop.

The argument made here is that the discontinuation of a mining operation following it not being profitable has effects beyond the mining company itself. The ability to sustain other systems when operating, such as the environmental and social ones, are lost with the loss of the economic sustainability of the company. Taking proper mitigation and restoration actions, after all, requires funding.

**The environment sets the limit**

The analysis did not only reveal evidence of a weak approach to sustainability. At the core of the strong sustainability perspective is the limits that the environmental sub-system imposes on the social and economic sub-systems. One such limit was identified by the Freelance Journalist as the scarcity of natural resources, including minerals and metals. This view was shared by one of the State Geologists (2) at SGU.

…we need to understand that we cannot maintain our consumption the way it is today. We need to consume less. There is no doubt about it.

While neither one of the respondents go as far as to argue that it is necessary or feasible to completely refrain from mining battery minerals and metals – or other raw materials –, they question the motivation and necessity behind the extent of the production and consumption. In response to the assumed manyfold increase of the demand for battery minerals and metals the Freelance Journalist said:

I want to emphasise that there are huge opportunities available to make things in a way that saves resources completely differently than today. […] The point is that it would be possible to build a society where the resource demands are dramatically much lower than today and still maintain what is good about a modern society. It is not about lowering the indoor temperature to 15 degrees Celsius and to bike in blizzards and headwind in the middle of winter, but instead it would still be an exceedingly modern society but with incredibly much lower resource use.

What is expressed above is that society and the economy can thrive even if environmental constraints are allowed to limit the production and consumption of resources. While this is suggestive of a perspective on sustainability in line with that of strong sustainability, the clearest articulation of a strong sustainability perspective was provided by the Vice Chairman and Director of Mining Questions at SSNC.

There will never be any green mines because it entails such a destruction of the environment that cannot reasonably be restored.

By saying this, the respondent emphasises that it does not matter to what degree sustainability can be achieved in terms of the social and economic aspects of mining – what matters is the inevitable and irreversible negative effects that mining has on the environment. As it is impossible to completely avoid impacting the environment of the mine site, claiming that mining can be done sustainably would therefore be incorrect.

**5.3.2 Handling the trade-offs of mining battery minerals and metals**

Trade-offs between different sustainability aspects cannot be avoided and solutions to them may not be obvious. The way in which sustainability aspects are handled is characterised by some concerning shortcomings, but there are also efficient tools in place to reach acceptable solutions. Below, the three sub-themes *the equation does not add up, shortcomings in the handling of sustainability aspects,* and *keys to sustainable mining* are presented, highlighting the interaction between the sustainability aspects and what is required to improve the sustainability of mining battery minerals and metals considering the current state of the Swedish mining sector.

**The equation does not add up**

Regardless of the respondents’ views on the sustainability of mining battery minerals and metals, the analysis of the interviews showed that it would not be possible to mine without at least some trade-offs having to be made. For example, the Freelance Journalist said:
It is possible to do things better or worse, but really, even if you do it well, some environmental problems remain. And land-use problems and social problems.

At the core of this statement is the inevitability of having to accept certain externalities and the complexity that it entails for any discussion about mining. The problem of negative sustainability impacts from mining cannot be properly solved, as there is no one true solution. Further, when the trade-offs between different sustainability aspects cannot be balanced, it makes these conversations even more difficult. Regarding the ongoing land-use conflict between the mining company Talga and the Sami villages in the area of their proposed mine, the Freelance Journalist could not imagine a fair solution:

Yeah, what do we do about this? That is genuinely difficult to say. I do not even want to try to give any sort of answer to that, but only to ascertain that there will be situations that are really complicated.

Simply put, what the Freelance Journalist argues is that there are no easy or universal solutions to the issues related to the mining of battery minerals and metals. What is considered to be the best solution to the trade-offs will depend on who is asked and how they perceive sustainability and sustainable mining. According to the analysis, this also extends into the weighing of trade-offs in the permitting processes. As the Deputy Chief Mining Inspector at the Mining Inspectorate put it:

It becomes from case to case. There are no general guidelines there. We have the national interest system which provides some direction of course, but relatively often there are more than one national interest in the same place and then you are simply back to it being a difficult trade-off.

There is no one-size-fits-all rule that can be applied to mining, due to the complexity of the systems within which it takes place. Rather, the decision-making (e.g., the Mining Inspectorate and the Swedish Land and Environment Court) are left with the task of deciding on the best solution in each unique situation. However, when solutions are proposed, the analysis revealed that they are not necessarily thought to match the problems that they are intended to fix. An example of this was provided by the Freelance Journalist when asked about how the Swedish mining sector could contribute towards the sustainable supply of battery minerals and metals in a global context.

The industry itself says that “Well, is it not better that we mine in Sweden, instead of it being done in countries with much more lenient environmental regulations?” And that sounds tempting, of course. But I am of the opinion that even if we open 30 or 50 mines in Sweden – which are the numbers that have been mentioned by SGU – it will not lead to mines being closed in the Democratic Republic of Congo. I do not think anyone believes that.

According to the Freelance Journalist, the issue of the unsustainable battery mineral and metals mining in certain countries is not a symptom of the lack of a sustainable production in other countries, as some seems to be claiming. It is therefore not as simple as one country taking over the production from another, less sustainably producing, country.

In the end, the analysis suggests that the ease with which problems of mining battery minerals and metals sustainably can be answered comes down to the level of complexity ascribed to the problems and the level of complexity allowed for the solutions. One of the State Geologists (1) at SGU brought this up:

The impacts on the surrounding can be a very complex question. What does natural background values look like – for example, there can be naturally high background values of heavy metals in areas with mine worthy concentrations. Mining affects a community in many ways, socially and environmentally. It is complex.

By saying this, the respondent emphasises that mining is not conducted in a vacuum, but rather in a set of interconnected sub-systems with unique conditions. When talking about the sustainable mining of battery minerals and metals, a systemic approach is therefore required.

**Shortcomings in the handling of sustainability aspects**

The analysis revealed a lack of knowledge in the Swedish mining sector, stemming from the bedrock and its processes being underexplored. This lack of knowledge makes it more difficult to mine as it means that the potential of the bedrock is unknown. However, it could also affect the sustainability of the mining operations.
that are started. One of the State Geologists (1) at SGU was particularly concerned about the limited understanding of the Earth system.

Geoscience is an important subject for understanding natural resources and the environment from many perspectives. That is, all three, the economic, social, and environmental [perspectives].

What the respondent means by this is that the lack of knowledge about the processes at play translates into the full extent of the effects of human interference also being unknown. For example, it is not possible to predict how water bodies may be impacted from mining if it is not known how the geosphere and the hydrosphere interact in a particular context. A proper systems approach to mining thereby becomes impossible, as does accurately measuring the quality of the systems. But it is not only the lack of knowledge within the field that worries the State Geologist (1).

With fewer people having knowledge in geology and geoscience self-proclaimed experts appear, talking about exploitation and the environment […] But there are few experts with knowledge. It creates a dangerous situation where no one knows what is true. The rock is the unknown and then anyone can step up and be an expert and say things with any agenda. That is a dangerous development.

Here the State Geologist (1) highlights that geology and mining are subjects that people generally know little about and that this opens up for interpretations that may be both untrue and damaging. The Director of Legal Affairs at Svemin further made a connection between this lack of knowledge amongst people in general and the resistance to mining.

If you look towards instances of large public resistance and such, it is often in areas unfamiliar with mines. There it has become especially controversial with mine establishments.

With the statement above, the respondent highlights that those who have experience with how society, the environment, and the economy are affected by mining are less likely to oppose it and instead meet such developments with acceptance. What the lack of knowledge does is therefore to create distrust towards the sustainability of mining and the actors claiming mining operations to be sustainable. An example of this was provided by one of the State Geologists (1) at SGU, who explained that statements are sometimes made about the quality of things without being based on actual evidence.

When it comes to social sustainability… We have a situation where […] in our eagerness to help the industry, we have instead overturned the whole question because we have created a situation where parts of society distrust us due to us not having had enough information. That is, if we lack knowledge in important societal questions related to geology and natural resources and make claims anyways, in directions that support the industry, society lose trust in us as an expert authority. That is a very dangerous development.

By saying this the social consequences of not having enough information, on top of the environmental ones, are highlighted. Knowledge and trust thereby go hand in hand. However, the analysis also revealed a link to dishonesty, or sense of dishonesty. In relation to Talga’s proposed graphite mine in Vittangi the Vice Chairman and Director of Mining Questions at SSNC said the following:

And they also claim that it will be possible to coexist with the Sami people. But – and it is three Sami villages that this concerns – that is actually a lie because it is four mines and it will not only be mining during the summer half of the year as Talga claims in its first application, but there will be mining going on all year.

The claim made above is not only about a lack of information creating scepticism, but rather about a belief in a purposeful attempt to lie.

A final shortcoming in the handling of the sustainability aspects was identified from the analysis as the issues associated with the Swedish Environmental Code and, to some degree, the permitting process in general. As the Senior Manager for Green Batteries at Northvolt explained:

Talking about preconditions for the industry in general in Sweden – or in all countries really – I do not think that anyone is benefited by long decision-making processes [and] unclear rules. […] Because there is nothing that becomes more sustainable from making it more complex. It is better to have high demands and a quick process. […] I recently saw a compilation of how long it takes in all EU countries to gain
some type of decision on mining and Sweden is doing quite poorly and that is not something that anyone benefits from.

What the respondent does in the extract above, and what other respondents did as well, is not to question the high demands enforced with the regulations. Instead, what is being said is that the complexity of the permitting processes fails to translate into a higher quality of sustainability. The lack of transparency in terms of how trade-offs will be made and the lack of speed in which the decisions are made simply result in a less attractive investment climate and fewer mines benefitting the green transition.

**Keys to sustainable mining**

The analysis revealed that at the heart of a sustainable mining operation is local acceptance and a social licence to operate. This was, for example, expressed by the Environment and Community Manager at Talga.

> It is important [that] we have a strong focus with our neighbouring and host communities that we would operate in in the future. […] And some level of social licence to operate and some level of trust within the local communities and the indigenous communities in which we seek to operate.

With the statement above, the respondent shows an understanding of the power that local communities have. With acceptance being provided or withheld, so is opportunities for companies to use the resources found locally. While it may not be possible to make everyone agree on every decision that mining necessitates, acceptance should be a goal. However, that requires communication with and cooperation between the involved parties. In relation to the trade-offs made by the company, the Manager of Social Sustainability at Boliden said the following:

> We will never be able to reach an exact consensus, but it is important to create an understanding of how we reason.

With this, the Manager of Social Sustainability recognises the need to acknowledge the different perspectives that the mining company and the local communities may have and to engage in an active conversation about them. The different perspectives further do not need to hinder such cooperation, as was brought up by the Environment and Community Manager at Talga.

> We see there is great opportunities to be able to work with our host communities and the Sami and [Sami villages] in the areas. […] They have continued to engage with us while they continue to make it clear they do not want a mine in the area. They have not really cut us off or anything like that. […] Things have not reached a point where it is unworkable or untenable.

Despite the Environment and Community Manager describing the Sami villages around the planned mine to be fundamentally opposed to it, that is not seen as a reason for either of the parties to not engage in a dialogue about it. It is the communication and cooperation with affected communities that make it possible for the mining companies to avoid or minimise a lot of the negative sustainability impacts. This, too, was brought up by the Manager of Social Sustainability at Boliden.

> Reindeer husbandry, for example, we meet with ongoing through all these phases and work in accordance with the mitigation hierarchy and try to avoid, minimise, [and] mitigate damage, and finally compensate, if we cannot successfully mitigate damage.

By saying this, the Manager of Social Sustainability highlights the practical potential that communication and cooperation have in terms of finding solutions to mine more sustainably. The demands put on the mining companies to gain acceptance from the local communities, including what matters to them in terms of sustainability, thereby translates into actions practiced by the companies.

5.3.3 Mining for the greater good

At the end of the day, the spatial boundaries of the sustainability impacts of mining battery minerals and metals can be defined very differently. The negative impacts – and some of the positive ones – are experienced at the local level. But the global demand for battery minerals and metals for the green transition also cannot be ignored. Below, the two sub-themes the need to mine is a global responsibility and the price
of mining is paid locally are presented, highlighting the added complexity provided by the different spatial scales at which the sustainability aspects – and the trade-offs between them – take place.

The need to mine is a global responsibility

The analysis showed an overall acknowledgement of the need to mine in order to meet the global demand for battery minerals and metals, whether done in Sweden or elsewhere. For example, the Freelance Journalist said:

The first thing one needs to be honest about, I think, is that we will need more of these metals and elements, and we will also need some more mines, even if we tighten up the management of batteries in an optimal way. It cannot be ignored.

On a similar note, one of the State Geologists (1) at SGU highlighted the current inability to rely on secondary production.

Recycling of already mined metals is only a small part. If we are to accommodate the societal need that has been predicted today, it demands significant new mining. Many constructions that contain recyclable raw materials have a relatively long lifetime and can only be recycled many decades into the future. The recycling equation therefore does not nearly add up.

Although some reluctance against mining is suggested in both statements, the inevitable need for battery minerals and metals for the global energy transition cannot be overlooked. The complexity does not lie in whether or not these materials should be mined, but where the mining should take place.

In the context of sustainable mining, many respondents highlighted the (more) sustainable mining practices in Sweden. For example, one of the State Geologists (2) at SGU acknowledged the potential for the sustainable mining of battery minerals and metals in Sweden by making a comparison between the current Swedish mining sector and the cobalt mining sector in the DRC.

And what has been pressed on is, recently, that mining in Sweden is sustainable and have great opportunities to be sustainable in regard to battery metals. Because compared to, for example, mining in [the DRC]… It is not particularly sustainable […]. It is almost looked upon as slavery in some parts of [the DRC] and it is not at all as environmentally sustainable or sustainable in any way.

By this, the respondent implies that by not displacing the negative effects of mining in countries with poor regulations and instead source the raw materials domestically, the total negative effects of mining could be reduced. Other respondents made similar comparisons with the Chinese mining sector and with mining sectors in other countries in general, thereby arguing for domestic production.

In relation to the acknowledgement of the need to mine battery minerals and metals and the potential for Sweden to mine these raw materials sustainably, the analysis further revealed a sense of responsibility. With Sweden having both the geological potential to mine and the potential to do so sustainably, several respondents brought up the responsibility that the Swedish mining sector has to utilise this potential. The Freelance Journalist, for example, made it clear that if battery minerals and metals can be mined in Sweden, they should be.

It is of course perfectly reasonable that where there are sensible, good deposits to make use of in Sweden, they should be made use of. There cannot be some sort of exemption voucher like “We do not want any mines, that can be done elsewhere in the world”.

What the Freelance Journalist implies by this is that consumers of battery minerals and metals should also be required to step up in terms of production. It simply would not be fair to not contribute to the supply while expecting others to do so, thereby displacing the negative effects of mining elsewhere. Currently, though, this is not the case. Several respondents pointed this out by referencing the Swedish and European import dependency. However, many also brought up other instances, beyond domestic battery minerals and metals mining, in which Sweden is taking responsibility and should continue to do so. Consumers such as Northvolt make a point of placing the same high demands on all producers independent on where in the world they operate and actors such as SGU share their experience and knowledge of sustainable mining practices with others.
The price of mining is paid locally

While the analysis showed that the need to mine is a global concern, it simultaneously appears that the local aspect of mining cannot be stressed enough. As the Director of Legal Affairs at Svemin put it:

…a mine must be where the ore or the mineralisation is which means that we cannot chose. With wind power plants, for example, you can often work with localisation, even on the local scale. […] But that type of consideration is difficult to do with a mine sometimes, as the mine needs to be where the ore is.

With this, the respondent highlights the highly site-specific nature of mining due to geological restrictions. It further sometimes forces conflicts to surface, when mine-worthy concentrations of minerals and metals are found in places where a mine would not be suitable.

Of course, the extraction of minerals is a sustainability interest in and of itself, which is put against the more local interests.

The statement made above by the Deputy Chief Mining Inspector at the Mining Inspectorate capture the core of the issue on a general level. Other respondents provided examples of such trade-offs, including the destruction of nature and loss of biodiversity at the mine site, the infringement on the Sami people’s ability to practice their cultural heritage on their own land, and the hindrance of other economic interests (e.g., agriculture and tourism) in the area. While different in terms of which sub-systems are affected and how, what these and other examples have in common is the connection to land-use conflicts on a local scale and the complexity that it brings in terms of lower-level sub-systems in the global question of the energy transition and electrification of society.

When global interests are put against local ones, the local interests easily become a priority for those living and working in an affected area. The threat of an area being changed can uncover sentiments of attachments toward that place and the lack of benefits being experienced where the impacts take place can create frustration and a sense of injustice. The complexity of dealing with the latter type of sentiments, in particular, was brought up by the Manager of Social Sustainability at Boliden.

Yeah well, it is a challenge to get local understanding. And that is maybe also not something to expect either, that an individual which is directly affected is supposed to put on the international hat and overall responsibility for the climate. You simply have to accept that there are these private interests that are opposed to such a project, despite the total benefit to the climate and the world being completely overwhelming.

What the respondent means by this is that although it may be obvious how the mining of battery minerals and metals could contribute on a global scale, it may not be fair to expect that to outweigh the equally real but relatively smaller concerns of the locals. Simply complaining about NIMBYism does not make the complex situation that mining creates locally justice. However, the Manager of Social Sustainability also noted that the total benefit for the climate is gaining recognition, even by those who are generally most negatively affected by mining.

What we have felt is that there already has begun to be a shift there. If you take the Sami villages, for example, which are often against us claiming land, they are aware that they maybe are the ones being hit the hardest by climate change […]. So, they have gotten an increased understanding of that we need to produce these metals to handle the green transition…

With the statement above, the respondent highlights that while the local effects of mining continue to be a concern, the discussion is becoming more nuanced.

Another set of nuances identified during the analysis was that of the multiple roles that mines can play for local communities. Communities can rise and fall with the opening or closing of mines, either through opportunities emerging or being taken away when the mine comes to town. The Director of Research and Innovation at Svemin explained how mines can even constitute the foundation and bearing of some local communities.

Many of the mines in Sweden today have been situated in sparsely populated areas and many mining communities have also grown up around, really, mines, where there have previously not been any communities. […] When mining communities are closed down or do not gain continued permission it
creates tensions in society, because then they see that schools must be closed, there is emigration, the service disappears, restaurants disappear.

Accordingly, mines can contribute positively to the social and economic sustainability of communities by enabling both necessary services and appealing extras. Mining is therefore not only an expense locally. In such a case, the attachment to and identity of a community could even be dependent on the existence of a mine. However, mines do not always deliver on the promise of local social and economic benefits. Although most respondents withheld that mining means more than just damage to most local communities, a contrasting view was brought up by some of the respondents. For example, the Freelance Journalist questioned whether a mine is enough to sustain communities with little else to offer their inhabitants.

The experiences of what mines entail for the regional development, they are not entirely positive. […] Not even in Gällivare or Kiruna the mine is enough to sustain the population level. These municipalities are losing inhabitants. There are large problems on the labour market and the housing market.

What the respondent means by this is that mines may be synonymous with hope for some, but that the hope can also develop into disappointment. A mine may solve the decline in population, work opportunities, and other social and economic aspects in the short term, but with time the trend often returns towards a downwards path. This could potentially lead to a loss in social acceptance when it turns out that the benefits do not outweigh the damages.

Finally, the analysis suggests that establishing mines can also take opportunities away from others. The analysis showed this to be a pressing and complex issue in Sweden, considering that much of the land with known mining potential is used by the Sami people when exercising their cultural heritage. The Vice Chairman and Director of Mining Questions at SSNC expressed particular concern about this.

…short-term interests, like this is a question of, that at the same time have a large environmental impact cannot outweigh the Sami people’s right to continue to exercise their culture and reindeer husbandry which they are acknowledged the right to, among other by the Instrument of Government.

With this, the Vice Chairman and Director of Mining Questions is essentially saying that it would not be fair to take away the rights of a minority for the sake of a small contribution towards the global energy transition or the potential for the temporary growth of some local communities. It highlights that this is not just a question of whether or where to mine battery minerals or metals – or even how to do so sustainability –, but also a question of recognising peoples’ rights and acting accordingly when attempting to solve the trade-offs between competing interests. The Sami people has an attachment to Sápmi that is not just rooted in culture, but that is also legally recognised.
6 Discussion

In this section, the analysis of the empirical results is discussed in the context of previous research. Theoretical and practical implications of the study are provided, as well as reflections on the study and future research on the subject.

6.1 Assessing the EU’s potential for sustainability contributions

The empirical findings reveal four things when related to the existing body of literature on the mining of energy minerals and metals. Firstly, the elements of comparison and subjectivity that are applied to the sustainability concept make it impossible to provide a clear answer to how the EU mining sector would contribute towards the sustainable supply of energy mineral and metals. Secondly, the assessment of the net-contribution is further complicated by the inevitable need to make trade-offs between sustainability impacts that take place on different spatial scales. Thirdly, the above-mentioned limitations of the application of the sustainability concept when assessing the contributions of the EU mining sector highlights the opportunity to also bring questions of justice into the discussion. Finally, even if the EU were to contribute to the mining of energy minerals and metals to a larger extent, the direct impacts would likely be limited beyond the borders of the EU. The following sections address each of these revelations.

6.1.1 Comparative and subjective assessments of sustainability contributions

The assessment of the contributions of the EU mining sector towards a sustainable supply of energy minerals and metals is characterised by two elements: the comparison of mining practices on a national level and the subjectivity of the understanding of sustainable mining.

The analysis of the interviews explicitly suggest that the mining practices employed in Sweden make the Swedish mining sector able to contribute to the sustainable supply of battery minerals and metals. This can be interpreted to support the claim made by some (e.g., Thies et al., 2019; da Silva Lima et al., 2022) that a strengthened EU mining sector would benefit the sustainability of energy mineral and metals mining. It should, however, be noted that the claims made about the sustainability of the Swedish mining industry are formulated as comparisons with other, current, battery mineral and metal mining countries such as the DRC and China. These are examples of countries where the mining practices are questioned from a sustainability perspective due to a multitude of environmental, social, and economic issues that are exacerbated by pre-existing vulnerabilities (e.g., Lébre et al., 2020; Mancini et al., 2020; Agusdinata et al., 2022, p. 8). Concluding that mining of energy minerals and metals in the EU would be conducted sustainably in and of itself would therefore be to oversimplify the matter.

According to Cowell and colleagues (1999), the perceived sustainability of mining ultimately depends on the attitude towards trade-offs between environmental, social, and economic aspects of sustainability. The analysis of the interviews shows that trade-offs cannot be avoided when mining battery minerals and metals. The analysis of the reviewed media articles also corroborates this through the strong acknowledgement of trade-offs between different aspects of sustainability. Assuming a strong or nested approach to sustainability, mining therefore cannot be conducted sustainably (Cowell et al., 1999), neither in Sweden, the EU, nor elsewhere. On the contrary, in accordance with the mainstream weak or non-nested approach to sustainability in the literature on extractive industries, mining can be sustainable provided that adequate mitigation measures are taken to minimise the damage (Conde, 2017). The empirical findings therefore corroborate the inability to provide a definitive answer to how the EU mining industry could contribute to the sustainable supply of energy minerals and metals. The extent and direction of any EU contribution will ultimately come down to on how sustainability is defined and whether it is assessed in comparison to outright unsustainable mining practices or not.
6.1.2 Added complexity through inevitable trade-offs on multiple spatial scales

The EU’s ability to sustainably contribute to the mining of energy minerals and metals is complicated by two factors: the difference in spatial scales at which sustainability aspects take place and the inevitability of some of these sustainability aspects being in conflict with one another.

From a systems perspective, Simon (1962) argues that it is the interaction of different sub-systems – such as the environmental, social, and economic ones – that adds complexity. While the mining of energy minerals and metals is motivated by the need for an energy transition to mitigate climate change (Vidal et al., 2013), the literature on sustainability impacts of mining battery minerals and metals shows that such mining is associated with damages to all three sub-systems (e.g., Kelly et al., 2020; Lébre et al., 2020; Mancini et al., 2020; United Nations Conference on Trade and Development, 2020; da Silva Lima, 2022). This is also highlighted in the analysis, not least through the display of negative sustainability aspects identified in the reviewed media articles. Because sustainability is concerned with all aspects of the environment, society, and the economy (e.g., Purvis et al., 2019; United Nations, n.d.), an assessment of the sustainability contribution of mining energy minerals and metals in the EU is complicated by the need to account for sustainability impacts beyond the mitigation of climate change.

According to the analyses of the results from the media articles and the interviews, the sustainability aspects of mining battery minerals and metals further present themselves on different spatial scales. Bell and Morse (2018, p. 14) argue that it is the applied spatial (and other) boundaries that provide context to a system. The application of different spatial boundaries (e.g., a local and a global boundary) therefore results in different contexts. Such an added complexity emerges in the analysis. Most notably, the analysis of the stakeholder interviews reveal that while the mining of battery minerals and metals contributes to the mitigation of global climate change through the energy transition, the ones paying the price are predominantly those at the local level where the mining takes place. Not only does the goals of sustaining the different sub-systems impacted by the mining show signs of the mismatch that Meadows (2009, p. 85) refer to as suboptimisation. The assessment of the net-contribution of mining energy minerals and metals is also complicated by the difficulty of comparing sustainability aspects on different spatial scales against one another.

As the analyses of the media articles and the interviews acknowledge, some trade-offs between different sustainability aspects cannot be avoided when mining battery minerals and metals. According to the analysis of the interviews, this is especially the case when the global demand for battery minerals and metals imposes restrictions on land-use on a local level. Rittel and Webber (1973) argue that highly complex problems lack solutions that can be deemed objectively correct and that it is therefore necessary to settle for solutions that are considered good enough. With the world considering an energy transition a must (e.g., European Union: European Commission, 2019; Intergovernmental Panel on Climate Change, 2022; United Nations Environment Programme, 2022), it implies that some trade-offs will have to be accepted regardless of whether it makes the mining of energy minerals and metals unsustainable or not. The issue, which the analysis of the interviews also shows, is that there are currently no guidelines for how to reach an agreement on which trade-offs can be accepted and where.

6.1.3 Going beyond the concept of sustainability

The inability to agree on what sustainability entails highlight a limitation to the sole application of the sustainability concept when assessing the contributions of a EU energy mineral and metals mining sector.

The need to mine energy minerals and metals to enable the transition of the global energy system is highlighted in the analysis of the interviews regardless of the respondents’ views on the sustainability of mining. A strong or nested approach to sustainability implies that mining cannot be sustainable (Cowell et al., 1999). The acknowledgment that Sweden needs to take responsibility for the mining of battery minerals and metals regardless of the negative sustainability impacts therefore suggests that it is not enough to evaluate the contributions of a EU energy mineral and metals mining sector solely from a sustainability perspective. Rather, the merit of a justice perspective is suggested by the emergence of a sense of unfairness that the domestic geological potential for battery mineral and metals mining is not taken advantage of while others
mine their resources. The energy justice and just transition frameworks call for an equitable distribution of both benefits and burdens (Sovacool & Dwokin, 2015; McCauley & Heffron, 2018), including in the sourcing of raw materials for energy technologies (Heffron, 2020; Bainton et al., 2021). By having the EU member states expose themselves to the same burdens of mining that Sovacool and colleagues (2019) argue are currently being displaced outside of the Union, the establishment of a stronger EU mining sector could contribute to a more just distribution of energy mineral and metals mining on a global scale.

By strengthening the EU energy mineral and metals mining sector, the global distribution of negative sustainability impacts would become fairer. However, the empirical findings show that the site-specific nature of mining results in most of the negative sustainability aspects taking place on a local level. The analysis of the interviews suggests that there is a sense of unfairness related to the distribution of mines within Sweden as well. This is most clearly highlighted through the claims that the proposed graphite mine in the north of Sweden constitutes an infringement on the rights of the Sami people. Drawing on Schlosberg (2007, p. 14) the rights of the affected communities need to be recognised and respected for a just distribution of benefits and burdens to be properly achieved. Similarly, the local communities should be involved in the decision-making processes (Sovacool & Dwokin, 2015). Not only do recognition and participation contribute to a more just distribution of burdens, but also a higher level of acceptance within the affected local communities (Prno, 2013). Through participation, this acceptance can translate into a shared and deepened understanding of sustainability (Prno, 2013; Bice, 2014; Horlings, 2015).

6.1.4 Addressing unsustainable mining on a global scale

The sustainability contributions of a EU energy mineral and metals mining sector beyond the borders of the EU are limited by the lack of a direct connection between the mining in different countries.

The analysis of the interviews suggests that a battery mineral and metals mining industry in the EU would have the potential to supply these raw materials in a comparatively more sustainable manner than is currently the case. However, this does not automatically translate into an overall more sustainable supply chain of energy minerals and metals. A causal relationship between the initiation of mining in one place and the discontinuation of mining in another place cannot be assumed. This is highlighted in the analysis of the interview results and supported by Manhart and colleagues (2017). In line with the characteristics of a wicked problem (Rittel & Webber, 1973), unsustainable mining practices are symptoms of another problem. Unless the underlying issue is a lack a more sustainable supply sources of energy minerals and metals elsewhere, simply establishing mining operations in the EU will not address the cause of unsustainable mining. Lèbre and colleagues (2020) and Owen and colleagues (2020) argue that the unsustainable mining practices in many top-producing countries are a consequence of pre-existing environmental, social, and governance related risk factors. It is therefore unlikely that the mining of energy minerals and metals in the EU would have a direct impact on the overall sustainability of the supply chain.

Although a direct contribution towards a more sustainable supply of energy minerals and metals may be difficult to achieve simply by scaling up the mining in the EU, indirect contributions could still have an impact on the sustainability of the supply chain. The EU highlights the need to work broadly when establishing a more sustainable supply of energy minerals and metals, including by creating leverage in the negotiation with non-EU suppliers and by contributing with experience and expertise in these countries (Schüler, 2018, p. 8–9). So, too, do stakeholders of a Swedish battery mineral and metals mining sector, according to the analysis of the interviews. There is therefore still potential to improve the sustainability of energy minerals and metals production on a global scale, although not in an as straight forward manner as some propose. Regardless, a domestic mining sector for energy minerals and metals would be important, as it is through the practical contribution that changes in the non-domestic mining can be achieved. As Farooki and colleagues (2018, p. 11) stress, it shows that the EU is serious about taking responsibility for producing the raw materials it consumes and creating a more sustainable supply chain.
6.2 Implications of the study

The impending climate crisis has brought on the need for a transition towards renewable energy sources and electrification (e.g., European Union: European Commission, 2019; Intergovernmental Panel on Climate Change, 2022; United Nations Environment Programme, 2022), thereby creating a significantly increased demand for certain minerals and metals (Vidal et al., 2013; World Bank Group, 2017; Watari et al., 2019; Hodkinson & Smith, 2021). However, for such a transition to have a net-positive effect on global sustainability and not just GHG emissions, it is necessary to understand and handle the sustainability aspects associated with the raw materials being used for energy and electrification technologies (Mancini et al., 2019). This study contributes both theoretically and practically to such an understanding by accounting for different sustainability aspects on different spatial scales and the trade-offs that inevitably occur between them.

In terms of theoretical contributions, the study corroborates previously showcased results. This includes the subjectivity involved in the assessment of the sustainability of mining practices, as proposed by Cowell and colleagues (1999) amongst others, and the merit of a systems approach to sustainability, as proposed, for example, by Bell and Morse (2008). While the analysis of the reviewed media articles implies that the sustainability of mining battery minerals and metals is perceived differently by different actors, this was made explicit in the analysis of the interviews. In addition to corroborating already showcased results, the study also brings attention to the limitations of focusing solely on sustainability when discussing the potential contributions of the EU towards energy mineral and metals mining. Although sustainability aspects of mining energy minerals and metals constitutes the scope of the study, the inability to reach consensus on what sustainable mining entails opens up for a broader, and potentially more fruitful, discussion that also encompasses justice. This also translates into the practical implications of the study.

Practically, the empirical findings imply a need for a greater focus on justice regarding the production of minerals and metals used in the energy transition. The importance of mining these raw materials is undeniable. However, by conducting mining without regard for the local communities being directly impacted by it, new sustainability problems are created. Both sustainability and sustainable mining are regarded as wicked problems (e.g., Everingham, 2007, p. 93; Peterson, 2009; Murphy, 2012; Blok et al., 2015; Endl, 2017), meaning that they are only symptoms of other problems and that any attempt at handling them will create unforeseen consequences (Rittel & Webber, 1973). But this wickedness is not an excuse to disregard consequences that could not only be foreseen, but also mitigated. By combining a justice perspective with that of sustainability, an overall more positive contribution of the mining of energy minerals and metals in the EU could be made.

6.3 Reflections and recommendations for future research

Although the goal has been to provide as rigorous answers as possible to the research questions, it has not been possible to completely avoid shortcomings when conducting the study. Firstly, due to the inability to provide sufficient evidence of reliability and validity of the quantitative results of the study, these results and the conclusions drawn from them should be approached with caution. Although the results are not unreasonable, they simply cannot be properly supported. A second opinion, at least, on the coding of the articles would have been needed for an adequate reliability test to be conducted. Similarly, more than one coder would have also benefited the trustworthiness of the interview results. Despite other measures having been taken to ensure an accurate interpretation of the empirical findings, including member checking, mistakes and biases may still be present in the analysis.

The lack of data collected directly from local communities that would become affected by potential future mining operations constitutes a second limitation. Not only does this lack of data imply that the perspectives of a stakeholder group are missing, but also that the whole data set is skewed. The analysis is conducted on the available data and because the data set is incomplete it has resulted in a biased interpretation. A local perspective would have been of particular interest in terms of how those directly affected by (the prospect of) mining perceive the contributions towards enabling the energy transition, considering that this was a topic
brought up by respondents representing other stakeholder groups. Future studies of a similar character should attempt to capture this.

Following the implications of the study, an opportunity to incorporate a justice perspective into the research on the sustainability contributions of mining energy minerals and metals has further been brought to attention. Considering the difficulty to agree on what sustainable mining entails, developing an understanding of just mining could provide a tool for increasing the social sustainability of mining while also allowing local perceptions on environmental and economic sustainability to influence mining practices. It would therefore be of interest if future studies investigated this potential: can a justice perspective in fact increase the sustainability of mining across all three sub-systems, what would that imply for the future mining of energy minerals and metals in the EU, and how would it affect the perception of sustainability contributions?
7 Conclusions

Following the scope of the study – to determine the potential for the EU to contribute domestically towards a sustainable supply of energy minerals and metals in the coming decades, considering the interactions of different associated environmental, social, and economic aspects of sustainability on different spatial scales – three conclusions can be drawn from the empirical findings.

Firstly, in terms of the current state of the mining industry, there is a sense of potential for the ability to sustainably mine energy minerals and metals. Mining in the EU is not associated with the same extent of disregard towards and damage of the environmental, social, and economic systems that mining in many of the top-producing countries are. However, that does not mean that there are no negative sustainability impacts associated with mining in the EU. The environment and communities in proximity to the potential mines are at risk of having to bear the burden of the energy transition. Going beyond a sustainability perspective, the increased focus on recognition and participation has the potential to benefit both the distributive justice of mining energy minerals and metals and the acceptance of such operations on a local level.

Secondly, the only clear consensus on the interactions of the sustainability aspects associated with mining energy minerals and metals is the inevitability of having to make trade-offs between them. The demand for energy minerals and metals for renewable energy sources and electrification technologies is constantly put against other, primarily local, interests. At the same time, this demand is recognised to be more important than other aspects of sustainability, regardless of whether trade-offs are otherwise perceived to be acceptable or not. At present, no guidelines for how to make the decision on when and where to mine exists, due to the different approaches to sustainability and the added complexity of the sustainability aspects in conflict occurring on different spatial scales. For the successful and fair establishment of a EU energy mineral and metals mining sector, this will be needed.

Finally, the contributions that a EU energy mineral and metals mining industry could have on the sustainable supply of these raw materials depends on how sustainability is defined and whether the level of sustainability is assessed comparatively or not. Although the EU will likely be able to conduct the mining of energy minerals and metals more sustainably than many current producers, the global supply chain for energy minerals and metals is highly complex and its sustainability cannot be increased through simple and localised quick fixes. The direct contributions towards a more sustainable supply chain through the establishment of a stronger EU mining sector for energy minerals and metals would therefore be limited on a global scale. Indirectly, though, such a domestic mining sector could contribute towards a more responsible and just supply chain with potential to influence mining practices beyond the borders of the EU.

While the analyses of the empirical findings should be interpreted with caution due the limited evidence of reliability, validity, and trustworthiness, this study contributes to the discussion on the sustainable supply of energy minerals and metals by corroborating previous conclusions and highlighting the limitations of only applying a sustainability perspective to the question. It is important to continue to consider the sustainability aspects of mining, but adding a justice perspective could help mitigate the challenges of different actors not being able to agree on what sustainable mining entails. Future research will however be needed to determine this potential.
8 References


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9 Acknowledgements

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Appendix A: Interview guide

Table 7–11 contain the questions that all respondents were asked or answered in some form, provided that they were applicable to the particular respondent. Depending on how each respondent answered the questions in Table 11, they were either asked the questions in Table 12 or Table 13. Because the respondents represent different perspectives and possess knowledge about different things, not all respondents were asked all of the questions.

Table 7. Background questions about the respondent.

<table>
<thead>
<tr>
<th>Main questions</th>
<th>Sub-topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which title would you like me to use when I refer to you in the thesis?</td>
<td></td>
</tr>
<tr>
<td>Could you briefly describe your role?</td>
<td>a) Main areas</td>
</tr>
<tr>
<td></td>
<td>b) Daily tasks</td>
</tr>
<tr>
<td>How do you come in contact with sustainability questions in your job?</td>
<td>a) Frequency in contact with sustainability questions</td>
</tr>
<tr>
<td></td>
<td>b) Type of sustainability aspects</td>
</tr>
<tr>
<td></td>
<td>c) Type of sustainability questions</td>
</tr>
</tbody>
</table>

Table 8. Questions about the pre-conditions of mining battery minerals and metals in Sweden.

<table>
<thead>
<tr>
<th>Main questions</th>
<th>Sub-topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>How would you describe the pre-conditions to mine [battery minerals and metals] in Sweden?</td>
<td>a) Geological pre-conditions</td>
</tr>
<tr>
<td></td>
<td>b) Environmental pre-conditions</td>
</tr>
<tr>
<td></td>
<td>c) Social pre-conditions</td>
</tr>
<tr>
<td></td>
<td>d) Economic pre-conditions</td>
</tr>
<tr>
<td></td>
<td>e) Institutional (e.g., political, legal) pre-conditions</td>
</tr>
</tbody>
</table>
Table 9. Questions about the interpretation of the sustainability concept.

<table>
<thead>
<tr>
<th>Main questions</th>
<th>Sub-topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>How do you perceive the relative importance of environmental, social, and economic sustainability in your role?</td>
<td>a) Relative importance of environmental, social, and economic sustainability</td>
</tr>
<tr>
<td></td>
<td>b) Environmental, social, and economic sustainability as dependent on each other or separate</td>
</tr>
</tbody>
</table>

Table 10. Questions about the sustainability aspects of mining battery minerals and metals in Sweden.

<table>
<thead>
<tr>
<th>Main questions</th>
<th>Sub-topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which sustainability aspects do you associate with the mining of [battery minerals and metals]?</td>
<td>a) Environmental aspects</td>
</tr>
<tr>
<td></td>
<td>b) Social aspects</td>
</tr>
<tr>
<td></td>
<td>c) Economic aspects</td>
</tr>
<tr>
<td></td>
<td>d) Positive aspects</td>
</tr>
<tr>
<td></td>
<td>e) Negative aspects</td>
</tr>
<tr>
<td></td>
<td>f) Spatial scales of the sustainability aspects</td>
</tr>
</tbody>
</table>

Table 11. Questions about the trade-offs between the sustainability aspects of mining battery minerals and metals in Sweden.

<table>
<thead>
<tr>
<th>Main questions</th>
<th>Sub-topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which trade-offs between sustainability aspects do you associate with the mining of [battery minerals and metals]?</td>
<td>a) Reasons for non-reconciliation</td>
</tr>
<tr>
<td></td>
<td>b) Spatial scales of trade-offs</td>
</tr>
</tbody>
</table>

Would you say that some trade-offs between sustainability aspects are acceptable if it facilitates the mining of [battery minerals and metals] in Sweden, or that such mining should only be conducted if no trade-offs have to be made?
Table 12. Questions asked if the respondent thinks some trade-offs between sustainability aspects are acceptable to mine battery minerals and metals in Sweden.

<table>
<thead>
<tr>
<th>Main questions</th>
<th>Sub-topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which negative sustainability aspects could be accepted to gain the positive</td>
<td>a) Relative importance of the different scales</td>
</tr>
<tr>
<td>sustainability aspects of mining?</td>
<td></td>
</tr>
<tr>
<td>How does the difference in spatial scales of the sustainability aspects affect</td>
<td></td>
</tr>
<tr>
<td>the trade-off between them?</td>
<td></td>
</tr>
<tr>
<td>How do you work towards reaching an agreement on trade-offs?</td>
<td></td>
</tr>
</tbody>
</table>

Table 13. Questions asked if the respondent does not think some trade-offs between sustainability aspects are acceptable to mine battery minerals and metals in Sweden.

<table>
<thead>
<tr>
<th>Main questions</th>
<th>Sub-topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Why is it not acceptable to make trade-offs between sustainability aspects?</td>
<td>a) Relative importance of environmental, social, and economic sustainability</td>
</tr>
<tr>
<td></td>
<td>b) Environmental, social, and economic sustainability as dependent on each</td>
</tr>
<tr>
<td></td>
<td>other or separate</td>
</tr>
</tbody>
</table>
## Appendix B: Quantitative analysis

**Table 14.** Overview of the theoretical connections and definitions of the codes.

<table>
<thead>
<tr>
<th>Code</th>
<th>Theoretical connection</th>
<th>Theoretical definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustainability aspects</td>
<td>Systems thinking</td>
<td>Behaviour changes of the system, which impacts its quality.</td>
</tr>
<tr>
<td>Positive environmental sustainability aspects</td>
<td>Systems thinking</td>
<td>Behaviour changes to the environmental subsystem which increases its quality.</td>
</tr>
<tr>
<td>Positive social sustainability aspects</td>
<td>Systems thinking</td>
<td>Behaviour changes to the social subsystem which increases its quality.</td>
</tr>
<tr>
<td>Positive economic sustainability aspects</td>
<td>Systems thinking</td>
<td>Behaviour changes to the economic subsystem which increases its quality.</td>
</tr>
<tr>
<td>Negative environmental sustainability aspects</td>
<td>Systems thinking</td>
<td>Behaviour changes to the environmental subsystem which decreases its quality.</td>
</tr>
<tr>
<td>Negative social sustainability aspects</td>
<td>Systems thinking</td>
<td>Behaviour changes to the social subsystem which decreases its quality.</td>
</tr>
<tr>
<td>Negative economic sustainability aspects</td>
<td>Systems thinking</td>
<td>Behaviour changes to the economic subsystem which decreases its quality.</td>
</tr>
<tr>
<td>Trade-offs</td>
<td>Systems thinking; Complexity</td>
<td>Conflicts between the goals of different sub-systems.</td>
</tr>
<tr>
<td>Acknowledged trade-offs</td>
<td>Systems thinking; Complexity</td>
<td>The occurrence of compromises between the goals of different sub-systems.</td>
</tr>
<tr>
<td>Acceptable trade-offs</td>
<td>Systems thinking; Complexity</td>
<td>Compromises between the goals of different sub-systems are necessary to increase the quality of the system.</td>
</tr>
<tr>
<td>Unacceptable trade-offs</td>
<td>Systems thinking; Complexity</td>
<td>Compromises between the goals of different sub-systems decrease the overall quality of the system.</td>
</tr>
<tr>
<td>Spatial scales</td>
<td>Systems thinking; System boundaries</td>
<td>The spatial boundary that creates the structure of the system.</td>
</tr>
<tr>
<td>Local scale</td>
<td>Systems thinking; System boundaries</td>
<td>The sub-system is spatially defined in accordance with the boundaries of the communities in proximity to the proposed mine.</td>
</tr>
<tr>
<td>National scale</td>
<td>Systems thinking; System boundaries</td>
<td>The sub-system is spatially defined in accordance with a national boarder.</td>
</tr>
<tr>
<td>Global scale</td>
<td>Systems thinking; System boundaries</td>
<td>The sub-system is spatially defined in accordance with the boundaries of the Earth.</td>
</tr>
<tr>
<td>Code</td>
<td>Rule</td>
<td>Examples</td>
</tr>
<tr>
<td>------</td>
<td>------</td>
<td>----------</td>
</tr>
<tr>
<td>Positive environmental sustainability aspects</td>
<td>Any direct or indirect positive impact on the environment being attributed to the mining of battery minerals and metals in Sweden.</td>
<td>Reduced emissions; Climate change mitigation</td>
</tr>
<tr>
<td>Positive social sustainability aspects</td>
<td>Any direct or indirect positive impact on society being attributed to the mining of battery minerals and metals in Sweden.</td>
<td>Community growth; Avoided displacement of social damages (e.g., child labour, health risks)</td>
</tr>
<tr>
<td>Positive economic sustainability aspects</td>
<td>Any direct or indirect positive impact on the economy being attributed to the mining of battery minerals and metals in Sweden.</td>
<td>Community growth; Jobs (providing tax revenues and income)</td>
</tr>
<tr>
<td>Negative environmental sustainability aspects</td>
<td>Any direct or indirect negative impact on the environment being attributed to the mining of battery minerals and metals in Sweden.</td>
<td>Biodiversity loss; Destroyed nature; Contaminated water and air</td>
</tr>
<tr>
<td>Negative social sustainability aspects</td>
<td>Any direct or indirect negative impact on society being attributed to the mining of battery minerals and metals in Sweden.</td>
<td>Threats towards the Sami culture; Land-use conflicts; Abandoned mining communities</td>
</tr>
<tr>
<td>Negative economic sustainability aspects</td>
<td>Any direct or indirect negative impact on the economy being attributed to the mining of battery minerals and metals in Sweden.</td>
<td>Threat towards Sami people’s businesses</td>
</tr>
<tr>
<td>Acknowledged trade-offs</td>
<td>Conflicts of interest being acknowledged in association to the mining of battery minerals and metals in Sweden without opinions on which interest outweighs the other(s).</td>
<td>Climate change mitigation vs local nature values; Climate change mitigation vs Sami rights; Local mining vs import dependency</td>
</tr>
<tr>
<td>Acceptable trade-offs</td>
<td>Opinions on the conflict of interest associated with the mining of battery minerals and metals in Sweden where mining is seen as necessary or more important than other interests.</td>
<td>Coexistence is a possibility; The energy transition is necessary; the negative impacts are fewer or less significant in Sweden</td>
</tr>
<tr>
<td>Unacceptable trade-offs</td>
<td>Opinions on the conflict of interest associated with the mining of battery minerals and metals in Sweden where other interests than mining is seen as necessary or more important.</td>
<td>Coexistence is not a possibility; Sami rights outweigh the need to mine; The negative impacts are significant</td>
</tr>
<tr>
<td>Local scale</td>
<td>Sustainability impacts being experienced in proximity to the proposed mine.</td>
<td>Jobs (providing employment and income); Destruction of nature;</td>
</tr>
<tr>
<td>National scale</td>
<td>Sustainability impacts being experienced throughout the whole country.</td>
<td>Jobs (creating tax revenues);</td>
</tr>
<tr>
<td>Global scale</td>
<td>Sustainability impacts being experienced throughout the whole world.</td>
<td>Contributions to the energy transition; Mitigation of climate change</td>
</tr>
</tbody>
</table>
## Appendix C: Qualitative analysis

### A MULTIFACETED (LACK OF) UNDERSTANDING OF SUSTAINABILITY

<table>
<thead>
<tr>
<th>Theme</th>
<th>Sub-theme</th>
<th>Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Theme</strong></td>
<td>SUSTAINABLE MINING IS AN AMBIGUOUS CONCEPT</td>
<td>Ambiguity of the sustainability concept</td>
</tr>
<tr>
<td><strong>Sub-theme</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EQUALLY IMPORTANT Pillars</td>
<td>Economic sustainability a pre-requisite</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sustainability as interacting sub-systems</td>
</tr>
<tr>
<td></td>
<td>THE ENVIRONMENT SETS THE LIMIT</td>
<td>Need for a reduction in production and consumption</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sustainability as nested sub-systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Theme</strong></td>
<td>HANDLING THE TRADE-OFFS OF MINING BATTERY MINERALS AND METALS</td>
<td></td>
</tr>
<tr>
<td><strong>Sub-theme</strong></td>
<td>THE EQUATION DOES NOT ADD UP</td>
<td>Context-based assessments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Impossible trade-offs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mismatch between problems and solutions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Need for a systems perspective</td>
</tr>
<tr>
<td></td>
<td>SHORTCOMINGS IN THE HANDLING OF SUSTAINABILITY ASPECTS</td>
<td>Dishonesty and distrust</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Issues with the environmental legislation</td>
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<tr>
<td></td>
<td></td>
<td>Lack of knowledge</td>
</tr>
<tr>
<td></td>
<td>KEYS TO SUSTAINABLE MINING</td>
<td>Cooperation</td>
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<td></td>
<td></td>
<td>Mitigation</td>
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<td>Openness</td>
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<td></td>
<td></td>
<td>Trust and acceptance</td>
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<tr>
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<td></td>
</tr>
<tr>
<td><strong>Theme</strong></td>
<td>MINING FOR THE GREATER GOOD</td>
<td></td>
</tr>
<tr>
<td><strong>Sub-theme</strong></td>
<td>THE NEED TO MINE IS A GLOBAL RESPONSIBILITY</td>
<td>Import dependency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mining is necessary</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Swedish mining is sustainable in a global context</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Taking responsibility and being a role model</td>
</tr>
<tr>
<td></td>
<td>THE PRICE OF MINING IS PAYED LOCALLY</td>
<td>Lack of consideration for indigenous rights</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Localisation and land-use conflicts</td>
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<tr>
<td></td>
<td></td>
<td>Mines enable local communities</td>
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<tr>
<td></td>
<td></td>
<td>Recognition of global contributions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unmet local expectations</td>
</tr>
</tbody>
</table>

*Figure 17. Overview of the themes, sub-themes, and codes used to analyse the interview transcripts.*
<table>
<thead>
<tr>
<th>Code</th>
<th>Definition</th>
<th>Theoretical connection</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambiguity of the sustainability concept</td>
<td>The sustainability concept is lacking meaning or is losing its meaning.</td>
<td>Defining sustainability</td>
<td>You can say that all questions today are about sustainability. [...] So everyone is just talking about sustainability and does not know what sustainability actually is. [...] Everything becomes sustainable nowadays. And not least the mining industry – incredibly sustainable and green.</td>
</tr>
<tr>
<td>Context-based assessments</td>
<td>Assessments of the sustainability of mining is based on context (e.g., spatial, geological, etc.) and applied on a case-by-case basis.</td>
<td>Systems thinking; Wicked problems</td>
<td>It becomes from case to case. There are no general guidelines there. We have the national interest system which provides some direction of course, but relatively often there are more than one national interest in the same place and then you are simply back to it being a difficult trade-off.</td>
</tr>
<tr>
<td>Cooperation</td>
<td>Cooperation is necessary to work towards acceptable solutions to the trade-offs.</td>
<td>Social license to operate; Resistance to mining</td>
<td>And there you also have to listen to what others say, of course. When it comes to the reindeer husbandry the specialists become very important. Affected Sami villages, but also the Sami parliament, and now, since roughly a year ago, we also have the consultation order which says that we are supposed to consult representatives of the Sami people in questions that can affect them [...]. So that becomes very important. They are the ones that know the most about how their industry is actually affected.</td>
</tr>
<tr>
<td>Dishonesty and distrust</td>
<td>Actions and statements made on false grounds and/or the sentiment that actions and statements are made on false grounds.</td>
<td>Social license to operate; Resistance to mining</td>
<td>Talga has also applied for three additional mines. And they have applied for processing concession first for one mine and then for the other three. And they still have not been granted any processing concession. And our position regarding the graphite mine is that Talga has tried to take a short cut and applies for a permit for one mine instead of all four and thereby make their environmental impact assessment much simpler.</td>
</tr>
<tr>
<td>Economic sustainability a pre-requisite</td>
<td>Without economic viability, environmental and social sustainability cannot be achieved.</td>
<td>Defining sustainability</td>
<td>Yes absolutely, and an addition there is also regarding something that our companies often say: [...] it must be profitable for a company to be able to afford to invest in the transition as well.</td>
</tr>
<tr>
<td>Import dependency</td>
<td>Not enough battery minerals and metals are produced in Sweden and the EU, creating an import dependency and vulnerability</td>
<td>Criticality</td>
<td>Also, with the EU and Sweden being so dependent on import for many of these metals, not least the so-called battery metals, it makes us vulnerable.</td>
</tr>
<tr>
<td>Topic</td>
<td>Description</td>
<td>Relevant Concepts</td>
<td></td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>--------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Impossible trade-offs</td>
<td>Conflicts of interest where no right or easy answer exists.</td>
<td>Wicked problems</td>
<td></td>
</tr>
<tr>
<td>Issues with the environmental legislation</td>
<td>Any criticism towards the current Swedish environmental legislation.</td>
<td>Talking about preconditions for the industry in general in Sweden – or in all countries really – I do not think that anyone is benefited by long decision-making processes [and] unclear rules. […] Because there is nothing that becomes more sustainable from making it more complex. It is better to have high demands and a quick process. […] I recently saw a compilation of how long it takes in all EU countries to gain some type of decision on mining and Sweden is doing quite poorly and that is not something that anyone benefits from.</td>
<td></td>
</tr>
<tr>
<td>Lack of consideration for indigenous rights</td>
<td>The rights of indigenous peoples are not considered to the extent that they should be according to national and international regulations.</td>
<td>Justice [S]hort-term interests, like this is a question of, that at the same time have a large environmental impact cannot outweigh the Sami people’s right to continue to exercise their culture and reindeer husbandry which they are acknowledged the right to, among other by the Instrument of Government.</td>
<td></td>
</tr>
<tr>
<td>Lack of knowledge</td>
<td>More knowledge needs to be created, gathered, or compiled through research, surveys, or other methods.</td>
<td>Systems thinking With fewer people having knowledge in geology and geoscience self-proclaimed experts appear, talking about exploitation and the environment […]. But there are few experts with knowledge. It creates a dangerous situation where no one knows what is true. The rock is the unknown and then anyone can step up and be an expert and say things with any agenda. That is a dangerous development.</td>
<td></td>
</tr>
<tr>
<td>Localisation and land-use conflicts</td>
<td>Conflicts of interest following the site-specific nature of mining.</td>
<td>Systems thinking [A] mine has to be where the ore or the mineralisation is, which means that we cannot chose. With wind power plants, for example, you can often work with localisation, even on the local scale. […] But that type of consideration is difficult to do with a mine sometimes, as the mine needs to be where the ore is.</td>
<td></td>
</tr>
<tr>
<td>Mines enable local communities</td>
<td>Establishing a mine creates and/or grows communities in the vicinity of the mine.</td>
<td>Social license to operate Many of the mines in Sweden today have been situated in sparsely populated areas and many mining communities have also grown up around, really, mines, where there have previously not been any communities.</td>
<td></td>
</tr>
<tr>
<td>Mining is necessary</td>
<td>Without the continued and increased mining of minerals and metals, the green transition will not be doable.</td>
<td>Combating climate change Recycling of already mined metals is only a small part. If we are to accommodate the societal need that has been predicted today, it demands significant new mining. Many constructions that contain recyclable raw materials have a relatively long lifetime and can only be recycled many</td>
<td></td>
</tr>
<tr>
<td>Mismatch between problems and solutions</td>
<td>Proposed solutions do not actually address the problem(s) they are intended to solve.</td>
<td>Systems thinking; Wicked problems</td>
<td>The industry itself says that “Well, is it not better that we mine in Sweden, instead of it being done in countries with much more lenient environmental regulations?” And that sounds tempting, of course. But I am of the opinion that even if we open 30 or 50 mines in Sweden – which are the numbers that have been mentioned by SGU – it will not lead to mines being closed in the Democratic Republic of Congo. I do not think anyone believes that.</td>
</tr>
<tr>
<td>Mitigation</td>
<td>The actions needed and/or taken to reduce the impacts of mining.</td>
<td>Sustainable mining; Social license to operate</td>
<td>The mines are in an area which is the winter grazing land for Talma [Sami village] and a part of our efforts to minimise the impacts on their activities has been to only operate our mining – our mine production – during the summer months.</td>
</tr>
<tr>
<td>Need for a reduction in production and consumption</td>
<td>It is not reasonable and/or feasible to continue the current rate of production and consumption.</td>
<td>Strong sustainability</td>
<td>Because somehow, we need to understand that we cannot maintain our consumption the way it is today. We need to consume less. There is no doubt about it.</td>
</tr>
<tr>
<td>Need for a systems perspective</td>
<td>Sustainability in mining needs to incorporate all aspects of the system.</td>
<td>Systems thinking; Strong sustainability; Sustainability as nested systems</td>
<td>The impacts on the surrounding can be a very complex question. What does natural background values look like – for example, there can be naturally high background values of heavy metals in areas with mine worthy concentrations. Mining affects a community in many ways, socially and environmentally. It is complex.</td>
</tr>
<tr>
<td>Openness</td>
<td>Communication and transparency are necessary to work towards acceptable solutions to the trade-offs.</td>
<td>Social license to operate; Resistance to mining</td>
<td>It is very important for us that we work with an open and transparent process, so that we can do this step by step and always explain which trade-offs we must make.</td>
</tr>
<tr>
<td>Recognition of global contributions</td>
<td>The acknowledgement of global contributions of mining, in spite of a resistance or scepticism towards it.</td>
<td>Systems thinking</td>
<td>What we have felt is that there already has begun to be a shift there. If you take the Sami villages, for example, which are often against us claiming land, they are aware that they maybe are the ones being hit the hardest by climate change […]. So, they have gotten an increased understanding of that we need to produce these metals to handle the green transition […].</td>
</tr>
<tr>
<td><strong>Sustainability as interacting sub-systems</strong></td>
<td>The environmental, social, and economic sub-systems interact with each other to achieve sustainability.</td>
<td>Systems thinking; Weak sustainability; Sustainability as nested sub-systems; Wicked problems</td>
<td>I mean, I do not see that we would value the different pillars of sustainability differently, they are integrated pillars that are all necessary for a long-term sustainable mining.</td>
</tr>
<tr>
<td><strong>Sustainability as nested sub-systems</strong></td>
<td>Environmental sustainability is required for social sustainability, and social sustainability is required for economic sustainability.</td>
<td>Systems thinking; Strong sustainability; Sustainability as nested systems; Wicked problems</td>
<td>There will never be any green mines because it entails such a destruction of the environment that cannot reasonably be restored.</td>
</tr>
<tr>
<td><strong>Swedish mining is sustainable in a global context</strong></td>
<td>Mining in Sweden contributes positively to the global sustainability by being more sustainable than mining in other countries.</td>
<td>Sustainable mining; Systems thinking; Wicked problems; Justice</td>
<td>And what has been pressed on is, recently, that mining in Sweden is sustainable and have great opportunities to be sustainable in regard to battery metals. Because compared to, for example, mining in [the DRC]… It is not particularly sustainable […] It is almost looked upon as slavery in some parts of [the DRC] and it is not at all as environmentally sustainable or sustainable in any way.</td>
</tr>
<tr>
<td><strong>Taking responsibility and being a role model</strong></td>
<td>Countries, organisations, and companies need to take responsibility for the sustainable supply of minerals and metals in a fair way.</td>
<td>Justice</td>
<td>It is of course perfectly reasonable that where there are sensible, good deposits to make use of in Sweden, they should be made use of. There cannot be some sort of exemption voucher like “We do not want any mines, that can be done elsewhere in the world”.</td>
</tr>
<tr>
<td><strong>Trust and acceptance</strong></td>
<td>Without trust and acceptance from local communities, it is difficult or impossible to mine.</td>
<td>Social license to operate; Resistance to mining</td>
<td>It is important [that] we have a strong focus with our neighbouring and host communities that we would operate in in the future. […] And some level of social licence to operate and some level of trust within the local communities and the indigenous communities in which we seek to operate.</td>
</tr>
<tr>
<td><strong>Unmet local expectations</strong></td>
<td>Local expectations have either not been realised or been displaced.</td>
<td>Social license to operate; Resistance to mining</td>
<td>And the talk about that it will generate so many jobs. It turns out that it actually never generates the thousands or hundreds of new jobs that the companies say it will be.</td>
</tr>
</tbody>
</table>
Appendix D: Reliability of the quantitative analysis

The reliability of the quantitative analysis was determined using Krippendorff’s alpha (α). Krippendorff’s alpha is one of several reliability coefficients (e.g., Krippendorff, 2004b). It can take on any value between -1 and 1, where 1 corresponds to complete agreement, 0 corresponds to a level of agreement no better than chance, and -1 corresponds to a level of agreement lower than the agreement expected to occur by chance. The choice of Krippendorff’s alpha was made based on its versatility and its subsequent applicability to most instances of reliability testing. For example, it does not impose any restrictions on the sample size or number of categories, and it can be applied to all orders of data (i.e., nominal, ordinal, interval, and ratio) (Krippendorff, 2004b; Krippendorff, 2011).

The order of data, the amount of times coding and recoding occurred, and the occurrence or lack of missing data determines the computational steps used to calculate the reliability (Krippendorff, 2011). The codes used for the quantitative analysis consisted of labels, which places the analysed units on the nominal scale. According to the norm of testing for stability, the articles were coded on two instances. Further, because not coding something constituted a conscious choice, instances where only one of the two rounds of coding resulted in a unit being coded were not interpreted as a case of missing data. These preconditions resulted in three steps being applied in the calculation of the reliability coefficient: the construction of a reliability data matrix, the construction of a coincidence matrix, and the calculation of α.

D.1 The reliability data matrix

In accordance with the first step provided by Krippendorff (2011) to calculate the reliability coefficient, a reliability data matrix was constructed (Figure 18). The matrix was given two rows, corresponding to each of the rounds of coding, and 133 columns, corresponding to the number of units being coded in at least one of the two rounds of coding. A letter denoting the code used for each unit during the applicable round of coding was put into the cells. Table 17 provides an overview of which letter corresponds to which code. On instances where the letter for a unit is the same in both rows, the units were coded the same in both rounds of coding (e.g., units 1, 2, and 5-10 in Figure 18). As is seen in Table 17, the letter m denotes an uncoded unit, meaning that the unit was only coded in one of the two rounds of coding (e.g., unit 3 in Figure 18). Any other combination of two letters (e.g., unit 4 in Figure 18) means that the units were coded in both rounds of coding, but with different codes.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>First round</td>
<td>c</td>
<td>b</td>
<td>a</td>
<td>g</td>
<td>b</td>
<td>h</td>
<td>b</td>
<td>c</td>
<td>a</td>
<td>h</td>
</tr>
<tr>
<td>Second round</td>
<td>c</td>
<td>b</td>
<td>m</td>
<td>b</td>
<td>b</td>
<td>h</td>
<td>b</td>
<td>c</td>
<td>a</td>
<td>h</td>
</tr>
</tbody>
</table>

Figure 18. Part of the reliability data matrix used in the first step of determine the reliability of the analysis of the articles. Adapted from Krippendorff (2011).

26 Normally, if the coefficient was used to test for reproducibility, it would be the number of observers (i.e., coders) that helped determine the computational steps.
Table 17. The letters used to denote each of the codes used in the analysis of articles.

<table>
<thead>
<tr>
<th>Codes</th>
<th>Denotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive environmental sustainability aspects</td>
<td>a</td>
</tr>
<tr>
<td>Positive social sustainability aspects</td>
<td>b</td>
</tr>
<tr>
<td>Positive economic sustainability aspects</td>
<td>c</td>
</tr>
<tr>
<td>Negative environmental sustainability aspects</td>
<td>d</td>
</tr>
<tr>
<td>Negative social sustainability aspects</td>
<td>e</td>
</tr>
<tr>
<td>Negative economic sustainability aspects</td>
<td>f</td>
</tr>
<tr>
<td>Acknowledged trade-offs</td>
<td>g</td>
</tr>
<tr>
<td>Acceptable trade-offs</td>
<td>h</td>
</tr>
<tr>
<td>Unacceptable trade-offs</td>
<td>i</td>
</tr>
<tr>
<td>Environmental mitigation actions</td>
<td>j</td>
</tr>
<tr>
<td>Social mitigation actions</td>
<td>k</td>
</tr>
<tr>
<td>Economic mitigation actions</td>
<td>l</td>
</tr>
<tr>
<td>Uncoded</td>
<td>m</td>
</tr>
</tbody>
</table>

D.2 The coincidence matrix

Following the second step provided by Krippendorff (2011), a coincidence matrix was constructed (Figure 19). The use of 13 codes (including “Uncoded”) resulted in an inner part of the coincidence matrix with 13 rows and 13 columns. The frequency at which the paired values (i.e., the values from each of the cells corresponding to a specific unit) occurred in the reliability data matrix were put into the coincidence matrix twice (once for the first coding and once for the second coding). By doing so the frequency of units being coded with the same variable in both rounds of coding run diagonally through the matrix. Outside of the matrix, at the bottom and on the right-hand side, the cells show the sum of the frequencies in each column and row, respectively. The bottom right cell, containing the number 266, display the total number of paired values (i.e., double the number of units coded in at least one of the rounds of coding).

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The paired values for unit one in the reliability data matrix would translate into a 2 in the cc-cell in the coincidence matrix while the paired values for unit four in the reliability data matrix would translate into a 1 in the gb-cell and a 1 in the bg-cell of the coincidence matrix.
Figure 19. The coincidence matrix used in the second step of determine the reliability of the analysis of the articles. Adapted from Krippendorff (2011).

### D.3 Calculating $\alpha$

The final step provided by Krippendorff (2011) consists of calculating the reliability coefficient based on the frequencies in the coincidence matrix. The coefficient for the reliability of the analysis of the articles was calculated using Equation 1,

$$
\alpha_{\text{nominal}} = \frac{(n-1) \sum c O_{cc} - \sum c n_c (n_c - 1)}{n (n-1) - \sum c n_c (n_c - 1)},
$$

where $n$ = the total number of paired values (i.e., the value in the bottom-right cell of the coincidence matrix), $O_{cc}$ = the frequency of a value being coded the same in both rounds of coding (i.e., the values cutting diagonally through the coincidence matrix), and $n_c$ = the total amount of units coded with a certain code during each of the rounds of coding (i.e., the sums at the end of each row/column in the coincidence matrix) (see Figure 20 for a generic version of the coincidence matrix, containing the same denotations as Equation 1).
Figure 20. A generic coincidence matrix.