# Project Report

# Environmental and social consequences of mineral extraction for low-carbon technologies

## Cobalt, lithium and nickel extraction, impacts and relation to the SDGs

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**Abstract**

Moving towards a sustainable future requires substantial upscaling of low-carbon technologies, many of which rely heavily on key critical minerals. To be in line with the Paris agreement, the International Energy Agency estimates demand for minerals to quadruple by 2040. Demand for cobalt, lithium and nickel is expected to see the largest growth, due to their use for batteries in the rapidly growing electric vehicle market. In this report we address the extraction of these three minerals, their extraction processes along with their social and environmental consequences. We highlight some supply risks and current policies and initiatives related to the extraction process of cobalt in the Democratic Republic of the Congo (DRC). We also explore the supply risks and geopolitical considerations regarding the high concentration of mineral processing in China. Lastly, we show the connection between the social and environmental consequences and the UN's sustainability development goals (SDGs).

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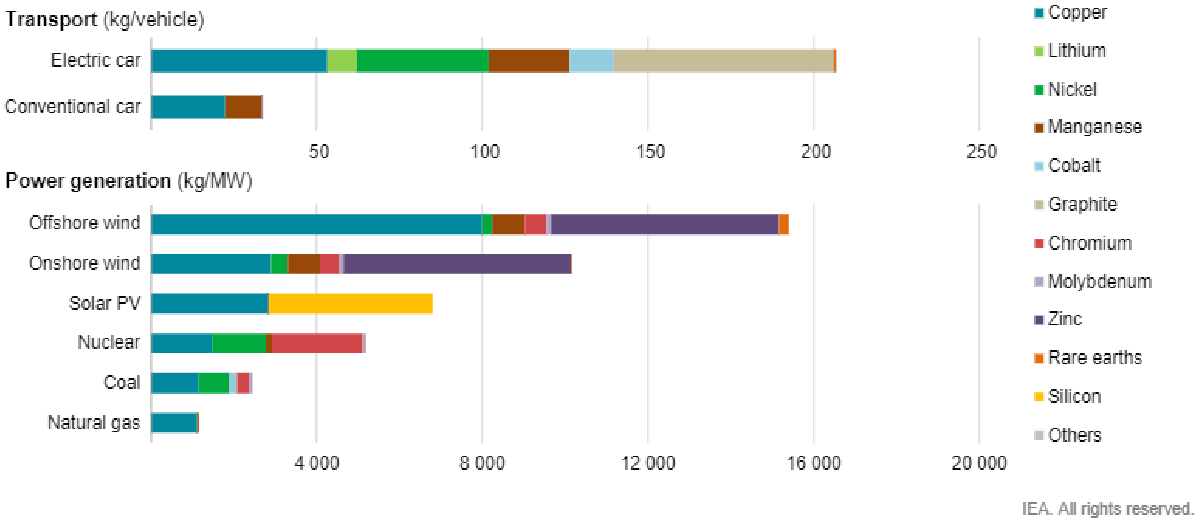
# List of abbreviations

| | |
|---|---|
| ACP | African, Caribbean and Pacific countries |
| ASM | Artisanal and small-scale mining |
| $CO_2$-eq. | $CO_2$ equivalents |
| DRC | The Democratic Republic of the Congo |
| EoL | End of Life |
| EU | European Union |
| EV | Electric vehicle |
| GWP | Global warming potential [$CO_2$-eq.] |
| IEA | International Energy Agency |
| LCA | Life cycle analysis |
| LIB | Lithium-ion battery |
| LSM | Large-scale mining |
| NGOs | Non-governmental organizations |
| REE | Rare-earth elements |
| SDG | UN's sustainability development goals |
| SDS | IEA's sustainable development scenario |
| SSR | Security Sector Reform |
| STEPS | IEA's current policy scenario |
| UN | United Nations |

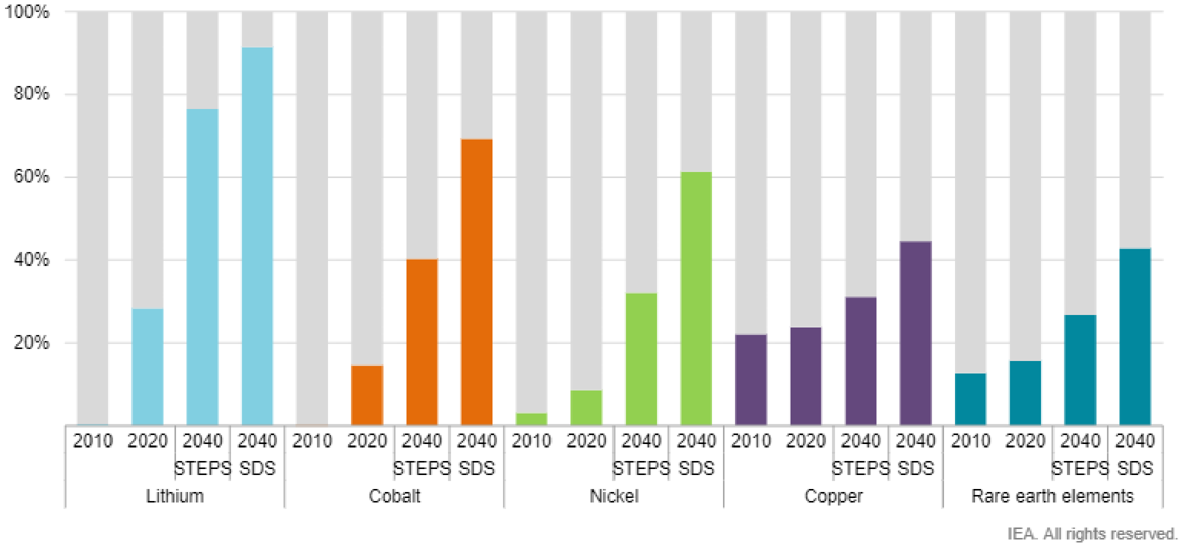
# 1 Introduction

The transition to a low-carbon society comes with significant growth in renewable energy technologies, electric infrastructure, and batteries for electric vehicles (EVs). In a Sustainable Development Scenario (SDS) – a scenario following a trajectory to be in line with the Paris agreement goals – total mineral demand is set to quadruple within 2040 (International Energy Agency, 2021). The key technologies in the transition will enable sustainable energy production and sustainable transport. Figure 1 displays the minerals contents of the technologies expected to play a key role in the coming years. Figure 2 shows the growth in demand for lithium, cobalt, nickel, copper, and rare-earth elements (REE) under IEA's Sustainable Development Scenario (SDS) in 2040 (International Energy Agency, 2021).



Notes: kg = kilogramme; MW = megawatt. Steel and aluminium not included. See Chapter 1 and Annex for details on the assumptions and methodologies.

*Figure 1: Minerals used in selected clean energy technologies (International Energy Agency, 2020, p.6).*



Notes: Demand from other sectors was assessed using historical consumption, relevant activity drivers and the derived material intensity. Neodymium demand is used as indicative for rare earth elements. STEPS = Stated Policies Scenario, an indication of where the energy system is heading based on a sector-by-sector analysis of today's policies and policy announcements; SDS = Sustainable Development Scenario, indicating what would be required in a trajectory consistent with meeting the Paris Agreement goals.

*Figure 2: Share of clean energy technologies in total demand for selected minerals (International Energy Agency, 2020, p.7).*

In this report we investigate the conditions surrounding the extraction of some of the key minerals for the transition to a low-carbon society. The aim is to account for both social and environmental consequences of mineral extraction for low-carbon technologies and to see them in the context of the UN's sustainability development goals (SDGs). In line with the scope of the International Energy Agency (IEA) report, the scope of this report is limited to critical minerals, not examining bulk minerals such as steel, aluminium and cement. Specifically, the report takes a closer look at the three minerals: cobalt, lithium and nickel. These minerals were chosen because, according to the IEA report (2021), they are expected to have the most growth until 2040.

To be able to link the social and environmental consequences of minerals for low-carbon technologies with the UN's SDGs, we have chosen the following research question:

> *What are the environmental and social consequences of mineral extraction for low-carbon technologies, and how do these link to the SDGs?*

The two scenarios outlined by the IEA report are proposed as a range for future development. The stated policy scenario (STEPS) was created from a sector-by-sector analysis of current and stated policies. The sustainable development scenario (SDS) models the development necessary to be completely in line with the Paris agreement and the 2-degree target, most notably by reaching net-zero emissions by 2050 for most countries.

This report is the result of our summer project and was done within the Department of Sustainable Energy Technology within SINTEF Industry. The results from this report contribute to SINTEF's project eaSi-system, which revolves around a framework for systematic SDG impact assessment of new technologies. In the next section of the report, section two, we address the extraction of some of the minerals for low-carbon technologies needed to transition to a low-carbon society. Further in this section, we explain the mineral extraction processes along with their social and environmental consequences. Regarding cobalt extraction, we highlight some supply risks and current policies and initiatives that are present in the location of the extraction process, more specific in the Democratic Republic of the Congo. In the next section, section three, we take on a more holistic view and address the supply risks and geopolitical considerations regarding the processing of minerals for low-carbon technologies, which are concentrated in China. Finally, in the last section, section four, we show the connection between the social and environmental consequences of the minerals accounted on in this report in connection with the UN's sustainability development goals (SDGs).

# 2 Mineral extraction for low-carbon technologies

## 2.1 Cobalt extraction

Future cobalt demand is expected to be in the range of 6 to 30 times the demand of today, depending upon assumptions about battery chemistry and climate policies (International Energy Agency, 2021). There has been research on new battery chemistries for lithium-ion batteries (LIBs) to reduce cobalt usage (Ferguson & Lu, 2020), and car manufacturers such as Tesla have announced their transition towards cobalt-free battery cathodes (Calma, 2020). Despite potential efforts to reduce or substitute cobalt in batteries, there will be a significant growth of demand in the coming years. Satisfying this demand for cobalt will require ramping up an extraction process that already has environmental and significant social consequences.

***Figure 3: Global cobalt production (Pagnamenta, 2018)***

Cobalt mining has gotten much publicity due to the poor working conditions and child labor in the cobalt mines in the Democratic Republic of the Congo (DRC). The DRC is the leading source of cobalt extraction in the world, mining approximately 70% of the world's primary demand in 2020 (Geological Survey, 2021). Some 90% of cobalt is mined as a by-product of either copper or nickel (International Energy Agency, 2021), with the notable exception of artisanal mines in DRC and in Morocco. This means that most cobalt mines are also copper or nickel mines. In a life-cycle impact assessment perspective this leads to challenges of allocation, meaning how to divide the environmental burdens most correctly between co-products of a production process.

### 2.1.1 Environmental consequences in DRC

An impact assessment from 2008, in advance of the construction of the Kalukundi copper/cobalt mine in Katanga (DRC), uncovered a range of environmental impacts with the most significant ones within two categories: harm to the local ecosystem and harm to the local water system (Heydenrych, 2008).

The land occupied by the open-pit mining operations leads to disruption of the local ecosystem. Among effects of high significance are: the direct loss of rare habitats in the copper-cobalt vegetation communities, loss of local endemic species and direct loss of local biodiversity. In addition, the mines require dewatering of the pits, meaning large amounts of surplus water will be released into the local environment. The contaminated mine-water can disrupt the current flow patterns of the local water system and pollute the local rivers and water sources. Water pollution will affect the local population through their drinking source (Heydenrych, 2008), leading them to consume unusually large amounts of cobalt and associated metals, which is known to be harmful to human health (Křibek, 2011). After decommissioning, the water sources dried out by the dewatering of the mines are expected to be dry for another 45 years before recovering to pre-mine levels (Heydenrych, 2008). Ecosystem exposure to high concentrations of minerals has unknown but potentially significant effects, such as a chain effect by harming pollinators (Heydenrych, 2008).

Due to the poor infrastructure in the DRC, transportation related to the mines is done by trucks on dirt roads. This results in massive local air pollution, firstly particulate matter in the air resulting from large trucks on soft roads, secondly pollution of toxic minerals from the debris from transporting trucks (Heydenrych, 2008). In 2015-2016, about 15-20% of cobalt production in the DRC came from artisanal and small-scale mines (ASM) (Banza Lubaba Nkulu et al., 2018). Due to their small size, ASM do not disrupt the local ecosystems as much through land-use as the larger mines. However, the distributed nature of ASM generally brings the polluting effects of the mines closer to people's homes. The activities related to the extraction and handling in ASM contribute to the distribution of metals into the air, polluting the local area with minerals through dust settling.

High concentrations of the minerals were found in the urine of local communities living in direct proximity to the Katanga mines. The concentrations were higher in children than in adults, and in general the concentrations of copper were the largest (Křibek, 2011). Cobalt concentration in the urine of the local population has been measured as 70-fold larger than in a control area, uranium was 13-fold higher. This average cobalt concentration was way beyond the Canadian standard for surface soil for residential use (1100 micrograms/g vs. 22 micrograms/g) (Banza Lubaba Nkulu et al., 2018). As mentioned, high concentrations of these minerals are detrimental to human health; cobalt and uranium have been suggested as possibly carcinogenic to humans, while high concentrations of copper are suspected to be linked to neurodegenerative disease (IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, 2006; Pohanka, 2019; Bjørklund et al., 2020).

In conclusion, the main direct environmental effects of cobalt extraction in the DRC are: disruption of ecosystems and loss of biodiversity by land-use, disruption of local water flows, pollution of the aquatic environment polluting the local population, drying out of water sources by dewatering mines, mineral pollution of the ecosystem, and mineral and dust pollution of the local population.

### 2.1.2 Environmental impacts of the entire cobalt value chain

While the impact assessment of the Kalukundi mine gives insight into the local environmental effects, these effects are not the only environmental impacts of cobalt production. The environmental impacts of most metals, including cobalt, are dominated by the purification and refining stages, where they are transformed from concentrate into metallic form (Nuss & Eckelman, 2014). For a more holistic environmental impact assessment of cobalt production, it is necessary to include all processes in the production value chain. Even though most of cobalt extraction is happening in the DRC, China is the world's leading refiner, processing over 60% of the global production (International Energy Agency, 2021).

A life-cycle assessment (LCA) of the cobalt extraction process was performed in Sydney, Australia, examining the cradle-to-gate impacts found the main source of environmental impacts to be fossil fuel consumption. This was mostly due to emissions from medium-voltage electricity used in the cobalt processing and the blasting operation. The most notable impact category was global warming, but there were also significant effects on eutrophication and human health. The LCA results validate the fact that the cobalt mining is harmful both for the cobalt miners and for the local population. The main sources for impact on human health were the electricity used in the process, blasting and exposure to cobalt ore in production. The findings validate the previously discussed impacts on human health, further identifying arsenic, cadmium, cobalt, and manganese as the most significant contributors. There were few effects from sulfidic tailings and waste emissions in the cobalt production process (Farjana et al., 2019).

The impact on land and water use was found to be small in the LCA, contrasting the findings of the Kalukundi impact assessment. Reasons for this might be the qualitative nature of the Kalukundi assessment, focusing on local impacts that might be less relevant in a global cobalt value-chain perspective, or potential weaknesses in the methods as measuring land-use impacts in LCA is difficult. Furthermore, the Kalukundi project might vary from the average cobalt mine in the DRC, especially when considering the large portion of ASM. This might be part of the explanation for the small impact. An older LCA examining multiple metals using data from 2005 found a comparable result for global warming potential (GWP) of cobalt production, 8.3 kg $CO_2$-eq./kg compared to 11.73 from the Australian LCA (Nuss & Eckelman, 2014).

The LCA findings indicate that the local environmental impacts as described in the Kalukundi impact assessment are not the most significant when considering the entire cobalt production value chain. The local environmental consequences are real and must be considered in mine construction and expansion, but the largest improvements to environmental impacts might come from an increased share of renewable and low-carbon electricity in the cobalt value chain as well as from managing emissions from blasting.

### 2.1.3 Cobalt recycling

Increased recycling of cobalt can contribute to securing the growing future supply and to lowering the social and environmental impacts of cobalt production by substituting primary production. In 2005, about 22% of discarded cobalt was collected and transmitted to scrap markets for recycling, 10% was downgraded to other scrap markets and 69% was sent to landfills (Harper et al., 2011). In China, the main refiner and producer of cobalt (International Energy Agency, 2021), the recycling rate of cobalt in 2013 was below 40%, meaning more than 60% of the cobalt was still stored in End-of-Life (EoL) products (Zeng & Li, 2015). EoL products end up in landfills, where the minerals of the products become exposed to the nature and thus harm both the environment and human health.

The major opportunity for secondary cobalt recovery exists in the cobalt contained in battery applications (Sun et al., 2019). Additionally, battery applications will make up the majority of the growth in demand for cobalt in the coming years (International Energy Agency, 2021). This means that cobalt recycling mostly means battery recycling. Even though the present LIB recycling rate globally is only 5-7%, a high degree of recycling of LIBs in the future is inevitable to secure the stability of the LIB-minerals value chain, therein the cobalt value chain (Pinegar et al., 2019). The recycling will have additional environmental benefits by reducing primary cobalt production and thereby environmental impacts (Pinegar et al., 2019). Commercial large-scale recycling of LIB has not seen much upscaling yet, despite successful lab-level hydrometallurgical processes for recycling (Lupi et al., 2005; Freitas & Garcia, 2007). This is partially due to the difficulty of achieving high yield and quality of the recycled product because of the complexity of LIBs, safety concerns and the cost of recycling processes with current technology (Pinegar et al., 2019). There is a lack of viable collection mechanisms for spent LIBs, a lack of environmental regulations for recycling and little knowledge of the potential cost reductions of increased recycling (Mayyas et al., 2018). A closed-loop recycling system with full recycling could supply large parts of the future demand for cobalt needed in LIBs (Mayyas et al., 2018). Another potential future cobalt source to alleviate primary production is sub-sea mining. There are vast mineral resources located under the oceans, but still considerable challenges to overcome in order to make sub-sea mining successful and economically feasible (Sharma, 2011).

### Social consequences in DRC

As previously stated, approximately 70% of the extraction of cobalt comes from the Democratic Republic of the Congo. Of this, approximately 15-30% of cobalt production takes place within so-called artisanal and small-scale mining companies (ASM), while the remaining share takes place within large-scale mining companies (World Economic Forum, 2020). DRC is one of Africa's largest, richest, and most central countries (Solhjell & Leraand, 2019). At the same time, the country is one of the least developed ones in Africa and scores particularly low on the UN poverty index from 2019 (MPI) (United Nations Development Programme, 2020). The significant resources the country holds makes DRC attractive for foreign stakeholders. Nevertheless, little of this wealth benefits the country and therefore does not help the DRC reduce its poverty (Andrews et al., 2008). The major poverty problem greatly affects the working conditions for the population, more specifically: poor sanitary and security conditions and widespread child labor in the artisanal mining sector.

***Sanitary and safety conditions***
Firstly, the poverty in the DRC significantly affects the sanitary and safety conditions in the artisanal mining sector. The safety conditions in the artisanal mining cities are very poor. Miners dig in small pits without any safety equipment, coordination or knowledge about earlier operations that can affect the ground stability (Tsurukawa et al., 2011). If the mines are not constructed or managed safely, this can pose dangerous conditions for the miners, ending in fatal accidents. According to Amnesty International's report "This is what we die for" (Amnesty International, 2016), accidents in the mining sector are quite common.

In addition to the poor safety conditions, the sanitary conditions are terrible. There are no latrines constructed in the mines and the quality of drinking water is poor. In addition, alcohol, prostitution and narcotics are common in the artisanal mining community, which impacts the workers' general health negatively (Tsurukawa et al., 2011). The mining sites also expose the workers to dangerous minerals such as dust containing cobalt and copper, that can cause fatal lung disease, shortness of breath, decreased pulmonary function and have been linked to cancer and neurodegenerative diseases (IARC Working Group of the Evaluation of Carcinogenic Risks to Humans, 2006; Pohanka, 2019; Tsurukawa et al., 2011).

Regardless of these harmful conditions, the Mining Code (from 2002) and regulation implemented by the DRC do not provide any guidance for safety equipment or how to handle substances which pose a danger to the workers' health (Amnesty International, 2016). The workers in cobalt mines take considerable health and safety risks that can have fatal consequences. However, despite the poor working conditions in artisanal mining, more mining projects mean more work and therefore more salary for the workers (Amnesty International, 2016).

***Child labor***
Secondly, in addition to the Republic of Congo scoring low on the UN poverty index, about half of the country's population is under the age of 15, as a result of strong population growth in the country in recent decades (Tsurukawa et al., 2011). The number of children working in the mines to recover cobalt is thus very high and is estimated to be about 40 000 (Amnesty International, 2016). However, such child labor is strictly prohibited for children under the age of 15, according to Article 133 of the Mining Code (from 2002), where the regulation further in Article 26 emphasizes that only Congolese citizens of legal age are allowed to work as miners (Tsurukawa et al., 2011). We therefore see that there is a weakness in the authorities' regulations on mining in the country, as child labor takes place to a considerable extent.

Child labor in mines is one of the worst forms of child labor, according to ILO Worst Forms of Child Labour Convention (1999), No. 182. Child labor that takes place before an appropriate minimum age, interfering with the physical, mental or moral development of children, such as mining, contradicts the Declaration of Children's Rights (Tsurukawa et al., 2011). Work on the extraction of cobalt includes especially work in confined spaces, for many hours, taking place underground and exposing workers to dangerous substances. In addition to such work, children in particular are often set to dig in small mines, where it is easier for a child to get to than an adult (Tsurukawa et al., 2011). Such work places children at significant health and safety risks.

Despite this, there is a large proportion of children who are completely dependent on such work to afford educational expenses and to live (Tsurukawa et al., 2011). There are also traders who do not want changes in the number of children working in the mines – the more miners that leave the sector, the more the income of the traders decreases (Tsurukawa et al., 2011). In addition, child labor is considered cheaper than adult labor, seen in the context of low law enforcement against child labor (World Economic Forum, 2020). Regardless of this, the artisanal mining sector is no place for children. In addition to the health and safety risks associated with artisanal mining, prostitution also occurs on such mining sites (Tsurukawa et al., 2011), which violates the Convention on the Rights of the Child, articles 19 and 34, and the convention about the Worst Forms of Child Labour (International Labour Organization, 1999), article 3, both signed and ratified by DRC. The government is thereby required to prohibit and eliminate such incidents. However, there is a lack of capacity within the government to monitor and enforce safeguards to improve the conditions for the artisanal workers (Amnesty International, 2016).

### 2.1.4 Economic development of DRC

The extraction of minerals such as cobalt in the Democratic Republic of the Congo has contributed to a large extent to the country's national economy. Even though little of the wealth from the extraction benefits the country to a great degree, as earlier mentioned, the resources located in the country attract major foreign stakeholders, which contribute to developing the region of DRC. In such, the mining sector is a key growth driver for the country's economic development (Andrews et al., 2008). This development is, however, characterized as long termed (Geenen, 2012).

In the past, the DRC has not been able to harness its mineral wealth's revenues generated by the mining sector in a sustainable way. The sector has thus contributed little to the country's economic development and generated little value to the region (Andrews et al., 2008). The country has been affected by conflict, wars, and corruption, which have influenced the mining sector negatively, contributing to expanded informal artisanal mining. The DRC is currently ranked 170th out of 180, on the Corruption Perception Index for 2020. The DRC has a score of 18, where 0 is highly corrupt and a score of 100 is very clean (Transparency International, 2020). The governance of DRC has also been responsible for limiting policies for investments in private sectors (Andrews et al., 2008). The mining sector in DRC has therefore been dominated by several large enterprises owned by the government for years, which have provided infrastructure, schools, transport, etc. to the region.

The government in DRC has further focused on attracting investment from other countries, such as China, to obtain mineral rights or work under partnership agreements with state-owned enterprises, to enhance the country's development and path creation (Andrews et al., 2008). The concept "path creation" involves the establishment of new development paths in a region, including large-scale investments and value creation, typically generated by firms or institutions. The concept can be seen as a key element underpinning the regional development process. Forms of "strategic coupling" are a central part of path creation, shaping the regional assets to fit the need of firms in global production networks (MacKinnon, 2012). For China specifically, however, the investment in construction of facilities and enterprises in DRC has mainly been about securing access to minerals and ensuring maximum value added. As the World Bank report (Andrews et al., 2008) states, the Chinese investments are a part of an overall political policy and strategy to secure access to mineral resources for Chinese companies. Agreements between the governance of DRC and Chinese companies have therefore been based on infrastructure financing in return for access to developed mineral deposits (Tsurukawa et al., 2011). In doing so, China has been able to “strategically couple” itself to the DRC and the country’s important mineral resources, which has been of importance for solving the DRC’s possible “lock-in” effects due to the corruption and conflict situated in the country (MacKinnon, 2012). Being “locked-in” to existing paths of development will inhibit the country’s capacity to adapt to broader processes of economic change.

Through the partnership between DRC and China, the economic region of DRC has grown due to the job creation in the formal mining sector, increased cash flow and improved infrastructure systems (Tsurukawa et al., 2011). However, the formal large-scale mining companies do not offer sufficient jobs for the population of DRC. This results in widespread artisanal and small-scale mining, which can limit the economic development of the country due to their informal organization. ASM are often the only source of income for poor communities and are associated with poor working conditions and minimal respect of human rights. Therefore, formalizing the ASM sector can provide decent income opportunities and safer workplaces for the miners and reduce child labor in artisanal mines (World Economic Forum, 2020). The ASM sector therefore requires formalization to enhance value creation in the DRC and reduce poverty (World Economic Forum, 2020).

### 2.1.5 Supply risk for cobalt extraction in DRC

The extraction process of cobalt is mainly located in the Democratic Republic of the Congo, posing a significant source for supply risk. From there, the cobalt is transported to China, where approximately 60% of the global processing is located (International Energy Agency, 2021). As DRC is reported as the leading country for extracting cobalt, China is the leading country within processing, with almost 50% of the country’s export trading activity consisting of processing trade (Yu & Tian, 2012). The connection between DRC and China therefore plays an essential role in the value chain of cobalt since this is where most of the extraction and processing of the mineral takes place.

Due to the concentrated nature of the cobalt value chain, with the majority of extraction located in DRC and processing and refining in China, the risk of supply chain disruptions is high. (van den Brink et al., 2020). If, for any reason, the DRC would not be able to supply cobalt to China to be processed, this would have a disrupting effect on the entire value chain, from the extraction to end use. This was, for example, the situation when the Covid-19 pandemic occurred in 2020. It forced shutdowns and reassessments of consumers’ cobalt requirements (Greenfield et al., 2020), and for the extraction of cobalt in particular, the local quarantine measures and shutdowns were significantly disrupting the process (Dyatkin & Meng, 2020). This caused a huge disruption in the cobalt supply chain, when the DRC was not able to continue with the extraction, which limited or cut off the delivery from DRC to China for processing, which further limited the production of products consisting of cobalt (Greenfield et al., 2020).

As the situation above shows, relying on one nation's extraction of a mineral can be severely problematic and could cause geopolitical conflicts. However, not all countries have access to and can extract cobalt. The raw-mineral availability is therefore critical to all firms and countries that extract, refine and process minerals into products (Alonso et al., 2007). A disruption in one part of the supply chain can disrupt the functioning of the overall supply chain, as the companies in the supply chain serve as "bridges" between countries and companies (van den Brink et al., 2020). Furthermore, a severe disruption in cobalt's supply chain could eventually lead to a shift in market forces towards requiring other goods, and therefore other supply chains, leading to irreplaceable economic harm (Alonso et al., 2007).

### 2.1.6 Current policies and initiatives

There are several current policies and initiatives in the DRC that seek to contribute to develop the country economically and to map and reduce the environmental and social consequences of the mining sector. The Mining Code is one policy that has great impact on the mining companies in the DRC, requiring the companies to report on environmental impacts and improve the social impacts in the mining sites. Another initiative is the Security Sector Reform (SSR), which aims to improve the security, stability, and development in the DRC, and thereby contributes to improving the social and environmental consequences of the mining sector and reducing poverty in the country.

#### *The Mining Code*

The Congolese Mining Code was established by the Congolese Congress in 2002, to formalize the mining sector and to replace the outdated mining legislation in the country (Schoutheete et al., 2021). At this time, the DRC was recovering from a terrible and long-standing war and decades of mismanagement of state-owned mining companies (Mulé, 2018). Among other things, the president of the DRC encouraged people to start digging for themselves, because of the collapse in the mining industry in the country (Stanwick & Stanwick, 2020). As a result, the government established a mining code in 2002 to encourage and attract foreign investment in the mining industry, to recover the country by trying to formalize the sector. The Mining Code offered a first-come first-served licensing system for mining exploration, a stabilization clause guaranteeing foreign investors current mining-code provisions for at least ten years after granted permit by the government, and a standardized tax system for the mining output. This contributed to a significant growth in the mining sector (Stanwick & Stanwick, 2020). However, the Mining Code did not offer any guidance regarding the safety equipment or how to handle substances which pose a danger to mine workers' health (Amnesty International, 2016). Thus, the code was viewed deficient, since it did not include significant guidance concerning social and environmental consequences of the mining sector. The actors in the mineral value chain also saw little incentive to enter the formal sector, due to insecurity, tax burden, lack of state investments and few artisanal mining zones.

In 2018, the DRC substantially amended the country's 2002 Mining Code, due to the notable growth in the mining sector (Stanwick & Stanwick, 2020). The times had changed since 2002, and the investor-friendly code did not make sense anymore (Mulé, 2018). Therefore, the DRC government revised it to create more favorable conditions for the government itself. Among other things, it reduced the stabilization clause from ten to five years, to give the government a greater degree of flexibility in changing the conditions for mining in the DRC (Schoutheete et al., 2021). This impacted the mining companies negatively and the companies urged the government to not implement the proposed Mining Code, since it would probably damage the foreign investment. In March 2018, however, the new Mining Code was adopted and replaced the previous code from 2002 (Stanwick & Stanwick, 2020).

The new Mining Code requires mining companies, including cobalt mining sites, to provide a mitigation and rehabilitation plan to limit and correct environmental damages caused by mining (Stanwick & Stanwick, 2020). In addition, it includes measures to prevent abuse in mineral-mining companies (Brandao, 2019). In such, the new Mining Code places more emphasis on the environmental protection and social responsibilities of the mining companies to reduce negative environmental and social outcomes and to contribute to sustainable growth. However, implementation and monitoring of its implementation are key activities that might be challenging for the DRC government to enact due to lack of resources and expertise (Brandao, 2019). Nevertheless, mining companies will benefit adhering to sustainability principles in the new Mining Code. It will contribute to building a long-term partnership with the DRC government, maintain a social license to operate in the mining sector, and positively affect a company's image and stability in the region, attracting foreign investment (Brandao, 2019).

The changes in the revised Mining Code have been poorly received by the mining operators in the region. The mining companies have little bargaining power and could be at risk of less favorable regulation without being able to influence such decisions in the future (University of Western Ontario, 2020). There is some evidence, however, that the formalization of the artisanal mining sector can be successful in reducing social consequences such as child labor. Successes have so far been limited in scale, and the DRC's efforts have been limited due to regulatory ambiguity in the Mining Code (University of Western Ontario, 2020). In addition, there has not been sufficient time since the Mining Code was revised to create a great amount of success stories. To improve the situation in the country, multi-stakeholder engagement is necessary, bringing together different actors in the civil society to improve the situation (University of Western Ontario, 2020).

### *The European Union and the Security Sector Reform*

The European Union (EU) has contributed significantly to the development of the DRC over the last few years, covering a wide range of actions: diplomatic and technical support, humanitarian and development aid, and military operations (Hoebeke et al., 2007). The EU's relation to the DRC is based on a strong support for political, economic and commercial development in the country, under the so-called Cotonou Agreement. The agreement aims to reduce poverty in the ACP (African, Caribbean and Pacific) countries and integrate them into the world economy. The EU places great significance on regional stability and has been greatly involved in efforts to bring about stability in the ACP countries. In fact, the DRC is the country that has received most attention from the EU's new security and defence policy since it was established (Justaert & Keukeleire, 2010).

For the DRC, the political and security tensions in the country represent a threat to stability, security and regional development. The DRC has, for decades, been driven by war, corruption and poor governance, where security and police forces have been part of the problem (Andrews et al., 2008). Security is therefore one of the most important challenges for the development in the DRC (Justaert & Keukeleire, 2010). To deal with this challenge, the DRC governance has implemented a Security Sector Reform, where the EU and the United Nations (UN) play an active supporting role. Since 2003, this reform has resulted in several initiatives to strengthen the police, military and justice sectors in DRC to increase stability, security and regional development (Hendrickson & Kasongo, 2017). As for the mining sector in the DRC, this reform can contribute to demilitarize the artisanal mining areas in the eastern part of the country and re-establish civilian control. These artisanal mining areas have been exploited by military forces, who abuse their legal powers for individual economic gain. Corruption, bribery and human-rights abuses are a persistent problem in these mines (Koning, 2010). The reform can thereby improve the social conditions in the mining areas. A formalization of the sector can also help this transition. According to the European Commission (European Commission, 2020), to achieve sustainable development and growth, a more peaceful environment is needed, which can be achieved through the reform.

### 2.1.7 Cobalt extraction in the rest of the world

The remaining 30% of the world's cobalt demand (in 2020) come from a range of countries, but most significantly Russia exported 4.5%, Australia 4.1%, the Philippines 3.4%, Cuba 2.6%, and Canada 2.3% of total primary cobalt supply. Production in Australia has been called ethical, with regulated and protected working conditions. There is a focus on sustainability and minimizing the environmental footprint of the mines (Miller, 2020). Australia has the second largest cobalt resources (Geological Survey, 2021) and is thus well positioned for further upscaling of production. The Karakul region in Russia has potential as a good strategic location for increased cobalt production. Located between Mongolia and Siberia, the belt has access to important Trans-Siberian transport infrastructure and proximity to the large Chinese market (Proactive Investors, n.d.).

There are, to the best of our knowledge, few publications about considerations of sustainability, working conditions and environmental impacts of cobalt extraction in other countries than the DRC. Two possible explanations are: either there are few environmental and social impacts of cobalt extraction in other countries, or there are impacts but they are not examined or documented. One can speculate further that in developed countries with well-functioning regulations and unionization of workers (such as Australia, Canada and the Philippines), one would not expect to see social consequences remotely comparable to those found in the DRC. For Russia or Cuba, the latter explanation might be more likely, and investigation of the extraction processes might reveal undiscovered impacts.

## 2.2 Lithium extraction

Lithium is the critical mineral with fastest growing demand (International Energy Agency, 2021). It has multiple uses, such as in ceramics, glass and lubrication greases (Peiro, et al., 2013), but in the last decade its use has been dominated by LIBs, being responsible for 31% of production in

2010 (US Geological Survey, 2011), 46% in 2017 (US Geological Survey, 2018) and 71% in 2020 (US Geological Survey, 2021). Unlike cobalt, lithium is non-substitutable in current LIB chemistries (Titirici, 2021), meaning lithium production will follow LIB and thus EV growth. The IEA estimates in their most optimistic scenario for 2040, the SDS, that LIB demand will grow nearly 40 times, resulting in lithium demand growth by 42 times relative to 2020 (International Energy Agency, 2021)

Lithium is produced from two different types of sources: brine salt lakes and spodumene (a type of pegmatite) ores (International Energy Agency, 2021). Extracting lithium from brines is done by pumping up lithium-rich water from the underwater reservoirs into large open pools where the water evaporates, leaving lithium carbonate and other by-products for further processing. Most of the global lithium reserves are located in brine lakes in the lithium triangle, an area in the Andes bordering Argentina, Bolivia and Chile (Ahmad, 2020), with Chile being the single largest producer of lithium from brines (International Energy Agency, 2021). Brine production has historically been the largest source, accounting for around 60% of lithium production in 2013, while the rest came from mining spodumene (Peiro et al., 2013). The growing demand in recent years has led to growth in lithium production from spodumene, resulting in Australia emerging as the largest producer of lithium (International Energy Agency, 2021).

*Figure 4: Map of the lithium triangle in South America (Roth, 2019).*

The global lithium reserves have been estimated by Vikström et al. (2013) to be 15 Mt and by USGS (US Geological Survey, 2021) to be 21 Mt. The global yearly production was 0.082 Mt in 2020 (US Geological Survey, 2021). In IEA's most optimistic scenario, the SDS, demand for lithium is expected to grow by 42 times within 2040 (International Energy Agency, 2021), while in their stated policies scenario (STEPS) demand for lithium is expected to grow 13 times within 2040. Thus, IEA estimates yearly production to be somewhere between 1.07 and 3.53 Mt. In contrast, Vikström et al. (2013) previously estimated yearly production of lithium to maximally reach 0.4 Mt, in 2088. IEA's growth estimates are thus considerably larger for both of their scenarios, STEPS and SDS. While Vikström et al. (2013) reached their estimate through mathematical curve-fitting models, based on historical production data from before 2013, IEA's estimates are in a range between current policies of 2020 (STEPS) and necessary production to reach the climate target of the Paris agreement (SDS).

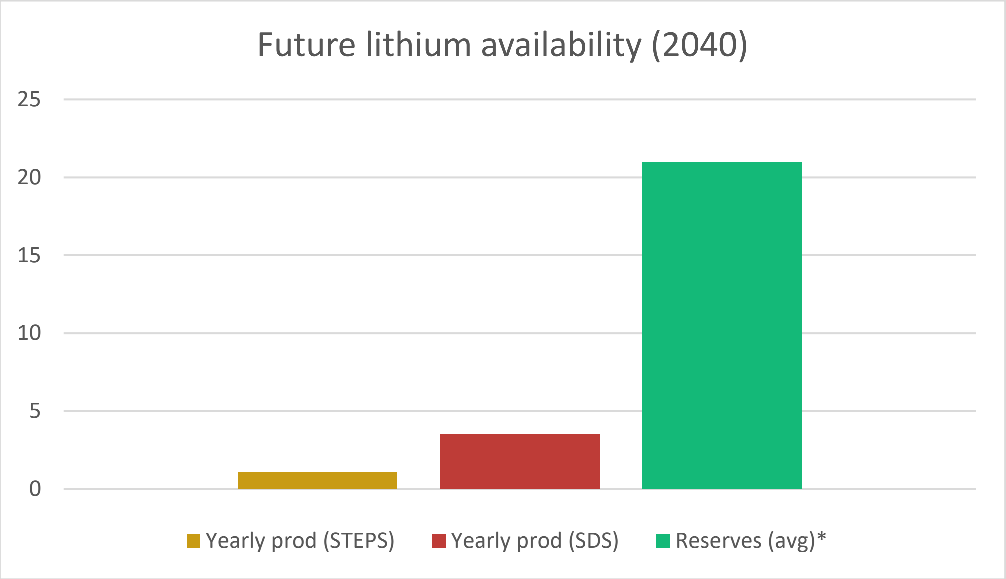


***Figure 5: Estimated yearly production in 2040 (International Energy Agency, 2021) compared to global reserves in 2020 (US Geological Survey, 2021). Note: the reserves are estimated for 2020; as reserves have historically grown the actual reserves are most likely larger.***

The boom that has taken place in the EV market between 2010 and 2019, which is expected to continue, also explains why the IEA expects a much higher production volume. Figure 6 shows the exponential growth in EVs that happened from 2010 to 2019, and Figure 7 shows the estimated continued growth towards 2030 (International Energy Agency, 2021). Exponential growth is very difficult to predict, leading to an uncertainty in development of future lithium production. The requirements to reach the climate targets are more certain and will rely on a huge increase in yearly production.

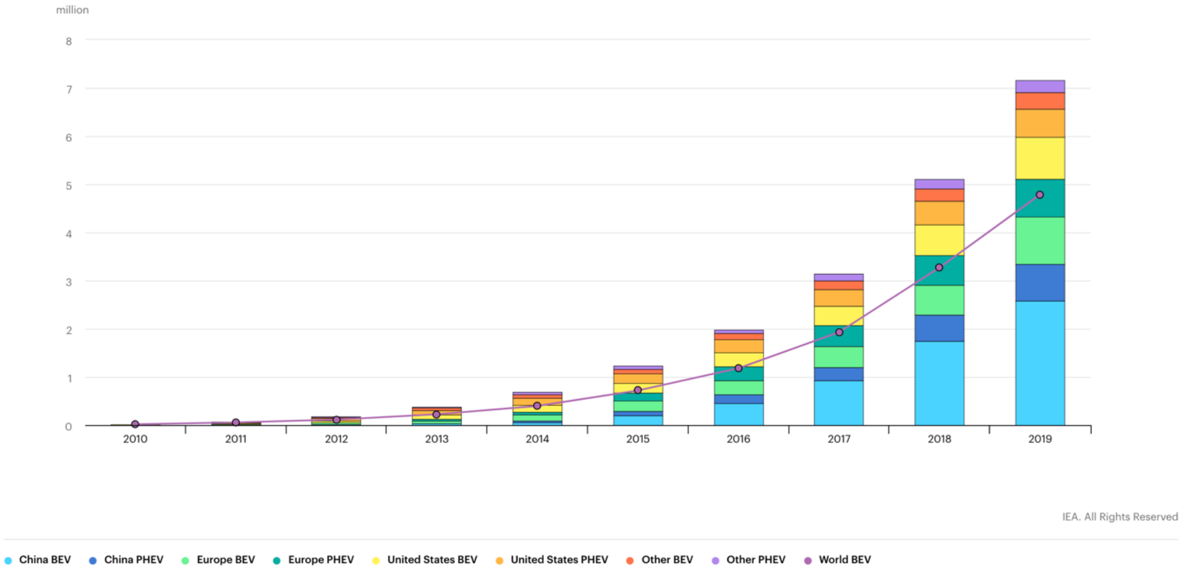


*Figure 6: Global electric car stock, 2010 – 2019 (International Energy Agency (1), 2020).*

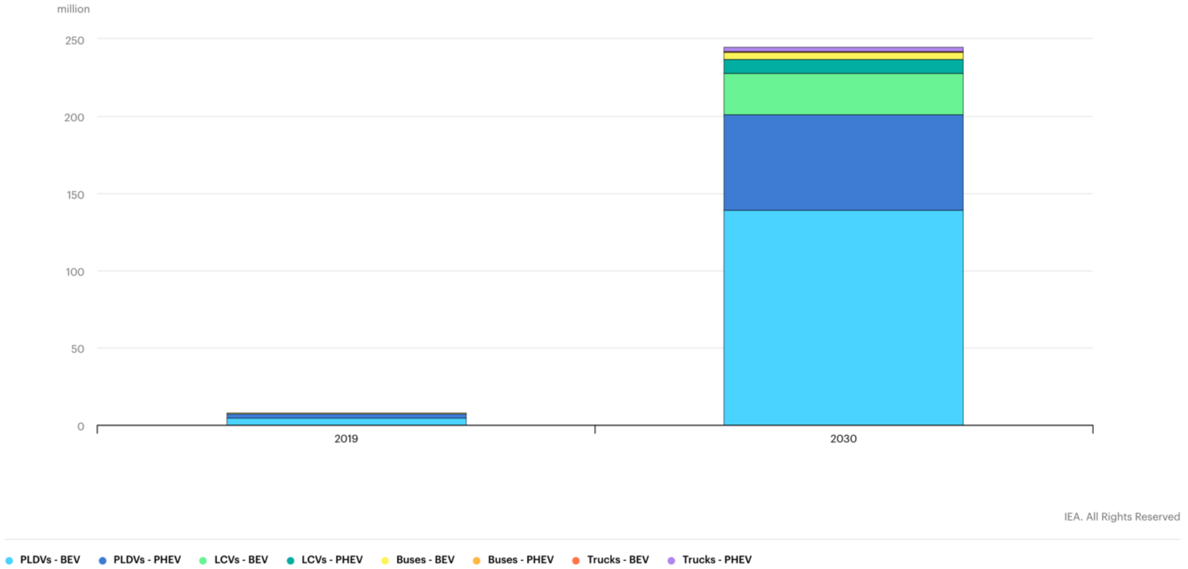


*Figure 7: Global electric vehicle stock in the Sustainable Development Scenario, 2019 and 2030 (International Energy Agency (2), 2020).*

There are different views on how limiting the global lithium reserves will be for LIB development. There seems to be a range of different estimates, with different measures of lithium availability: resources, reserves, in-situ reserves and the interrelation of these (Vikström et al., 2013). Gruber (2011) indicates that lithium availability will not constrain LIB development, highlighting that the global resources will be sufficient to meet demand past the year 2100. The study assumes both a conversion of resources into reserves and high recycling rates of over 90%. Yaksic & Tilton (2009) and Vikström et al. (2013), on the other hand, have pointed out a risk of shortage of lithium in the near future. These contrasting views seem to agree in the short term that establishing and upscaling the lithium production at the fast rate demanded by the EV industry will be challenging (Gruber, 2011; Ambrose & Kendall, 2020). Vikström et al. (2013) highlight how the maximum production capacity is going to be limiting in the short term.

Regardless of which estimate one accepts, the finite nature of lithium could result in eventual depletion. A much higher degree of recycling and/or alternative battery technologies are necessary for sustainable lithium production in the future (Yaksic & Tilton, 2009; Vikström et al., 2013; Swain, 2017).

### 2.2.2 Environmental consequences

The locations of lithium brines in the lithium triangle and China are characterized by dry landscapes and are thus highly susceptible to water shortages and climate risk (International Energy Agency, 2021). Mining operations in Chile have been linked to water scarcity (Aitken et al., 2016) and criticized for polluting waters and covering landscapes in blankets of salt (Ahmad, 2020). Operations of lithium extraction have also been alleged by natives of the Salta and Catamarca provinces to be contaminating the streams used by humans and livestock (Ahmad, 2020). The Salar de Atacama in Chile is the single largest source of lithium in the world (Vikström et al., 2013). Lithium extraction has consumed 65% of the water supply in the region, created water shortages and impacted the abilities of local farmers to grow crops and maintain livestock (Ahmad, 2020). Lithium extraction has also been reported to harm soils and contaminate the air, poisoning fish and killing livestock (Ahmad, 2020). In addition, there are potential impacts of waste generation and disposal, and land subsidence (Kaunda, 2020).

### 2.2.3 Lithium recycling

Currently, less than 1% of total annual production of lithium is recovered through recycling (International Energy Agency, 2021; Sonoc et al., 2015; Swain, 2017). Swain (2017) explores the potential for lithium recovery from low-grade primary and secondary resources such as clays, brine, seawater, ores and LIB. The paper highlights recycling of LIBs as particularly important, because of its projected growth and thus large potential to provide additional lithium supply. As the cost of lithium is much lower than that of other minerals used in LIBs, the motivation to recover lithium has been low. Ambrose & Kendall (2019) propose that in the future recycled lithium could replace primary demand by 11% by 2050 and 28% by 2100, given policy support and technical innovation. Swain (2017) suggests that 100% of LIBs need to be recycled with 90% recovery rate of lithium in order to meet future supply demand.

### 2.2.4 Social consequences

Research on the social consequences of lithium extraction is limited. In our literature review, we discovered only a few articles studying the impacts from lithium extraction in Argentina, Bolivia and Chile, which were much smaller than the impacts of cobalt extraction in the DRC. According to an article by Egbue (2012), there are no considerable social consequences regarding the safety and health risks of working conditions in large mines in Chile, due to the great alignment with international standards. In smaller and medium-sized mines, however, the enactment of laws can be a problem, due to economic margins. In addition, mining of lithium is primarily sub-surface mining, with systematic risk prevention, which reduces the risks of accidents compared to underground mining techniques, according to Egbue (2012). There are also few instances of child labor in the lithium extraction in Chile, as the government usually enforces the laws that protect children from exploitation in the workplace (Egbue, 2012). Further on, shortage of water and unfavorable laws related to access and ownership of water have resulted in conflicts between the indigenous local communities and mining companies in Chile. As the extraction of lithium is assumed to grow and to have a severe impact on the ecosystem and landscapes of the region, it can possibly lead to a downfall in the indigenous communities that live in these areas. The expansion of the mining industry in Chile can affect the local and indigenous communities negatively, disrupting their agriculture, livestock and local economies (Ahmad, 2020).

In Bolivia, the lithium extraction has contributed to economic and social development. The rate of economic growth has improved greatly in Latin America and the living standards have improved significantly, especially for the indigenous population (Marøy, 2019). Despite the growth, Bolivia remains one of the poorest countries of South America, and there are claims from NGOs (non-governmental organizations) that the lithium extraction has not had much structural impact on the region. There have also been concerns about Bolivia’s rich natural resources and how the lithium extraction will affect the scarce freshwater resources. Bolivia has earlier been subjected to unfair extraction policies, where multinationals have profited while Bolivia has not been able to benefit from its resources. According to Marøy (2019), a common perception is that by gaining control over the natural resources, the national sovereignty will be restored, by also enhancing the benefiting revenues for the people of Bolivia.

In Argentina, it is reported that lithium mines fail to respect communities’ rights (FARN, 2019). When establishing an extractive project in Argentina, mining companies must meet several conditions; it requires approval of the local communities, compliance with national and international requirements and respect for human rights. The Environmental and Natural Resources Foundation (FARN) has investigated the social and environmental impacts of lithium mining in Argentina’s Jujuy province, revealing two mining companies failing to comply with the law (FARN, 2019).

## 2.3 Nickel extraction

Nickel is mainly used for industrial alloys, with stainless steel accounting for about 65% of primary nickel consumption (European Commission, 2017). According to the European Commission (2017), nickel is a mineral of high economic importance, but not a critical mineral due to its relatively robust supply. Still, IEA (2021) highlights nickel as a focus mineral because of its central role for batteries and low-carbon technologies.

Currently, there is considerable growth in nickel demand for clean energy technologies such as EVs and battery storage, hydrogen and low-carbon power generation (International Energy Agency, 2021). Nickel demand is estimated to grow between 2 to 3.5 times by 2040 by Elshkaki et al. (2017), and between 6 (STEPS scenario) and 19 times (SDS scenario) by 2040 by the International Energy Agency (2021). By IEA’s estimates, the share of nickel consumption used for clean energy technologies is expected to grow from 10% today, to between 30% (STEPS scenario) and 60% (SDS scenario) in 2040 (International Energy Agency, 2021).

Nickel is produced from two different sources: sulfides and laterites. The largest producing countries from sulfide sources are Russia, Australia and Canada, while the largest producers from laterites are Indonesia, the Philippines and New Caledonia (International Energy Agency, 2021; US Geological Survey, 2021). Historically, most nickel production has come from sulfides because of their low costs due to high nickel concentration and conventional mining methods. Laterites, on the other hand, require intensive hydrometallurgical processing, and production is thus more costly and energy intensive (Mudd & Jessup, 2008). Although sulfides are the main source of nickel production, laterite reserves are actually larger than sulfide reserves, displaying a large potential for future extraction. In recent years we have thus seen laterites emerging as a growing source of primary nickel production, which is expected to continue (Dalvi et al., 2004; Mudd & Jowitt, 2014).

Total world mine production of nickel in 2020 was 2.5 Mt, and total reserves are estimated to be 94 Mt (Geological Survey, 2021). Reports of current reserves and resources have grown steadily in the 20th century, indicating that we are unlikely to find peak-nickel conditions as we have found peak-oil (Mudd, 2010). The study notes that while lack of economically feasible resources is unlikely to cause peak-nickel, there could be a possible peak for production caused by emissions trading or taxing systems because of the higher emissions intensity of the growing laterite production pathway.

There are two types of primary nickel products: class-1 high-purity nickel (> 99.8%) and class-2 low-purity nickel (< 99.8%) (International Energy Agency, 2021). Because of high nickel concentrations, sulfides are the main source of class-1 high-purity products, laterites are more suitable for class-2 nickel (International Energy Agency, 2021; Mistry et al., 2016). Nickel used in batteries is class-1 high-purity nickel. Total demand for nickel is likely to be supplied, however, class-1 nickel products seem to have a risk for shortages. As batteries increase demand for class-1 nickel and most new production is coming from laterite sources mostly producing class-2 nickel, there might be potential shortages of class-1 nickel despite overall production being sufficient (International Energy Agency, 2021).

### 2.3.2 Environmental consequences

Of notable direct impacts from nickel production, there are $SO_2$ and heavy-metals emissions, land use, water pollution and conflicts with the local population. Smelting operations from sulfides-nickel production in Canada, Russia and Australia have led to $SO_2$ emissions causing acid rain, with toxicity and biodiversity impacts. In the last two decades, there have been successful efforts in most countries to reduce the $SO_2$ emissions (Mudd, 2010), and there have been reports of ecosystems in Sudbury, Canada, recovering well following the $SO_2$-emissions control (Keller et al., 1999).

Nickel extraction has also led to direct emissions of heavy metals such as chromium (Gunkel-Grillon et al., 2014), having potentially severe effects on local ecosystems impacting the local ecosystems surrounding mining locations (Mudd, 2010). Harmfully high concentrations of chromium have been found in local surface waters surrounding a nickel-mining project in New Caledonia, which can potentially have severe effects on local ecosystems (Gunkel-Grillon et al., 2014). In New Caledonia and Indonesia there have also been issues regarding the occupation of valuable biodiversity areas (Mudd, 2010). As there has been successful control of $SO_2$ emissions, one can imagine similar successful efforts for heavy-metal emissions. Impacts on local aquatic systems and local ecosystems can be mitigated by careful consideration of impacts in the early stages of mining expansion.

In an LCA of nickel products, Mistry et al. (2016) found the primary extraction and refining process to be most impactful, mostly through on-site combustion of fuels and electricity consumption. Their data from 2011 covering all large producing countries except China represented 52% of global nickel production and 40% of ferronickel production. The two products examined were class-1 nickel and ferronickel (a class-2 nickel product). The primary extraction process and refining were responsible for 57-70% of impacts, and laterite-sourced production was found to have a much higher energy demand per nickel content than sulphidic production. The main contributors were on-site combustion of fuels and electricity consumed from power grids. 86% of class-1 nickel was produced via the less energy-intensive sulphidic production route.

It should be noted that Mistry et al. (2016) performed their LCA with an electricity mix based solely on electricity generation from black coal. In conjunction with the main findings of the study, this indicates the potential for large emission reductions by using cleaner electricity in the future (Mistry et al., 2016). There is a (large) potential in the nickel industry for new technology that can help supply the growing global demand while reducing the energy and greenhouse-gas intensity (Mudd, 2010).

### 2.3.3 Nickel recycling

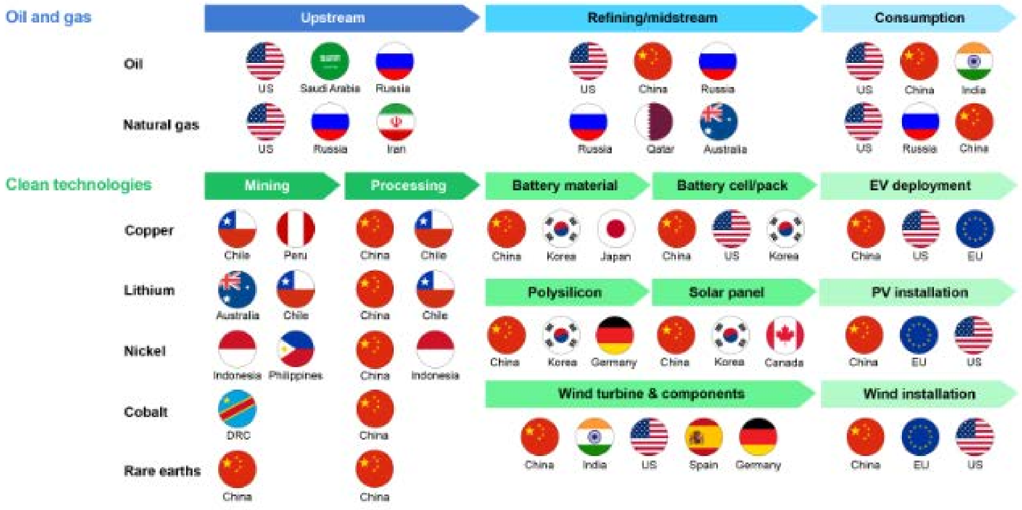
In the past, most nickel use was dissipative and difficult to recycle, but with increasing nickel use in non-dissipative applications, end-of-life nickel recycling today has grown to 57% (Henckens & Worrell, 2020). Opportunities for material-for-material substitution of nickel are limited. Nickel used for metal products can be substituted by a completely different mineral such as titanium or chromium, but in critical applications such as most LIB chemistries, nickel cannot be substituted (European Commission, 2017). Higher recycling rates by improved scrap recovery and more efficient recycling processes have the potential to provide a near infinite nickel supply (Henckens & Worrell, 2020; Mudd, 2010). LIBs take up around 7% of nickel production today (IEA, 2021), where nickel is mainly used for the battery cathode (Xu et al., 2021). LIB chemistries are moving mainly towards lower cobalt concentration, which usually means higher nickel concentrations, indicating a likely continued coupling between LIBs and nickel demand. With the expected growth rate of LIBs, they will become an increasingly important recycling pathway for nickel in the future. Current recycling of LIBs focuses mostly on cobalt recovery, leaving valuable resources to be disposed as waste products (Xu et al., 2021). The recycling process can be improved by better battery design, with more standardization and consideration of the recycling process in production (Xu et al., 2021). As LIB recycling improves and increases, we can expect to see higher rates of nickel recovery as well.

### 2.3.4 Social consequences

Research on the social consequences of nickel extraction is limited and we found few articles covering this subject in our review. Most available research covers environmental consequences. However, there are a few social consequences to consider. According to (Opray, 2017) in Colombia, the nickel extraction impacts the health of the mine workers and the residents of the nearby communities due to pollution from the extraction. This can have a negative impact on the region’s economic development and further value creation. In addition, (Hudayana & Widyanta, 2020) detail the conflict in Sulawesi, Indonesia, that exists between the local community and nickel mining companies. Violent conflicts have arisen in Indonesia from local activists resisting mining operations and their negative impacts (Hudayana & Widyanta, 2020). In New Caledonia, indigenous people (Kanaks) have utilized the nickel sector to achieve political emancipation and spatial rebalancing, resulting in positive effects from the nickel extraction (Kowasch, 2018). Kowasch (2018) suggested creating a sovereign wealth fund from the nickel industry in New Caledonia, for example based on the Norwegian model, to ensure equitable redistribution of the extraction profits. Finally, cobalt is often a by-product of nickel mining, which can connect nickel extraction to the major social consequences associated with cobalt extraction. However, as most of nickel extraction takes place without cobalt co-production, these consequences should be allocated more towards cobalt extraction than nickel extraction (US Geological Survey, 2021).

# 3 Mineral processing for low-carbon technologies and supply risks

The transition to a low-carbon society with increased focus on clean energy comes with new trade patterns, countries and geopolitical concerns (International Energy Agency, 2021). While most of the extraction of different minerals for low-carbon technologies is spread across different countries, the processing operations are highly concentrated, mainly in China (International Energy Agency, 2021). This is shown in Figure 8, which illustrates the indicative supply chains for oil and gas and selected clean energy technologies. This specific concentration of processing in China can be viewed as concerning regarding supply risks and geopolitical considerations.



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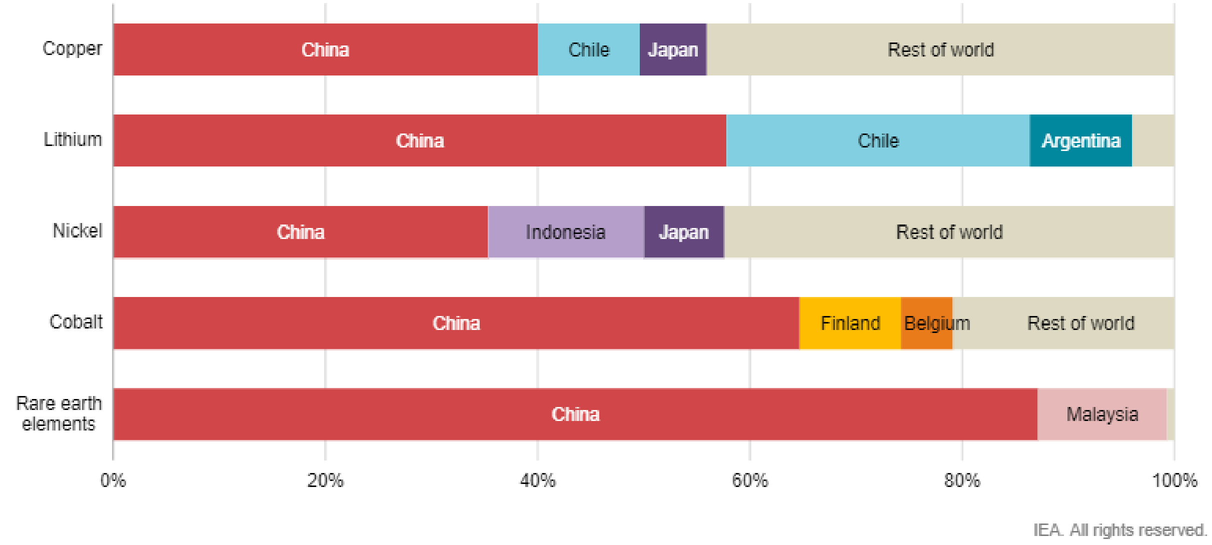
Notes: DRC = Democratic Republic of the Congo; EU = European Union; US = United States; Russia = Russian Federation; China = People's Republic of China. Largest producers and consumers are noted in each case to provide an indication, rather than a complete account.

***Figure 8: Indicative supply chains of oil and gas and selected clean energy technologies (International Energy Agency, 2021, p.29).***

## 3.1 Processing in China

According to the International Energy Agency's (2021) report on the role of critical minerals in clean energy transitions, China has a significant presence across the board of mineral processing operations. As one can see in Figure 9, which shows the share of processing volume by country for selected minerals, China has a dominant position. China's share of refining is about 35% for nickel, approximately 50-70% for lithium and cobalt, and almost 90% for rare earth elements (International Energy Agency, 2021). This shows China's critical role in the supply chain of minerals for low-carbon technologies. The total production of metals has increased in China over the past few decades, making China a dominant supplier of 34 metals, where the European Commission considered 23 of the metals as critical resources (Habib et al., 2016). As China's processing share is assumed to continue to increase, the country will gain more influence and control over the supply chain of these minerals (Gulley et al., 2019). This can be somewhat problematic, considering critical-mineral availability and supply risk (Gulley et al., 2019).



Note: The values for copper are for refining operations.
Sources: World Bureau of Metal Statistics (2020); Adamas Intelligence (2020) for rare earth elements.

***Figure 9: Share of processing volume by country for selected minerals, 2019 (International Energy Agency, 2021, p.31).***

## 3.2 Supply risks of processing concentrated in China

Because of the specific concentration of processing operations of critical minerals for low-carbon technology in China, the minerals are highly subject to supply risks (Rabe et al., 2017). By this we mean that the supply chain of the various minerals is subject to disruptions, which, in turn, disrupt the overall supply chain. This can cause shortages and rapid increases in prices (van den Brink et al., 2020). In the context of supply risks associated with processing in China, the supply chain is subject to so-called geopolitical supply risks. These address the risk of potential supply disruptions caused by one country, or several, controlling the market for a particular mineral (Habib et al., 2016). The country's control over the majority of the minerals needed for a transition to a low-carbon society presents severe concerns for other countries in need of those minerals. A disruption in the supply chain can therefore have significant cross-border consequences.

The Chinese government has earlier applied various policies to attempt to claim greater control over the mineral industry, e.g., by implementing export quotas and restrictions, industry restructuring and navigating production levels of minerals. This has raised concerns about availability and higher prices in the future (Rabe et al., 2017). These matters are of great importance to the countries that receive processed minerals from China and are in need of those metals to develop a low-carbon society. According to International Energy Agency (2021), the high levels of concentration of processing operations, in combination with the complexity of supply chains, increase the risks from trade restrictions, physical disruptions and other developments in the producing country.

## 3.3 China's "Going Out Strategy"

In addition to having a dominant position in the processing operations of minerals for low-carbon technologies, China also makes substantial investments in overseas mineral-extraction assets. This is a central part of China's so-called "Going Out Strategy", which was implemented in the 1990s. The strategy encourages Chinese companies to expand overseas foreign direct investment, particularly investment in mineral resources and infrastructure in developing countries (Gulley et al., 2019). Therefore, since the 1990s, China has been actively investing and trading with countries around the globe and developing economic, political and diplomatic relationships with these countries (WU, 2012). An example is the Democratic Republic of the Congo, where China has invested greatly in construction of facilities and enterprises in the cobalt-extraction mining industry (see section 2.1.6 for further elaboration). The strategy has, however, faced several difficulties, including energy-geopolitical risks, pipeline politics and resource nationalism (WU, 2012). In addition, the strategy has been perceived by other countries as an attempt of China to mitigate the country's own mineral supply risk through foreign direct investment, limiting the mineral availability for other countries because of production-capacity constraints (Gulley et al., 2019). The overseas investment thereby increases China's influence over the supply chain, in conjunction with its leading processing position, enhancing China's dominant position in the mining industry.

## 3.4 The relation between China and the EU

Increased dependency on China is slowing down the European competitiveness in global markets and is raising concerns regarding future pricing and availabilities of raw minerals (Rabe et al., 2017). Such minerals are identified by the European Commission as critical due to their high economic significance to the EU while entailing high supply risks (Rabe et al., 2017). Europe's growth in low-carbon technologies is not guaranteed, due to the dependency on stable supply and pricing, which further depends on the Chinese interests and policies for the raw mineral industry. This implies that EU and EU policy must follow developments and policy changes in Chinese industrial policies and other implications for EU firms, since China is the predominant supplier of raw minerals to the EU (Rabe et al., 2017).

Attempts by China to establish greater control over the mineral industry have raised several concerns among members of the European renewable energy community, especially regarding the prices of the raw minerals. This has led to the development of both short- and long-term strategies to cope with uncertainties regarding the supply of critical minerals and dependency on China (Rabe et al., 2017). Action taken by the EU includes charges against China regarding trade violations through the World Trade Organization and bilateral negotiations to avert export duties. In addition, the dependency on China underlines the need for European businesses to assess their supply risks and prepare risk management plans for best practice, both short and long term (Rabe et al., 2017).

# 4 Mineral extraction linked to the SDGs

The majority of impacts from mineral extraction are negative. However, one should keep in mind the overarching positive effects of moving to a low-carbon society with clean energy technologies. We found that most improvements to the mineral production industry could be linked to SDGs. However, we have here focused only on the effects of current practices, not linking potential improvements to the SDGs. We have categorized the links by color into positive effect, weak positive effect, weak negative effect and negative effect. Additionally, cobalt extraction's link to SDG 8 is yellow, due to having both a negative and a positive effect. Table 1 provides an overview of the relation to the SDGs.

| **SDG** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cobalt** | 🟩 | ⬜ | 🟥 | ⬜ | 🟧 | 🟥 | ⬜ | 🟨 | 🟢 | ⬜ | 🟥 | ⬜ | ⬜ | ⬜ | 🟥 | 🟥 | ⬜ |
| **Lithium** | 🟩 | 🟧 | 🟧 | ⬜ | ⬜ | 🟥 | ⬜ | 🟢 | ⬜ | ⬜ | 🟧 | ⬜ | ⬜ | ⬜ | 🟥 | ⬜ | ⬜ |
| **Nickel** | 🟩 | ⬜ | 🟧 | ⬜ | ⬜ | 🟧 | ⬜ | 🟢 | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | 🟧 | 🟧 | ⬜ |

***Table 1: Visualization of the linkage between mineral extraction and the SDGs***

## 4.1 Cobalt extraction

**SDG 1: No poverty**

*1.1: Reduce extreme poverty*

Positive effect: Cobalt mining provides work and thereby contributes to reduce local poverty.

**SDG 3: Good health and well-being**

*3.2: End preventable deaths of children under 5*

Negative effect: Toxicity and direct security risks for children working in cobalt mines, and pollution affecting local population in general.

*3.9: Reduce number of deaths from air, water and soil pollution*

Negative effect: The direct exposure to pollution from mines and transport has a negative impact on human health.

**SDG 5: Gender equality**

*5.1: End discrimination against all women and girls*

Negative effect: Discrimination against women in artisanal mining.

*5.2: Eliminate violence against all women and girls*

Negative effect: There is much violence and abuse of women in and around the cobalt mining industry in DRC.

**SDG 6: Clean water and sanitation**

*6.1: Universal access to clean drinking water*

Negative effect: Pollution from cobalt mining is harming the local water sources.

*6.2: Access to adequate sanitation and hygiene*
Negative effect: Terrible sanitation and hygiene in the cobalt mines.

*6.3: Improve water quality by reducing pollution*
Negative effect: Pollution by heavy metals from cobalt mining due to pumping and release of underground water into local water systems.

**SDG 8: Decent work**
*8.1: Sustain per capita economic growth*
Positive effect: To the degree that the cobalt mining industry is a large part of the GDP in the DRC, meaning it contributes to the current growth of GDP in DRC, which has been upwards in recent years, and >7% in 2018-2019.

*8.7: Eradicate forced labor and child labor*
Negative effect: Child labor in the cobalt mines.

**SDG 9: Industry, innovation and infrastructure**
*9.a: Facilitate sustainable and resilient infrastructure development in developing countries*
Weak positive effect: Investments in the cobalt industry by China have also led to some slight improvements in Congolese infrastructure.

**SDG 11: Sustainable cities and communities**
Negative effect: Mining (in particular ASM) harms cities and communities, forced moving, pollution and disruption of cities and communities.

**SDG 12: Responsible consumption and production**
*12.4: Achieve environmentally sound management of chemicals and wastes*
Weak negative effect: Wastes and chemicals from mining, in mine water, particles from underground minerals through air and air pollution from road transport are handled poorly.

**SDG 15: Life on land**
*15.1: Sustainable use of terrestrial and inland freshwater ecosystems*
Negative effect: Disruption of local aquatic ecosystems by the release of large amounts of polluted mine water.

*15.5: Reduce degradation of natural habitats*
Potential negative effect: By harming the unique copper-cobalt natural habitats.

**SDG 16: Peace, justice and strong institutions**
*16.1: Reduce all forms of violence*
Negative effect: Violence related to conflicts between large-scale regulated mining and ASM miners.

*16.2: End abuse and violence against children*
Negative effect: Child labor is occurring.

*16.5: Reduce corruption and bribery in all their forms*
Negative effect: Corruption and bribery related to the cobalt mining industry, caused by the sheer profitability in combination with the existing political troubles of DRC.

## 4.2 Lithium extraction

**SDG 1: No poverty**
*1.2: Reduce poverty*
Weak positive effect: Lithium mining provides work, reducing local poverty.

**SDG 2: Zero Hunger**
Weak negative effect: Lithium mining harms water supply for local food production.

**SDG 3: Good health and well-being**
*3.9: Reduce number of deaths from air, water and soil pollution*
Weak negative effect: Pollution from lithium extraction, locally and in processing.

**SDG 6: Clean water and sanitation**
*6.1: Universal access to clean drinking water*
Negative effect: Brine extraction dries out water supply, disrupting availability of drinking water for local population.

*6.3: Improve water quality by reducing pollution*
Negative effect: Lithium extraction is harming local water quality.

*6.4: Ensure supply of fresh water to address water scarcity*
Negative effect: Lithium is blocking the possibility to improve the water scarcity.

*6.6: Protect and restore water-related ecosystems*
Weak negative effect: Harming local unique aquatic ecosystems.

**SDG 8: Decent work and economic growth**
*8.1 Sustain per capita economic growth*
Weak positive effect: The lithium mining industry contributes to economic growth.

**SDG 11: Sustainable cities and communities**
*11.4: Protect and safeguard the worlds cultural and natural heritage*
Weak negative effect: National parks considered natural heritage are being harmed.

**SDG 15: Life on land**
15.1: Sustainable use of terrestrial and inland freshwater ecosystems
Negative effect: Extraction is drying out water sources and harming inland freshwater ecosystems.

## 4.3 Nickel extraction

**SDG 1: No poverty**

*1.2: Reduce poverty*

Weak positive effect: Lithium mining provides work, reducing local poverty.

**SDG 3: Good health and well-being**

*3.9: Reduce number of deaths from air, water and soil pollution*

Negative effect: $SO_2$ emissions and heavy-metal emissions (largely mitigated), GHG emissions from processing and refining.

**SDG 6: Clean water and sanitation**

*6.3: Improve water quality by reducing pollution*

Weak negative effect: Emissions of $SO_2$ and heavy metals where not mitigated are polluting waters.

**SDG 8: Decent work**

*8.1: Sustain per capita economic growth*

Weak positive effect: The nickel mining industry contributes to economic growth.

**SDG 15: Life on land**

*15.1: Sustainable use of terrestrial and inland freshwater ecosystems*

Weak negative effect: (Largely mitigated) extraction is drying out water sources and harming inland freshwater ecosystems.

**SDG 16: Peace, justice and strong institutions**

*16.1: Reduce all forms of violence*

Weak negative effect: Violent conflicts have arisen in Indonesia from local activists resisting mining operations and their negative impacts.

# 5 Summary

In this report we have addressed the environmental and social consequences of cobalt, lithium and nickel extraction, and their impact on the SDGs. Extraction of these three minerals has significant negative environmental effects on the local ecosystem through direct and indirect pollution, harming ecosystems and biodiversity, water sources, and posing health risks to local populations. Review of LCAs of the mineral production processes showed that for these minerals the majority of impacts are caused by electricity use and fossil-fuel combustion in the processing and refining stages of production. While the minerals are used largely in products for rich countries, most of the extraction and processing is done by poor people in developing countries under poor working conditions, most notably cobalt mine workers in the Democratic Republic of the Congo. Working conditions are terrible, with tremendous safety and health risks. Child labor is very common, and in addition to being obviously unethical, cobalt mining is one of the worst forms of child labor. Mineral extraction has a considerable supply risk, with 70% of cobalt production sourced from the Democratic Republic of the Congo, and 60% of all mineral processing happening in China. This aggregation poses supply risks in terms of potential shortages due to natural disasters, global pandemics or geopolitical conflicts. Increasing supply of critical minerals is necessary for a clean energy transition and a low-carbon future. But upscaling of production comes with notable tradeoffs when considered in relation to the UN's SDGs, in terms of negative local environmental effects and mostly negative local social effects.

# 6 Further research

There is little research available on the social impacts of cobalt extraction in other countries than the DRC and about the social impacts of lithium and nickel extraction. This lack of information can either indicate that there are no significant social consequences present in these countries or that there are undiscovered social consequences present. Further research is thus needed to map these impacts.

The policies and initiatives implemented in the DRC to reduce social and environmental consequences of mineral extraction in the area do not seem to have generated significant impacts. Therefore, there is a need for further research regarding this relation and why the policies and initiatives are not helping.

The extraction of the minerals is evidently limited to the countries where reserves are located. However, the processing of the minerals is not, with most of the processing concentrated in China, potentially causing supply risks. Research on ways and opportunities to relieve the supply-chain risks for these minerals seems, hence, promising.

Work on extraction of cobalt through sub-sea mining indicates that this mining process can solve issues surrounding conventional cobalt extraction. Currently, sub-sea mining is infeasible economically and requires technological progress. Further research on sub-sea mining is therefore required to decide about its potential for the future.

As most of the environmental impacts of the mineral extraction occur in the processing stages, improvements and innovations in this area would have a large impact. It should be noted that processes for mineral production are based on mature technologies, which are unlikely to have significant undiscovered improvements. However, more research would increase the chances of discovering new and more efficient processing paths for mineral production.

New substitutes for low-carbon technologies or direct mineral substitutes could help relieve some of the primary production demand for critical minerals. Research on new battery chemistries, mineral substitutes for critical minerals or entirely different ways to reach the same goals could be useful.

A common denominator for the three minerals examined in this report is their use in LIBs. Improving the recycling rates of LIBs would improve recycling rates of minerals and thus the environmental and social impacts of primary production. There is currently much research on LIBs about battery chemistries, future development and sustainability. Suggestions for improving the recycling rate of LIBs include standardization of battery packs, designing batteries to easily allow for mechanical recycling and improvements to the recycling process itself. Future research attention could be directed towards which efforts would be most fruitful to actually increase the recycling rate of LIBs, as the forementioned possibilities have not yet been fully implemented.

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