CHALMERS
UNIVERSITY OF TECHNOLOGY

Impact of Battery Material Supply Chains on the Sustainable Development Goals

Global Versus Domestic Sourcing for Swedish Electric Cars

Master's thesis in Supply Chain Management

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Master's thesis SEEX30
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Abstract

The market for electric vehicles has grown significantly during the last decade. Competition is rising over the supply of battery minerals, e.g., lithium and nickel, as the demand for electric vehicles increases. This calls for the investigation of new sustainable supply chains for the electric vehicle market. This thesis investigates the impacts on the Agenda 2030 Sustainable Development Goals (SDG) of the current battery supply chain as well as the impacts of a potential alternative sourcing - building a domestic Swedish battery supply chain. This is done by mapping the current battery supply chain and designing a theoretical domestic battery supply chain. The impacts of the two supply chain options are analyzed from a sustainability perspective in the context of the SDGs.

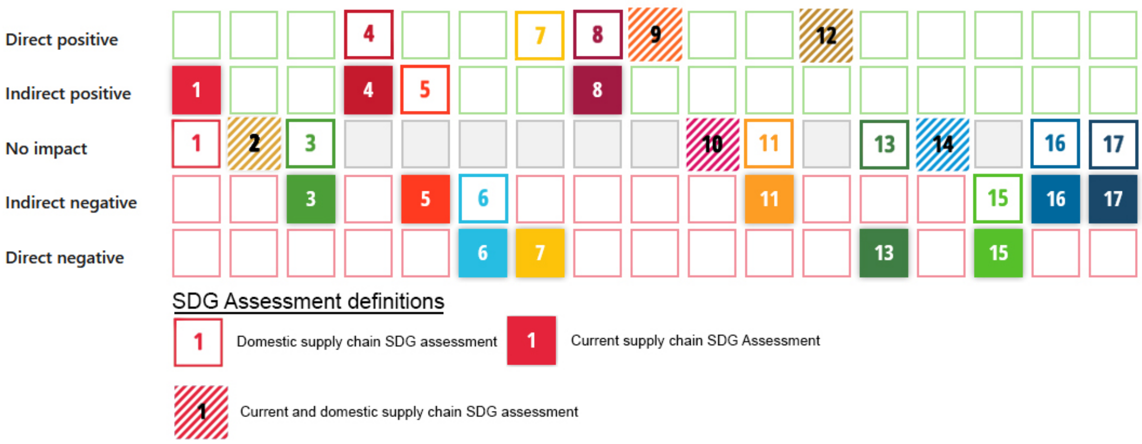

Figure 0.1: *A simplified figure of the main results.*

The impacts of the current supply chain are negative in terms of land-use, local environmental and ghg-emissions from extraction, refinement and production. All these issues are alleviated in a potential domestic supply chain. Hence, we conclude that domestic sourcing of lithium and nickel for Swedish electric vehicles would be beneficial from an SDG perspective. However, the prospect of an entirely domestic supply chain is uncertain from an economic perspective. The prospect of a domestic supply chain is further hampered by the estimated 10-15 years it takes to start up mining operations. Nevertheless, further extraction of battery minerals is critical to cover the battery demand forecasted up until 2030.

Keywords: Sustainable development goals, Agenda 2030, Supply chain management, Supply chain resilience, sustainability, electric vehicles, lithium, nickel, reshoring

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Sammanfattning

Marknaden för elfordon har vuxit kraftigt under det senaste decenniet. Konkurrensen om tillgången på batterimineraler, ex. litium och nickel, ökar i takt med att efterfrågan på elfordon ökar. Detta motiverar analyser av nya hållbara försörjningskedjor för elbilsmarknaden. Denna avhandling undersöker effekterna på de globala målen inom Agenda 2030 av den nuvarande batteriförsörjningskedjan samt effekterna av en potentiell alternativ anskaffning av batterimineraler - en inhemsk batteriförsörjningskedja. Detta görs genom att kartlägga den nuvarande batteriförsörjningskedjan och utforma en teoretisk inhemsk batteriförsörjningskedja. Konsekvenserna av de två alternativen för försörjningskedjan analyseras ur ett hållbarhetsperspektiv utifrån de globala målen inom Agenda 2030.

Figure 0.2: *En förenklad figur av avhandlingens resultat i en grafisk representation.*

De negative effekterna av den nuvarande leveranskedjan gäller markanvändning, lokal miljö och ghg-utsläpp från utvinning, raffinering och produktion. Alla dessa effekter skulle vara lägre i en inhemsk försörjningskedja. Vi drar därmed slutsatsen att inhemsk anskaffning av litium och nickel för svenska elfordon skulle vara fördelaktigt ur ett hållbarhetsperspektiv. Utsikterna för en helt inhemsk försörjningskedja är dock osäkra ur ett ekonomiskt perspektiv. Möjligheterna för en inhemsk försörjningskedja påverkas dessutom negativt av att det i genomsnitt tar 10-15 år att starta nya gruvor. Oavsett så är behovet av ytterligare utvinning av batterimineraler avgörande för att täcka den förväntade efterfrågan på batterier fram till 2030.
Nyckelord: globala mål, Agenda 2030, Supply chain management, Supply chain resilience, hållbarhet, elfordon, litium, nickel, reshoring.

Acknowledgements

We want to send our warmest thanks to our supervisors Anders Ahlbäck and Johannes Morfeldt for their expertise and support throughout the whole thesis, together with our examiner Daniel Johansson for managing the project. Furthermore, we want to thank the partner Mistra Carbon Exit for making the thesis possible, together with Gothenburg Center for Sustainable Development for allowing us to use the tool to assess the different SDGs. Lastly, we want to send our warmest thanks to our participating interviewees for sharing their expertise and insights of the battery supply chain and sustainability challenges.

Lowe Aspeqvist & Edvin Gunnarsson, Gothenburg, May 2023

Contents

List of acronyms

BEV Battery Electric Vehicle.

EV Electric Vehicle.

ghg Greenhouse gases.
GII Gender Inequality Index.
GMV Gothenburg Center for Sustainable Development.

HDI Human Development Index.
HEV Hybrid Electric Vehicle.
HPAL High Pressure Acid Leaching.

ICEV Internal combustion engine vehicle.
IPCC The Intergovernmental Panel on Climate Change.

JIT Just in Time.

LCA Life Cycle Assessment.
LCO $LiCO_2$.
LFP $LiFePO_4$.
Li-Ion Lithium-ion.
LMV Light means of transport.

MHP Mixed hydroxide precipitate.
MPC Maximum Permissible Concentration.
Mt Million Metric Tons.

NMC $LiNiMnCoC_2$.
NZT Net-zero target.

OECD The Organisation for Economic Co-operation and Development.

PHEV Plug-In Hybrid Vehicle.

REE Rare-earth elements.

SDG Sustainable Development Goals.

UN United Nations.

1
Introduction

There is a need for a sustainable supply chain for materials as the electric vehicle (EV) market continues to grow at a rapid pace (Aase, Musso, & Schwedhelm, 2021; Weimer, Braun, & Hemdt, 2019). The underlying value chain of the battery industry is based on the transformation of raw materials into viable products. There are a variety of sustainability issues associated with the extraction of the underlying materials and processes since these are based on metals and minerals (Parajuly, Ternald, & Kuehr, 2020). The basis for the supply chain is partially the metals lithium and nickel to name a few (Weimer et al., 2019). As presented by Morfeldt, Davidsson Kurland, and Johansson (2021a), Swedish battery demand is expected to grow, indicating that the associated issues with production will grow as well.

The demand for raw materials and production will follow the growth of the EV market. As this is happening, the growth needs to be sustainable and with potential solutions within the supply chain. The focus should not only be ecological but also social and economic sustainability. The Sustainable Development Goals (SDG) presented by the United Nations (UN) can be used to identify the sustainability impact of the 17 goals. There are also 169 targets specified within the 17 goals which allows a deeper sustainability impact analysis. This thesis aims at mapping the supply chain for current battery production and comparing the results to a domestic supply chain locally sourced in Sweden. The conditions for re-designing the supply of raw materials with sourcing in Sweden seem possible based on the techno-economic potential of extracting battery metals and minerals that has been confirmed (Martinsson & Wanhainen, 2022).

The project builds on ongoing research in conjunction with Mistra Carbon Exit (`www.mistracarbonexit.com`) into the demand side of materials for battery manufacturing and the potential for battery recycling. As sustainability is a large societal issue, there is a need to further research the current supply chain from a sustainability perspective with a basis in the SDGs.

The replacement of Internal combustion engine vehicle (ICEV) with EVs is viewed as one of the answers to the climate crisis. Since Sweden has committed to implement Agenda 2030 (Miljödepartementet, 2022), the transition to EVs should contribute to achieving the SDGs while based on sustainable supply chains. The electrification of transport requires more research to find sustainably sourced materials to replace the current carbon-driven economy. Minerals used for battery production are one of the largest sustainability issues in terms of electric vehicles and therefore alternative sourcing methods should be explored(International Energy Agency, 2022e).

Within the automotive industry, there are several different types of EVs developed. The most common types include Hybrid Electric Vehicles (HEVs), Battery Electric Vehicles (BEVs) as well as Plug-In Hybrid Vehicles (PHEVs) (Egbue & Long, 2012). Furthermore, there are also a variety of different kinds of batteries. Lithium is a critical raw material in the production of lithium-ion batteries. There have been previous extraction of lithium in Sweden, however there is no current extraction (Martinsson & Wanhainen, 2022). Several of the existing lithium deposits in Sweden are expected to be possible to use for extraction (SGU, 2023). Lithium is one of the materials on the critical materials list presented by the European Union in 2020 and is, therefore, of extra high interest for the supply chain of battery production (European Commission, 2022). The dominant choice for automotive manufacturers is currently lithium-ion batteries (Li-Ion) and is therefore used as the basis for this thesis (Lipman & Maier, 2021)

Different kinds of battery chemistries are used in Li-Ion batteries. The specific names refer to specific chemical combinations, such as $LiCO_2$ (LCO), $LiNiMnCoC_2$ (NMC), and $LiFePO_4$ (LFP), where NMC- and LFP-types are most widely used within the automotive industry as of now (Lipman & Maier, 2021). Furthermore, these chemical definitions are based on the cathode side. For anodes, graphite is the most widely used material (Lipman & Maier, 2021). Cobalt is a widely used material for some of these chemistries (International Energy Agency, 2022e). However, the proportion of cobalt is decreasing in favor of an increasing share of nickel (International Energy Agency, 2022e). There are several reasons for this change. Partially it is related to price shifts as the cobalt price has risen significantly in the last two years. Furthermore, there are instability issues in the cobalt supply chain due to 70% of cobalt being mined in the Democratic Republic of the Congo (International Energy Agency, 2022e). The many variants of battery chemistries make the entire supply chain of a Li-Ion battery rather complex. Hence, this thesis contributes with an analysis of the supply chains of nickel and lithium for EV batteries specifically.

Calls have been made in recent literature to implement recycling within the supply chain and its importance for the assurance of enough supply of lithium (Egbue & Long, 2012; Kallitsis, Korre, & Kelsall, 2022; Maisel, Neef, Marscheider-Weidemann, & Nissen, 2023; Nurdiawati & Agrawal, 2022; Tadaros, Migdalas, Samuelsson, & Segerstedt, 2022; Talens Peiró, Villalba Méndez, & Ayres, 2013). Although recycling will be an integrated part of the supply chain, the demand-growth in the EV-market is too large to be accommodated by recycled raw materials and is expected to only provide a small contribution to supply according to a report by the Swedish government organization Naturvårdsverket (2023). Recycling is also discussed by Olivetti, Ceder, Gaustad, and Fu (2017) where they argue that recycling within the supply chain is not likely to provide any solution to supply in the short-term time horizon. Furthermore, Naturvårdsverket (2023) conclude that new mines will be required to open in order for the supply of battery-related materials to meet the growing demand.

1.1 Purpose

This master thesis aims at comparing different sourcing methods from a supply chain perspective required to produce batteries used for EVs sold in Sweden. A method is required in order to structure the comparison. The method will be applied in a case study to compare the impact on the SDGs from the shift towards domestic sourcing of lithium and nickel instead of imports. Through this, the thesis aims at combining the theory of supply chain management with the sustainable development goals presented by the UN. This research could be highly relevant for the growing industry of battery production and for policymakers.

1.2 Research question

RQ.1 - What benefits and drawbacks does the current supply chain have related to the United Nations Sustainable Development Goals?

RQ.2 - What implications would a re-designed supply chain for battery production with locally sourced materials in Sweden have on the United Nations Sustainable Development Goals?

1.3 Delimitations

As there are several different EVs, battery types and chemistries together with different approaches to perform a SDG analysis of the supply chains, some delimitations are required to be set in place.

- The thesis considers Battery Electric Vehicle (BEV), but neither Hybrid Electric Vehicle (HEV), nor Plug-In Hybrid Vehicle (PHEV).
- The thesis only considers Lithium-ion (Li-Ion) batteries, and only lithium as well as nickel in terms of raw materials.
- The thesis is limited to only considering the material demands for the electrification of the Swedish passenger car fleet.
- The thesis does not analyze recycling as an alternative sourcing-method, but rather focuses on virgin raw-materials sourcing.
- The SDG analysis will be cradle-to-gate, i.e., only considering the SDG implications to the moment the EV leaves the factory. With this method, the user and end-of-life phases will therefore not impact the SDG analysis
- The SDG-analysis only considers the largest producing countries of each raw material
- The SDG-analysis considers the future electrification of the Swedish passenger car-fleet, i.e., the effects on the SDG that a switch to domestic sourcing would incur in this specific perspective.

1.4 Background

As the supply chain for the batteries for EVs contains a wide variety of specific materials, this chapter gives a background to the different types of materials that are used. Furthermore, a theoretical background for supply chain management is provided to combine the interdisciplinary fields applied in the thesis.

1.4.1 Supply chain management theory

The design of the supply chain is an important part of creating sustainable networks. It can be designed to reduce ghg-emissions in the supply chain. Furthermore, supply chains can be designed with economic and social sustainability in mind as well. In the context of economic sustainability, matching the supply and demand of a network is essential (Simchi-Levi, Kaminsky, & Simchi-Levi, 2003). Supply chain management is often divided into strategic, tactical and operational levels (Simchi-Levi et al., 2003). The strategic level is high-level decisions dealing with long-term effects and decisions, whereas the tactical level includes medium-term decisions and the operational level includes daily activities (Simchi-Levi et al., 2003). Following this definition, the design of supply chains is composed of strategic decisions. The field of supply chain management handles all these different facets and is in large part about the designing of supply chains to work as effectively as possible or to reach a certain goal.

Sourcing needs to be decided based on a strategy as the supply chain is designed. van Weele (2018) explains that several decisions need to be made in regard to sourcing. Decisions need to be made regarding single or multiple sourcing, global or local/-domestic sourcing, and sourcing must be decided if it should be on a partnership or on a competitive basis. Sourcing is a key element of supply chain management and a further extension of sourcing is purchasing which decides a large part of operational decisions based on the chosen strategy (van Weele, 2018). Global sourcing might incur supply chain resilience risks. There are economic risks to a global sourcing strategy as global markets experience exchange rates (Simchi-Levi et al., 2003). Furthermore, geopolitical risks should be considered, especially in the wake of the Russian invasion of Ukraine in 2022, Covid-19, and the Evergreen blocking the Suez Canal in 2021 (The Visual Journalism Team BBC News, 2022; Theo Leggett, 2021).

The idea of reshoring[1] has been a widely discussed subject within supply chain management, especially as a result of the Covid-19 pandemic (Barbieri et al., 2020). Reshoring is a known concept widely discussed in the US since 2005 as an emerging concept after a large part of US manufacturing was moved to China (Tate, 2014). The trend of local sourcing is also growing with the growth of reshoring, not only for geopolitical reasons but as a strategy that is more sustainable and provides flexibility for customers (Tate, 2014). Flexibility is a desirable strategy for companies since

[1] Reshoring is a concept defined as moving back a section of a business or an entire business from a foreign country to its' original country, i.e. this is a location-based decision (Cambridge University Press, n.d.; Gray, Skowronski, Esenduran, & Johnny Rungtusanatham, 2013)

this provides the opportunity to handle a variety of different scenarios (Simchi-Levi et al., 2003). Ashby (2016) argues that there is a need for a shift from offshoring based on reducing costs and increasing profits towards a more long-term view with sustainability in mind in terms of sourcing decisions.

The consequences of supply chain disruptions have strong negative implications as the economy is more globalized and reliant on optimized Just in Time (JIT) supply chains. The recent rise of reshoring represents one action possible out of several to create supply chain resilience. Supply chain resilience is defined by Ponomarov and Holcomb (2009) as:
"The adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function."
- Ponomarov and Holcomb (2009)

Previous resilience strategies have involved a number of different methods to create resilience within the supply chain. Gatenholm and Halldorsson (2022) compiles the strategies applied in supply chain management as sharing information between actors, redundant suppliers, flexible suppliers, inventory buffers, backup sourcing, and finally the sharing of risk between actors and the usage of multiple-sourcing. This is supported by Tukamuhabwa, Stevenson, Busby, and Zorzini (2015) which compiled 91 articles and suggested that previous research within supply chain resilience has focused on redundancy, agility, collaborations, and flexibility. Ponomarov and Holcomb (2009) argues that better supply chain resilience leads to better sustainable competitive advantages.

Freight transport systems is used to move goods throughout the world and is a key element of supply chain management. The freight transport systems make up the links that connect nodes within a supply chain network. The different modes include road transportation, air transportation, maritime transportation, rail transportation, intermodal, telecommunications, and pipelines (Rodrigue, 2020). Only air, road, rail and maritime transportation will be considered for the scope of this thesis. Intermodal is not considered as it is a combination of freight transport systems. Intermodal as well as telecommunications is not relevant to mineral transportation. All the different modes have different benefits and drawbacks shown below in table 1.1.

Table 1.1: *Different freight transport modes and their respective benefits and drawbacks (Rodrigue, 2020)*

Freight transport mode	Benefits	Drawbacks
Road	Cheap High flexibility/accessibility	Low capacity High ghg-emissions
Rail	Low CO_2-emissions High capacity	Low flexibility/accessibility Relatively slow
Air	Flexible Fast Limited capacity	Expensive High CO_2-emissions
Sea	Cheap Low CO2-emissions High capacity	Slow Low supply chain resilience

1.4.2 Nickel

Nickel is a critical mineral used worldwide in a variety of industries. Mudd and Jowitt (2014) estimated that the total amount of nickel reserves in the world is 296 Million Metric Tons (Mt), however, estimates can drastically change depending on how the assumptions are made. Geological Survey (2022) estimated that the total amount of nickel in the world is at least 300Mt, with the possibility that extensive amounts of nickel could be found on the ocean floor, which would extend these estimates.

The global mine production of nickel in 2020 was approximately 2.5 Mt (International Nickel Study Group, 2021). Indonesia is the largest producer of nickel, producing almost 0.8 Mt of nickel ores (International Nickel Study Group, 2021). The second largest producers are the Philippines and Russia, producing respectively 0.3Mt and 0.25Mt of all nickel in 2020, respectively. Overall, the global share of nickel produced in Asia has increased from 34% in 2016, to 51% in 2020. Nickel extracted in Europe has seen a decrease, from 14% in 2016, to 12% in 2020 (International Nickel Study Group, 2021).

There are two main deposits of interest - laterite and sulphide deposits for nickel. The worldwide division is around 40% sulphide deposits and 60% laterite deposits (International Nickel Study Group, 2021). Other sources estimate that the division is 30% sulphide deposits and 70% laterite deposits (Elias, 2002; König, 2021). When extracted, the nickel will have different element purity depending on the deposit (International Energy Agency, 2022e). If the nickel has an element purity of below 99.8%, it is classified as class 2 nickel (also known as low-grade). Class 2 nickel is mostly extracted from laterite deposits. Since this nickel is of lower quality, it is mainly used for stainless steel production. Nickel that has an element purity of above 99.8% is classified as class 1 nickel (also known as high-grade or battery-grade nickel). Class 1 nickel is suitable for battery production, whereas class 2 needs to be processed in order to reach the required element purity for battery production (International Energy Agency, 2022e).

Sulphide deposits are estimated to be around 60% of total class 1 nickel extraction, following 40% from laterite deposits (König, 2021). Sulphide deposits are the most used for the class 1 nickel because of the high element purity directly from extraction combined with easier processing methods (Elias, 2002). Even though class 1 nickel is optimal for battery production, 70% is used for stainless steel production, whereas battery production is only around 5% of the total supply (International Nickel Study Group, 2021). The usage of class 1 nickel in stainless steel production can pose a challenge for electrification. However, International Energy Agency (2022e) presents a growing market share for class 1 nickel in the battery industry with an increase from 4% to 7% between 2020 and 2021.

Processing solutions for transforming low-grade nickel into high-grade nickel have seen growing interest following the increased demand for battery-grade nickel. High Pressure Acid Leaching (HPAL) is one commonly used processing method which allows class 1 nickel to be produced from laterite deposits (Meshram, Abhilash, & Pandey, 2019). There are challenges with HPAL processing due to extensive use of acid, which leads to high capital costs and three times the amount of emissions of ghg compared to sulphide processing (International Energy Agency, 2022e; Meshram et al., 2019). Attempts at commercializing of HPAL processing are being tried in Indonesia where the world's largest HPAL-plant is planned to produce 0.125Mt nickel annually (Reuters, 2023). The plant is expected to be operating in 2025. There are further new processing technologies for nickel such as Mixed hydroxide precipitate, which allows laterite materials to be transformed into sulphide materials through an intermediate product (International Energy Agency, 2022e). Nickel matte is another battery-grade mineral that can be produced from laterite materials, however at high ghg emission rates (International Energy Agency, 2022e).

Nickel ore extraction is related to health and environmental impacts connected to the challenges of mineral toxicity. According to Parmar and Thakur (2013), nickel is one of the most toxic metals, especially when involved in the food industry. The most common health risk from nickel is dermatitis, where the metal causes irritation on the skin. Parmar and Thakur (2013) explains that high exposure to nickel can cause bone, lung, and nose cancer. An indication of this is shown in the city of Norilsk in Russia, where the nickel producer Norilsk Nickel is positioned. The mortality rate in Norilsk from lung cancer is 1.2-2.5 times larger than the overall rate in Russia (Lavelle M, 2021).

One of the most extensive environmental impacts of nickel extraction can also be found in Norilsk. The pollution from the factory has caused dying or already dead forests to the size of 5.9 million acres and the only rival to the pollution rate of sulphur dioxide emissions from Norilsk is erupting volcanoes (Lavelle M, 2021).

The price of nickel has seen extensive increases in the last years (International Energy Agency, 2022e). From January 2021 to May 2022, the price of nickel almost doubled. According to International Energy Agency (2022e) there are three reasons for this price increase. The first is an insufficient amount of investment in the supply chain, due to the earlier low prices. Second, there are challenges in production connected to the pandemic, and third, Russia's invasion of Ukraine has caused further price increases. Additional developments in the war could pose future critical supply risks for high-grade nickel from Russia (International Energy Agency, 2022e). There has been an increase in demand for high-grade nickel, but not as unequivocal as for lithium. The majority of the high-grade nickel is still used in other applications than EV-batteries (International Energy Agency, 2022e).

1.4.3 Lithium

With EVs recent rise to prominence, the demand for lithium has skyrocketed over the last ten years and is expected to rise even further in the upcoming ten years (International Energy Agency, 2023). In a Net-zero target (NZT) with 1.5 degrees Celsius, the lithium required for this demand is 100 times higher than what is produced today (Bridge & Faigen, 2022). With complicated infrastructural processes for extraction, as well as limited geographical deposits, lithium is a key resource for the growth of the EV market (Talens Peiró et al., 2013).

The different production sources for lithium include pegmatites[2]. Lithium can also occur in brines (Talens Peiró et al., 2013). Within all of the different configurations, as lithium is highly reactive, it does not occur in a pure form, which means it needs to be processed further before it is usable within EV-production. Furthermore, as the metal is processed, it must be stored in a way where it cannot react with oxygen (SGU, 2023). To extract the lithium from brine, salt water is evaporated over a period of 12-18 months through natural evaporation (Talens Peiró et al., 2013). The extraction of lithium from pegmatites includes various chemical processes depending on which mineral the lithium occurs within (Talens Peiró et al., 2013). This process requires a lot more energy as this process often involves heating the mineral to 1100 degrees Celsius (Talens Peiró et al., 2013).

The reserves of lithium are estimated to be around 39 Mt, although it should be stated that estimations vary (Talens Peiró et al., 2013). The largest deposits are located in South America, more specifically Bolivia, Argentina, and Chile (Talens Peiró et al., 2013). However, the largest producers of lithium today are Australia with 52%, Chile with 22%, and China with 12% of global production respectively (Bridge & Faigen, 2022). As the extraction of lithium requires large infrastructural investments and geological surveys, there are still many unexploited reserves (International Energy Agency, 2022e). Investments are ongoing in countries such as Bolivia, however, from the start of a project it usually takes 5-10 years before the raw material is produced and shipped (International Energy Agency, 2022e).

Deposits of lithium are regularly discovered as this is a sought-after material within

[2]A pegmatite is a form of igneous rock (Tikkanen, n.d.)

the current rise of EVs. At the start of 2023, India announced that they had discovered reserves of an estimated 5.9 Mt of lithium in the area of Jammu and Kashmir (Geological Survey of India (GSI), 2023) which would make India the country with the sixth largest reserves in the world (Hendrix, 2022). The region of Kashmir is highly politically destabilized and tensions have been high since India's independence in 1947, which is further testament to geopolitical risks when lithium reserves are discovered in politically destabilized regions (Hendrix, 2022).

There are several potential negative effects of mining and using lithium. Lithium is a mineral that is toxic to organisms when entering the body at high concentrations (Bolan et al., 2021). As the usage and extraction of lithium are increasing, the risks of contamination to the local environment as well as risks to public health increase as a consequence (Zeng, Li, & Liu, 2015). This challenge can be exacerbated if not the correct recycling systems and infrastructure is set up to handle lithium waste through all stages of production (Zeng et al., 2015). Lithium has potential toxicity to ecosystems as well as to human health (Bolan et al., 2021). There are several documented negative health effects for humans, which has led to studies on risk management to handle the health risks (Bolan et al., 2021). Studies that examine if communities are willing to risk these potential local effects concluded that water pollution is one of the most relevant effects on nearby communities of open-pit lithium mines (Crespo-Cebada, Díaz-Caro, Gil, & Sanguino, 2020)

The demand for further lithium extraction is expected to grow as the market for EVs continues to grow. In 2011, the battery market for lithium was estimated to use around 0.007 Mt of lithium (Talens Peiró et al., 2013). Within ten years the market grew to 0.3Mt (Lipman & Maier, 2021). The demand for lithium in the battery market is expected to keep growing exponentially, with forecasts expecting the demand in 2028 to be 2.8Mt of lithium. The expected mining capacity combined with projects currently in the pipeline only expects to provide around 2Mt of lithium (Lipman & Maier, 2021). The lithium market has experienced a significant price increase as demand has increased and availability decrease in the last couple of years (Bridge & Faigen, 2022).

2

Method

The methodology for the thesis uses a combination of a variety of segments. The combination of these segments is visualized in fig. 2.1 and is further described in the following sections. The method was developed to combine the interdisciplinary field required to answer RQ.1 and RQ.2. The left side of the figure where the flowchart splits (fig. 2.1 is related to RQ.1 and the right side plus the comparison represents the parts specifically related to RQ.2.

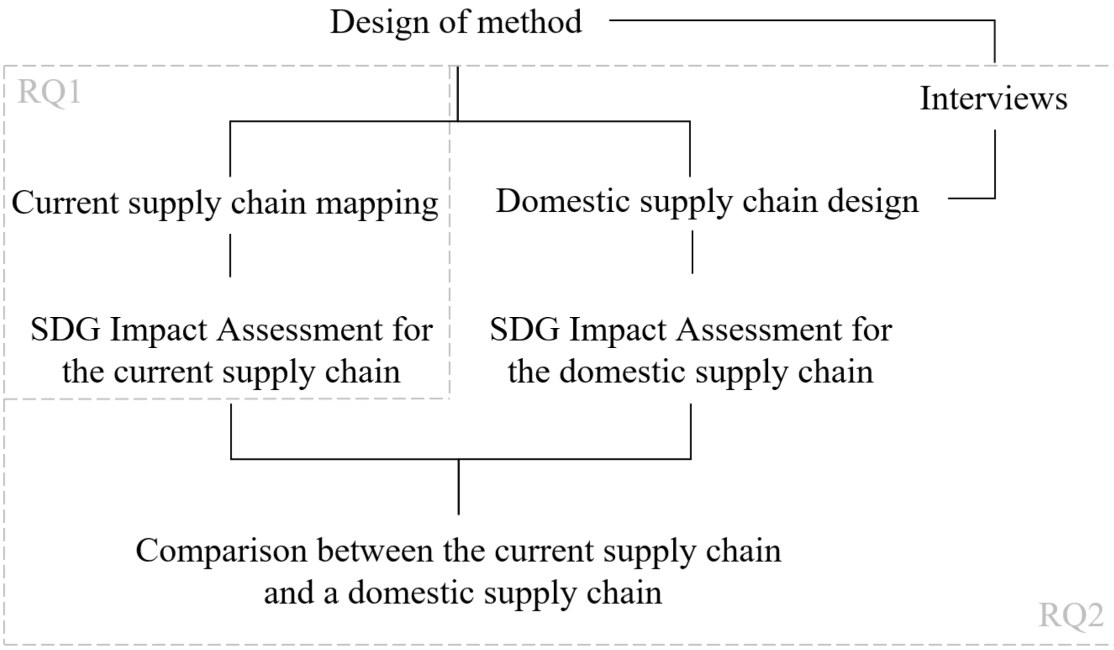


Figure 2.1: *Flowchart of the different segments in the thesis and how they work together.*

The Design of Method refers to the method (see section 2). The SDG analysis (section 3.2) was performed based on the mapped Li-Ion battery supply chain (section 3.1). The interviews (described in section 2.1) serve as underlying empirical data for creating the domestic supply chain (section 4) as well as to perform the SDG-analysis for the domestic supply chain (section 4.4). These steps were then combined and compared to draw conclusions (section 5) regarding the benefits and drawbacks of the supply chains, as formulated in RQ.1 and RQ.2.

2.1 Interviews

To achieve an overall view of Sweden's position internationally in terms of both raw material sourcing for battery production, as well as potential supply chain strategies, interviews with some of the larger actors along the supply chain were carried out. Interviews were performed to gather further empirical data to confirm the data gathered from articles, studies and papers. The interviews were performed in a semi-structured method with similar themes for each respondent (Lind, 2014). However, the questions differ as the respondents work in different fields, roles and organizations. This provided flexibility to ask further questions if some areas are of higher interest depending on the respondent. Four individuals were interviewed to acquire expert opinions to be used as empirical data in order to get a better understanding of the sustainable development goals, minerals, and the battery supply chain.

To adhere to research ethics, it is important to consider the respondent's voluntariness, privacy, confidentiality and anonymity as argued by Lind (2014). Therefore, all respondents are kept anonymous. Furthermore, keeping all respondents anonymous was used to get full honesty in the answers, as many of the respondents are working for organizations that might have reservations about giving out certain information. These organizations might particularly have restrictions to give out information about suppliers, supply chains, partners and the integration of SDGs. Before the start of the interview, all respondents were asked to confirm their consent to participate in the interview. We aimed to accomplish this to keep the academic integrity of the thesis whilst still protecting the rights and integrity of the respondents. Since the respondents are anonymous, a system is devised with referrals to each respondent with a letter (A-D), as seen in table 2.1.

Table 2.1: *Respondents A to D with date and time for each interview.*

Respondent	Date	Time	Role
A	23/3-2023	~60 minutes	Public authority
B	30/3-2023	~60 minutes	Public authority
C	31/3-2023	~50 minutes	Practitioner
D	4/4-2023	~60 minutes	Practitioner

All interviews were performed digitally as our respondents are spread out over a large geographical area. Both authors were present for each interview, one taking notes and one asking the questions. However, both authors were ready to ask questions if anything came up that could add to the empirical data.

2.1.1 Interview guide

An interview guide was created to support the interviews as suggested by Lind (2014). The interviews can be kept similar in structure even if the respondents are in different fields and organizations with the use of themes in the interview guide. In further regard, the respondents might interpret questions differently depending on the context and therefore it is highly relevant to have similar themes to keep the data structured. The chosen themes are as follows:

- Sustainability
- Sustainable development goals
- Supply chain management in regard to batteries
- Current sourcing
- Swedish sourcing

The questions are not included in the thesis to keep all participants anonymous. As some of the questions contain names of the organization where the respondents are active, or other organizations which they are partners with, the questions are left outside the thesis.

2.2 Sustainable development goals

The framework for the evaluation of the supply chains is set by the 17 Sustainable Development Goals (SDG) presented in the United Nations (UN) for the 2030 Agenda for Sustainable Development, adopted by all UN member states in 2015 (UN, n.d.). The SDGs incorporate a holistic view of sustainability and are connected economically, socially as well as environmentally (UN, n.d.). In conjunction with the 17 goals, there are 169 corresponding targets (UN, n.d.). The goals are defined as the following by UN (n.d.). All definitions are quotes from UN (n.d.):

- Goal 1, No poverty
  - End poverty in all its forms everywhere
- Goal 2, Zero hunger
  - End hunger, achieve food security and improved nutrition and promote sustainable agriculture.
- Goal 3, Good health and well-being
  - Ensure healthy lives and promote well-being.
- Goal 4, Quality Education
  - Ensure inclusive and equitable quality education.
- Goal 5, Gender equality
  - Achieve gender equality
- Goal 6, Clean water and sanitation
  - Ensure availability and sustainable management of water.
- Goal 7, Affordable and clean energy
  - Ensure access to affordable, reliable, sustainable and modern energy for all.
- Goal 8, Decent work and economic growth
  - Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.
- Goal 9, Industry, innovation and infrastructure
  - Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.
- Goal 10, Reduced inequalities
  - Reduce inequality within and among countries.

- Goal 11, Sustainable cities and communities
  - Make cities and human settlements inclusive, safe, resilient and sustainable.
- Goal 12, Responsible consumption and production
  - Ensure sustainable consumption and production patterns.
- Goal 13, Climate action
  - Take urgent action to combat climate change and its impacts.
- Goal 14, Life below water
  - Conserve and sustainably use the oceans, seas and marine resources for sustainable development.
- Goal 15, Life on land
  - Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification and halt and reverse land degradation and halt biodiversity loss.
- Goal 16, Peace, Justice and strong institutions
  - Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.
- Goal 17, Partnership for the goals
  - Strengthen the means of implementation and revitalize the global partnership for sustainable development.

A number of indicators are used to measure the progress of implementing the SDGs (Hák, Janoušková, & Moldan, 2016). A first set of indicators were introduced in 2015 with 330 in total (Hák et al., 2016). The number of indicators has since then been refined to 231 and divided into three different tiers (United Nations Department of Economic and Social Affairs, 2022). The purpose of the tiers is not to rank the different indicators, but rather help organizations to create implementation strategies for the 17 goals (United Nations Department of Economic and Social Affairs, 2022). The three tiers are defined as followed:

- Tier 1 - ”Indicator is conceptually clear, has an internationally established methodology and standards are available, and data are regularly produced by countries for at least 50 per cent of countries and of the population in every region where the indicator is relevant.” (United Nations Department of Economic and Social Affairs, 2022)
- Tier 2 - ”Indicator is conceptually clear, has an internationally established methodology and standards are available, but data are not regularly produced by countries.” (United Nations Department of Economic and Social Affairs, 2022)
- Tier 3 - ”Indicator is conceptually clear, has an internationally established methodology and standards are available, but data are not regularly produced by countries.” (United Nations Department of Economic and Social Affairs, 2022)

Hák et al. (2016) argue that some of the indicators might be difficult to use and that they should be slimmed down. This has been done in later versions of the UN documents to make the SDGs easier to implement (United Nations Department of Economic and Social Affairs, 2022). It should be noted that the targets have been developed over time and indicators have been changed. Older literature on the subject has limited use since conclusions made in these include issues which since then have been adjusted. J. D. Sachs et al. (2019) argue that stakeholders have difficulties to operationalize the 17 goals and suggest what they refer to as six building blocks. This argument is further strengthened by Swain (2017) which argues that the SDGs has been difficult to quantify and implement. The suggested method by J. D. Sachs et al. (2019) re-configures the 17 goals into collected building blocks which include:

1. Education, gender, inequality
2. Health, well-being, demography
3. Energy decarbonization, sustainable industry
4. Sustainable food, land, water, and oceans
5. Sustainable cities and communities
6. Digital revolution for sustainable development

J. D. Sachs et al. (2019) argue that these building blocks will make it easier to operationalize within institutions. The idea of linking the goals to one another has been done by other authors as well. (Le Blanc, 2015) uses network theory to link goals and shows that the 17 goals can be categorized into different thematic areas. Le Blanc (2015) argues for strong collaboration and ”break the silos” between different organizations and institutions to reach the goals. With each country expected to create its own strategic plans, this can take different forms. Swain (2017) argues that developing countries should focus on economic and social sustainability whilst developed countries should instead focus more on social and environmental goals.

2.3 Sustainable development goals impact assessment

An analysis of the SDG-impacts of the current and a proposed domestic battery supply chain was performed (See section 3.2 and 4.4). The SDG impact analysis was performed from the perspective of comparing global and domestic sourcing with the help of the SDG impact assessment tool provided by GMV (`https://sdgimpactassessmenttool.org/en-gb` (?)), further described in section 2.3.1. This tool is called the SDG Impact Assessment Tool (?).

2.3.1 Method for impact assessment

The SDG impact assessment addressed the impacts of the sourcing strategies through the lens of SDGs. This was accomplished by analyzing the impacts on the most relevant targets within the SDGs.

The method in which the tool was used, was based on the instructions provided by GMV, which consists of five steps (Gothenburg Center for Sustainable Development (GMV), n.d.). Since the SDG impact tool has a broad approach, a decision was made to specify the instructions for this thesis. These five steps are set as follows:

1. Gather a team
2. Define, refine, draw the line, set a scope for the task
3. Sort the SDGs into relevant, not relevant and don't know
4. Assess your impact by choosing between a positive impact, indirect positive impact, no impact, indirect negative impact, negative impact, or more knowledge required.
5. Chose a strategy for the future

In order to translate the assessment tool into an academic methodology into the thesis, some changes to these instructions were made. First of all, gathering your forces is instead interpreted as mapping the supply chain (see section 3.1) and gathering knowledge. ”Define, refine and draw the line” can be seen as the mapping of the supply chain. The tool then is used to assess steps 3 and 4 and to structure the discussion. Choosing the strategy forward can be seen as drawing conclusions based on the analysis. The steps suggested by GMV are therefore transformed into the following steps for the purpose of this thesis:

1. Gather information
2. Map the supply chain
3. Sort the SDGs
4. Assess the impact
5. Draw conclusions

The method to map the supply chain was to gather knowledge through the various journal articles, paper and studies to combine this knowledge together into a fully mapped supply chain. As supply chains are complex networks (Simchi-Levi et al., 2003), The mapped supply chain was kept at a schematic level as supply chains are complex networks (Simchi-Levi et al., 2003). Furthermore, it is also as the purpose of mapping the supply chain is to determine the SDG impacts, and detailed information is not always available.

Sorting of the SDGs was performed to simplify the process of analyzing the impacts. Each SDG was deemed relevant or not relevant which thereafter structures the order of when each SDG will be analyzed. The SDG impact assessment tool suggests this step to easier perform the analysis and argues it has no impact on the final result (Gothenburg Center for Sustainable Development (GMV), n.d.).

The assessed impact was based on the UN definition of each SDG. Specific targets were used to assess the impact of specific characteristics. After this stage, the SDGs with connected targets were assessed based on the previous information from the mapped supply chains (See section 3.2 and 4.4) but also combined with new sources if required. A resulting impact assessment indicates whether the supply chain has a direct negative impact, indirect negative impact, no impact, indirect positive impact or direct positive impact on the specific goal. The definitions for the various impact categories are shown below in table 2.2. The interpreted definitions are based on the definition provided by Gothenburg Center for Sustainable Development (GMV) (n.d.).

Table 2.2: *Definitions of SDG impacts*

SDG Impacts	Definition
Direct positive impact	Clearly connected and visible positive impact
Indirect positive impact	Positive impacts from secondary sources or only minor positive effects
No impact	Negligible or no impact
Indirect negative impact	Negative impacts from secondary sources or only minor negative effects
Direct negative impact	Clearly connected and visible negative impact

2.3.2 Confidence of the assessed impacts

The treatment of confidence in information used as input to the assessment is important for the result and its authenticity. The confidence in the results is of high interest as the SDGs span many different topics. There could be knowledge gaps or missing information in certain areas which reduces the confidence level in the impact analysis. For this reason, a priority list for how to make the assessment and its' confidence was devised. The list is as follows, with number 1 representing the highest confidence and number 4 representing the lowest confidence.

1. Specific journal articles, studies or papers etc.
2. General journal articles, studies or papers, or expert opinions.
3. General indicators such as transparency index, Human Development Index (HDI), etc.
4. Qualitative discussion when none of the above options are available for making an assessment of the impact.

"Specific" refers to articles, studies or papers performed on the specific subject. For example, SDG5, Gender Equality uses an article by Abrahamsson et al. (2014) which examine gender equality in mining for Sweden. This is therefore a specific article to SDG5. "General" instead refers to a study, article or paper on a more general level. This can for example be as Loayza and Rigolini (2016) found that mining districts generally have lower poverty. However this study was not performed in a area of this thesis. Therefore this is a more general study on the subject and treated as "general". The list was devised in order to handle the breadth of the issues discussed as they span many interdisciplinary fields both in terms of the SDGs, and in terms of supply chain management, geology, economics, etc. The method of using a confidence scale was inspired by how the The Intergovernmental Panel on Climate Change (IPCC) uses similar tools (Ridge et al., 2010). Our confidence scale can be seen as a representation of the X-axis in fig. 2.2 where Ridge et al. (2010) defines the confidence of different types of evidence (in this case, the aforementioned priority list). The Y-axis defined by Ridge et al. (2010) connecting to the agreement within the scientific community on the issue will not be considered in this thesis. The list of varying degrees is refered to as empirical bases.

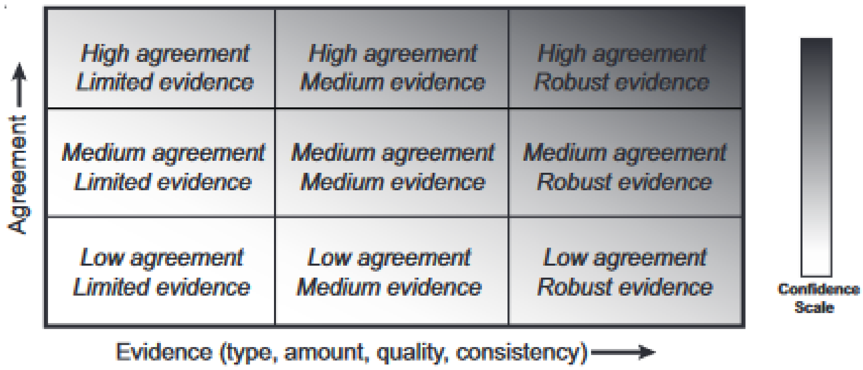


Figure 2.2: *The IPCC-method of confidence. From Ridge et al. (2010)*

In our confidence scale, each source was given points for its' confidence characteristics as defined above, where specific journal articles were 1 point, general journal articles were 2, etc. These points, or the usage of these types of sources are visualized and reported in the final results.

2.3.3 Attributional vs. consequential impacts

Within the field of Life Cycle Assessment (LCA), there are different kinds of LCAs which include consequential LCA as well as attributional LCA (Ekvall, 2020). The consequential LCA focuses on how environmental impacts will change in response to specific decisions (Ekvall, 2020). The attributional LCA instead focuses on the environmental attributes of a life cycle (Ekvall, 2020). Inspired by this methodology, the SDG impact analysis was decided to be assessed either consequentially or attributionally. With this distinction, the impact analysis performed was done with attributes in mind. As this thesis aims at looking at a shift from global to domestic sourcing of raw materials, this in itself has consequential implications, however, the analysis instead looks at the attributes of the supply chains to assess the impact of the shift. The reason for choosing an attributional approach is due to the assumption that no reductions of production will be made to the current production. This in turn is assumed as the demands of battery minerals is expected to rise significantly. Furthermore, this removes a layer of complexity to the analysis and attributes from the various countries can be compared.

3
Current battery supply chain

This section presents a schematically mapped supply chain and the distribution flows of the current battery supply chain. A SDG impact analysis was performed in section 3.2 based on the mapped current battery supply chain. The results from the SDG impact analysis are presented in section 3.2.18 and are used to answer RQ1.

3.1 Current lithium-ion battery supply chain

The major steps of the Lithium-ion (Li-Ion) supply chain for EVs involves six steps in the form of mining, raw material processing, cell production, battery cell production, EV-production, and recycling or re-use (International Energy Agency, 2022e). What makes the supply chain complicated is that each of these different steps is controlled by different actors and that reserves are geographically spread out. China is in many cases the largest producer of refined minerals but not the largest producer of raw materials (Bridge & Faigen, 2022). A similar pattern is seen for both lithium and nickel throughout the Li-Ion-supply chain. This highlights that refining capabilities are of high importance to create a domestic supply chain. A simplified, schematic view of the Li-Ion-supply chain can be seen in 3.1. In this example (fig. 3.1), sections of the supply chain that are related to both the use and end-of-life phases of batteries' life cycle, including disposal or recycling, are excluded since they are considered outside of the scope of the thesis.

The schematic supply chain in fig. 3.1 is a highly simplified version of an actual supply chain, which is a complex dynamic network with changes occurring over time (Simchi-Levi et al., 2003). All different parts of the vehicle have their own set of supply chains, and the same is true for the material production and manufacturing of components. Resources are applied at various nodes within these networks to accomplish specific tasks (Gadde, Håkansson, Jahre, & Persson, 2022), for example, producing a battery cell. Lithium is used for anodes as well as cathodes within the supply chain (see fig. 3.1). The steps in the supply chain are broken down into the production of resources, the production of material (material refining), component manufacturing, and the production of technology which includes the battery cells and the EVs (International Energy Agency, 2023). The average EV requires around 29 kilograms of nickel and around 6 kilograms of lithium per EV (SGU, 2023). Around 185 kgs of minerals are required in total, where lithium represents 3.2% and nickel 15.7% (SGU, 2023).

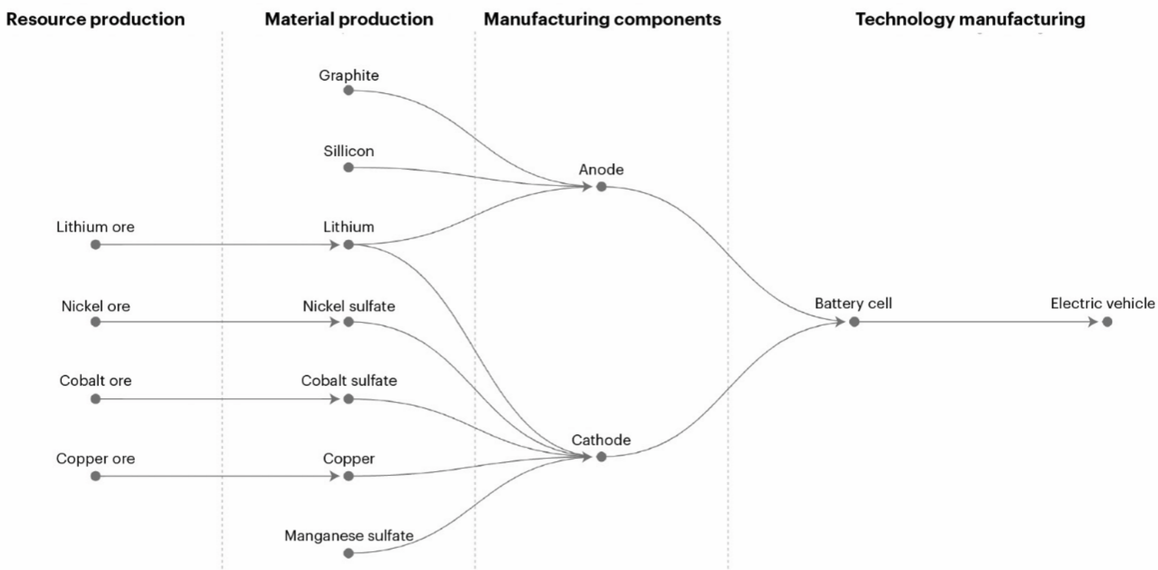


Figure 3.1: *The supply chain of EVs (International Energy Agency, 2023)*

3.1.1 Nickel Supply Chain

Russia is the largest extractor of class 1 nickel, producing 20% of the world's demand. 67% of class 1 nickel produced is used to supply Europe, with the rest used to supply China (International Energy Agency, 2022e). Russia is one of the major suppliers in the EV-battery industry. Both Australia and Canada produce nickel from sulphide ores and are the two largest suppliers following Russia (International Energy Agency, 2022e).

Nickel production per country can also be measured and reported as primary nickel. Primary nickel has undergone basic processing and is not necessarily extracted from a mine, but could be acquired from recycling or refining imported ore. Therefore, when analyzing worldwide primary nickel production, the largest actors differ compared to the ordinary mine production. China is in this context the largest supplier producing 0.75Mt of primary nickel followed by Indonesia at 0.623Mt in 2020 (International Nickel Study Group, 2021). Important to acknowledge is that primary nickel still can be low-grade in need of further processing to be suitable for battery production.

Addressing the market shares of battery-grade nickel refining per year is of importance since both laterite and sulphide deposits can be used to produce class 1 nickel. According to Bridge and Faigen (2022) 48.9% of the battery grade nickel is refined in China, followed by Finland at 17.3%, Indonesia at 11.3%, Japan at 9.1%, and last Australia at 5.8%. China is the largest importer of class 1 nickel around 130 000 tonnes according to International Nickel Study Group (2021). International Energy Agency (2022e) presents that China dominates the downstream EV battery supply chain. China was also the largest nickel mineral processing country in 2020 (International Energy Agency, 2022e).

Finland is the largest nickel producer in Europe with four refineries and smelters, with further projects in collaboration with companies such as Norilsk Nickel (Russia) and BASF (Germany) in progress (Dehaine Quentin, P. Michaux Simon, Pokki Jussi, Kivinen Mari, & Butcher Alan R., 2020). According to European Commission (2022), Finland could supply 16% of the total European demand for nickel. Dehaine Quentin et al. (2020) estimates that Finland could be supplying a large EV production plant with cathode materials for 500 000 EVs per year.

3.1.2 Lithium Supply Chain

Lithium supply is highly reliant on production infrastructure and not only the availability of reserves (Egbue & Long, 2012). This has led to countries such as China taking a major part of the downstream supply chain after the extraction of lithium. Australia provides 52% of the mineral production of lithium but only refines 8.8% (Bridge & Faigen, 2022). The largest contributor in the form of refining is China with 60.4% of all refined lithium (Bridge & Faigen, 2022). Egbue and Long (2012) describes the supply chain of lithium in a similar fashion to International Energy Agency (2023), however, adds the stage of recycling. This creates an additional stage in the supply chain, where lithium from EVs are sent upstream to the stage of mineral processing to be re-used again. The trade flows of lithium oxide, lithium hydroxide, and lithium carbonates are visualized in fig. 3.2 where red represents export and green imports. The figure clearly shows how large flows are exported from South America to China for refining of minerals (Olivetti et al., 2017). These trade-flows do not include concentrates of lithium, therefore, Australia is not as large as could be expected by total production (Olivetti et al., 2017).

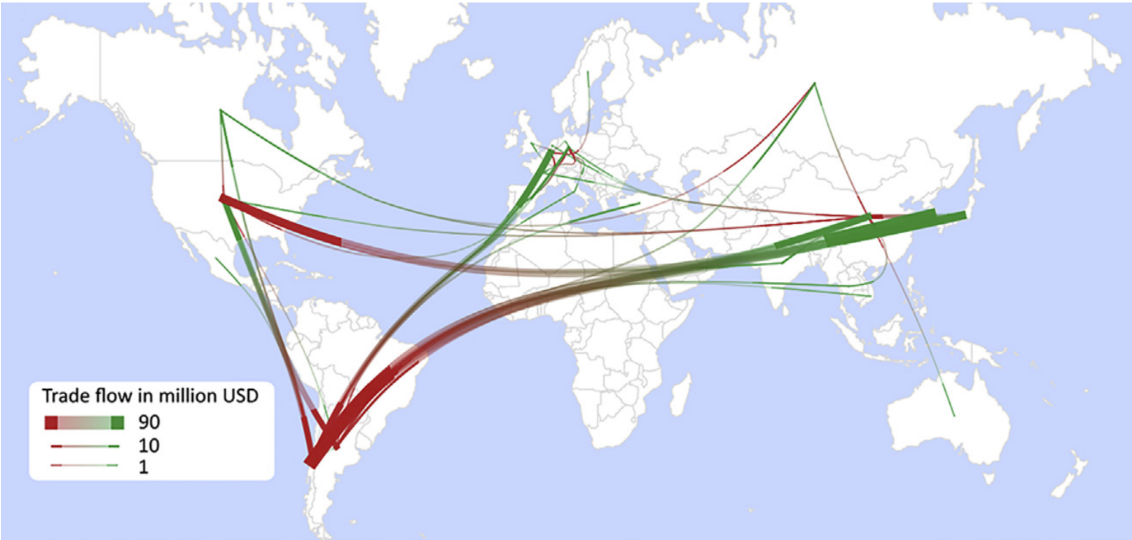


Figure 3.2: *The trade flows of lithium oxide, hydroxide and lithium carbonates (Olivetti et al., 2017). The red color represents export and the green color imports*

One of the major risks to supply chain resilience is geopolitical risks. Over 90% of reserves are located within only five countries (Egbue & Long, 2012), geopolitical reasons could lead to quick shifts in the availability of supply, which in turn could affect the EV-market, similar to what happened with semi-conductors during the covid-pandemic (Frieske & Stieler, 2022). The high geographical concentration of lithium is further problematic as the countries with high amounts of reserves can handle this commodity similar to oil to control prices. This could make the entry barriers within the market much higher, which could hinder the further expansion of raw materials mining and refining (Egbue & Long, 2012). A further problem within the lithium supply chain includes the extraction methods (as explained in 1.4.3). As the process of extracting lithium from brine is 12-18 months, possible supply disruptions might lead to increasing prices of lithium due to higher lead times as there is no elasticity within the process (Egbue & Long, 2012).

The market conditions and usage areas of lithium are changing with the recent and ongoing growth of the EV-market. The end-use of lithium has changed significantly in the last ten years. 23% of all mined lithium end-use was within battery-production in 2011 (Egbue & Long, 2012). Comparatively, 80% of all end-use for lithium was for batteries in 2022 (Garside, 2023). This number is expected to reach 95% by 2030 (Bridge & Faigen, 2022).

3.1.3 Battery production

The battery supply chain can be divided into two separate channels with anode and cathode as seen in fig. 3.1. This is of relevance since lithium is a part of the supply chain of the anode as well as for the cathode (International Energy Agency, 2022e). Based on this division, the following shares of production were true for 2020:

Table 3.1: *Cathode and anode production percentages based on country. Data from Bridge and Faigen (2022)*

Country	Cathode	Anode
China	30-42%	58-65%
Japan	30-33%	19-25%
South Korea	7-15%	6-7%
United States	∼0%	10%
Rest of production	3-10%	3%
Total production:	∼3 million tonnes	∼1.2 million tonnes

China is the largest producer of both cathode and anode (see table 3.1) and has a majority of the market share in anode production. China's dominant position in the EV-battery production can be seen in fig. 3.3 with 79% of production in 2022 (O'Dea, 2023). The second largest producer is the United States with 6.2% of production, followed by Hungary with 4% of production (O'Dea, 2023) as visualized in fig. 3.3. The rest of the production is spread out over a number of countries across the world.

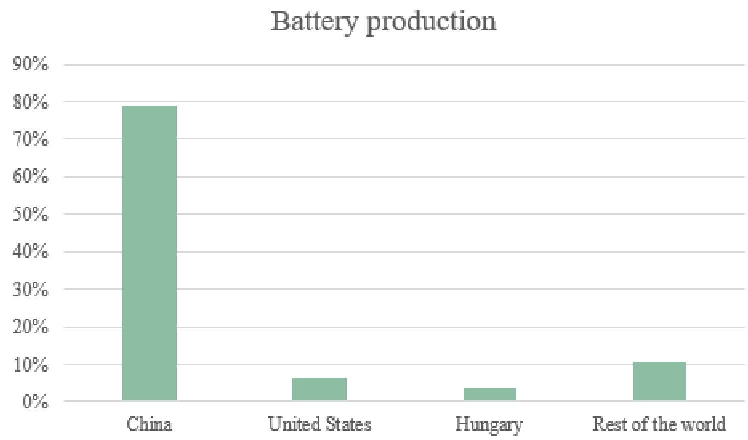


Figure 3.3: *Shares of production of Li-Ion-batteries for EVs in 2022. Data from O'Dea (2023)*

Forecasts for 2025 indicate that China's dominant position will remain, however, with other countries expanding EV-battery production, China's share of production is expected to decrease to 65%. Germany is expected to overtake the US and have around 11.3% of production (O'Dea, 2023). Although China is a small actor in terms of raw materials production, they are positioned to control the refinement of materials, production of battery cells and production of batteries in the supply chain.

3.1.4 Mapped lithium-ion battery supply chain

With all the information gathered (See section 1.4 and 3.1), a completed schematic of the current Li-Ion-battery supply chain can be seen in fig. 3.4. As discussed in section 1.4.1, supply chains are highly complex networks rather than simple chains. Due to this, the supply chain presented in fig. 3.4 is only a sketch of the parts relevant to this thesis. The sketch represents the parts of the supply chain that have been analyzed in-depth and are further assessed in the SDG-analysis.

The supply chain is divided into different parts as visualized in fig. 3.4. Lithium has two sources that both need to be processed to be turned into pure lithium. The same is true for the case of nickel with similar steps in the process.

The flows of the current battery supply chain are mapped based on Section 3.1 and visualized in figure 3.5. Lithium is shown in a teal color and the nickel material flows are visualized in red. Through this visualization, it becomes clear how the material flows are separated and drawn from different parts of the world. A clear node in Asia, and more specifically China, can be seen in the flows. China has built downstream capabilities in the supply chain after the extraction of raw material which was discussed in chapter 3.1.3. This is clearly seen in the production and refinement of lithium.

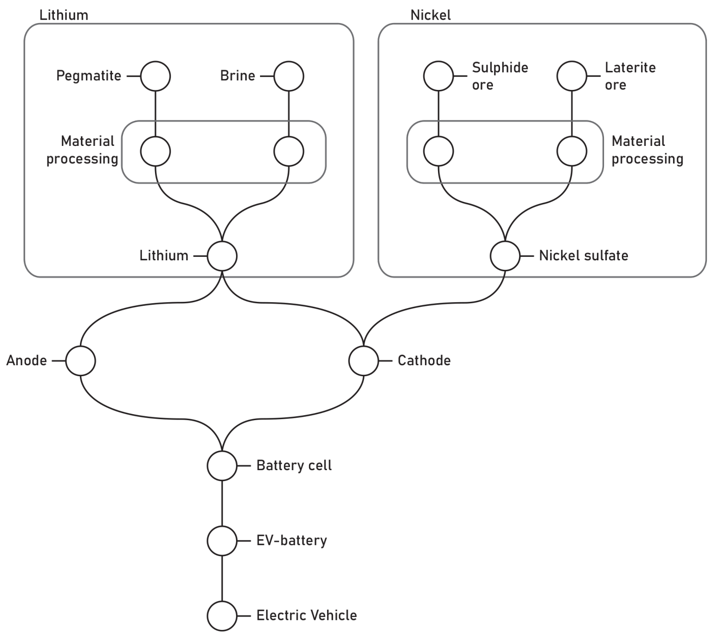


Figure 3.4: *Schematically mapped supply chain.*

The pure materials of lithium and nickel sulfate are used for the production of cathodes and anodes after extraction and refining. Thereafter, the cathodes and anodes are used in the production of the battery cells, used for the production of EV-batteries and electric vehicles.

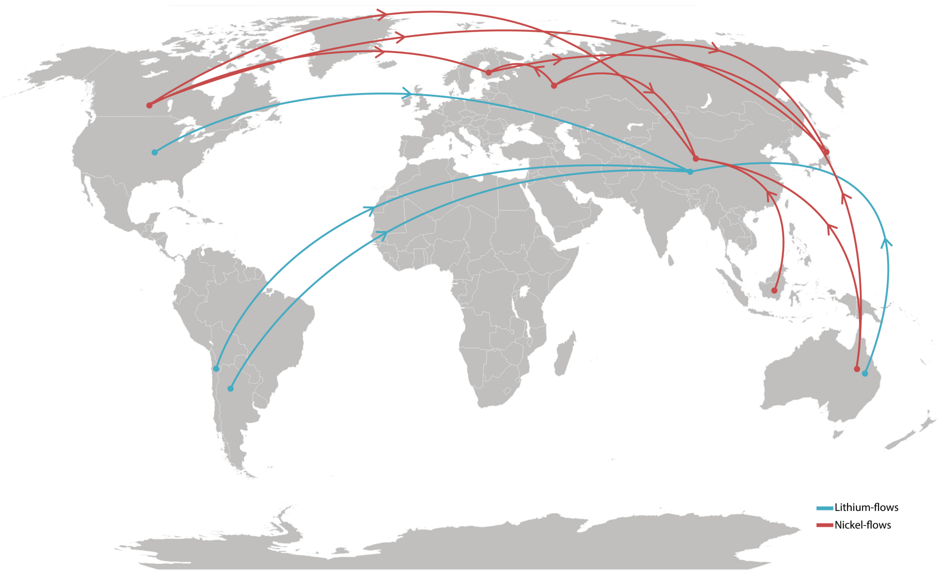


Figure 3.5: *Largest actors and flows in mining and refining. Lithium is shown in a teal color and the nickel material flows are visualized in red.*

3.2 SDG impact analysis of the current supply chain

This section describes the results of the SDG-analysis. Only the largest countries within the supply chain have been considered to lower the complexity of the analysis and to provide a holistic view of the sustainable development goals of the supply chain (see chapter 2).

3.2.1 SDG1 - No poverty

We argue that the final impact assessment of SDG1 in the current supply chain is an *indirect positive impact*. However, SDG8 (see section 3.2.8) might provide a better understanding of how the supply chain impacts economic development. The indicators for target 1.4 is broad and aim at measuring the proportion of a population that has access to basic services and the ratio of adult populations with secure rights to land (United Nations, 2015). This definition explains why economic development might be a more relevant indicator for this goal in the context of the battery supply chain.

SDG1 aims at ending all forms of poverty across the world and consists of seven different targets (United Nations, 2015). Target 1.4 "ensuring equal rights for resources" (United Nations, 2015) is of most relevance to the Li-Ion battery supply chain.

SDG1 aims at ensuring equal rights to economic resources. In the context of the Li-Ion battery supply chain, this includes not only access to raw materials and natural resources but also to technology and the end product. Mineral deposits are concentrated in small geographical areas which inherently makes their disposition unequal across the world. Furthermore, access to technology is highly nationalized, and in a further respect, in the control of private companies. With technology, geographical areas, and resources being in the control of private companies, this brings competition where the resources are located through land use as exemplified in the salt flats in South America (United Nations Conference on Trade and Development, 2020). Within this region, local farmers have to compete for water and land use with companies extracting lithium from brines (United Nations Conference on Trade and Development, 2020). However, Loayza and Rigolini (2016) found that the mining district in general have lower poverty than districts without mining. Therefore mining might help combat poverty.

3.2.2 SDG2 - Zero hunger

We argue that the final impact assessment of the current supply chain is *no impact* because of the risks are mostly positioned in the future and the connections are not clear for SDG2 with the connected targets. SDG2 could be considered to have indirect connections with the current supply chain in terms of pollution and drought caused by extraction as well as increased electricity prices from production but assessed not clear enough in the context of SDG2.

SDG2 is defined as ”End hunger, achieve food security and improved nutrition and promote sustainable agriculture” by the United Nations (2015). The focus of the targets of SDG2 is increasing food production in a sustainable way and ensuring nutritious food for all people. Supporting a resilient and robust food production in terms of both pricing and protection against climate change is also one main area within the targets (United Nations, 2015).

One example seen is the waste from the extraction of both nickel and lithium is at risk of polluting the surrounding groundwater and soil (Nevskaya, Seleznev, Masloboev, Klyuchnikova, & Makarov, 2019; Sadik-Zada, Gatto, & Scharfenstein, 2023). This has a direct negative impact if there is surrounding agriculture, which may pollute food production. Lithium brine’s extensive water usage might also cause drought, negatively impacting surrounding livestock and farms. However, these kinds of conflicts are currently rare (Sadik-Zada et al., 2023). Therefore, drought risks from lithium production are currently not considered to have an impact on SDG2.

Electricity usage for battery production has an indirect negative impact on food production. The total global battery capacity is estimated to account for 15% of the total dispatchable energy capacity in 2030 (International Energy Agency, 2022k). This could indirectly affect food producers by increasing the price of electricity due to an increase in demand for electricity. However, we argue that this effect on electricity prices has no impact as there is extensive work towards increasing the electricity generation capacity following the increase in demand, which is shown in International Energy Agency (2022k).

3.2.3 SDG3 - Good health and well-being

The final impact assessment of SDG3 is that the current supply chain has an *indirect negative impact* on the goal. We argue that even though there are proposed regulations that could have a positive impact on SDG3, these have directly followed the negative impacts on both environment and workers from the battery supply chain.

SDG3 covers a variety of issues for good health and well-being. Two targets is identified as most relevant to the battery supply chain. First, target 3.9 ”By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination”. Second, target 3.D ”Strengthen the capacity of all countries, in particular developing countries, for early warning, risk reduction and management of national and global health risks” (United Nations, 2015).

Analyzing the battery supply chain from a health aspect, the large amount of toxic minerals handled increases the risk of negative effects on workers and the environment. Nickel is considered one of the most toxic minerals in the world (Parmar & Thakur, 2013). Workers in contact with the mineral can experience the most common health effect dermatitis, commonly known as ”nickel-allergy”, which causes itching and sore skin (Parmar & Thakur, 2013). When exposed to higher levels of nickel, there are further risks, such as the development of bone, lung, and nose cancer (Parmar & Thakur, 2013).

Negative aspects can be caused by lithium as well. Lithium is considered highly toxic at high concentrations (Bolan et al., 2021). The chemical properties of lithium allow it to have high mobility when released in nature and groundwater. This could direct it into both drinking water as well as plants that have the ability to more easily absorb lithium, causing increased toxicity within these (Bolan et al., 2021). Large exposure to lithium can cause disruptive heart rates, whereas overdoses can lead to coma (Bolan et al., 2021). However, lithium is also a well-used treatment for bipolar disorder (Łukasz, Rybakowska, Krakowiak, Gregorczyk, & Waldman, 2023). There are also established health risks connected to this treatment, which among others affect kidney function Łukasz et al. (2023). Bolan et al. (2021) states that there is an urgent need for further research. We argue that this is strongly connected with the need to analyze the actual impacts of the increased waste followed by the increased demand for EV batteries.

Within the EU there are several initiatives that have affected the worldwide battery supply chain. One of them is the ”The European Green Deal” which also has strong connections with new proposed regulations that EV batteries, Light means of transport (LMV), as well as industrial batteries with capacities above 2kWh, will be required to have a ”digital battery passport” (European Parliament, 2022, 2023). This implies that battery manufacturers need to adhere to standards for traceability of the minerals used in a specific battery together with information such as capacity, performance, durability, and chemical composition (European Parliament, 2022). This applies pressure on battery manufacturers worldwide to openly share information about their mineral composition, which also aspire these companies to ensure a clean battery supply chain. These new regulations have a clear positive impact, where worldwide battery production is required to meet these standards.

3.2.4 SDG4 - Quality education

The final impact assessment of SDG4 and the connected targets is an *indirect positive impact*. Both the mining and educational initiatives from the companies mentioned are shown to have positive impacts, however these initiatives in relation to SDG4 are hard to measure.

SDG4 is defined as ”Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all” (United Nations, 2015). The connected targets have an overall focus on establishing an infrastructure to ensure quality education for all citizens, for children as well as increasing knowledge towards sustainability and technology advancements (United Nations, 2015).

Studies have shown that mining industries create a positive impact on education in the surrounding local area. This is explained in Hajkowicz, Heyenga, and Moffat (2011) where case studies have been made on the Australian mining industry. The result from the study shows that mining is positively associated with several areas of life improvement, including educational attainment (Hajkowicz et al., 2011). This should also be considered a positive impact in the context of the battery supply chain as both nickel and lithium are produced for the battery industry in Australia. However, we argue that this should be considered an indirect positive impact on SDG4 as this is an effect of the existence of the mining industry as a whole and not specifically nickel and lithium.

The second area which has a positive impact on SDG4 is the direct work of larger companies within the battery supply chain that embrace education for the employees or through other initiatives. This is shown by Contemporary Amperex Technology Co., Limited (CATL), one of the world’s largest battery manufacturers that provides opportunities for education within the company, without any earlier experience required (CATL, 2023). The goal of the education program is to offer a position at the company when it is finished (CATL, 2023). Another example is LG Chem, also one of the largest manufacturers in battery production. The company has several initiatives not only connected with company education but also an additional focus on youth education which is part of their social contribution activities (LG Chem

Ltd., 2019). These two examples show a direct positive impact on SDG4 and the targets because of the active work from these major companies.

3.2.5 SDG5 - Gender equality

The final impact assessment on SDG5 is assessed as an *indirect negative impact.* There is substantial work remaining for gender equality to reach the goals of Agenda 2030 and to achieve gender equality for the countries active within the supply chain.

SDG5 is defined by the UN as "Achieve gender equality and empower all women and girls " (United Nations, 2015). This goal consists of 9 different targets (United Nations, 2015). Many of the targets for SDG5 are not directly impacted by the Li-Ion-battery supply chain, however, we hypothesize that the supply chain certainly does have indirect effects.

Abrahamsson et al. (2014) explain that women face a variety of problems in mining which go against SDG5 such as harassment, and discrimination due to mining being male-dominated and restrictive norms. Abrahamsson et al. (2014) argues that this negatively impacts local communities as well as the workers who are a part of those communities. Harassment and discrimination hinder a diversity of lifestyles and hamper the development of gender equality (Abrahamsson et al., 2014).

SDG5 can be tracked via the Gender Inequality Index (GII). The index tracks empowerment, reproductive health and labor (United Nations Development Programme, 2023). A lower score in the index is more equal, and a higher score is less equal. The largest producing countries in terms of nickel and lithium within the current supply chain ranks as follows in table 3.2.

Table 3.2: *Gender Inequality Index (GII) rank and value for the largest actors within the Li-Ion-battery supply chain. Data from 2021 and via United Nations Development Programme (2023).*

	GII Rank	**GII Value**
Canada	17	0.069
Australia	19	0.073
Chile	47	0.187
China	48	0.192
Russia	50	0.203
Indonesia	110	0.444

Australia and Canada rank highly and quite close in the GII whilst Chile, China, and Russia rank quite a bit lower, all with fairly similar GII values as seen in table 3.2. Last is Indonesia which ranks at place 110 with a GII-the value of 0.444 which is low and indicates severe inequality. Although indices are general across each country, the GII gives an indication of the differences as the largest actors operate within these countries in the battery supply chain. This in turn can provide an indication of the severity of structural inequality across genders. Furthermore, as the supply chain itself is diverse and spans across industries, the index provides an understanding on an aggregated level regarding SDG5. Data from the GII is used by the UN to track the progress of SDG5 as well.

3.2.6 SDG6 - Clean water and sanitation

The final impact assessment on SDG6 from the current supply chain is assessed as having a *direct negative impact*. Extensive water usage and pollution from the extraction of minerals are shown to be areas with the most negative impact. Mitigation is required in order to meet these challenges.

Clean water and sanitation consist of a number of targets where target 6.3 is the most relevant target for the battery supply chain. This target is defined by the United Nations (2015) as "improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally".

The negative impacts can be seen in the surrounding areas of mining operations. One study made by Nevskaya et al. (2019) on the Allarechensk Copper-Nickel Mining Waste Dump showed extensive nickel pollution in all of the closely positioned water bodies. The examinations showed that the nickel concentration was between 3 and 79 times higher than the Maximum Permissible Concentration (MPC), with the highest observed value at 4736 times higher than the MPC (Nevskaya et al., 2019).

One large challenge regarding lithium brines is extensive water usage (Sadik-Zada et al., 2023). Lithium brines are saltwater themselves, however in the evaporation process, freshwater is flowing into the brine from below (Sadik-Zada et al., 2023). This leads to a decrease in groundwater levels, which in turn could lead to droughts for the surrounding inhabitants, as well as endangering their livestock. Furthermore, according to Sadik-Zada et al. (2023), rainwater and groundwater are directly used in lithium extraction. Conflicts in rural areas where extraction is taking place have less demand for water because of the scarce number of inhabitants. However, Sadik-Zada et al. (2023) argues that with an increase in lithium extraction, future conflicts may arise.

Another challenge of the extensive water usage required can be seen in Chile (Liu & Agusdinata, 2020). The stored water level, which includes soil moisture, surface water, and groundwater of Chile decreased by 1.16mm per year between 2002 and 2017. The mining industries use 50 times the total water usage of the country (e.g. 50 times the water usage of the country with the mining industry excluded), and 100 times the amount of the tourism industry Liu and Agusdinata (2020). We argue that this is a direct negative impact on SDG6 even though the measurement is for the mining industry as a whole. This is because Chile is one of the largest producers of lithium, which makes the extensive water usage of lithium brines a large part of the total mining water usage.

3.2.7 SDG7 - Affordable and clean energy

The final impact assessment on SDG7 from the current supply chain is assessed to have a *direct negative impact*. This is assessed by analyzing the energy mix in the countries where the largest actors are active. It is assumed that all actors use the average energy mix within the country and that no special contracts for renewable energy for the actors' production are used. As shown in table 3.3, the average energy mix for the largest countries is highly varied. However, the average of renewable energy sources in the energy mix over the largest countries is 31.5%. China is the main location for many of the largest actors, where the share of renewable energy sources is 26.7%. As all different stages of the supply chain consume electricity, everything from the extraction of the ores to the refinement and the production of battery cells, it can be concluded that the lack of renewable energy sources has a large effect on SDG7.

SDG7 is defined by the UN as "Ensure access to affordable, reliable, sustainable and modern energy for all" (United Nations, 2015). This is a highly relevant goal for all the parts of the supply chain ranging from the extraction of raw materials to the production of batteries for electric vehicles as all these parts are energy intensive. Note that the definition of the goal specifically denotes the attributes: affordable, reliable, sustainable, and modern.

The targets for SDG7, include target 7.2 which defines modern energy as renewable energy with the specific target of substantially increasing the share of renewable energy in the energy mix (United Nations, 2015). Based on this target, the notions of sustainable and modern can be joined together and analyzed based on the data in table 3.3. The United Nations defines renewable energy as solar, wind, geothermal, hydro, ocean, and bio-energy (UN, 2022).

Table 3.3: *The energy mix of the largest countries in the current battery supply chain for lithium and nickel. Data from The International Energy Agency (International Energy Agency, 2022a, 2022b, 2022c, 2022d, 2022f, 2022i).*

	Australia	Canada	Chile	China	Indonesia	Russia
Coal	53%	5.7%	30%	63.4%	62%	16.1%
Natural gas	18.8%	12%	18%	3%	16.4%	43%
Hydro	5.7%	59.2%	19.2%	17.4%	8.3%	19.7%
Wind, solar, etc.	19.2%	6.3%	20%	9.3%	5.5%	0.3%
Biofuels and waste	1.2%	16.4%	6.5%	1.8%	5%	0.4%
Oil	1.8%	0%	5.2%	0%	2.7%	0.6%
Nuclear	-	14.4%	-	4.7%	-	19.7%

In all the countries where the largest actors are active in the supply chain, 99.6% to 100% of the populations have access to electricity based on the available data (International Energy Agency, 2022a, 2022b, 2022c, 2022d, 2022f, 2022i). It can be determined from this data that all the largest actors have access to reliable energy.

3.2.8 SDG8 - Decent work and economic growth

We argue that the final impact assessment of SDG8 from the current supply chain should be assessed as *indirect positive*. There are benefits and drawbacks to the current supply chain. Workers' safety is a clear negative part of the supply chain. However, the current development seen in the industry will create further employment opportunities and economic growth, which is positive.

SDG8, Decent work and economic growth aim at promoting sustainable and inclusive economic growth together with productive employment and work for all (United Nations, 2015). The goal consists of 12 targets in relation to work, labor rights, economic growth, economic productivity, employment, and safe working environments (United Nations, 2015).

Hajkowicz et al. (2011) found that the mining industry in Australia is positive for income and employment. We argue that the same can be assumed in the rest of the world - that the mining industry provides jobs and economic growth, especially combined with the increasing demand for materials required for EVs. Walser (2002) shows that mining increases local opportunities for employment. This is not only economic benefits, but also positive social effects for the surrounding communities (Walser, 2002). The downstream parts of the supply chain, mainly industrial manufacturing, also provide these benefits to the surrounding local area.

The UN (n.d.) explains that the current economic recovery from the negative economic effects in the wake of covid-19 is further slowed down by inflation, uncertainties, challenges in the labor market, and supply chain disruptions. One of the main risks for supply chain resilience within the Li-Ion-battery supply chain is geopolitical risks connected to 90% of lithium reserves being located in only five countries (as discussed in chapter 1.4.3). A strong supply chain resilience to avoid supply chain disruptions is therefore paramount to sustainable economic growth. With supply chain disruptions such as Russia's invasion of Ukraine (The Visual Journalism Team BBC News, 2022) and the recent US-China trade war (Kapustina, Lipkova, Silin, & Drevalev, 2020), some countries where top actors within the supply chain are located are currently engaging in activities that hamper economic growth. The geographical concentration of lithium could therefore lead to future negative impacts on the resilience of the supply chain and SDG8

Target 8.8 aims at promoting safe working environments and protecting worker rights (United Nations, 2015). Nickel itself is highly toxic and the extraction of nickel can be potentially harmful if not handled correctly, not only for workers but also for the surrounding environment (Sadik-Zada et al., 2023). This impact can in turn have negative consequences for the local community as well, as seen in Norilsk where lung cancer is 1.2-2.5 times more common (Lavelle M, 2021). With these facts in mind, the safe working environments of nickel extraction can be questioned and should be considered when discussing the current attributional impact on SDG8.

3.2.9 SDG9 - Industry, innovation and infrastructure

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

The final impact assessment of SDG9 from the current supply chain is a *direct positive impact*. A united front is seen, bringing the research of technological development and infrastructure for EVs and batteries forward.

SDG9 is described by the United Nations (2015) as "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation". Almost all of the targets in this goal are considered to be relevant since battery technologies are being further developed and researched worldwide in several different contexts (International Energy Agency, 2022e).

A clear example of technological development in the battery supply chain is the development of HPAL nickel processing. Developments of HPAL processing are made possible by larger companies due to the extensive capital cost (Meshram et al., 2019). This can be seen in Indonesia where a large HPAL plant started operating in 2021, financed through a joint venture between Harita Group and Chinese company Ningbo Lygend Mining Co. (International Energy Agency, 2022e). An additional HPAL plant is expected to be finished in Indonesia in 2025 and is considered to become the world's largest plant (Reuters, 2023). However, the processing of the low-grade laterite ores releases three times the amount of ghg compared to the processing of sulfide ores (International Energy Agency, 2022e). We argue that the emissions should be considered outside the scope of SDG9. Therefore, this solution allows more efficient use of resources through innovation, together with possibilities for further developments on HPAL, which therefore has a direct positive impact on SDG9.

Innovation of HPAL can be seen in companies such as Clean Teq in Australia. The company has focused on making the HPAL processing clean by powering the plant through solar panels instead of the normally used coal-fired boilers (International Energy Agency, 2022e). Heat and steam generated from the HPAL plants can be recovered and could be used to power other activities (International Energy Agency, 2022e). This is a clear example where the battery supply chain development has a direct positive impact on SDG9.

The development of the EV supply chain has seen extensive support from governments worldwide. Masiero, Ogasavara, Jussani, and Risso (2016) presents that the government of China has subsidized EVs in order to decrease pollution, generate jobs and bring technological development forward since the country took a leading position in the development of EVs back in 2009. Masiero et al. (2016) discusses that tax benefits are one specific supporting factor that has encouraged EV producers to continue EV-development. These tax benefits have been made available both from the central government as well as local districts (Masiero et al., 2016). However, Li, Yang, and Sandu (2018) discusses that currently the authorities are fragmented within the country which can pose challenges due to different standards, depending on the geographical position. A centralized decision unit therefore could have a positive impact on coordination (Li et al., 2018). The governmental support through policies and tax benefits shows a direct positive impact on SDG9, bringing incentives for further developments within the industry.

Further examples of government support can be seen in China's infrastructure. One example is the rapid growth of charging stations within China. The number of charging stations has gone up from 440,000 in 2017 to 3,521,000 in 2021 (Lau, Andrew Wu, & Wing Yan, 2022; Li et al., 2018), which may have been the result of the implementation of policy incentives. This should also be considered a positive impact.

3.2.10 SDG10 - Reduced inequalities

The final impact assessment on SDG10 from the current supply chain is assessed as *no impact*. The current supply chain does have an impact on equality in the world, however, we argue it is negligible. The most relevant targets within the supply chain are the equalization of income for the bottom 40% of the population (target 10.1) and the promotion of social, economic, and political inclusion (target 10.2).

SDG10 aim at reducing inequality among and within countries (United Nations, 2015). The goal consists of ten separate targets which focus on reducing inequality based on income, inclusion, opportunities, improving regulation, representation, and immigration (United Nations, 2015).

The targets of SDG10 intersect with SDG5, Gender Equality, and SDG1, No Poverty as the targets of SDG10 carry similarities. This can be seen in SDG5 how women face discrimination within the mining industry which goes against the goal of reduced inequality as well (Abrahamsson et al., 2014). The extraction of raw materials and their deposits provide unequal opportunities in different communities which is problematic in terms of SDG1 (Loayza & Rigolini, 2016). Furthermore, there are unequal opportunities in terms of who controls the land, resources, and water which intersects with the targets of SDG1 (United Nations Conference on Trade and Development, 2020).

3.2.11 SDG11 - Sustainable cities and communities

We argue that the final impact assessment of SDG11 from the current supply chain is *indirectly negative*. The nodes in the supply chain are highly differentiated and the nodes are therefore conducive to a variety of issues. For example, nickel production can lead to highly polluted air as seen in Norilsk, Russia, where the amount of sulfur dioxide in the air is around the same as from a currently erupting volcano (Lavelle M, 2021). This in turn has increased the risk of lung cancer by 1.5-2 times which negatively affects nearby communities (see Section 1.4.2).

SDG11 aims at making cities inclusive, safe, resilient, and sustainable (United Nations, 2015) and consists of 10 targets (United Nations, 2015). Cammarano, Perano, Michelino, Del Regno, and Caputo (2022) argue SDG11 is one of the most relevant goals for supply chain management.

Although this can be true for supply chain management in general, it is not necessarily the most relevant SDG for the Li-Ion battery supply chain as many of the areas in which supply chain management has its' largest impact are from ghg emissions in last-mile solutions[1] (Cammarano et al., 2022). The most relevant targets of SDG11 include target 11.6 which aims at reducing the per capita environmental impact of cities (United Nations, 2015).

One of the largest risks to consider for nearby cities and communities for lithium extraction is water quality. The pollution of lithium into groundwater can have negative health consequences which can impact nearby communities as discussed in the context of SDG3 (see Section 3.2.3). The largest risk for open-pit lithium mines is possible water pollution and can therefore negatively impact nearby communities (Crespo-Cebada et al., 2020) (see Section 1.4.3). The factors which impact SDG11 are highly interconnected with SDG3, SDG6, SDG7, SDG8 and SDG12 (See sections 3.2.3, 3.2.6, 3.2.7, 3.2.8, 3.2.12).

3.2.12 SDG12 - Responsible consumption and production

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

We argue that the final impact assessment on SDG12 from the current supply chain is a *direct positive impact*. Sustainable solutions are required in order to create a balance of consumption as the battery industry grows. There are clear examples of initiatives towards reaching the targets of for example waste management and solutions within the battery supply chain and maximizing material and mineral efficiency.

SDG12 focuses on sustainable consumption and production which is highly relevant in the context of the growing battery demand. The targets most relevant to the battery supply chain are "12.2 By 2030, achieve the sustainable management and efficient use of natural resources", "12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse" and "12.A Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production" (United Nations, 2015).

Governments are motivated to contribute with policies that bring the battery industry within the country forward. China's dominance in the downstream production of batteries has been made possible by favorable support with policies from the government as discussed in SDG9 (See section 4.4.9. Monteiro, da Silva, and Moita Neto (2019) shows that companies who collaborate with the government promote campaigns connected to waste management more willingly and in a more practical approach. Furthermore, Monteiro et al. (2019) discusses that a more proactive approach to waste management generates value both from decreased waste, but also

[1] Last mile is defined as the last part of the delivery of products to a customer. This part is often characterized by a short distance (Hayes, 2022).

together with the value from minerals that otherwise might be considered as waste. The increased focus on waste management is a direct positive impact on the goal, especially targets 12.2 and 12.5.

There is a further need to drastically increase mineral production as demand for battery minerals is growing. HPAL is one of the technologies brought forward in order to transform low-grade nickel into high-grade, which can be used in batteries International Energy Agency (2022e). However, HPAL has three times higher emissions of ghg compared to the processing of nickel from sulfides (International Energy Agency, 2022e). This has a direct negative impact on the goals. There are technologies and solutions such as solar-powered or clean HPAL according to International Energy Agency (2022e), which could be considered to have a direct positive impact on target 12.A, bringing the technology forward in the producing countries.

The United Nations imposed a battery durability standard that set up specific requirements for battery producers to fulfill in March 2022 (International Energy Agency, 2022e). This requires manufacturers to ensure that the batteries produced will keep the capacity of at least 80% for five years or 100,000km, and 70% capacity for eight years or 160,000km (International Energy Agency, 2022e). China, Canada, Australia, Russian Federation, and Norway, include countries that have adopted this standard, showing extensive compliance with ensuring efficient and sustainable batteries (International Energy Agency, 2022e). This has a direct positive impact on the SDG12, increasing the lifespan of the batteries which in a long-term context helps balance the consumption by making the batteries more efficient.

3.2.13 SDG13 - Climate action

13 CLIMATE ACTION

The final impact assessment of SDG13 is that the current supply chain has a *direct negative impact.* Many of the other SDGs intersect with SDG13. The largest countries where the main actors are active in the supply chain have a negative impact on target 13.2.

SDG13, Climate Action consists of five targets aimed at mobilizing towards climate change and raising awareness on climate change (United Nations, 2015). This goal has been identified to be linked to organizational performance within supply chain management and therefore, SDG13 can be impacted by actions within supply chain management (Cammarano et al., 2022). The most relevant target for the Li-Ion battery supply chain is target 13.2 which aims to integrate measures to combat climate change into the UN member's national policies and strategies (United Nations, 2015). This target more specifically also measures the total ghg-emissions in each country as well as determining the number of countries with specific climate action plans (United Nations, 2015).

Greenhouse gases is at the center of SDG13 and many of the sources of ghg-emissions within the supply chain can be traced to the production of the batteries including the extraction of raw materials. 24.2% of ghg-emissions originate from energy use in industry, and 16.2% of ghg-emissions originate from transport (Ritchie, 2020). Degen and Schütte (2022) found that 74% of ghg-emissions in battery cell production are from just three steps relating to coating and drying. If these processes use renewable energy sources or are optimized in terms of energy use, ghg-emissions in battery cell production may decrease significantly (Degen & Schütte, 2022; Morfeldt, Davidsson Kurland, & Johansson, 2021b). Furthermore, the HPAL processing of low-grade laterite nickel ore consumes three times the amount of energy compared to the processing of sulfide ores (International Energy Agency, 2022e). As analyzed in Section 3.2.7, Affordable and clean energy, the assessment for SDG7 is that the current setup has a direct negative impact in terms of the supply chain based on the energy mix for the largest actors in the supply chain. A majority of the countries where the largest actors are active therefore have a direct negative impact on SDG13. Switching to renewable energy sources could drastically reduce the ghg-emissions of the cell production (Degen & Schütte, 2022).

Geographical distances in the supply chain are far, and emissions from transport pose a large challenge in terms of SDG13. This can be exemplified by a possible route for lithium which might start in Chile, be transported to China for refinement, then be transported to Japan for cathode production, and then finally shipped to Europe for use in EVs. This widespread characteristic is problematic for the current supply chain. Moving supply chains into a smaller geographical area would most likely reduce ghg-emissions considerably as the distances required to move are much lower. However, the mode of transport is of high importance since a change to a worse alternative could significantly decrease the positive impact of shorter transportation distances (see chapter 1.4.1 for comparisons). As previously mentioned, 16.2% of ghg-emissions originate from transportation. Out of all the total ghg-emissions in the world, 76% of these consist of CO_2, and the transport sector accounts for 26.5% of all CO_2-emissions (Yoro & Daramola, 2020). This has a negative impact on SDG13. Furthermore, the production of batteries used for EVs has the effect of significantly reducing CO_2-emissions which is beneficial for SDG13 as EVs replace ICEVs (Morfeldt et al., 2021b).

3.2.14 SDG14 - Life below water

The final impact assessment of SDG14 from the current supply chain is assessed to be *no impact*. There are negative aspects to consider, however, resulting from transport between nodes within the supply chain as the battery supply chain is only a minor part of global shipping and is not responsible for all the issues shipping causes.

SDG14, Life below water aims to sustainably use marine resources such as oceans for further sustainable development (United Nations, 2015). This goal consists of 10 targets focused on a variety of marine resource conservation (United Nations, 2015). Many of the main concerns highlighted by the UN in regards to SDG14 are pollution, overfishing, acidification, eutrophication, and ocean warming (United Nations, 2015). Lithium production with the brine method uses a lot of water(Liu & Agusdinata, 2020), however, SDG14 is focused on oceans and seas rather than inland water use. This subject is further covered in Section 3.2.3, Good Health and Well-being, and Section 3.2.6, Clean Water and Sanitation. In regards to the Li-Ion battery supply chain, the maritime transport used to connect the nodes within the supply chain is the most relevant part for SDG14.

Maritime transport and shipping routes impact the oceans in a variety of ways. Ecosystems might be threatened through shipping. Large animals such as whales and sharks are highly vulnerable to shipping, which can negatively impact ocean ecosystems (Pirotta, Grech, Jonsen, Laurance, & Harcourt, 2019). This in turn has a negative impact on target 14.2 for SDG14 which aims at managing and protecting marine ecosystems (United Nations, 2015). Furthermore, ocean ecosystems are also negatively impacted by noise pollution created by shipping, which is a threat to aquatic life (Folegot, 2012). Shipping also contributes to ocean acidification (Hassellöv, Turner, Lauer, & Corbett, 2013). This negatively impacts target 14.3 which aims at minimizing ocean acidification (United Nations, 2015).

3.2.15 SDG15 - Life on land

The final impact assessment of SDG15 is that the current supply chain has a *direct negative impact*. It is clear that the early stages of the battery supply chain (mining and processing of lithium and nickel) are highly relevant for SDG15. There are negative impacts throughout all stages of the mining, starting from the opening of a mine (deforestation and destruction of the current biodiversity), high amount of water usage for lithium extraction during the active operations (risking desertification and drought), and ending with risk of pollution of the biodiversity from the tailings left behind.

Life on land is defined by the UN as "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss" (United Nations, 2015).

Target 15.3 has a strong relation to the battery supply chain and is defined as "By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought, and floods, and strive to achieve a land degradation-neutral world" (United Nations, 2015). The lithium brines risk causing droughts in the surrounding environment due to extensive water usage (Sadik-Zada et al., 2023).

Conflicts are currently rare between mining companies and local inhabitants over extensive water usage because of the scarce number of inhabitants and extraction taking place in rural areas (Sadik-Zada et al., 2023). However, this still is a cause for concern. One clear example is the challenges with water usage in Chile. According to Liu and Agusdinata (2020), the stored water level[2] of Chile decreased by 1.16mm per year between 2002 and 2017. The mining industries use 50 times the total water usage of the country, and 100 times the amount of the tourism industry Liu and Agusdinata (2020). Similar to SDG6 (see Section 3.2.6), we argue that this shows a direct negative impact on SDG15 and target 15.3, even though the measurement is for the whole mining industry, because of Chile´s being in a leading position of lithium production.

The extraction of raw materials disturbs nature and wildlife in the close vicinity of the mining operations. More than 50 articles have studied biodiversity and ore mining (Monteiro et al., 2019). When mining operations are up and running it is almost impossible to fully commit to the goal and restore ecosystems (Monteiro et al., 2019). A clear aspect of this was presented in the Background (See Section 1.4.2) regarding acid rain from the nickel smelters in Norilsk, causing harm to the surrounding environment (Lavelle M, 2021). Compensation through fees that support restoration projects is one of the ways mining companies work towards decreasing negative impacts on SDG15 (Lavelle M, 2021). An alternative mentioned by Monteiro et al. (2019) is to find ways to collaborate between mining companies and governments in order to mitigate the negative impacts. This could be to avoid unnecessary deforestation together with combating desertification, as mentioned in target 15.3. The authors also state that common ways of ensuring a united front in facing the challenges connected with the mining industry are through continuous monitoring of the environmental impacts from the companies (Monteiro et al., 2019).

One of the useful ways of keeping control of the mining facilities is through mining licenses (Monteiro et al., 2019). These mining licenses could be seen as restrictions since there are direct negative impacts on the opening of mines in the context of SDG15. Crespo-Cebada et al. (2020) discuss that the opening of a mine fully risks the elimination of the already existing biodiversity in the surrounding area. There could be significantly worse impacts if the mines are positioned in areas with high biodiversity (Crespo-Cebada et al., 2020).

Even though a mining or processing facility has been shut down, tailings and mineral waste could still be polluting and damaging the biodiversity for a long time. A clear example can be seen in SDG6 (see Section 3.2.6) where a study was made on a nickel and copper mining waste dump in Russia. This showed nickel pollution in the soil and water 3-79 times higher than the MPC (Nevskaya et al., 2019). There are challenges with pollution from lithium in water as plants easily capture the polluted water (Bolan et al., 2021). The pollution stays in the environment or is consumed by creatures in the surrounding areas. This shows clear risks that mines could continue to damage the biodiversity even though a plant might not currently be active,

[2]The stored water level includes soil moisture, surface water, and groundwater

showing a clear negative impact on SDG15.

3.2.16 SDG16 - Peace, justice and strong institutions

We argue that the final impact assessment of SDG16 from the current supply chain is an *indirect negative impact*. There are several areas at risk of conflict, indirectly related to the battery supply chain. 20% of the global battery grade nickel is currently produced in Russia which indirectly works against SDG16 due to the invasion of Ukraine. There are further geopolitical risks in recent developments such as newly discovered lithium deposits in Jammu and Kashmir and extensive water usage from lithium brines, which risks future conflicts.

SDG16 goal is to ”Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels” with targets focusing on peace, ending corruption and abuse (United Nations, 2015).

The current impact within the Li-Ion battery supply chain for SDG16 is Russia’s invasion of Ukraine in 2022. This poses a challenge in the nickel industry (International Energy Agency, 2023). Russia has actively engaged in the SDGs, shown in the voluntary SDG-analysis published in Analytical Center for the Government of the Russian Federation (2020). However, since the war Russia has been isolated from other countries which makes future collaborations for sustainability much harder to achieve (The Visual Journalism Team BBC News, 2022). The war in Ukraine had an extensive impact on nickel trading, both with drastically increasing prices as well as closing down the London Metal Exchange for a period of time (International Energy Agency, 2022e; International Nickel Study Group, 2021). There are no current sanctions on battery-grade nickel from Russia (Reuters, 2022). Based on the aforementioned arguments, we argue that the battery supply chain has an indirect negative impact on SDG16 in this context.

There are newly discovered lithium ores in the area of Jammu and Kashmir, India (Geological Survey of India (GSI), 2023) (see Section 1.4.3). The estimated 5.9 Mt ore bodies would position India as the sixth-largest country in terms of lithium reserves (Hendrix, 2022). The extensive demand from the battery supply chain could further risk conflicts as there already is geopolitical instability in the area. We argue that similarities can be seen in the large water usage of lithium brines discussed in SDG6 (See Section 3.2.6). The risks are connected to the future increase in demand for lithium. It is too early to tell what impacts this might have in the context of SDG16 and the battery supply chain. However, it shows an increased risk of conflict.

3.2.17 SDG17 - Partnership for the goals

The final impact assessment of SDG17 is assessed as an *indirect negative impact*. Many of the countries where the largest actors in the supply chain are active such as Australia, Canada, and Chile, are members of the The Organisation for Economic Co-operation and Development (OECD), which we argue has an indirect positive impact on SDG17. However, there are issues relating to the largest actors within the battery supply chain even if minor actors have a positive impact. The goal is difficult to map, however there are several instances where countries with the largest actors in the supply chain actively work against the targets of SDG17.

SDG17, partnership for the goals, has the largest amount of targets with 19 in total. These aim at mobilizing resources, assisting developing countries, implementing various investment promotions, promoting the sharing of technologies, and much more to help each other, and partner, to fulfill SDGs (United Nations, 2015). In one the latest SDG-reports, the UN calls for more international cooperation in the wake of the covid-19 pandemic (United Nations, 2015). With a very high amount of different collaborations available and no specific collaborative indexes which was described in Section 3.1, it is difficult to fully map each different actor's collaborative efforts within the supply chain. Mapping the collaborative efforts in conjunction with all the 19 available targets is an even larger task. However, looking at the various countries it is clear that the largest actors within the battery supply chain are establishing their own specializations based on their available resources.

Russia's impact in terms of partnership for the goals can not be seen as beneficial with the invasion of Ukraine. This has hindered further partnership with Russia and isolated Russia on the world stage (The Visual Journalism Team BBC News, 2022). This led to soaring nickel prices which in turn has led to worse trade possibilities and therefore also worse opportunities for collaborations (International Nickel Study Group, 2021). Russia has recently had a clear negative impact on the partnership for the goals with these developments.

Questions can be raised in regards to China and the United States with the recent trade war which can be argued to actively go against specific targets in relation to SDG17. This is exemplified by targets 17.7 (”*Promote the development, transfer, dissemination, and diffusion of environmentally sound technologies/../*”(United Nations, 2015)), 17.10 (”*Promote a universal, rules-based, open, non-discriminatory and equitable multilateral trading system/../*”(United Nations, 2015)), and 17.17 (”*Encourage and promote effective public, public-private and civil society partnerships, building on the experience and resourcing strategies of partnerships/../*”(United Nations, 2015)). Kapustina et al. (2020) argues that the trade war has led to the following effects:

- That the effects include the limitation for Chinese companies to access Ameri-

can technology, which hinders the digitalization and modernization of industry in China and connects to target 17.7.
- The reduction of trade and creation of jobs which links to target 17.10.
- The reduction of federal budget deficits which we argue can be connected to target 17.17.

It is clear that China as the largest country where many actors are active within the battery supply chain has a clear negative impact on the partnership for the goals.

3.2.18 SDG impact summary of the current supply chain

The SDGs show different results in terms of impacts connecting to the Li-Ion battery supply chain. The results can be seen visualized in fig. 3.6 with either a direct positive impact, an indirect positive impact, no impact, an indirect negative impact, or a direct negative impact. The assessments have been performed with varying empirical bases as described in section 2. The empirical base is visualized above the SDG impact assessment result as numbers. If there is a 1, this represents base 1 (Specific journal articles, studies or papers etc), if both 1 and 2 is present, this represents the usage of both specific and general journal articles and so on. The full pdf created by the SDG impact assessment tool can be found in Appendix A.

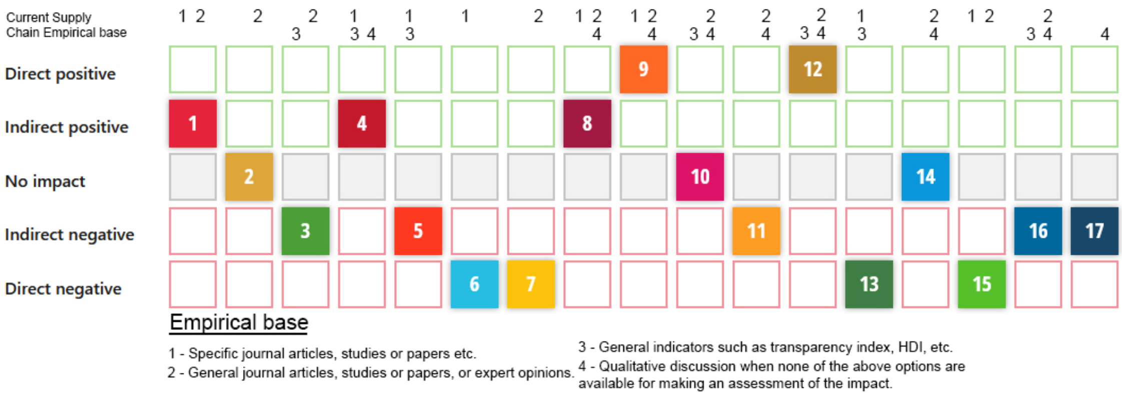


Figure 3.6: *All resulting assessments summarized with direct positive, indirect positive, no impact, indirect negative or direct negative impacts. This graphic has been created by using the tool provided by GMV.*

The benefits and drawbacks of the current supply chain are spread out throughout the SDGs. The benefits of the current supply chain are in terms of SDG 1 (No poverty), 4 (Quality education), 8 (Decent work and economic growth), 9 (Industry, innovation and infrastructure), and 12 (Responsible consumption and production). The drawbacks of the current supply chain are for SDG 3 (Good health and well-being), 5 (Gender equality), 6 (Clean water and sanitation), 7 (Affordable and clean energy), 13 (Climate action), 15 (Life on land), 16 (Peace, justice and strong institutions), 11 (Sustainable cities and communities), and 17 (Partnership for the goals). The remaining goals, 2 (Zero hunger), 10 (Reduced inequalities), and 14 (Life below water) can be seen as negligible or indifferent.

4

Domestic battery supply chain

This section proposes a design for a Swedish battery supply chain from raw material extraction to EV production. Following the suggested design of the supply chain, the supply chain is analyzed on its' potential SDG impacts. This provides the required result to answer RQ2.

4.1 Swedish nickel deposits

There is currently no extraction of nickel in Sweden, however, historically there has been mining of the mineral in small-scales (Martinsson & Wanhainen, 2022). Early deposits were extracted in southern Sweden. A project financed by the Swedish government in the early 1900s analyzed opportunities for the extraction of nickel in the region of Västerbotten. The nickel deposits found were not expected to be economically viable and extraction of the nickel was not established (Martinsson & Wanhainen, 2022). This has changed in the last decade as demand for battery minerals has increased, which has resulted in increased prospecting (Sveriges Geologiska Undersökning, 2023).

One deposit that has seen growing interest is a nickel deposit consisting of three ore bodies in Rönnbäcken (Martinsson & Wanhainen, 2022). For the deposit in Rönnbäcken, there are already mining licenses granted, which are currently the only licenses of nickel extraction in Sweden (Martinsson & Wanhainen, 2022). According to Martinsson and Wanhainen (2022), the deposit is of sulphide type at 320 Mt with 0.10% nickel. The mining company Bluelake Minerals, responsible for the plant and mining licenses, claims that the deposit could consist of 600 Mt with 0.18% nickel which could produce 23 000 tonnes of nickel annually for 20 years. Bluelake Minerals further states that Rönnbäcken is one of Europe's most known undeveloped reserves (Bluelake Mineral, n.d.). This indicates that Rönnbäcken and nickel mining in Sweden could be a future possibility.

4.2 Swedish lithium deposits

Sweden does currently not have any open lithium mines either for primary extraction or as a bi-product, however, there has been previous extraction of lithium in Sweden (SGU, 2023). The reserves present in Sweden are in pegmatite form with 1-2.5% Li_2O. There have only been limited attempts in Sweden to explore lithium extraction (Martinsson & Wanhainen, 2022). The Bergby-project in central Sweden has recently received eight licenses for further exploration to possibly provide lithium for Northvolt (United Lithium, n.d.). According to United Lithium (n.d.), the Bergby project pegmatite has a concentration of 0.03-4.56% Li_2O. The size in Mt is unknown or undisclosed by United Lithium for the Bergby project. The area which is covered by exploration license covers around 100 square kilometers (United Lithium, n.d.).

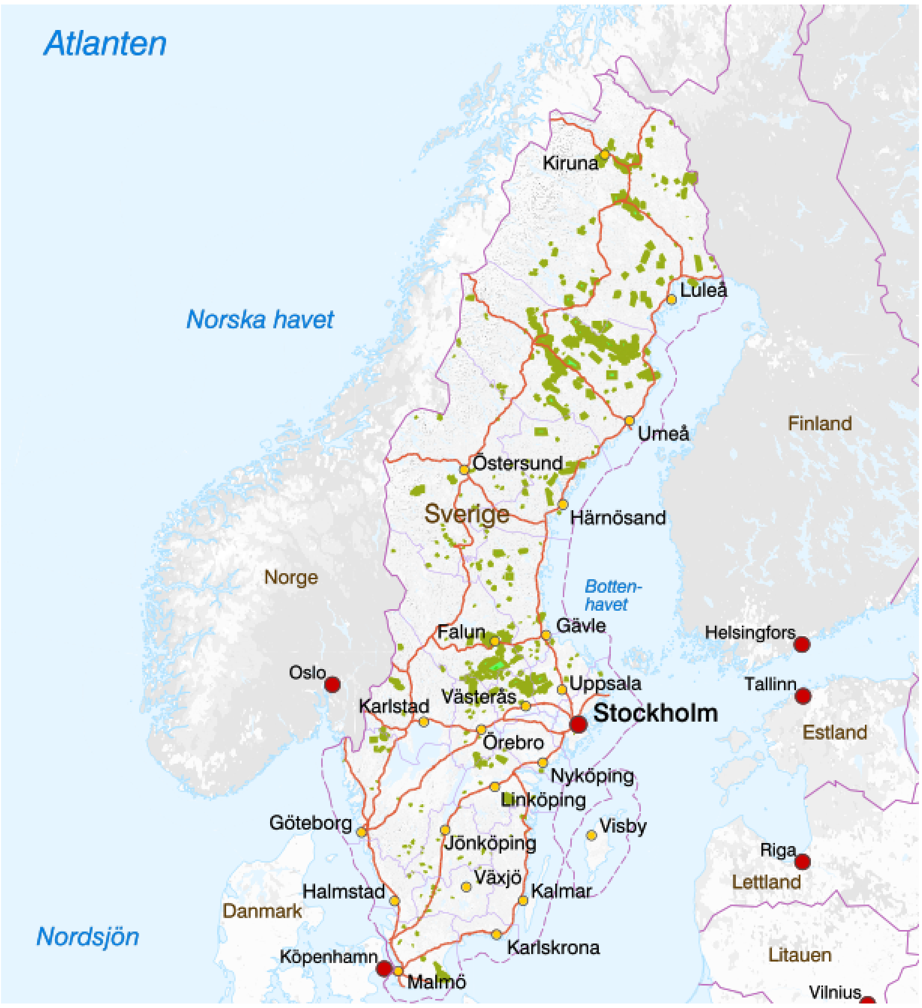


Figure 4.1: *Screenshot from SGUs Kartvisare showing exploration licenses for lithium (in yellow/green) in Sweden. (Sveriges Geologiska Undersökning, 2023)*

There might be several more opportunities for lithium extraction in Sweden if more geological surveys are performed (Martinsson & Wanhainen, 2022). However, Martinsson and Wanhainen (2022) states that currently there has not been that much exploration in regards to lithium. SGU provides information where previous exploration licenses have been granted in their tool SGUs Kartvisare as seen in fig. 4.1 (Sveriges Geologiska Undersökning, 2023). Most attempts to find minerals and potential for mining in Sweden have been focused on the eastern part of the country with quite large areas of Sweden still left unexplored.

4.3 Suggested domestic supply chain

A domestic supply chain is suggested to ascertain the differences between a global and a domestic supply chain in terms of impacts on the SDGs. This should be seen as a suggestion by the authors as a possible supply chain based on currently available information. The suggested supply chain is based on the information gathered in Section 1.4 and 3.1 combined with information gathered from the interviews. There are still possible undiscovered deposits in the world, which potentially includes Sweden (see fig. 4.1), as seen by India's latest discovery of a large lithium deposit. This thesis only aims at comparing the different sourcing methods, not answering the question of whether it is possible from a geological standpoint or if the currently known deposits would provide enough supply for the predicted demand. This is outside the scope and therefore the suggested supply chain is based on the best possible sources as known today and assumed to work both commercially and with a sufficient amount of lithium and nickel available to make a comparison possible.

The suggested supply chain starts at the raw material stage for both lithium and nickel as visualized in the schematically mapped supply chain in fig. 3.4. The suggested domestic supply chain is visualized in fig. 4.2. Starting with lithium extraction, Sweden's deposits of lithium consist of pegmatites based on the information provided in the Background for lithium(see chapter 1.4.3). The most promising lithium deposits are in Bergbyn outside of Gävle as visualized in fig. 4.2.

We suggest having raw material extraction in Bergbyn and then transporting the extracted pegmatites to Gävle for material refining[1]. The reason for suggesting Gävle is due to its' geographical vicinity to the mine. After the material has been processed and the material has been refined to raw lithium, it should be transported to Skellefteå and Gothenburg for battery cell production. These locations are chosen as Northvolt Ett is located in Skellefteå (Northvolt AB, n.d.) for cell production and there are plans for a future battery plant in Gothenburg for Volvo cars (Business Region Göteborg, n.d.). It is assumed cell production and battery pack production is performed at the same locations.

[1]As there is no current refinement of either lithium or nickel in Sweden, the geographical locations for refining is a suggestion.

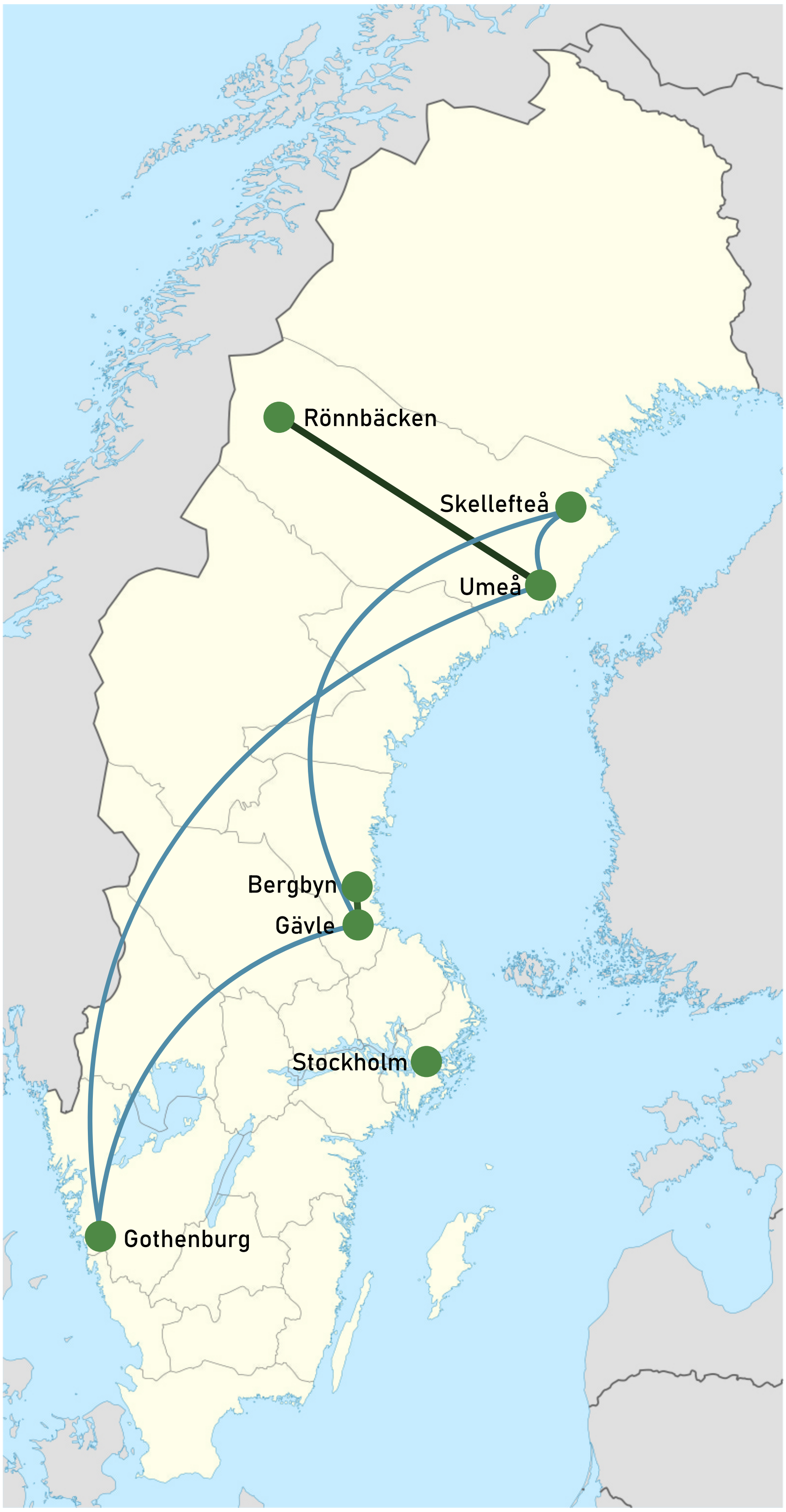


Figure 4.2: *The suggested domestic supply chain with nodes and links where the straight lines represent raw material flows and blue lines represent refined material flows.*

Nickel in Sweden comes in the form of sulphide ore as ascertained in the Background for Nickel (see chapter 1.4.2). The most promising nickel project is Rönnbäcken in Västerbotten (see fig. 4.2) and is therefore chosen for raw-material extraction in the domestic supply chain. As this location is far away from any larger cities in Sweden, the suggested location for raw material refinement is Umeå as this location is the closest larger city in the area. It is easier to recruit workers if the location is located in a larger city. After this stage, the nickel sulfate is shipped to Skellefteå and Gothenburg for battery cell production.

This suggested supply chain will be used as a basis for the SDG-analysis and comparison between domestic and global sourcing. It is assumed that rail and road transport will be the main mode of transport. Rail is available to all nodes visualized in fig. 4.2 except to/from Rönnbäcken, where the closest railway station is at Storuman, around 100km by road from Rönnbäcken (Trafikverket, 2022). It should be noted that the transport should be considered intermodal as the rail will have to be re-loaded at railway stations to their final destinations. However, in the scope of the SDG-analysis this is negligible as these distances are just a couple of kilometres whilst with global sourcing the distances can be expected to be significantly longer.

4.4 SDG impact analysis of the domestic supply chain

This section performs a SDG-analysis for the domestic supply chain in a similar structure as for the current supply chain (See Section 3.2). As the proposed domestic battery supply chain is hypothetical, expert opinions have been included in order to strengthen the analysis. The expert opinions are based on the interviews described in chapter 2.1. At the end of each SDG there is a comparison and discussion regarding the shift from the current to the domestic context. Lastly, the SDG impacts are summarized.

4.4.1 SDG1 - No poverty

We argue that the final impact assessment of a domestic supply chain in Sweden would have *no impact* on SDG1. As argued in Section 3.2.1, No Poverty, economic growth might be a more relevant indicator for this goal and that SDG8 might provide a better understanding of its impacts. The comparison of the SDG impact assessment from the domestic to current supply chain result in a *minor deterioration and a negative impact*.

For SDG1 we argued that the current global sourcing model for battery minerals and the current supply chain had an indirect positive impact. Competition over land and resource might have a negative impact on poverty, however, Loayza and Rigolini (2016) found that mining districts, in general, have lower poverty. Sweden does, like all other countries, have poverty, however at much lower levels than many other countries in the world (Statistikmyndigheten, 2021). Although this exists, its' connections to the Li-Ion battery supply chains are vague and indirect. The same is true for a potential domestic supply chain. As there are no differences to the analysis made in Section 3.2.1, No Poverty for the current supply chain, a domestic supply chain would therefore make no difference on SDG1.

4.4.2 SDG2 - Zero hunger

The final impact assessment on SDG2 from a domestic supply chain is that it has *no impact*, showing few direct connections between the domestic supply chain and SDG2. The comparison of the SDG impact assessment from the domestic to current supply chain result in *no difference and no impact*.

The assessment for SDG2 was no impact for the current supply chain. This assessment was based on the water usage from lithium brines and indirect challenges of energy consumption which could damage farmers and agriculture (International Energy Agency, 2022k; Sadik-Zada et al., 2023).

The available lithium deposits in Sweden are pegmatites United Lithium (n.d.). Challenges connected with extensive water use of lithium brines are not relevant for pegmatites. Furthermore, the pegmatites are not expected to be connected to the possible future conflicts discussed by Sadik-Zada et al. (2023). Smart City Sweden (n.d.) argues that Sweden's farmland production capacity is good and the services of cultivated land are satisfactory. Furthermore, Sweden's production value has seen an increase during the last decade while at the same time, there has been a decrease of ghg emissions (Smart City Sweden, n.d.). Data also show an increase in productivity according to Smart City Sweden (n.d.). The change to a domestic Li-Ion battery supply chain would have a negligible impact on the goal since the assessments of both the alternatives show no impact on SDG2.

4.4.3 SDG3 - Good health and well-being

We argue that the final impact assessment on SDG3 for the domestic supply chain is *no impact*. There are several regulations and authorities to mitigate health risks present which could be considered a positive impact. However, these regulatory bodies are seen as the response to mitigate and control the possible health risks which are made possible because of the battery supply chain and similar industries. The comparison of the SDG impact assessment from the domestic to current supply chain result in a *minor improvement and a positive impact*.

The final assessment for the current supply chain was that it has an indirect negative impact on SDG3 and the connected targets. This is due to the toxicity of nickel and lithium which could risk health implications for the employees throughout the battery chain when handled (Bolan et al., 2021; Parmar & Thakur, 2013). Regulations with traceability are in high focus, for example, the proposed regulations connected to the "battery-passport" which also put up demands to create a clean battery supply chain (European Parliament, 2022).

We argue that the same health risks connected to the extraction of minerals will apply to the domestic battery supply chain. However, there are clear regulatory actors connected with mines in Sweden. Examples of these are The Swedish Environmental Protection Agency, The Swedish Agency for Marine and Water Management, and Kammarkollegiet which are some of the actors with the aim to safeguard environmental and other public interests (Klimat- och näringslivsdepartementet, 2022).

The numerous regulatory actors show the multitude of required approvals for the mining industry for the domestic battery supply chain which should be seen as having a direct positive impact on SDG3. However, the increase in the production rate and handling of toxic lithium and nickel from the domestic battery supply chain should be seen as a negative impact on SDG3 since the expanded handling of could lead to further health risks.

4.4.4 SDG4 - Quality education

The final impact assessment is that the domestic supply chain would incorporate the already highly established educational programs within Sweden, and therefore should be seen as a *direct positive impact* on SDG4. The comparison of the SDG impact assessment from the domestic to current supply chain result in a *minor improvement and a positive impact.*

The overall assessment of the current battery supply chain was an indirect positive impact on SDG4. This was argued by addressing the different initiatives from the two of the largest manufacturers CATL and LG Chem (CATL, 2023; LG Chem Ltd., 2019). The positive impacts of mining operations in surrounding areas in Australia were addressed as well (Hajkowicz et al., 2011).

There are initiatives throughout the domestic battery supply chain striving towards increasing the knowledge base. For example, at Volvo Cars there are initiatives such as Tekniksprånget which is an internship for students that have finished high school (Volvo Cars, 2023). Furthermore, additional internships and global graduation programs are available at Volvo Cars for students that are at the end of their university studies (Volvo Cars, 2023). Similar initiatives to strengthen knowledge are seen at Northvolt, which offers a 6 months graduation program, with the goal to offer the graduate a position to work at the end of the period (Northvolt, 2023). LKAB is also offering internships and study visits which show a clear focus on developing learning opportunities at an early stage (LKAB, n.d.). LKAB Academy Foundation is an initiative with the goal of supporting different educational development projects, strengthening the overall knowledge of the domestic supply chain (LKAB, n.d.). Domestic educational opportunities are in many ways made possible through the governmental agency Swedish Board of Student Finance, which offers several different solutions in order to promote and finance further education (CSN, n.d.).

There are similarities between companies offering educational programs in both the current and the domestic supply chain. However, we argue that the support from the Swedish Board of Student Finance should be seen as a promoter of the already established educational system within the domestic battery supply chain. Therefore, the switch to a fully domestic battery supply chain would enhance the learning opportunities and therefore have a positive impact.

4.4.5 SDG5 - Gender equality

We argue the final impact assessment of SDG5 is that a domestic supply chain has an *indirect positive impact*. The GII-value is applied to assess a Swedish domestic battery supply chain and its' impact on SDG5. Sweden ranks 4th with a GII-value of 0.023 in the GII. Comparatively, the world average is a GII-a value of 0.465 (United Nations Development Programme, 2023). Sweden is one of the most equal nations in the world based on this data. However, equality in Sweden is still problematized and questioned. (Gillberg, 2019) argues that although many formal restrictions on women in Sweden have been removed, inequality remains. The comparison of the SDG impact assessment from the domestic to current supply chain result in an *improvement and a positive impact*.

The assessment for the current supply chain was an indirect negative impact on SDG5 as the countries active in the supply chain hold a variety of ranks in the GII with several countries showing inequalities. The report by Abrahamsson et al. (2014) is largely based on studies performed in Sweden. Abrahamsson et al. (2014) present several problematic areas in terms of gender equality in the mining industry, such as discrimination, harassment and restrictive norms. Gillberg (2019) argues that there are inequality issues such as sexual harassment, salaries, parental leave and how resources in society are divided between men and women in Sweden. Furthermore, inequality remains in social structures which are informal (Gillberg, 2019).

Comparing Sweden to the largest countries in the Li-Ion battery supply chain, it is clear that a domestic supply chain would have a positive impact on SDG5. Some of the countries within the supply chain rank rather high, for example, Canada and Australia. However, the dominant country China where most of the largest actors are active has a GII-value of 0.192 and ranks 48th in the world (United Nations Development Programme, 2023). Based on the assessment for global sourcing versus the assessment for domestic sourcing, we argue that a domestic supply chain would have a positive impact SDG5.

4.4.6 SDG6 - Clean water and sanitation

We argue that the final impact assessment of SDG6 from a domestic supply chain is an *indirect negative impact*. In Sweden, there are regulations already in place together with future developments of these connected to waste management and mining. The comparison of the SDG impact assessment from the domestic to current supply chain result in a *minor improvement and a positive impact.*

The assessment of SDG6 for the current battery supply chain was a direct negative impact. This was argued through the extensive water usage connected with the extraction of lithium from brines (Liu & Agusdinata, 2020; Sadik-Zada et al., 2023). Furthermore, there are risks of water pollution in the surrounding areas of waste dumps, where a measurement showed 3-79 times the MPC of nickel in the closely positioned water bodies of the Allarechensk Copper-Nickel Mining Waste Dump in Russia (Nevskaya et al., 2019).

Regarding Sweden's environmental work, Respondent B states that:
"*Detta gäller även på miljösidan, vi är duktiga på miljöteknik. Vi har också en miljölagstiftning som ställer höga krav, vilket är ett måste för att de ska kunna operera.*" [This also applies to the environmental side, we are good at environmental technology. We also have environmental legislation that sets high standards, which is a must for them to be able to operate.] (Respondent B, personal interview, March 30th, 2023)

This statement is supported by the extensive legislation regarding environmental aspects and sustainable technologies in Sweden. An example directly connected with the battery supply chain is the waste management ordinance which was issued in 2020 (Klimat- och näringslivsdepartementet, 2020). The ordinance sets regulations on municipalities and private companies to be able to trace waste by weight, mode of transport when it was transported and the actor responsible for the end management (Klimat- och näringslivsdepartementet, 2020). There are already laws issued regarding waste from sulphide ores. The sulphide ores are classified as dangerous which requires organizations to follow additional regulations when handling the ore (Klimat- och näringslivsdepartementet, 2020). These extensive regulations should be considered a direct positive impact on SDG6, decreasing the risks of pollution from waste in surrounding water bodies connected to mining and further downstream activities.

Expansion of the battery supply chain poses challenges to the environment. This is presented in Naturvårdsverket (2023) where the exponential growth risks an increase in pollution of surrounding soil and water bodies, strongly connected with the mining of critical resources. Furthermore, Naturvårdsverket (2023) presents that the environmental damage extraction might have in the future is highly dependent on the demand and development of the critical minerals, where the extraction takes place, and how well the regulations of the mining industry can minimize the effects.

There are several areas that could be seen as positive impacts on SDG6 in the case of a switch to a domestic battery supply chain. As previously discussed in SDG2 (see Section 4.4.2) the challenges connected with extensive water usage of lithium extraction from brines will not be the case for Sweden, due to the deposits being pegmatites (United Lithium, n.d.). By positioning the whole battery supply chain in Sweden, all actors would also be obliged to follow the waste management ordinance, taking a holistic approach in every part of the supply chain. This should also be considered positive on SDG6 since the risk of pollution connected to waste in the environment will be lower. The overall assessment is that in the context of SDG6 with the connected targets, a switch to a fully domestic battery supply chain will have a positive impact on the goal.

4.4.7 SDG7 - Affordable and clean energy

We argue that the final impact assessment for a domestic supply chain in Sweden is a *direct positive impact* on SDG7. The Swedish energy mix consists of 59% renewable energy sources based on the UN definition of renewables (UN, 2022). The comparison of the SDG impact assessment from the domestic to current supply chain result in an *improvement and a positive impact.*

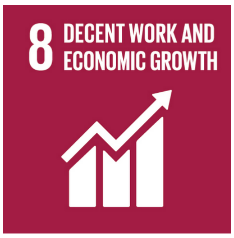
The conclusion for the current supply chain was that it had a direct negative impact on SDG7. The largest countries in the current supply chain had on average 15% renewable energy within their energy mix. Respondent B said this in regard to the Swedish energy mix:
"*En annan sak som särskiljer oss, är att vi har en annan energimix, vi släpper ut lite CO_2 jämfört med andra länder.*"[Another thing that distinguishes us is that we have a different energy mix, we emit little CO_2 compared to other countries.] (Respondent B, personal interview, March 30th, 2023)

This statement is supported by data from the International Energy Agency (2022j) which shows an energy mix in Sweden consisting of 43% hydropower, 31% nuclear power, 16% windpower, 9% geothermal power and 1% solar. This amounts to 59% renewable energy. This is a number that continues to increase in Sweden with more solar- and wind power underway (Swedish Energy Agency, 2022). What should be noted is that Sweden's energy sources have a very low ghg-footprint. Swedens emissions are therefore very low in the energy-sector. With all parts of the supply chain requiring energy, this can be seen as a positive aspect of a domestic supply chain. The average share of renewable energy sources in the world is 28.7% compared to Swedens 60%, this would lead to a large improvement in the amount of renewable energy used within the Li-Ion battery supply chain (International Energy Agency, 2022g).

The targets of SDG7 focus on providing access to affordable, reliable and modern energy services, and also increasing the share of renewable energy in the global energy mix. A full domestic supply chain increases the clean swedish energy mix in the supply chain and therefore directly positively impacts the energy mix used. As the average energy mix of all the countries in the current supply chain is at 15%, the swedish 60% would lead to an increase in renewable energy used in the supply chain in the world context. The increased energy demand can be expected to further pressure the development of clean energy and extraction tools using clean energy in Sweden showing additional positive impacts on the goal.

Comparing the theoretical domestic supply chain to the current Li-Ion battery supply chain, it is clear that the energy mix in Sweden is better from the viewpoint of SDG7. The conclusion for SDG7 in the current supply chain is that the impact is directly negative compared to Sweden, which we argue is directly positive. Although some of the largest countries in the current supply chain have larger shares of renewables, for example, Canada (65% renewables (International Energy Agency, 2022b)), it is still clear that if a domestic supply chain would be realized in Sweden, this would comparatively have a positive impact.

4.4.8 SDG8 - Decent work and economic growth



We argue that the final impact assessment of SDG8 from a domestic supply chain is a *direct positive impact*. Economic growth has recently been halted by covid-19, the Suez-canal blockade and Russia's invasion of Ukraine (Barbieri et al., 2020; The Visual Journalism Team BBC News, 2022; Theo Leggett, 2021). These impacts have recently been highlighted by the UN (n.d.) as the most problematic area for SDG8. The comparison of the SDG impact assessment from the domestic to current supply chain result in a *minor improvement and a positive impact.*

The impact for the current Li-Ion battery supply chain was as assessed indirectly positive for SDG8. Although questions can be raised in terms of mining safety for the current supply chain, the economic benefits of manufacturing industries and the mining industry should be emphasized (Hajkowicz et al., 2011; Walser, 2002).

Reshoring has emerged as a new option to combat the aforementioned geopolitical developments (Ashby, 2016; Tate, 2014). Reshoring can provide a more economically sustainable option (Ashby, 2016). Better sustainable competitive advantages can be expected which in turn leads to better and more sustainable economic development as reshoring provides supply chain resilience (Ponomarov & Holcomb, 2009). The concentration of battery minerals in a few countries is a considerable issue within the current battery supply chain, which particularly is the case for lithium (Egbue & Long, 2012). Domestic sourcing would be a form of reshoring that would increase the supply chain resilience of the Li-Ion battery supply chain. Although supply chain resilience in itself does not increase economic growth, supply chain resilience provides long-term opportunities and security for supply chains.

Nickel is a toxic material and impacts worker safety negatively, as concluded in Section 3.2.8. The same is true wherever nickel is extracted as the characteristics of the metal remain the same. However, worker safety and how toxicity is handled can vary widely between countries. When respondent A was asked how Swedish institutions handle hazardous or toxic processes the interviewee responded with the following:
"*Det beror väl på. Vi har höga krav i Sverige men det går. Blir väl ofta att man flyttar till ett annat land istället.*"[I guess it depends. We have high requirements in Sweden, but it is possible. You often end up moving to another country instead.] (Respondent A, personal interview, March 23rd, 2023)

A potentially toxic process can be assumed to be relatively safe as Sweden has high standards for the handling of hazardous processes (see Section 4.4.3) (Klimat- och näringslivsdepartementet, 2020). However, there can always be issues even if requirements are high. The high standards should be seen as an attributionally positive aspect of hazardous or toxic material handling in Sweden. A domestic supply chain would increase supply chain resilience and secure local economic development. This should also be a positive impact on Sweden's strong institutions and laws handling worker safety. Comparing a potential domestic supply chain to the current Li-Ion battery supply chain we argue that a switch would have a positive impact.

4.4.9 SDG9 - Industry, innovation and infrastructure

The final impact assessment for the domestic supply chain is a *direct positive impact* on SDG9. Developments are seen in the Swedish battery industry, both in terms of infrastructure and innovation of new technologies. The comparison of the SDG impact assessment from the domestic to current supply chain result in *no difference and no impact.*

The impact of the current Li-Ion battery supply chain was assessed as a direct positive impact on SDG9 with the connected targets. This was due to the extensive work and united front toward bringing industry and technology development forward.

There are clear similarities in technology advancements between the current and domestic possibilities, especially in the mining context which is described by Respondent B:
"*Sverige siktar ju på att vi ska alltid vara bäst i världen på allt vi gör. Det gäller*

även i gruvsammanhang, det har lett till att vi exporterar mycket gruvteknik. Exempelvis från Ericsson, som utvecklade 5G inuti gruvor i Sverige. Vi är teknikdrivande och innovativa." [Sweden always aims to be the best in the world in the things we do. This is also true within the mining context, which has led to us exporting a lot of mining-technologies. For example Ericsson, whom developed 5G inside the mines of Sweden. We are technology driven and innovative.] (Respondent B, personal interview, March 30th, 2023)

This is shown in (Wallbrandt, 2023) where the Swedish mining company LKAB is planning the development of an industry park in Luleå, planned to operate in 2027. The industry park has a focus on developing fossil-free and circular solutions for the by-products of iron ore extraction but is also strongly connected with the new findings of Rare-earth elements (REE) (LKAB, 2022). This is a clear example showing Sweden's strong position for innovation in the mining industry. Development and innovation are seen throughout the whole Li-Ion battery supply chain in Sweden. An example of this is the company Northvolt, which is planning on building a battery plant with the capacity of supplying 500,000 EVs annually with batteries (Business Region Göteborg, 2022). Furthermore, the joint venture between Northvolt and Volvo Cars also has planned a research and development branch positioned in Gothenburg (Business Region Göteborg, 2022).

It is difficult to ascertain any SDG impact differences between the two alternatives when comparing the theoretical domestic Li-Ion battery supply chain to the current Lithium-ion (Li-Ion) battery supply chain. It is clear that both alternatives have shown a positive impact on SDG9 with innovations and developments taking place. A clear focus on developing sustainable solutions and introductions of new research and development centers connected to the EV can be seen. However, as both of the impacts are assessed direct positive, we argue that a switch to a fully domestic supply chain of Li-Ion batteries has a negligible impact on SDG9.

4.4.10 SDG10 - Reduced inequalities

10 REDUCED INEQUALITIES

We argue that the final impact assessment of SDG10 from a domestic supply chain is *no impact*. Many of the targets have higher relevance related to SDG1, No Poverty and SDG5, Gender Equality. The comparison of the SDG impact assessment from the domestic to current supply chain result in *no difference and no impact*.

The current Li-Ion supply chain was assessed to have no impact on SDG10 as the relevance of the supply chain connected to the targets of SDG10 was minimal. There are no attributes relating to inequality among countries when analyzing a domestic supply chain as it only involves one actor. Therefore, inequality among countries has no impact on SDG10. Furthermore, a domestic supply chain would not increase inequalities among countries as it is assumed that no production would be reduced or moved by creating a domestic supply chain. As there are no significant differences between a global or domestic supply chain, a change from the current to a domestic supply chain is assessed as having no impact on SDG10.

4.4.11 SDG11 - Sustainable cities and communities

11 SUSTAINABLE CITIES AND COMMUNITIES

We argue that the final impact assessment of SDG11 from a domestic supply chain is *no impact*. Many of the targets intersect other SDGs and there are no identified positive nor negative impacts for a domestic supply chain. The comparison of the SDG impact assessment from the domestic to current supply chain result in a *minor difference and a positive impact*.

The current supply chain was assessed to have an indirect negative impact on SDG11. Many of the targets are intersected by SDG3, SDG6, SDG7, SDG8 and SDG12.

In the Background for Lithium (see Section 1.4.3) it was found that water pollution is one of the largest risk factors relating to lithium-mining (Crespo-Cebada et al., 2020). In regards to water and Swedish mining, respondent B said the following: *"De här gruvorna, som är Europas största dagbrott, vi har miljökonsulter som har kollat på vatten, de hittar ingenting 3km nedströms från gruvan."* [These mines, which are Europe's largest open-cast mines, we have environmental consultants who have looked at the water, they find nothing 3km downstream from the mine.] (Respondent B, personal interview, March 30th, 2023)

The mine discussed in the interview is the Aitik-mine in Lappland, Sweden. The high standards applied in Sweden can be expected to lower the impact on nearby cities and communities for open-pit compared to the situation in other countries. This in turn relates to Sweden's tough environmental and worker legislation as discussed in section 4.4.8 (Klimat- och näringslivsdepartementet, 2020). Based on this it is clear that the negative effects presented for the current supply chain is handled differently in Sweden. The impact on SDG11 can be seen as negligible compared to the current supply chain and therefore assessed as no impact.

4.4.12 SDG12 - Responsible consumption and production

We argue that the final assessment is a *direct positive impact* on SDG12 from the domestic battery supply chain. The respondents show extensive work towards solving the challenges of a domestic supply chain combined with the incorporation of regulations and green electricity. The comparison of the SDG impact assessment from the domestic to current supply chain result in *no difference and no impact*.

The impacts from the current battery supply chain were assessed to have a direct positive impact on SDG12 and the connected targets. This was largely due to the work to meet the demand of EV batteries and also to follow up on standards, such as the battery durability standard, imposed March 2022 (International Energy Agency, 2022e).

Respondent B discussed Sweden's position in the battery market as the following:
Redan idag är vår produktion, den har ett lägre koldioxiduttryck än någonstans i världen. Finland har också så. Det som produceras här är superbra, industrin tar ytterligare steg. [Already today, our production has a lower carbon footprint than anywhere in the world. Finland also has that. What is produced here is super good, the industry is taking further steps.] (Respondent B, personal interview, March 30th, 2023)

The high standards in terms of regulations which were discussed in SDG3 (see Section 4.4.3 supported by this statement. The relatively green electricity mix of Sweden discussed in SDG7 (see Section 4.4.7) together with the standards already shows the values and responsibility within the production. We argue that the domestic battery supply chain will incorporate green electricity together with the need to follow the regulations, which should be considered as a direct positive impact on SDG12. However, there are questions raised regarding the challenges connected with increased costs from a full domestic battery supply chain, discussed by Respondent C:
The raw material has a super high share of the cost of the overall battery cell, it is somewhere beyond 60%, and 60-90% is from the raw material cost. For that cost to be located in Sweden I can just imagine it would be increased directly. The question is, who is ready to pay for this? (Respondent C, personal interview, March 31st, 2023)

There are most likely increased costs of production in a domestic battery supply chain as stated by respondent C. However, we argue that this could incentivize technology advancements in order to bring down costs and optimize responsible production. An example of this is the need for new efficient refineries nearby Rönnbäcken which would be the source of nickel (see chapter 4.1).

Both the current and domestic supply chain is assessed to have a direct positive impact on SDG12. Sweden's sustainable energy mix and demanding regulation of the domestic supply chain could be considered better than the current supply chain. However, we argue that within the scope of SDG12, the work towards responsible production will continue in a rapid phase in both alternatives. Therefore the impact of the change for SDG12 would be negligible.

4.4.13 SDG13 - Climate action

We argue that the final impact assessment of SDG13 from a domestic supply chain is *no impact*. The domestic supply chain in Sweden would have an impact on SDG13, however it can be seen as negligible and not at the same degree as the current battery supply chain. The comparison of the SDG impact assessment from the domestic to current supply chain result in an *improvement and a positive impact.*

The conclusion for the SDG-analysis of the current supply chain was that global sourcing has a direct negative impact on SDG13. The largest impacts with relation to the battery supply chain stem from various kinds of ghg-emission sources as it is at the center of SDG13.

With 24.2% of ghg-emissions originating from industry (Ritchie, 2020), Sweden's energy-mix of energy sources with a CO_2-footprint is highly beneficial (see Section 4.4.7). The importance of this is exemplified by respondents B and D:
"*We try to use renewable energy to the extent possible.*" (Respondent D, personal communication, April 4th, 2023)

"*Det är några saker i en gruva som tar mycket energi, malmning/krossning, ventilation (speciellt om det är djupt). Kan man göra det med CO_2-neutral energi, och köra truckarna med batteri istället för diesel/bensin, så har man kommit långt på vägen. Redan idag är vår produktion, det har ett lägre koldioxiduttryck än någonstans i världen, Finland har det också så. Det som produceras här är superbra, industrin tar ytterligare steg, till exempel LKAB, SSAB osv som tar sådana steg.*" [There are a few things in a mine that take a lot of energy, ore crushing, ventilation (especially if it is deep). If you can do it with CO_2-neutral energy, and run the trucks with batteries instead of diesel/gasoline, you have come a long way. Already today, our production has a lower carbon footprint than anywhere else in the world, including Finland. What is produced here is super good, the industry is taking further steps, for example LKAB, SSAB etc. who are taking such steps.] (Respondent B, personal communication, March 30th, 2023)

It is clear that practitioners in Sweden are working on reducing industrial CO_2-emissions through the respondent's quotes. It is highly beneficial to produce in

Sweden as production is one of the main sources of ghg-emissions in the production of EV-batteries. Furthermore, 74% of the total ghg-emissions comes from only a few steps in battery cell production (Degen & Schütte, 2022). This would be drastically reduced if performed in Sweden. Therefore, mineral extraction, which was stated by respondent D but also together with the processing, are some examples from the supply chain where a domestic supply chain would be highly beneficial.

The concentration of consumption and production of EV-batteries into a smaller geographical area would be beneficial for SDG13 as concluded in section 3.2.13. 16.2% of all ghg-emissions originate from the transport-sector (Yoro & Daramola, 2020), which could be drastically reduced if less transport together with alternative means of transport is used. Transport domestically within Sweden would be beneficial with Sweden's large electrified rail network and a low-CO_2 energy mix. Based on this analysis, the comparison between the current supply chain and a domestic supply chain concludes in a positive change from a direct negative impact to a no impact scenario. A domestic supply chain would therefore be beneficial for SDG13.

4.4.14 SDG14 - Life below water

The final impact assessment from a domestic supply chain is assessed as *no impact* and there are no specific attributes that would be vastly different in Sweden compared to the current supply chain. The comparison of the SDG impact assessment from the domestic to current supply chain result in *no difference and no impact.*

Life below water is one SDG where the Li-Ion battery supply chain has negligible impact. The assessment of the current supply chain is that it has no impact and can be seen as negligible. As argued in Section 3.2.14, Life below water, maritime shipping have the largest impact on this particular SDG which would not be a factor in Sweden based on the designed domestic supply chain. Although this negative factor is not relevant in Sweden, there are no positive factors either. With no significant differences, we argue this remains as no impact.

4.4.15 SDG15 - Life on land

We argue that the final impact assessment of SDG15 from the domestic supply chain is an *indirect negative impact.* Increased mining activities show direct negative impacts on the local environment. However, there is a collaborative and responsible approach with extensive regulation to minimize the impacts on SDG15. The comparison of the SDG impact assessment from the domestic to current supply chain result in a *minor improvement and a positive impact.*

The assessment of SDG15 in the context of the current battery supply chain, there is a direct negative impact on the goal. The battery supply chain shows risks of pollution, deforestation, and damages the biodiversity, especially connected with the extraction of ores (see Section 3.2.15).

Respondent B discussed Swedish mining in the context of a domestic battery supply chain,:
"*Det är 0.04% av landytan i Sverige som är gruvor, och det är väldigt lite om man jämför med golfbanor, vägar eller jordbruk och det gör väldigt mycket nytta. Jag skulle säga att Sverige klarar det, och naturen klarar det.*" [There is 0.04% of the land area in Sweden that is mined, and that is very little compared to golf courses, roads or agriculture and it does a lot of benefit. I would say that Sweden can handle it, and the nature can handle it.] (Respondent B, personal communication, March 30th, 2023)

Mining in Sweden does currently not account for extensive land usage as seen from this statement, which is an important factor in the context of SDG15. There are still challenges such as deforestation if new mines open with an introduction of a domestic battery supply chain. Bergbyn and Rönnbäcken are the most promising mining locations for lithium and nickel (see Section 4.2 and 4.1). These locations are areas where mining activities have taken place over a long period of time. This indicates that expanding the mining activities within these areas might significantly reduce the harm to the surrounding environment compared to opening up brand-new mines. Mines might risk long-lasting environmental damage to communities if poorly closed down, affecting the surrounding biodiversity negatively (International Energy Agency, 2022h). With the already established proposal of Bergbyn and Rönnbäcken, this also could generate a positive impact in the surrounding areas.

According to Naturvårdsverket (2023) there might be potential difficulties to measure the future impact of mining extraction. The environmental damage mining might have in the future is highly dependent on the demand and development of critical minerals (Naturvårdsverket, 2023). Furthermore, the impact is influenced by where the extraction takes place and how well the regulations of the mining industry can minimize the effects (Naturvårdsverket, 2023). However, respondent A showed

a shift towards more responsibility:
"*En generell svårighet är att vi ofta löser problem för kommande generationer. Det är den här generationen som behöver ta kostnaden för det. Lätt att tänka att tidigare generationer är skyldiga. I miljöfrågan har man ofta tagit frågan långsamt framåt. Finns en annan ton nu, mer samverkan mellan näringsliv och miljö.* [A general difficulty is that we often solve problems for future generations. It is this generation that needs to bear the cost of it. It is easy to think that previous generations are guilty. When it comes to the environment, the issue has often been taken slowly. There is a different tone now, more collaboration between business and the environment.] (Respondent A, personal interview, March 23rd, 2023)

A clear focus on minimizing the risk of harming biodiversity in the already established partial battery supply chain can be seen in the statement by respondent A. An example of this is shown in the expansion of Volvo Cars new battery plant in Mariestad. Since the discovery of a strictly protected species of water salamanders, extensive work has been carried out to build new water bodies and relocate the endangered species away from the planned building sites (Dagens Industri, 2023). This is a result of Sweden's strict environmental regulation (Klimat- och näringslivsdepartementet, 2020, 2022). The focus on responsibility of companies and governmental actors to act in minimizing the environmental damage related to biodiversity is growing as explained by respondent A. This notion is also explained by respondent B in relation to SDG6 (see section 4.4.6) where the interviewee describes the focus on regulations for green technologies.

The clearest difference between impacts on the current and domestic supply chain is the high standards and regulations in Sweden. There are still challenges with SDG15 connected to the mining. However, based on the statements and a responsible approach of companies, we argue that a switch should have a positive impact on SDG15 overall.

4.4.16 SDG16 - Peace, justice and strong institutions

We argue that the final impact assessment of SDG16 from a domestic supply chain is *no impact*. Due to the already strong and inclusive institutions in Sweden, we argue that expanding the domestic battery supply chain will have no impact. The comparison of the SDG impact assessment from the domestic to current supply chain result in a *minor improvement and a positive impact.*

For SDG16, the impact from the current battery supply chain was determined to have an indirect negative impact on the goal. This was largely due to the impact of the sourcing of nickel from Russia, which has a direct negative impact from the invasion of Ukraine in the scope of SDG16.

Respondent A discussed the sustainable mindset which can be seen in Sweden: ”*Antingen i ett medlemsland i EU, eller utanför då ska det vara en mutual benefit för third party. Vi ska inte bara gå in tidigare och ta resurser utan det ska komma med fördelar för andra länder. Det gäller också processbearbetning.* [Either in a member state of the EU, or outside, then it should be a mutual benefit for third parties. We should not just go in earlier and take resources, but it should come with benefits for other countries. This also applies to processing.] (Respondent A, personal interview, March 23rd, 2023)

This statement gives a strong indication of the mindset of key actors within Sweden. There are strong incentives to create a unified front within technology advancements as discussed in SDG9 (see Section 4.4.9). Furthermore, there are regulatory authorities, discussed in SDG3 (see Section 4.4.3) enforcing high standards and guidance.

There are clear positive impacts from analyzing the switch from the current to a domestic battery supply chain. Removing the indirectly negative aspects from Russian nickel sourced into the supply chain should be considered to have a positive impact in terms of SDG16. The domestic supply chain would remove the future risks of conflicts connected to water usage, which also should be considered a positive impact. Even though some of the risks are considered in the future, we argue that the switch should be seen as positive in the context of SDG16. This is a result of a domestic approach based on high standards and regulations, with regulatory authorities monitoring the battery supply chain.

4.4.17 SDG17 - Partnership for the goals

We argue that the final impact assessment from a domestic supply chain is *no impact* on SDG17 as a domestic supply chain does not impact international cooperation in a significant negative way. The comparison of the SDG impact assessment from the domestic to current supply chain result in a *minor improvement and a positive impact.*

For SDG17, the assessment of the current battery supply chain resulted in an indirect negative impact (see Section 3.2.17). SDG17 aims to emphasize cooperation between countries in various forms. Creating a domestic supply chain is not beneficial for international cooperation and can be argued to go against what SDG17 aims at achieving. However, this is negligable. Judging Sweden from a cooperation standpoint alone though shows strong connections to various organizations throughout the world, for example in the OECD. As the assessment for the current Li-Ion battery supply chain remains indirectly negative, the domestic supply chain would comparatively be a better alternative.

4.4.18 SDG impact summary of the domestic supply chain

The SDGs show different results in terms of impacts connecting to the Li-Ion battery supply chain similar to the conclusions drawn for the current supply chain (see Section 3.2.18). The results for the domestic supply chain are visualized in fig. 4.3 with either a direct positive impact, an indirect positive impact, no impact, an indirect negative impact, or a direct negative impact. The full pdf created by the SDG assessment tool can be found in Appendix B. Just as the summary of the SDG impacts performed for the current supply chain, this summary has been performed with varying empirical bases. The empirical base is visualized below the SDG impact assessment result as numbers.

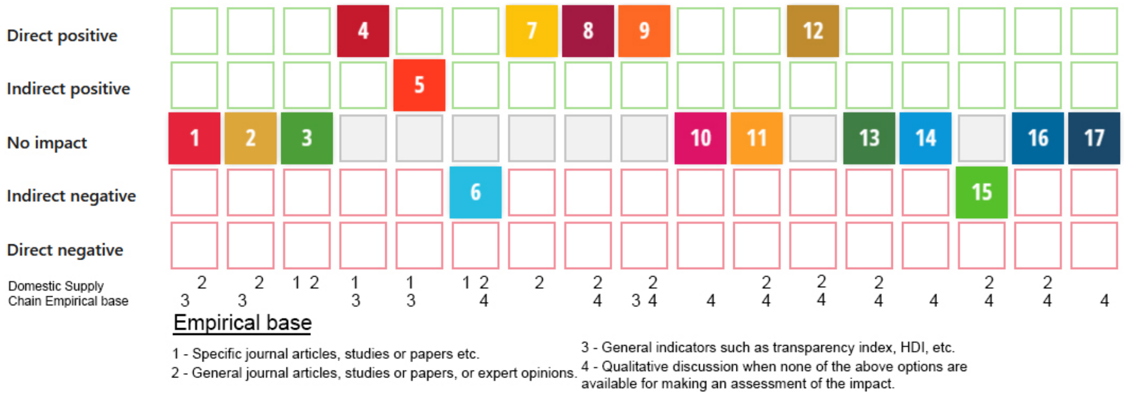


Figure 4.3: *All resulting assessments for the domestic supply chain. Summarized with direct positive, indirect positive, no impact, indirect negative or direct negative impacts. This graphic has been created by using the tool provided by GMV.*

The two analyses were combined to compare the results and the differences a domestic supply chain would induce. The result of this combination can be seen in fig. 4.4. The figure shows the domestic supply chain assessment as a framed rectangle whilst the current supply chain is a filled rectangle. If the current and the domestic assessment are equal, the rectangle is striped. Similar to fig. 3.6 and fig. 4.3, the numbers represent the empirical base used for that particular SDG.

As seen in fig. 4.4, a general conclusion is that the SDG impact assessment for the domestic supply chain has sources with a lower priority in the empirical base. This is logical since the domestic supply chain is not realized or in place. As the current supply chain is based mostly on studies, indices, and data this uses more of the higher priorities in the empirical base as per the ranking method with four different steps explained in chapter 2.

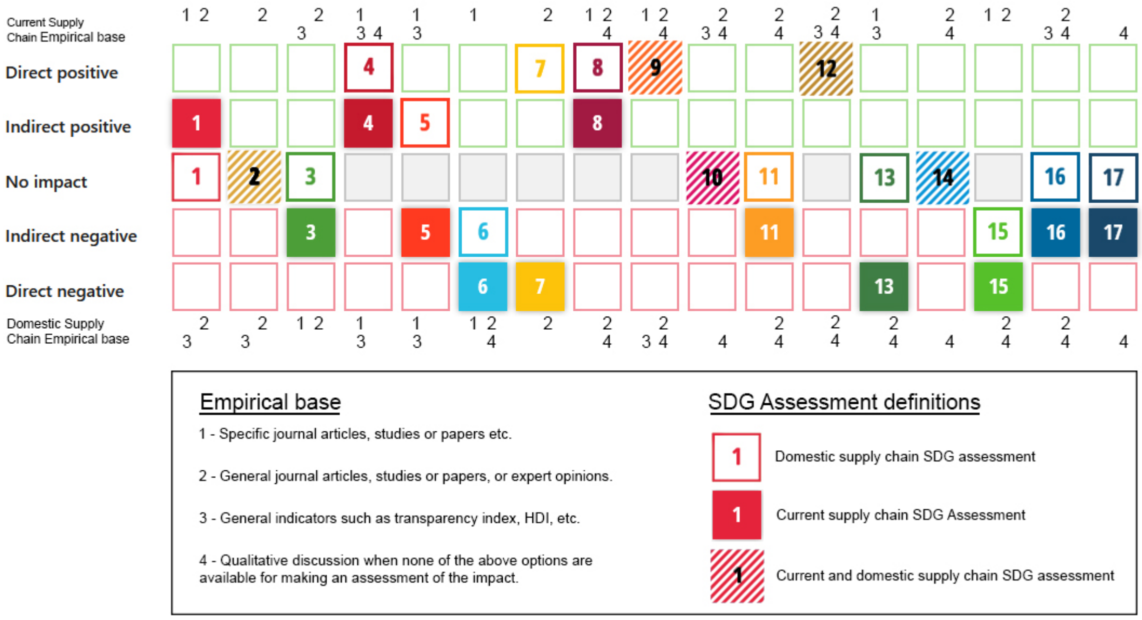


Figure 4.4: *The domestic supply chain impact analysis combined with the current supply chain.*

The general conclusion for the comparison is that all SDGs would either be unchanged or improved in the case of a domestic supply chain. Nine of the SDGs changed in the result. All changes were improvements in terms of impacts. What should be considered regarding this is that in many rankings and indices, Sweden often ranks rather high so we argue these results are to be expected. An example of the high ranking of Sweden can be seen J. Sachs, Kroll, Lafortune, Fuller, and Woelm (2022). This was further underlined by the responses from the interviews with experts. This is exemplified by respondent A in the context of discussing the possibilities of mining and production in Sweden:
"*Vi har höga krav i Sverige men det går. Blir väl ofta att man flyttar till ett annat land istället.*"[We have high requirements in Sweden, but it is possible. You often end up moving to another country instead.] (Respondent A, personal interview, March 23rd, 2023)

Our interpretation from this quote was that most of the time it is possible to have production in Sweden, but due to the high standards required, the price is often higher and therefore not economically competitive compared to other countries. Although there might be higher costs, an area of expected improvement is within traceability. The importance of traceability was discussed several times by Respondent D:
"*Within the existing battery chemistry, we do have the need to continue to use certain raw materials which are continuously associated with risks, inclusions, human rights, biodiversity, you name it.*" (Respondent D, personal interview, April 4th, 2023)
"*We place a lot of emphasis on where they are sourced from and what kind of risks are associated. We think about forced labor, corruption, biodiversity, areas of conser-*

vation such as rainforests, and so on, we will focus in the future on audits ourselves." (Respondent D, personal interview, April 4th, 2023)

The importance of traceability in order to minimize the battery supply chain risks is shown through these statements. Traceability should be simplified from a change to a domestic battery supply chain, due to the decrease in geographical as well as cultural distance between the actors. This would allow audits and policies more rapidly being implemented. Furthermore, there are strict regulations on waste management demanding the traceability of weight, change of ownership, and end management in Sweden (Klimat- och näringslivsdepartementet, 2020). With the large number of regulations connected to environmental and health impacts a change to a fully domestic battery supply chain should have a positive impact overall compared to the current battery supply chain.

There are clear benefits and drawbacks for a domestic supply chain as highlighted by this SDG-analysis. Furthermore, there are macroeconomic factors and regulatory factors such as traceability which is important to take into consideration as well.

5 Conclusion

The current Li-Ion battery supply chain as well as a hypothetical domestic supply chain has been examined through the lens of the United Nations Sustainable Development Goals. The basis for this assessment has been through the following research questions:

RQ.1 - What benefits and drawbacks does the current supply chain have related to the United Nations Sustainable Development Goals?
RQ.2 - What implications would a re-designed supply chain for battery production with locally sourced materials in Sweden have on the United Nations Sustainable Development Goals?

The areas for benefits and drawbacks are examined throughout chapter 3, Li-ion battery supply chain to answer *RQ.1*. The benefits and drawbacks of locally sourced battery materials in Sweden are examined in chapter 4, Domestic supply chain which answers *RQ.2*. With the wide variety of different areas, which the SDGs cover, this should be seen as a holistic view of the implications of having some, or all of the battery supply chain located in Sweden. There are several areas that would be beneficial, where the most impacted SDGs include SDG7, Affordable and Clean energy, SDG5, Gender equality and SDG13 Climate Action. What should also be considered is the increased demand expected within the EV-market. This includes the importance of increasing the supply of batteries for the passenger car fleet. The current extraction of materials such as lithium and nickel will not be enough to cover the demand based on current forecasts. This is true if new, incoming mines are considered as well. Therefore, it is essential that the potential supply shortage is addressed.

This thesis spans a number of subjects and is highly interdisciplinary. What brings these fields together is supply chain management and sustainability. There is a required shift within the field of supply chain management from a focus on reducing costs and increasing profits, towards a more long-term view with sustainability in mind. Sourcing decisions is a central aspect of this idea, as sourcing influences many aspects such as supply chain resilience, opportunities for freight transport systems, and vertically integrated supply chains through collaboration. We believe the benefits shown from an SDG-perspective further reinforces the idea that reshoring and local sourcing provides sustainable competitive advantages. This is because there are fewer negative SDG-impacts with domestic sourcing compared to global sourcing. The UN underlines that the latest geopolitical developments such as the invasion of Ukraine and covid-19 have impacted the SDGs in a variety of ways and the macro-economic impact of these events. This has also clearly been shown by the analysis provided in section 3. We conclude that local sourcing in Sweden can be beneficial for the SDGs.

It can also be concluded that the validity of an entirely domestic supply chain is uncertain. This statement is based on the aforementioned conclusions with information attained from the interviews and the mapped supply chains. One of the identified issues is that it takes 10-15 years to get a new mine operating. This means that active extraction within Sweden would not be possible until around 2030 to 2040. Another issue with the domestic supply chain lies in the uncertain nature of mineral reserves in Sweden. There is a high potential for more reserves to exist than currently known, however, increased prospecting is required. Furthermore, one of the largest issues is cost. All experts interviewed were in agreement that the largest challenge in Sweden for a domestic Li-Ion battery supply chain is cost. All were in agreement that it would be great with a fully domestic Li-Ion battery supply chain, however, the question is the economic viability. A remaining option is if parts of a supply chain can be established domestically, which is a more promising prospect.

As this thesis has underlined, the capabilities upstream within the current supply chain are highly concentrated to a few countries. With battery demand increasing rapidly whilst supply is limited, and expected to be further limited the coming decade, the concentration of upstream supply chain activities will be a growing issue. This in turn might impact sustainability as high-demand products with low supply historically have seemed to give way to questionable activities. A clear example of this in the battery supply chain is the concentration of cobalt. If demand rises further, this issue might increase for more core components within the Li-Ion battery supply chain. These are issues that need to be solved in a collaborative fashion with actors working together to find sustainable ways of expanding the EV-market in accordance with the Agenda 2030 Sustainable Development Goals.

5.1 Recommendations

We suggest four main areas for future research. First, we suggest integrating the approach of SDGs further into supply chain management research. As supply chain management often acts on a strategic level, the integration of SDGs is highly functional on a high level as well, which has been shown by the analysis in this thesis. This approach is well suited to handling the complexities of supply chains with a shift in supply chain management from the reduction of cost and profit to further incorporating sustainable supply chains. Second, we suggest conducting similar research in other areas than the EV battery market. This is suggested to verify the integrity of the method applied and the combination of SDGs and supply chain management. This could be done in a variety of other markets and areas where the global supply chain is the norm and where supply chain resilience might be an issue such as for example the semi-conductor-market, small-scale electronics, etc. Third, we suggest further developing the method of confidence in the field of supply chain management. As supply chain management often spans a number of fields such as engineering, management, macro- and microeconomics, business economics, and sustainability, the interdisciplinary nature of the field is at the heart of the subject. As this is the case, research on the subject might require a deep dive into a variety of subjects where other expert opinions are essential. Therefore a ranking system and the application of confidence in a variety of fields might be a good solution in order to increase the authenticity and validity of the research conducted. Fourth and last, we suggest conducting similar research on an EU level. Since the validity of a domestic supply chain can be disputed in a number of ways, focusing on the EU level might be more reasonable and provide better opportunities for the battery supply chain for EVs.

For policymakers, we suggest supporting initiatives related to the creation of a domestic Li-Ion battery supply chain within Sweden. This includes for example mining, where granting licenses and improving the process of permissions is essential. Furthermore, it includes granting permissions for the production of factories within the supply chain as well which is essential to the supply chain. Last, we suggest also supporting the expansion of upstream capabilities in the Li-Ion battery supply chain. This is due to a large part of the capabilities in the extraction- and refinement stage is controlled by a small number of actors within the supply chain. This might in turn lead to several issues, and therefore it is essential to expand upon these capabilities.

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A

Appendix A

On the following page the full SDG Impact Assessment for the current supply chain can be found.

SDG IMPACT ASSESSMENT TOOL

Lithium-ion battery supply chain SDG Impact Assessment

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Direct positive									9			12					
Indirect positive	1			4				8									
No impact		2								10				14			
Indirect negative			3		5						11					16	17
Direct negative						6	7						13		15		
Don't know - more knowledge needed																	

Description

This analysis has been conducted more thoroughly within the thesis itself. This is a summary. The largest actors within the supply chain have been considered to lower the complexity of the analysis and to provide a holistic view of the sustainability aspects of the supply chain based in the sustainable development goals.

Strategic choices

These are the prioritised areas that we will take action on.

- [ ] Positive impacts we can strengthen even further
- [ ] Negative impacts we can eliminate or minimise
- [x] Knowledge gaps we need to fill

NO POVERTY

End poverty in all its forms everywhere

Impact

INDIRECT POSITIVE

Motivation

We argue that the assessed impact of the current supply chain is an indirect positive impact. However, SDG8 might provide a better understanding of how the supply chain impacts economic development. The indicators for target 1.4 is broad and aim at measuring the proportion of a population that has access to basic services and the proportion of adult populations with secure rights to land. This definition explains why economic development might be a more relevant indicator for this goal in the context of the battery supply chain. SDG1 aims at ensuring equal rights to economic resources. In the context of the li-ion battery supply chain, this includes not only access to raw materials and natural resources but also to technology and the end product. Mineral deposits are concentrated in small geographical areas which inherently makes their disposition unequal across the world. Furthermore, access to technology is highly nationalized, and in a further respect, in the control of private companies. With technology, geographical areas, and resources being in the control of private companies, this brings competition where the resources are located through land use as exemplified in the salt flats in South America. Within this region, local farmers have to compete for water and land use with companies extracting lithium from brines. However, found that the mining district in general have lower poverty than districts without mining. Therefore mining might help combat poverty.

ZERO HUNGER

End hunger, achieve food security and improved nutrition and promote sustainable agriculture

Impact

NO IMPACT

Motivation

SDG2 have no direct connections to the battery supply chain. SDG2 could have indirect connections with the battery supply chain in terms of pollution, drought, and increased electricity prices. However, in the context of the battery supply chain, the final assessment is that the battery supply chain currently should be considered as having no impact on SDG2 with the connected targets.

GOOD HEALTH AND WELL-BEING

Ensure healthy lives and promote well-being for all at all ages

Impact

INDIRECT NEGATIVE

Motivation

Summarizing SDG3 with the connected targets, overall there is clear relevance with the battery supply chain. There are substantial work towards regulations and standards of traceability and waste management within the battery supply chain which should be seen as a positive impact on the goal and target 3.D. However, the battery supply chain with the increasing demand also follows the increased mineral pollution connected to waste management and extraction. There is a risk of increasing negative health impacts on the surrounding environment and workers if not clear regulations and safety measures are set, which has a negative impact on target 3.9. In addition, as the battery supply chain rapidly increases the need of handling toxic minerals, this should also be considered a negative impact on target 3.9. Overall, the regulations having a positive impact on SDG3 have followed the negative impacts from the battery supply chain. Therefore, the overall assessment of SDG3 is that the battery supply chain has an indirect negative impact on the goal.

QUALITY EDUCATION

Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

Impact

INDIRECT POSITIVE

Motivation

The first area with a positive impact on SDG4 is the existence of the mining industry, creating a positive impact on the surrounding areas. The result from a study by Hajkowicz, Heyenga, and Moffat (2011) shows that mining is positively associated with several areas of life improvement, including educational attainment. The second area which has a positive impact on SDG4 is the direct work of larger companies within the battery supply chain that embrace education for the employees or through other initiatives. This is shown by CATL, one of the world's largest battery actors which have opportunities for education within the company, with no experience required. The initiatives in relation to SDG4 are hard to measure. Though the overall assessment shows that combining both the mining and educational initiatives from the companies mentioned shows an indirect positive impact on SDG4 and the connected targets.

GENDER EQUALITY

Achieve gender equality and empower all women and girls

Impact

INDIRECT NEGATIVE

Motivation

With a wide variety of ranks in the Gender Inequality Index (GII) within the supply chain, there is still a lot of work to do in terms of gender equality to reach the goals of Agenda 2030 and to achieve gender equality. As many of the largest actors ranks rather low in the index, and with a high GII value, the actors in the supply chain are assessed to have an indirect negative impact on SDG5.

CLEAN WATER AND SANITATION

Ensure availability and sustainable management of water and sanitation for all

Impact

DIRECT NEGATIVE

Motivation

Overall, the battery supply chain shows direct negative impact to SDG6 and its targets. Extensive usage of water as well as pollution from the extraction of the minerals are shown to be the most affecting areas with negative impacts. In addition, with the future increasing demand for these minerals, mitigation is required in order to meet these challenges.

AFFORDABLE AND CLEAN ENERGY

Ensure access to affordable, reliable, sustainable and modern energy for all

Impact

DIRECT NEGATIVE

Motivation

The energy mix between the largest actors is highly varied. However, the average of renewable energy sources in the energy mix over the largest actors is 31.5%. Over the supply chain, China is by far the largest actor, and in this case, the share of renewable energy sources is 26.7%. As all different stages of the supply chain consume electricity, everything from the extraction of the ores to the refinement and the production of battery cells, it can be concluded that the lack of renewable energy sources has a large effect on SDG7. With this information, it can be concluded that the current supply chain has a direct negative impact on the sustainable development goal of now.

DECENT WORK AND ECONOMIC GROWTH

Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

Impact

INDIRECT POSITIVE

Motivation

There are benefits and drawbacks to the current supply chain. In terms of workers' safety and the hampering of economic development stemming from low supply chain resilience, it is clearly negative as of now. However, the current development will create further employment opportunities and economic growth, which is positive. Based on this, the assessment is that although work remains to create better working environments and not risk economic development, SDG8 should still be considered as indirectly positive.

INDUSTRY, INNOVATION AND INFRASTRUCTURE

Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

Impact

DIRECT POSITIVE

Motivation

There are clear positive connections between collaborations and governmental policy incentives to bring the development of the EV-industry forward. However, all developments are still connected with several sustainability challenges which continue to increase. In the context of SDG9, strongly relevant to the overall developments. The battery supply chain should be seen as having a direct positive impact on SDG9 due to the united front, bringing research and infrastructure for EVs and batteries forward.

REDUCED INEQUALITIES

Reduce inequality within and among countries

Impact

NO IMPACT

Motivation

Although the li-ion battery supply chain certainly has some impact on equality in the world, compared to other SDGs and the indirect nature of the impacts, SDG10 is assessed to fall within no impact.

SUSTAINABLE CITIES AND COMMUNITIES

Make cities and human settlements inclusive, safe, resilient and sustainable

Impact

INDIRECT NEGATIVE

Motivation

The factors which can impact SDG11 is highly interconnected with SDG3, SDG6, SDG7, SDG8 and SDG12. Many of the factors relating to this goal and the li-ion battery supply chain is consequential rather than attributional. This can be exemplified by that communities are made more sustainable through the results of battery production for EVs. As many of the factors relating to SDG11 however is negative, the final impact assessment for SDG11 is indirect negative.

RESPONSIBLE PRODUCTION AND CONSUMPTION

Ensure sustainable consumption and production patterns

Impact

DIRECT POSITIVE

Motivation

Because of growing demand of EVs and rapid growth of the battery industry, sustainable solutions follows in order to create a balance. Within the battery supply chain, there are clear examples of waste management and solutions to maximize material and mineral efficiency. Therefore, we argue that the battery supply chain has a direct positive impact on SDG12 with the connected targets.

13 CLIMATE ACTION

CLIMATE ACTION

Take urgent action to combat climate change and its impacts

Impact

DIRECT NEGATIVE

Motivation

SDG13 Climate Action consists of five targets aimed at mobilizing towards climate change and raising awareness on climate change. The most relevant target for the li-ion battery supply chain is target 13.2 which aims to integrate measures to combat climate change into the UN member's national policies and strategies. This target more specifically also measures the total GHG-emissions in each country as well as determining the number of countries with specific climate action plans. Looking at the supply chain itself, many of the other SDGs play a part within SDG13. We argue that the li-ion battery supply chain has no impact on the remaining targets of SDG13 except target 13.2 and is therefore considered as no impact. However, as the largest actors in the supply chain have a negative impact on target 13.2, the final assessment for SDG13 is that the current setup of the supply chain has a direct negative impact.

14 LIFE BELOW WATER

LIFE BELOW WATER

Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Impact

NO IMPACT

Motivation

It is clear the current Li-ion battery supply chain has a negative impact on life below water. However, as this is the transport between nodes within the supply chain, we argue this is an indirect negative impact. Furthermore, the battery supply chain is only a minor part of global shipping and is not responsible for all the issues shipping causes. Therefore, the supply chains impact on SDG14 is assessed to be ''no impact'' as this can be seen as negligible compared to other SDGs.

LIFE ON LAND

Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Impact

DIRECT NEGATIVE

Motivation

It is clear that the early stages of the battery supply chain, meaning mining and processing of lithium and nickel, are highly connected with SDG15. Throughout all stages of the mining, there are negative impacts starting from the opening of a mine (deforestation and destruction of the current biodiversity), high amount of water usage for lithium extraction during the active operations (risking desertification and drought), and ending with risk of pollution of the biodiversity from the tailings left behind. The final assessment of SDG15 with the connected targets are that the goal is highly relevant for the battery supply chain, which has a direct negative impact in several of the early stages on the goal.

PEACE, JUSTICE AND STRONG INSTITUTIONS

Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels

Impact

INDIRECT NEGATIVE

Motivation

The current largest impact within the li-ionbattery supply chain for SDG16 is Russia's invasion of Ukraine in 2022. The current supply of nickel is still flowing from the largest actor of battery-grade nickel, Russia. We argue this shows a indirect negative impact of SDG6.

PARTNERSHIPS FOR THE GOALS

Strengthen the means of implementation and revitalize the global partnership for sustainable development

Impact

INDIRECT NEGATIVE

Motivation

Many of the largest actors, Australia, Canada, and Chile are members of the OECD which we argue has an indirect positive impact on SDG17. However, with these issues in the largest actors within the battery supply chain, the final impact assessment is indirectly negative even if minor actors have a positive impact. The reason for assessing this as indirectly negative is due to the scale of the goal itself and the difficulty of fully mapping each instance of collaboration.

B

Appendix B

On the following page the full SDG Impact Assessment for the current supply chain can be found.

SDG IMPACT ASSESSMENT TOOL

Domestic lithium-ion battery supply chain SDG Impact Assessment

Direct positive				4			7	8	9			12					
Indirect positive					5												
No impact	1	2	3							10	11		13	14		16	17
Indirect negative						6									15		
Direct negative																	

Don't know - more knowledge needed

Description

This analysis has been conducted more thoroughly within the thesis itself. This is a summary of that analysis similar to the previous analysis for global supply chains. The largest actors within the supply chain have been considered to lower the complexity of the analysis and to provide a holistic view of the sustainability aspects of the supply chain based in the sustainable development goals.

Strategic choices

These are the prioritised areas that we will take action on.

- [ ] Positive impacts we can strengthen even further
- [ ] Negative impacts we can eliminate or minimise
- [x] Knowledge gaps we need to fill

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1 NO POVERTY

NO POVERTY

End poverty in all its forms everywhere

Impact

NO IMPACT

Motivation

Economic growth might be a more relevant indicator for this goal and that SDG8 might provide a better understanding of its impacts. We argue that a domestic battery supply chain in Sweden would have no impact on SDG1.

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2 ZERO HUNGER

ZERO HUNGER

End hunger, achieve food security and improved nutrition and promote sustainable agriculture

Impact

NO IMPACT

Motivation

Challenges connected with extensive water use of lithium brines will not be a part of the domestic supply chain. Therefore this will not result in future possible conflicts based on water. As of these facts, we argue that the impacts of SDG2 in a domestic li-ion battery supply chain would have no impact, showing few direct connections between the domestic supply chain and SDG2.

GOOD HEALTH AND WELL-BEING

Ensure healthy lives and promote well-being for all at all ages

Impact

NO IMPACT

Motivation

We argue that the final assessment is no impact on SDG3 from the domestic battery supply chain. There are several regulations and authorities present which could be considered a positive impact. However, these regulatory bodies are seen as the response to the negative aspects of the battery supply chain and similar industries to mitigate and control the possible damages from the production.

QUALITY EDUCATION

Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

Impact

DIRECT POSITIVE

Motivation

In the context of a domestic supply chain, there are initiatives throughout the battery supply chain striving towards increasing the knowledge base. For example, at Volvo Cars there are initiatives such as Tekniksprånget which is an internship for students that have finished high school. Furthermore, additional internships and global graduation programs are available at Volvo Cars for students that are at the end of their university studies. At the battery level, similar initiatives to strengthen knowledge are seen at Northvolt which offers a 6 months graduation program, with the goal to offer the graduate a position to work at the end of the period. At the mining level, LKAB is also seen offering internships and study visits which show a clear focus on developing learning opportunities at an early stage. Lastly, LKAB Academy Foundation is an initiative with the goal of supporting different educational development projects, strengthening the overall knowledge of the domestic supply chain \citep{lkabstudent}. Worth mentioning is that domestic educational opportunities are in many ways made possible through the governmental agency Swedish Board of Student Finance, which offers several different solutions in order to promote further education. The final assessment is that a domestic supply chain would incorporate the already highly established educational programs, and therefore should be seen as a direct positive impact on SDG4.

GENDER EQUALITY

Achieve gender equality and empower all women and girls

Impact

INDIRECT POSITIVE

Motivation

Although there is much to say in regard to gender inequality in the world and in Sweden, this thesis focuses on gender inequality in terms of the li-ion battery supply chain. In this respect, to assess a Swedish domestic battery supply chain and its' impact on SDG5, the GII-value is applied. With this, it can be seen that Sweden certainly has a positive impact. However, the problematic issues discussed by Gillberg (2019) and Abrahamsson et al. (2014) impacts this assessment. As this is the case, we argue the final assessment is that Sweden has an indirect positive impact on SDG5.

CLEAN WATER AND SANITATION

Ensure availability and sustainable management of water and sanitation for all

Impact

INDIRECT NEGATIVE

Motivation

As there are regulations already in place, together with future developments of these connected to waste management and mining, we argue that the impact of a domestic battery supply chain should be considered indirect negative on SDG6.

AFFORDABLE AND CLEAN ENERGY

Ensure access to affordable, reliable, sustainable and modern energy for all

Impact

DIRECT POSITIVE

Motivation

The energy mix in Sweden consists of 43% hydropower, 31% nuclear power, 16% windpower, 9% geothermal power and 1% solar. This amounts to 59% renewable energy in the energy mix based on the UN definition of renewables. This is a number which continues to increase in Sweden with more solar- and wind power underway. What should be noted is that Sweden's energy sources have a very low GHG-footprint. With all parts of the supply chain requiring energy, we argue that this has a positive impact on SDG7.

DECENT WORK AND ECONOMIC GROWTH

Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

Impact

DIRECT POSITIVE

Motivation

As mining and new industries bring positive economic growth to areas which has a positive impact. However, SDG8 also considers work-safety and security. In these aspects Sweden have strict laws and regulation and therefore we argue this would not impact SDG8 negatively. We argue that a domestic supply chain would have a direct positive impact on SDG8.

INDUSTRY, INNOVATION AND INFRASTRUCTURE

Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

Impact

DIRECT POSITIVE

Motivation

The development and innovation are seen throughout the whole li-ion battery supply chain in Sweden. An example of this is the company Northvolt, which is planning on building a battery plant with the capacity of supplying 500,000 EVs annually with batteries. Furthermore, the joint venture between Northvolt and Volvo Cars also has planned a research and development branch positioned in Gothenburg. This shows a clear direct positive impact on SDG9.

REDUCED INEQUALITIES

Reduce inequality within and among countries

Impact

NO IMPACT

Motivation

A large part of SDG10 aims at reducing inequality among countries. As the method of impact assessment focuses on attributional assessment, there are no attributes relating to inequality among countries when analyzing a domestic supply chain as it only involves one actor. Therefore, this part has no impact either. Furthermore, as it is assumed that no production would be reduced or moved by creating a domestic supply chain, the new supply chain would neither reduce inequalities among countries. As this is the case, we argue a domestic supply chain would have no impact on SDG10.

SUSTAINABLE CITIES AND COMMUNITIES

Make cities and human settlements inclusive, safe, resilient and sustainable

Impact

NO IMPACT

Motivation

The factors that might be beneficial for a domestic supply chain is in a wider context highly negligible and we argue the impact of a domestic supply chain has no impact on SDG11.

RESPONSIBLE PRODUCTION AND CONSUMPTION

Ensure sustainable consumption and production patterns

Impact

DIRECT POSITIVE

Motivation

With a domestic battery supply chain, there are most likely increased costs of production. However, in the context of SDG12 and responsible production, many of the technologies could be further advanced and optimized. For example, with the laterite ores in Rönnbäcken will most likely be the source of the nickel. With the connected need of refineries with implemented solutions, such as the widely discussed HPAL, this should be seen as a direct positive impact as we argue that there would be extensive to improve the technologies. Together with the need of price reductions, there would be further incentives for rapid developments. The final assessment of the domestic impact on SDG12 is that there would be extensive work towards solving the challenges, together with the incorporation of the supply chain in terms of regulations and green eletricity, which we argue should be considered as direct postive impact on the goal.

CLIMATE ACTION

Take urgent action to combat climate change and its impacts

Impact

NO IMPACT

Motivation

The concentration of consumption and production of EV-batteries into a smaller geographical area would be beneficial for SDG13. 16.2% of all GHG-emissions originate from the transport-sector, which could be drastically reduced if less transport is used. With Sweden's large electrified rail network and a low-CO2 energy mix, transport domestically within Sweden would be beneficial. With these factors in mind, we argue that a domestic supply chain in Sweden would still have an impact on SDG13, however not at the same degree as the current li-ion battery supply chain. With this in mind, the impact assessment forSDG13 is no impact as the energy mix used in Sweden provides a basis for negligible impact.

LIFE BELOW WATER

Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Impact

NO IMPACT

Motivation

Life below water is one SDG where the li-ion battery supply chain only has limited impact. The assessment of the current supply chain is that it has no impact and can be seen as negligible. The same can be said for Sweden as there are no specific attributes which would be vastly different in Sweden. Maritime shipping have the largest impact on this particular SDG which would not be a factor in Sweden based on the designed domestic supply chain. However, as this is judged as no impact in terms of global sourcing, with no significant differences in Sweden we argue this remains as no impact.

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15 LIFE ON LAND

LIFE ON LAND

Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Impact

INDIRECT NEGATIVE

Motivation

The overall assessment of a domestic battery supply chain shows that an increase in mining activities show direct negative impacts on the local environment. However, as there are extensive regulations and an overall collaborative and responsible approach towards minimizing the impacts on SDG15, we argue that the final assessment is that the impact of a domestic battery supply chain should be considered as indirect negative.

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16 PEACE, JUSTICE AND STRONG INSTITUTIONS

PEACE, JUSTICE AND STRONG INSTITUTIONS

Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels

Impact

NO IMPACT

Motivation

There are strong incentives to create a unified front within both technology advancement together with regulatory authorities. Therefore, in the context of a hypothetical domestic battery supply chain and the connections with SDG16, we argue that there is no impact on the goal, because of the already strong position of Sweden.

PARTNERSHIPS FOR THE GOALS

Strengthen the means of implementation and revitalize the global partnership for sustainable development

Impact

NO IMPACT

Motivation

SDG17 aims to emphasize cooperation between countries in various forms. Creating a domestic supply chain is not beneficial for international cooperation though and this goes directly against what SDG17 aims at achieving. Judging Sweden from a cooperation standpoint alone though shows strong connections to various organizations throughout the world, for example in the OECD. However, this does not alleviate the fact that assuming an entirely domestic supply chain would directly go against international cooperation. However, as it does not impact international cooperation in any negative way either, we argue that a domestic supply chain would have no impact on SDG17. As the assessment for the current li-ion battery supply chain remains as indirectly negative, the domestic supply chain would comparatively be a better alternative. However, it should be noted that in this case it would not necessarily be a better alternative as having a positive impact, but would rather limit actors within the current supply chain which has a negative impact on international cooperation.