Towards a resilient battery supply chain

Strategies and enablers for managing vulnerabilities and enhancing resilience for a Swedish Automotive OEM

Master's thesis in Supply Chain Management

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Abstract

The automotive industry is characterized by highly competitive environment that is rapidly developing. One of the most current innovative drivers is electrification, which has shifted the focus from internal combustion engines to electric motors as the main propulsion technology. The demand of electric vehicles is rapidly growing and the European automotive industry must adapt accordingly to follow the electrification journey. Also, the success of this transition is heavily dependent on the availability of batteries as the energy storage system that powers electric motors, as well as their corresponding raw materials and required manufacturing processes. Ensuring these crucial factors is therefore an aim that OEMs strive for since it is essential for remaining competitive in the automotive industry. However, there are vulnerabilities in the battery supply chain that inhibits the secure supply of batteries for electric vehicles and instead contributes to a fragile supply chain that is susceptible to disruptions. One way to counter this issue it is to increase the level of supply chain resilience through identifying the relevant supply chain vulnerabilities, addressing them through supply chain resilience enablers and shaping supply chain resilience strategies accordingly. To aid in this endeavor, this thesis explores two battery supply chains that a Swedish automotive OEM is interested in. Through literature reviews, a case study, internal validation sessions, interviews with external industrial experts and a workshop, this thesis concluded that there are seven battery supply chain vulnerabilities, of which five were of main interest, and seven supply chain resilience enablers that formed three battery supply chain resilience strategies. The strategies can be considered to, in line with the theoretical framework of supply chain resilience, increase preparedness for potential disruptions, being able to respond promptly during disruptive events and having the ability to recover from disruptions. Furthermore, this thesis proposes four key propositions to support the OEM in enhancing battery supply chain resilience. Firstly, it suggests evaluating the current state of battery supply chain resilience. Secondly, the OEM should consider implementing the identified strategies, either partially or in full. Thirdly, the potential impact of these strategies should be highlighted. Finally, a roadmap for the implementation of the strategies should be created. By following these recommendations, the OEM can strengthen its battery supply chain resilience.

Keywords: automotive industry, electrification, battery supply chain, supply chain resilience, raw materials for batteries, supply chain resilience enablers, supply chain resilience strategies.

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Secondly, we would like to thank everyone in the industrial sponsor that participated in this project. The progress of this project was dependent on their time and effort in answering our questions and participating in interviews, workshops and insightful feedback sessions. Additionally, we would like to direct a special thanks to our supervisor at the industrial sponsor for giving us the opportunity to write this project as well as the helpful feedback which was critical in formulating the scope of the thesis.

Finally, we would also like to express our thanks to all the external respondents that participated in our interviews. Without their endeavors, completing this project would not have been possible.

List of Acronyms

Below is the list of acronyms that have been used throughout the project arranged in alphabetical order:

LFP: Lithium-Iron-Phosphate (Lithium-Ferro-Phosphate)
NCA: Nickel-Cobalt-Aluminum
NMC: Nickel-Manganese-Cobalt
PD: Purchasing Department
OEM: Original Equipment Manufacturer

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1 Introduction

This chapter provides an overview of the project which is divided into four sections. The first section addresses the background of the thesis and how the supply of battery materials in future scenarios is crucial to be in line with new regulations and electrification. The second section outlines the aim of the project while section three presents the limitation. Finally, the fourth section introduces the objectives and research questions that will guide the project.

1.1 Background

The European automotive industry is undergoing a major transition from the production of vehicles with internal combustion engines (ICE) as the main propulsion technology towards electrification with electric vehicles (EVs) such as battery electric vehicles (BEVs) and plug-in-hybrid electric vehicles (PHEV) (Pavlínek, 2022). The reason for this transition is the implementation of stringent CO_2 emission regulations on newly manufactured vehicles by the European Commission. The aim of these regulations is to reduce the amount of CO_2 released by the transportation sector in order to limit global warming (European Commission, 2019; Pardi T, 2021). The extant ICE technologies fall short of the modern CO_2 emission standards, rendering automakers unable to achieve regulatory compliance. Consequently, many observers regard electric vehicles as the only feasible alternative to fulfill the mandated emission targets (McKinsey & Company, 2021).

However, the success of the electrification transition is heavily dependent on the availability of batteries which are the key components and a large cost driver of EVs, as the main propulsion technology usually consists of electric motors powered by lithium-ion batteries. Subsequently, battery technology, which fundamentally depends on critical materials like lithium, cobalt, and nickel, is regarded as necessary for renewable energy storage and automobile electrification (Kittner et al., 2019; Dunn et al., 2021). Major economies such as the U.S. (Federal Register, 2020), China (Ministry of Land and Resources, 2016), the EU (Blengini et al., (2020), Japan (Ministry of Economy, 2020), and Australia (Mudd et al., 2018) consider both lithium, cobalt, and nickel as critical materials due to their potential geopolitical supply risks and their importance in the renewable energy transition. Therefore, comprehending the demand for such critical materials and the importance of having a resilient and antifragile battery supply chains is essential for ensuring a green and low-carbon future (Hao et al., 2019; Fishman et al., 2018).

Moreover, the global demand for lithium, cobalt and nickel is escalating due to the rapid diffusion of EVs as these materials are used in the cathodes of batteries. However, the mining and refining of cobalt is distributed unevenly. For instance, approximately 70% of cobalt production occurred in the Democratic Republic of Congo (DRC), and approximately 67% of refining took place in China in 2019. This disparity raises significant concerns about future demand-supply imbalances among governmental and industry decision-makers as cobalt shortages seem inevitable in future scenarios (Dehaine et al., 2021). Therefore, a growing interest has emerged in understanding how to handle this type of geographically clustered value chains, as the strategic importance of batteries is increasing and achieving resilient battery supply chains is crucial for future competitiveness of the automotive industry (Schmuch et al., 2018).

The industrial sponsor of this thesis, a Swedish automotive OEM within the commercial vehicle industry, is a multinational manufacturing company that designs, produces, and sells a range of commercial vehicles, including trucks, buses, and vehicles for construction applications. They operate globally with production facilities in Europe, Asia, and the US., and the company has a long-standing commitment to sustainability and has set ambitious goals to reduce its environmental impact, which includes the electrification transition. The company's electrification journey began in 2006 when it launched its first hybrid truck. Since then, the OEM has continued to invest heavily in research and development to produce electric and hybrid vehicles across its brands. In 2018, the company announced its ambition to have electric vehicles account for 50% of its sales by 2030. To achieve this, the company is investing in a range of electrification technologies, including battery-electric and hydrogen fuel cell vehicles.

The OEM has a purchasing department (PD) that is responsible for sourcing all materials and components for their production and the battery supply chain naturally falls under that responsibility. Their purchasing department, which this thesis is conducted through, currently utilizes single sourcing through a strategic alliance with an Asian cell manufacturer who has approximately 5% of the market shares for battery manufacturing. The OEM sources battery modules that are assembled into complete battery packs in their vehicle manufacturing. The primary battery cathode chemistry that comes from the supplier is based on a nickel-cobalt blend. However, it is evident for the OEM that the future battery supply chain from their supplier will not suffice due to the increased EV demand and order logs that are already full for 6-7 years ahead. Additionally, if disruptions were to occur, the current alternatives for the OEM are few and there are not many ways to react, which could result in severe and undesired production stops. In this alert, the purchasing department has expressed their interest in exploring what could facilitate the development of resilient battery supply chains and what type of strategies that could be implemented. Over time, the ambition for the OEM is to have an in-house battery cell manufacturing solution as a primary option, as they believe it may benefit their future operations substantially.

1.2 Aim

This study aims to aid sourcing managers of a battery sourcing department for an OEM in the automotive industry with their electrification transition by investigating what supply chain resilience strategies are suitable to implement to support the creation of a resilient battery supply chain. Based on the compiled data collected through the methods, the study will support the OEM by finding correlations, drawing conclusions, and proposing relevant strategies, as well as aspects that enable these strategies to be realized. By considering the proposals, the automotive OEM can gain insights containing the required supply chain enablers and strategies to facilitate the creation of a resilient battery supply chain. Additionally, the intended outcome of the study is also to make an academic contribution to the realm of supply chain management, specifically through new findings based on primary industry data connected to resilient supply chains for scarce materials, to encourage future research and development of the topic.

1.3 Objectives and research questions

Supply chain uncertainties have been reported to frequently interrupt the operational efficiency and the profitability of firms. Factors such as increased global competition, customer value and the continuous increasing complexity impose crucial challenges for managing vulnerabilities within the supply chain and having established methods to react when disruption becomes reality (Daultani et al., 2015; Helbing et al., 2006; Kumar et al., 2010). Therefore, identifying the predominant vulnerabilities of a supply chain is crucial to proceed with any progress that is intended to address them. The industrial sponsor of this project is interested in understanding the supply chain vulnerabilities associated with the battery supply chains for nickel-cobalt and LFP batteries, thus formulating the first research question:

RQ1: *What types of supply chain vulnerabilities can be identified for the battery supply chains of nickel-cobalt and LFP cathodes?*

From previous research, it is evident that there are knowledge gaps concerning supply chain resilience strategies. Resilience strategizing, especially in the context of geography and industry, has not been investigated sufficiently. For instance, literature suggests that potential research questions and development trajectories within the field of supply chain resilience should aid companies, e.g., within manufacturing contexts, to improve their supply chain by ensuring that they are antifragile with the ability to handle vulnerabilities and shocks from possible external disruptions (Rahman et al.2022). Moreover, due to increased interest in the automotive industry for resilient battery supply chains, the purchasing department of the OEM has a desire to gain deeper insights regarding what enablers, defined as capabilities, skills, actions, or other factors that address the identified vulnerabilities, supports the creation of a resilient battery supply chain strategy. Specifically, what battery supply chain resilience strategies in this context could be identified to aid the OEM in their electrification journey. Combining the academic aspects and industry contexts with the background of this project, contributes to formulating the second research question:

RQ2: *What resilient battery supply chain strategies, with their required enablers, can be identified to support the electrification journey for an OEM in the automotive industry?*

Following the aim of the project, emphasis is placed on the second RQ. However, since the second RQ is based on the findings from the first RQ, entails that the objectives are interdependent. For the first RQ, the objective is to underline the vulnerabilities for two battery supply chains, with nickel-cobalt and LFP cathodes as primary focus, so that these vulnerabilities can be addressed further on in the project. For the second RQ, the objective is to highlight the areas that can enable resilient battery supply chain strategies as well as how these enablers empower any identified strategy from the primary data. The aim is also intended to make an academic contribution, which will be based on the theoretical input and the findings of RQ1 and RQ2. The academic contribution will be outlined in chapter *5. Analysis & Discussion.*

1.4 Delimitations

The main constraint of this study is that the duration, a 20-week period, of which it is executed under forces the project to be designed accordingly. From a supply chain management perspective, the battery supply chain in relation to supply chain resilience has several areas that can be studied and potential findings that can aid the industry as well as research and development of the topic. However, the limited study time implies that some factors in the battery supply chain, which could otherwise possess value to achieve the purpose of the project, are ruled out.

The second constraint of this project is that the central battery component that will be studied is the cathode. The reasoning behind this limitation is that the OEM has highlighted that the cathode component of a battery, and the cathode active material, is of primary interest since it is the main cost carrier and contains the raw materials that the OEM regard as scarce and underlying reason for supply disruption. Therefore, other components needed to manufacture a battery cell, i.e., anode material, electrolytes, separators, casing material or battery management system (BMS), is beyond the focus of this thesis and will only be briefly explained if deemed necessary for contextual reasons. The consequence of this constraint is that if future scenarios lead to comparable resilience issues for the remaining battery components, the propositions made in this project may lose their value as the outcome disregards both the battery cells' remaining components and their corresponding supply chains.

The third and last limitation is that this project will primarily investigate the upstream supply chain of batteries and battery materials, defined as cell manufacturing and backwards, since the amount of visibility and control downstream, defined as battery pack manufacturing and forward, is considered to be arbitrary by the OEM. However, the consequence of this exclusion is that all the processes after cell manufacturing, which may positively impact supply chain resilience and contribute to the aim of the project, are neglected. Figure 1.1 below visualizes the limitations and areas of focus of the battery supply chain.

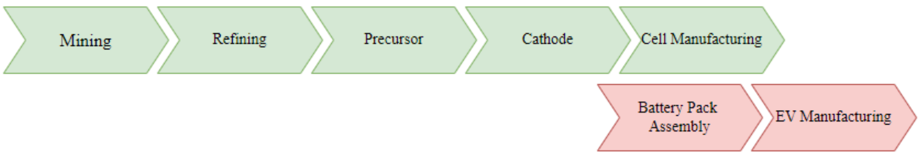


Figure 1. 1: Illustrates what parts of the battery value chain for the battery cathode that will be considered in this project. Green processes in the value chain (top level) indicate the focus areas, while red (bottom level) indicates the areas that will be excluded.

2 Theoretical framework

In the following chapter, the theoretical framework that is used as the basis for this thesis is presented. Two separate literature reviews were conducted in order to find theoretical definitions of the concepts used in this thesis. The chapter begins with introducing supply chain resilience, enablers for constructing a resilient supply chain and the three dimensions within the concept of supply chain resilience. The second section is related to the first research question, where a vulnerability within the context of supply chain is defined, followed by the different vulnerabilities identified throughout the literature review, this is elaborated more upon in chapter 3.2.1. The third section describes the definition of strategies with regards to supply chain resilience, which relates back to research question two. The last section addresses the different processes within a battery supply chain, the different raw materials used to manufacture the investigated battery compositions and lastly a definition of the two different cathodes (i.e., nickel-cobalt and LFP). Figure 2.1 provides an overview of the chapter and the different sections.

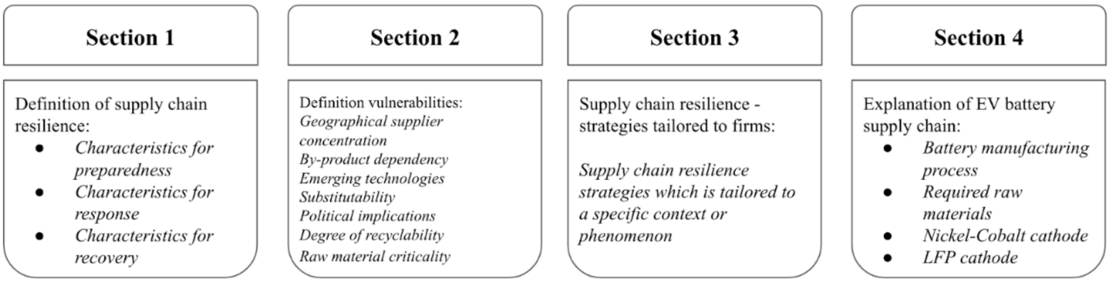


Figure 2. 1: Summary of the structure for theoretical framework. The content section 1 will return in chapter 5 and has also been used during the interviews from phase 3. Section 2 laid the foundation of RQ1, the content will be revisited in chapter 4. Section 3 had meaningful content that was used in chapter 5 when analyzing resilience strategies. Section 4 is an explanatory section to provide a holistic view of the battery supply chain, specifically for LFP and nickel-cobalt cathodes and their corresponding materials.

2.1 Definition of Supply Chain Resilience

As the supply chains of manufacturing firms in the industry are constantly challenged by new types of disruptions, the need for resilient supply chains that can withstand and counter chocks is greater than ever (Rahman et al., 2022). These disruptions can be characterized as short-term, such as lead time increase and production failures, or long-term, such as natural disasters and pandemics (Chen et al., 2020; Ivanov, 2022). Either way, researchers argue that in order to build supply chain resilience strategies, a definition of what supply chain resilience entails is needed as a point of departure (Kamalahmadi et al., 2016). Attempts to give a definition of the principle have been done several times often resulting in the similar terms being used interchangeably, but in essence convey the same meaning, which is: *Supply chain resilience is a supply chain's preparedness for unexpected disruptions, which includes their ability to respond to and recover promptly form prospective disruptions and return to their normal state or improved state to enhance their customer service, market share, and financial performance* (Rahman et al., 2022; Kamalahmadi et al., 2016).

While most manufacturing firms have addressed these issues from a risk management perspective, the struggle with identifying appropriate supply chain resilience strategies and the required enablers remain. Therefore, it is argued that resilience strategizing must be approached based on three recurring dimensions, which is preparedness, response and recovery (Hohenstein et al., 2015; Rahman et al., 2022). The preparedness dimension refers to how supply chain and operation managers must have the ability to anticipate the occurrence of disruptive events while simultaneously preparing their supply chains for expected and unexpected events in the context of their environment. The scale of the effect from disruptive events must be understood fully as well as the probability of them occurring must be minimized. The response dimension, on the other hand, refers to having the ability for immediate and effective action when supply chain disruptions may already be occurring or when they have the potential to do so. The available organizational resources should be utilized fully to minimize the disruptive effects, otherwise long-term undesired effects may become reality. Lastly, the recovery dimension refers to how supply chains must have the ability to not only reposition the firm back to its pre-disruptions state, but also transform the position of the firm and its supply chain to becoming more antifragile. The essential aspect for recovery is that returning to a pre-disruption state will not suffice long-term from a resiliency aspect, since the knowledge gained through a disruption should be used to strengthen vulnerable parts of supply chains (Kamalahmadi et al., 2016). Figure 2.2 below visualizes the dimensions of supply chain resilience.

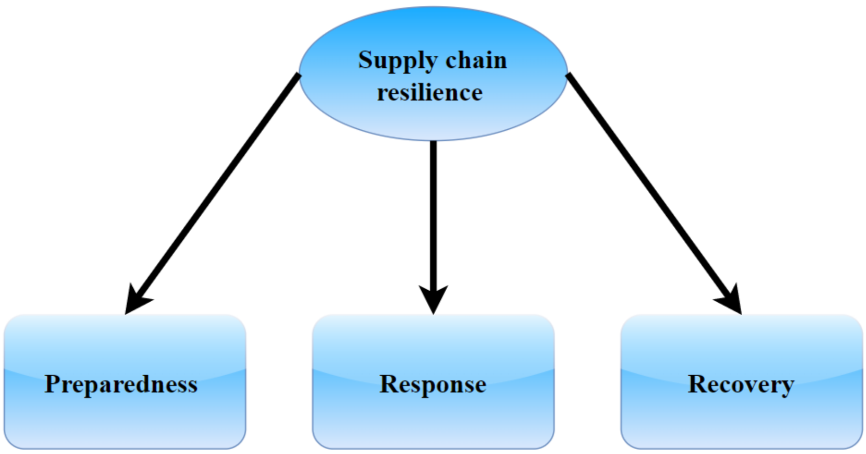


Figure 2. 2: Summary of the dimensions for supply chain resilience (adapted from Kamalahmadi et al., 2016)

2.1.1 Supply chain resilience enablers

The term *enabler* is generally defined as *"one that enables the other to achieve an end"*, which could be interpreted in a way that; enabling implies to make able, give power, competence or ability to achieve a specific outcome (Faisal, 2010). Supply chain resilience enablers could therefore be viewed as for instance capabilities, skills, actions or factors that enable firms to develop an antifragility for their specific supply chain context and address their vulnerabilities. The goal is to strengthen the competitive advantage of a firm by building supply chain resilience strategies that are based on relevant enablers (Birke et al., 2017).

Moreover, while several different supply chain resilience enabler terms are emphasized as fundamental building blocks for organizations that are aiming to create or develop resilience, the notions are used interchangeably between different sources and researchers. However, the central content is similar and refers to what type of characteristics enablers should have so that firms can generate abilities related to the dimensions of preparedness, response and recovery (Mahfouz & Arisha, 2017). Figure 2.3 below consolidates all the enabler characteristics and categorizes them into each supply chain resilience dimension.

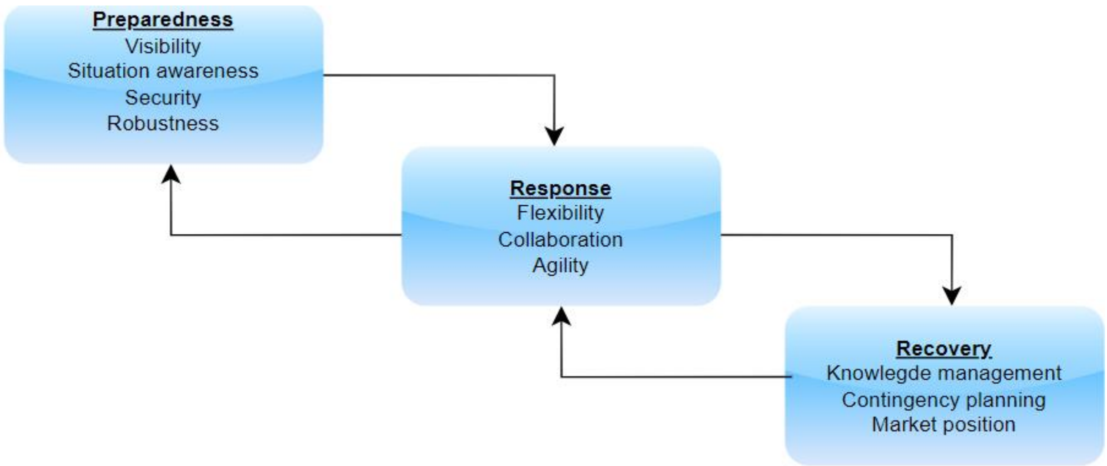


Figure 2. 3: Enablers for each supply chain resilience dimension (adapted from Mahfouz & Arisha, 2017)

2.1.1.1 Characteristics for preparedness

The preparedness dimension contains four proactive characteristics for resilience enablers which are visibility, situation awareness, security and robustness. The visibility functions as a warning that provides firms with adequate time to align their abilities and proactively counter upcoming disruptions before they impact operations. To enhance the amount of visibility in supply chains, firms often invest in IT-systems with the capability to enable full transparency through integrated information sharing and connectivity solutions (Mahfouz & Arisha, 2017; Han et al., 2020). As for situation awareness, the organization must understand the relevant supply chain vulnerabilities and utilize this knowledge to forecast possible disruptions, which also requires continuity planning, constant market studies as well as information sharing from all relevant actors in the supply chain network (Chowdhurry, 2017; Han et al., 2020). Security involves designing supply chains, from an end-to-end perspective, with the intention to strengthen parts that are fragile rather than reenforcing weak parts of the supply chains after incidents. Security is often achieved when actors in the supply chain work in synergistic manners with mutual benefits as the aim. Robustness is in essence the ability to sustain operations despite disruptions and retaining an arbitrary level of stability when changes occur. To achieve robustness, firms often ensure and prepare the availability of excess resources that can be utilized strategically during and after disruptions (Mahfouz & Arisha, 2017; Han et al., 2020).

2.1.1.2 Characteristics for response

The response dimension contains three concurrent characteristics for resilience enablers which are flexibility, collaboration and agility. Flexibility in supply chains is highlighted as the ability to adapt and adjust to disruptions rather than merely withstanding the damage. To achieve a flexible supply chain, firms often ensure that flexible supply and/or demand management is existent through the majority of the supply chain network (Mahfouz & Arisha, 2017; Han et al., 2020). Collaboration in the response dimension refers to responding to supply chain disruptions through collaborative planning, meaning that vertical and horizontal collaboration should be existent both internally in the organization but also externally with other partners in the network. Through collaborative planning, a holistic decision-making process via the whole supply chain network can be integrated to respond to disruptions and deploy actions accordingly. Agility represents response speed and how rapidly the organization is able to respond to supply and demand changes in the marketplace. This is especially important in dynamic environments where customer requirements are continuously changing and markets are constantly shifting, which is where the speed of the response is crucial to minimize the negative impacts of such disruptions (Mahfouz & Arisha, 2017; Han et al., 2020).

2.1.1.3 Characteristics for recovery

The recovery dimension contains three reactive characteristics for resilience enablers which are knowledge management, contingency planning, and market position. Knowledge management refers to having the ability of learning from past events. It involves training the employees in the organization and understanding the risk, while simultaneously observing aspects beyond the risks and identifying opportunities. By transferring that knowledge through organization, the ability to learn after a disruption and develop improved solutions for the future balance of the supply chain network can be cultivated in the organizational culture (Mahfouz & Arisha, 2017; Han et al., 2020). Contingency planning complements the ability to recover through continuously assessing the existing plans for recovery. The assessments can involve supply chain reconfiguration, simulating scenarios of disruptive nature and analyzing the effects as well as repositioning resources for optimal use. Market position in the recovery dimension refers to the ability to recover from disruption based on financial strength. A strong market position is generally associated with having the financial ability to restore and improve operations after disruptions, while simultaneously fulfilling customer demands and maintaining healthy supplier relationships (Mahfouz & Arisha, 2017; Han et al., 2020).

2.2 Supply chain vulnerabilities

Supply chain resilience strategies are intended to address the vulnerabilities of a supply chain in a way that makes the network as antifragile as possible. Vulnerabilities in supply chains can be defined as: *an exposure to serious disturbances, arising from risks within the supply-chain as well as risks external to the supply chain* (Chapman et al., 2002). Table 2.1 below summarizes the vulnerabilities that will be addressed from a battery supply chain perspective in section *4.1 RQ1: Identified Vulnerabilities*.

Table 2. 1: Summary of vulnerabilities that will be used as baseline for the empirical findings in RQ1.

Supply chain vulnerability	***Definition***	**Key findings**	**Sources**
Geographical supplier concentration	*"Products which are produced in a limited number of countries"*	• Reduced possibility of diversified supplier base in multiple countries • Could pose a significant impact on supply, cost and availability if supplier countries experience disturbance. • Reduced visibility	Singhal et al., (2011), USCC (2022), Achzet & Helbig (2013)
By-Product dependency	*"Minerals which are produced as by-product of a main mineral"*	• May affect the price and supply, leading to reduced flexibility. • May cause periodically oversupply or shortages	Slack et al., (2017), Langhammer (2010), Nasser, Gradel & Harper (2015)
Future technology demand - Emerging technology demand	*"Application areas of materials or products beyond the original use"*	• May affect the price and supply in the long-term • Increased probability of disruption due to the accelerated electrification in the automotive industry	Angerer et al., (2009), Ferro & Bonollo (2023), IEA (2022), Helbig et al., (2018)
Degree of substitutability	*"Ability to substitute a material, product or process in the case of supply disruption"*	• A material, product or process that possess a lower degree of substitutability is deemed more critical, which is undesirable	Helbig et al., (2018), Graedel et al., (2013)
Political implications	*"Vulnerability that is caused by regulatory measurements"*	• Actions such as export restrictions, taxes or trade embargoes in the supplier countries possess the possibility of disruptions. • May affect price and supply	Achzet & Helbig (2013)
Degree of recyclability	*"End-of-life recycling rate for Lithium-Ion-Batteries"*	• OEMs which do not have proper recycling programs may face legal actions and penalties if batteries are not discharged properly	Hua et al., (2020), Helbig et al., (2018), EuropaParlament (2022)
Raw material criticality	*"Raw material with high economic importance"*	• Higher degree of raw material criticality leads to a higher probability of disturbances in the supply chain • May also have environmental and social impacts	European Commission (2023)

2.2.1 Geographical supplier concentration

Geographical supplier concentration is an identified vulnerability which refers to a situation where a large part of specific raw materials or components produced stems from a limited number of countries. A high level of concentration is generally regarded as an undesired vulnerability in the supply chain of a firm since any disruptions or instabilities occurring in the supplier country could pose a significant impact on the availability, cost and delivery of the purchased raw material or component (USCC, 2022; Achzet & Helbig, 2013). The issue with country concentration is that it reduces the possibility for geographical segregation regarding supplier base, which implies that a few countries or regions in the world can create monopolies related to certain materials or products. Not having the possibility to communicate with multiple suppliers, preferably from different countries or regions, is regarded as a supply chain vulnerability that prevents firms from gaining deeper insights into their supply chain system design. The result of this is that alternatives to select the location of suppliers (local/global) and number of suppliers (single or multiple sourcing) are removed as well as the visibility in the network, i.e., the coordination and information sharing amongst the actors in the supply chain, is reduced if suppliers in concentrated countries are not willing to disclose any sensitive information (Singhal et al., 2011).

2.2.2 By-product dependency

The term by-product dependency is defined as the availability of a mineral comes from the extraction of primary mineral, where the by-product is a direct result of the main-mineral production and not by the actual need of the by-product (Slack et al., 2017). When a certain mineral is a by-product, the pricing and supply are deemed inflexible since there are complications regarding the amount of by-product production. This can result in periodically oversupply or shortages, affecting the entire supply chain. Hence, having a raw material which is produced as a by-product of a main mineral is thereby seen as a vulnerability which could have major negative impacts on the supply chain (Langhammer, 2010; Nassar, Graedel and Harper, 2015; Slack et al., 2017).

2.2.3 Future technology demand - Emerging technologies

Emerging technologies are defined as industrially applicable technical capabilities, which stimulate revolutionary innovations beyond the borders of individual industrial sectors, meaning technologies or components which have applications other than the original use. Emerging technologies have the possibility of affecting the availability, price and supply of a certain material in the long-term, resulting in shortages and fluctuation in prices. Moreover, the rapid deployment of clean energy technologies, such as the electrification of the transport sector, implies a significant increase in demand for multiple minerals,e.g., lithium, nickel, cobalt etc (Angerer et al., 2009; Ferro & Bonollo, 2023; IEA, 2022). Emerging technologies are identified as a vulnerability due to the multiple application areas of some of the raw materials used in the manufacturing process of batteries, where there are possibilities of increased demand for critical material for other industrial applications (Helbig et al., 2018).

2.2.4 Degree of substitutability

Substitutability is defined as the possibility to substitute a specific material, component, product, or process in the scenario of supply shortages. The degree of substitutability and the degree to which materials, components, products, or processes that may be substituted play an important role in determining the criticality of the desired material or value chain (Helbig et al., 2018; Graedel et al., 2013). Therefore, the possibility to design a supply chain to be antifragile is difficult when the core materials or components related to a firm's central products or services are few.

2.2.5 Political implications

Political implications can have several definitions, however, in the context of this project, political implications will be defined as supply chain vulnerabilities caused by the implementation of regulatory measures in the producing countries, i.e., where the mining, refining, precursor manufacturing and cell manufacturing occurs. Political decisions could impact price development and supply availability, due to actions such as export restrictions, taxes or a trade embargo (Azchet & Helbig, 2013).

2.2.6 Degree of recyclability

Degree of recyclability is defined as the end-of-life recycling rate for lithium-ion batteries. The recycling rate aims to determine how many percent of a battery reaching its end-of-life state can be obtained, measured in percent. Batteries racing their end-life contain many valuable resources, such as lithium, cobalt and nickel and the material that is eligible for recycling may vary depending on the battery chemistry. The recycling aspect is of interest since the resources recycled could be used to reduce the resource constraint on critical materials, improve the utilization of retired lithium-ion batteries while simultaneously helping protect the environment. Moreover, the business of lithium-ion batteries reaching their end-of-life is estimated to reach 3 billion USD (Hua et al., 2020; Helbig et al., 2018). In addition to the possible benefits of recycling lithium-ion batteries, the European Union has decided that a percentage of raw materials from recycled batteries must be used in the manufacturing of new lithium-ion batteries (EuropaParlamentet, 2022). Thus, Automotive OEMs which do not have proper recycling programs could face legal actions and penalties.

2.2.7 Raw material criticality

Critical raw material has been considered an enhancer to the probability of disruption. However, in order to have a systematic approach to defining what a critical raw material is and how to assess whether the material is critical or not, the definition presented by the European commission's report was used. The report defines critical raw materials as *"raw materials with a high economic importance to the EU economy, coupled with the risk associated with the supply of the material".* The European raw materials criticality assessment is a report published by the EU commission. The report evaluates raw materials that are deemed critical, where the evaluation is based on the material's economic importance, supply risk and environmental and social impact. These factors are evaluated based on the context of European countries and how they are affected (European Commission, 2023).

2.2 Supply chain resilience strategies - tailored to firms

The term strategy is defined as a competitive position by deliberately choosing a different set of activities to deliver a unique mix of value, in other words, the need to understand competitors and the selected market to determine how the business should act (Porter, 1997). The literature regarding supply chain resilience has previously been focused on generic strategies that firms can incorporate, but as companies operate more globally and the severity of disruptions affect different firms in different ways, companies are pursuing a variety of different strategies to enhance their supply chain resilience (Alicke & Strigel, 2020). Individual firms within specific types of company environments are interested in more differentiated guidance that highlights specific obstacles and challenges of which companies similar to theirs need to overcome. This implies that firms will benefit from strategies that are based on solid foundations where the focus is to acknowledge multifaceted and intricate challenges that exist at the business unit or product group level, which can result in unique and customized solutions. Consequently, this has discouraged the "one-size-fits-all" way of thinking and instead encouraged a supply chain design that mirrors the characteristics and strategic intent of a business when developing supply chain resilience strategies (Cohen et al., 2022). Moreover, it suggested that there are two factors, *homogeneity of internal supply chain processes (intra-company)* and *integration with other supply chain actors (inter-company),* that are influencing how resilience strategies are formed. The homogeneity of internal supply chain processes refers to the level of interconnectedness and shared resources within a company. This could be for instance planning, inventory control, logistics, procurement, manufacturing equipment etc. On the other hand, integration with other supply chain actors refers to the level of interconnection and alignment between a supply chain and its partner companies which are related to the level of sharing material flows, information flows and financial flows (Cohen et al., 2022). Homogeneity stages and integration degrees are listed below in table 2.2 and table 2.3 from low to high level.

Table 2. 2: Stages of supply chain homogeneity listed from low to high (Cohen et al., 2022)

Multiple independent supply chains	Companies with several independently managed supply chains with only very limited sharing of resources across the supply chains. Typically, companies with very broad and diverse product portfolios fall into this category.
Shared services	Companies whose multiple supply chains share some supply-chain processes or resources, typically functions such as procurement, logistics, or distribution.
Central guidance	Companies that manage all products centrally and in the same way, while having fundamentally different supply-chain structures for each. Usually, most internal resources such as personnel, plants, equipment, and IT systems are shared across the company.
"One-size-fits-all"	Companies that use one supply-chain setup to produce all its stock keeping units (SKUs). There might be slight differences in the way the SKUs are managed (e.g., priority rules, planning cycles) or handled (e.g., packaging). Such companies are usually seen as single-product-companies.

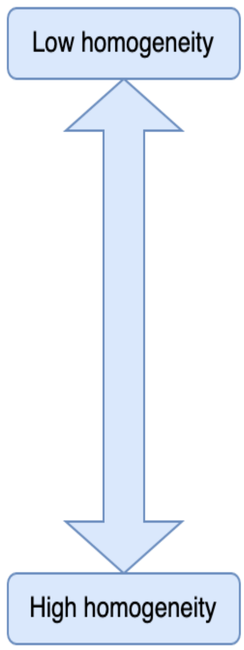
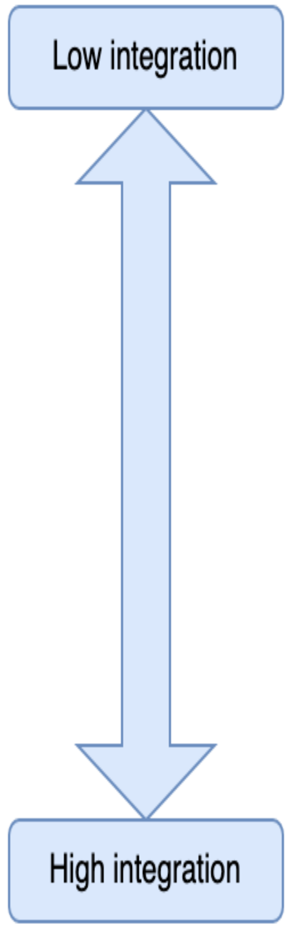


Table 2. 3: Degrees of supply chain integration listed from low to high (Cohen et al., 2022)

Less dependency/engagement	Companies that have arm's length relationships with their suppliers/supply-chain partners. These are typically companies that do part of value adding in-house, and externally sourced materials can be obtained in a transactional fashion. These companies do not have strategic suppliers and for most inputs they can easily switch sources.
Coordination with key partners	Companies that have only a limited number of strategic suppliers with which they coordinate efforts and share some information (e.g., market data). Most of the relationships are still transactional and less engaged.
Integrated systems	Companies that share some parts of the supply chain and have a system interface with their key partners (e.g., for customer or vendor-managed-inventory). These companies frequently share information with some strategic partners. Switching those partners would be very costly and disruptive.
Collaboration	Companies whose supply-chain processes are very interlinked with their partners. Goal alignment is typically strong between these companies and their partners. They may collaborate on the development of new products (e.g., Joint Design Manufacturing). Switching partners would be prohibitively costly in the short to medium term.
Vertical integration	Companies that control two or more, typically investment-intensive, stages of the production that in other contexts might be operated by separate firms. A company with this structure therefore does most of the value adding processes by itself.



2.3 EV battery supply chain

In this section, the electric vehicles battery supply chain will be explained to provide a holistic view of the required processes. The section will introduce the different steps in the manufacturing process, the raw materials used in the battery supply chain and the battery composition in terms of components. Moreover, this section will also highlight the two different cathode chemistry and their composition in terms of materials used to manufacture them.

2.3.1 Battery production and value chain

The production of lithium-ion batteries is initialized with the extraction of raw material through mining processes. The raw material may vary depending on the battery chemistry used for the cathode and anode material. The mining process involves the excavation and transportation of raw material to a refining facility, where the process involves multiple steps of chemical and mechanical process to purify the raw materials. Once the raw materials are refined, the subsequent step involves heating the refined material into metal oxide precursors which are used for cathode manufacturing. Thereafter, a chemical process which involves mixing precursor materials into finished cathodes is performed. When executing the cathode blending process, the aim is to combine the refined materials with other compounds, such as hydroxides or carbonates depending on the battery chemistry. The cathode manufacturing process involves blending the precursor materials with a binder and a solvent to create a slurry. The slurry is then coated onto a metal foul, typically made of aluminum or copper. The coated metal foil is then dried and heated in a furnace to high temperature, which transforms the precursor material into a cathode. The cathode is then rolled onto a spool for use in cell manufacturing. Once the manufacturing of the cathode material is complete, the cathode is assembled into a battery cell, along with the anode and electrolyte components which is visualized in figure 2.4 below. While it is common for the large battery manufacturers to control several parts of the battery supply chain, there are companies that only handle one specific part of the battery supply chain. For instance, some companies only focus on raw material extraction, while others might only handle precursor and cathode manufacturing (Qi et al., 2023).

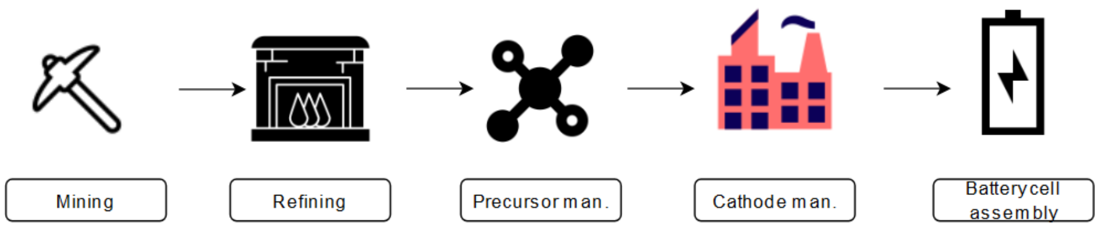


Figure 2. 4: Value chain of battery production for the cathode component from mining into finished battery cell

2.3.2 Raw materials for EV battery supply chain

Batteries are units containing chemical energy which can be converted into electrical energy on demand to power several different technological applications. A battery cell consists mainly of four components, a *negative anode pole*, a *positive cathode pole*, *electrolytes* which is a usually a liquid that contains ions with electrical conductivity, and a *separator* which is a thin membrane between the negative and positive pole to avoid direct contact between the electrodes which can cause short circuits (Winter & Brodd, 2004), the composition is further visualized in figure 2.5 below. The cathodes material could consist of Lithium-Manganese-Oxide (LMO), Lithium-Iron-phosphate (LFP), Nickel-Cobalt-Manganese (NCM) and Nickel-Cobalt-Aluminum (NCA) (Lu et al., 2013). Even though the lithium-ion batteries consist of multiple components, the main cost carrier in a battery is the cathode, which plays a major role in the increase or decrease of price/kWh for the batteries (Manthiram, 2020). The reason behind the cathode's price sensitivity stems from the critical raw materials used to produce the cathode. The supply for these materials is constrained and even though investments into new production facilities and technologies, such as recycling, are being developed, the future battery demand is still considered to be a reason for supply imbalances and price increase. Moreover, the demand for critical material used for the manufacturing of the cathode is forecasted to increase dramatically in the coming years. Lithium, cobalt, nickel and manganese for example are expected to rise by 940%, 230%,750% and 1500% respectively by the year 2050. This further poses vulnerabilities and potential supply disruptions since the production capacity is set to decrease before the end of the decade (Ampofo, 2023).

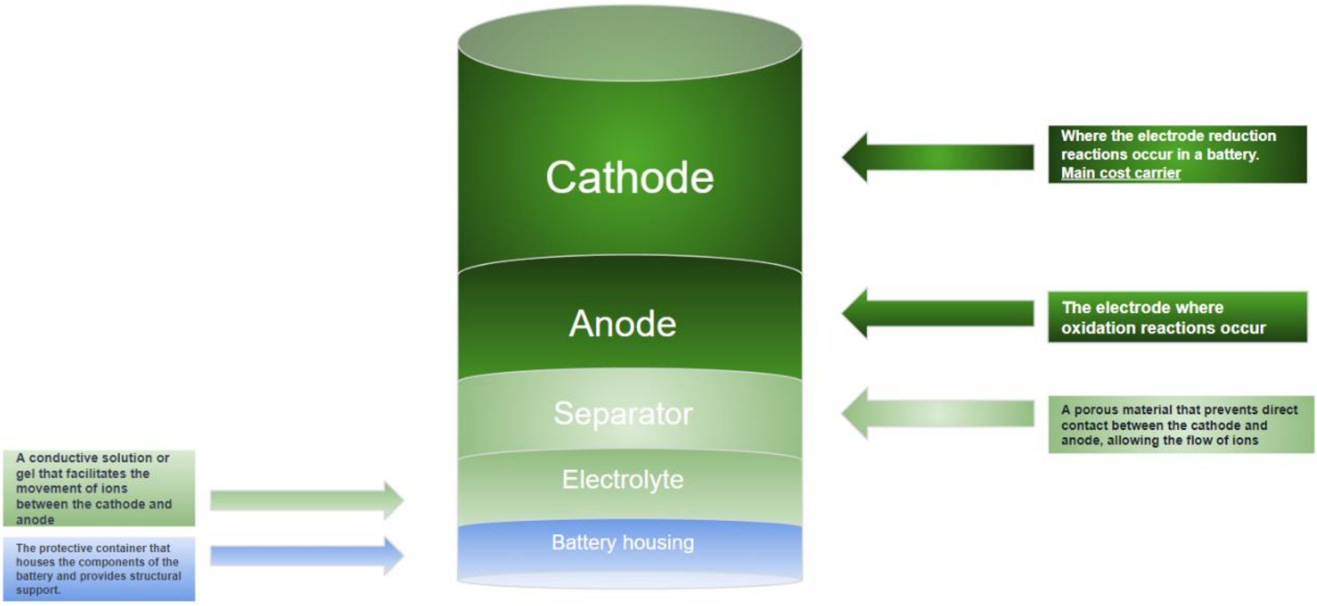


Figure 2. 5: Summary of the components included in a battery cell

2.3.2.1 Nickel-Cobalt cathodes

The Nickel-Cobalt cathode is the dominant type of cathode used in battery cell manufacturing for lithium-ion batteries in the EV industry. The reason for its dominance is due to its high energy density and long life-span property that has been viewed as key to overcome range issues and short product life with BEV (Nickelinstitute, 2022). Nickel-cobalt cathodes contain mostly nickel and cobalt, among other materials such as lithium, manganese and aluminum, but the percentages of the raw materials differ depending on the type of battery cathode and its chemical composition. Some compositions require a large percentage of cobalt while other compositions require substantially less. The amount of nickel is also adjusted accordingly, for instance, high-nickel cathodes require less cobalt and vice versa (IEA, 2022).

Although nickel and cobalt are popular materials that have the characteristics sought after for BEVs, they are also generally regarded as critical materials since they are geographically clustered and essential for many automotive manufacturers, making shortages in the future for these materials seem inevitable (Zeng et al., 2022). In addition, cobalt as a raw material is predominantly a by-product of nickel and copper extraction, which implies a by-product dependency (Erickson & Manthiram, 2020).

2.3.2.2 Lithium-Iron-Phosphate cathodes

The lithium-Iron-Phosphate (LFP) cathode is another cathode used in the manufacturing of lithium-ion batteries, where the cathode material is formed by combining the raw material of lithium, iron and phosphate. Since high-nickel based chemistries have been dominant in battery cathodes the past years, the prices for nickel and cobalt have increased as well as supply constraints becoming common, resulting in a resurgence for LFP-cathodes. Over the last two years, the interest in LFP-cathodes has led to a market share of 25%. Up until now, Chinese battery manufacturers have held a near monopoly of the production of LFP batteries due to obtaining patents on this particular battery chemistry, however, these patents are set to expire in 2022 (S.Writer, 2020; IEA 2022). Therefore, LFP-cathode materials have become desirable for foreign actors in the battery market.

The reason for the increased interest in the cathode material stems from the advantages over high-nickel-cobalt cathodes. Even though the LFP-cathode provides shorter range due to lower energy density, the cathode still provides several other advantages such as lower capacity loss, greater battery safety, which stems from the thermal and chemical stability, and reduced cost, mainly due to the low cost of iron and phosphorus (Preger et al., 2020; mpoweruk, 2020; IEA, 2022; BNEF). Besides the advantages in terms of performance, LFP batteries are known to have reduced environmental impact compared to other battery chemistries. The reason is that LFP-cathodes do not contain cobalt or nickel, two components which have been associated with inhuman labor and high levels of carbon footprint. Furthermore, the raw materials required for LFP-cathodes do not face the same supply shortage which both cobalt and nickel are facing, resulting in lithium being the only raw material which poses a supply chain risk in the LFP-chemistry composition (IEA, 2022; mkpoweruk, 2020; Firdaus, 2022).

3 Methodology

3.1 Introduction to methodology design

The methodology chapter describes how the master thesis has been structured and executed. The chapter has been divided into four different phases, where the aim of phase 1 was to obtain an understanding of the issue within the industrial sponsor. The first phase 1 was designed to establish research questions. This led to two different research questions that were answered in subsequent phases (2-4). A multi-method approach was applied to obtain the desired data, i.e., primary data collected through the process of semi-structured interviews, secondary data obtained from the company's internal data-management system and an in-depth literature study (Creswell, 2018; Yin, 2014; Stake, 2010). Lastly, the chapter highlights relevant approaches to ensure research quality related to reliability, validity, and the generalization, followed by the data analysis chapter, describing how the gathered data was analyzed before presenting the empirical findings. Due to the scope of the topic, several interviews and validation rounds were held, as well as two literature studies. This was considered necessary due to the scope of the project, each phase thus explaining the context of the methodology applied. Table 3.1 below summarizes each phase.

Table 3. 1: overview of the phases and their outcome

Phases	Research question	Data Needed	Data collection method	Outcome
Phase 1: Framing of the problem	*The aim for phase 1 was to determine the appropriate research questions for the project*	Current challenges of the OEM regarding the battery supply chain Internal reports/analysis on the topic of battery supply chain Information on the topic of batteries	Interviews with relevant internal staff at the OEM Internal reports provided by the supervisor at the OEM. Literature review I	A clear and holistic view of the company's current state Identified concerns within the OEMs PD Established research questions
Phase 2: Mapping and identification of vulnerabilities within the nickel-cobalt and Lithium-iron-phosphate battery supply chain	***RQ1:*** *What type of supply chain vulnerabilities can be identified for the battery supply chain of nickel-cobalt and LFP cathodes?*	Secondary data related to vulnerabilities for the EV battery supply chain Market data on the nickel-cobalt and LFP supply chain	Literature review II A case study divided into three layers, first one being data collection on internal reports, second one being databases provided by Bloomberg NEF and thirdly, reports obtained from consulting firms and academic journals	Identified and validated vulnerabilities based on secondary data Description of the battery value chain, from raw material to cell assembly, with country concentration for each process
Phase 3: Supply chain resilience enablers and strategies - Identification and pairing process	***RQ2:*** *What resilient battery supply chain strategies, with their required enablers, can be identified to support the electrification journey for an OEM in the automotive industry?*	Outcome from phase 2 to act as foundation for addressing vulnerabilities Inputs for resilience enablers and strategies from external industrial experts	Interviews with external experts Validation of findings with internal staff at the OEM Workshop for pairing enablers to strategies	Identified what supply chain resilience enablers industrial experts deem relevant when developing resilience for the battery supply chain A consolidation of battery supply chain strategies Paring required enablers to each strategy based on internal workshop

3.2 Phase 1 – Framing of the problem

The industrial sponsor has a purchasing department consisting of multiple stakeholders. The department, responsible for the batteries, consists of sub-departments such as raw material specialists, purchasers responsible for procuring the batteries, project commodity buyers, business and market analysts, etc. There is an interest within the department to evaluate the resilience of the current battery supply chain by identifying what in the supply chain vulnerabilities are existent and provide relevant supply chain resilience strategies and required enablers for the realization of such strategies. To address these concerns. Thus, phase 1 was initiated by applying a qualitative approach, containing a literature review, internal reports provided by the OEM and internal interviews to gain deeper insights into the issue.

The first literature review for the project was conducted to provide a proper foundation for the research topic, whilst the case-study methodology was used since it is deemed applicable when the researchers have a desire to generate a holistic view of a topic (Bryman & Bell, 2011; Gerring, 2019). According to the authors Gill et al., (2008), interviews as a data collection method are appropriate when there is a lack of knowledge regarding the topic discussed, which was argued to be in line with the scope of phase 1. For this project, a semi-structured approach was applied. The reasoning behind the interview structure was that the sequence of the questions asked may vary and do not necessarily follow a specific schedule. The method allows the respondent to address a question or topic in more detail and provides freedom in terms of reply (Bryman & Bell, 2011; Gill et al., 2008). Hence, the first round of semi-structured interviews were held in order to identify issues which the OEMs PD currently faces in their electrification journey. According to Bell et al., (2021), the researcher(s) must have a list of questions, aimed at covering a specific subject. This list is acquired by the development of an interview guide.

3.2.1 literature review I: Generating a holistic view of the topic

During the course of the project, two separate literature studies were carried out, the first of which, as described in this chapter, was carried out at the beginning of the thesis. This literature study differs from the second one in phase 2, in that it was carried out with the aim of generating a broader view of the topic of two battery technologies, Nickel-cobalt and LFP batteries, and their respective supply chain. Additionally, it also generated a holistic view of the battery industry. In order to obtain relevant studies and academic articles, electronic databases were used, such as Google Scholar, Science direct, Chalmers Library and Bloomberg NEF. The used search words were, but not limited to the following: *Lithium-Ion batteries, Electric vehicle batteries, LFP, Supply chain risk, supply chain risk assessment, Iron battery, Phosphate battery, Lithium battery, Supply chain resilience, supply chain mitigation strategies, battery supply chain, EV raw materials, Nickel-Cobalt batteries, cobalt.* Bryman & Bell (2011) suggests surveying bibliographies from initial references, which can be deemed as an effective way to gather relevant sources of information. The method was applied by relevant academic journals to serve as a guide to find additional sources. Additionally, the website Google Scholar has a function named "cited by ", which was used to find additional sources for the triangularity aspect of the thesis and/or receive different angles of a topic. This way of work was also applied in the second literature review.

3.2.2 Internal reports

Once the literature review was completed, the next step was to review internal reports from the industrial sponsor. These reports were considered necessary as they contributed to a general understanding related to the current position and development trajectory of the purchasing department. These reports consisted of battery supply chain data gathered by the OEM and was complemented with a market analysis carried out by external consulting firms, covering battery demand forecasts, current situation analysis and potential risks with suppliers. This data collection aided partially in formulating the three research questions that drove this study, with an accompanied methodology process that can be deemed suitable to provide an answer for the questions.

3.2.3 Development of interview guide

According to the authors Bell, Bryman & Harley (2018), it is important to develop an interview guide in order to ensure that the interviews conducted remain structured and focused, whilst also ensuring that all the relevant information is collected properly, in a systematic manner. An interview guide acts as a road map for the researcher(s) conducting the interview and explains the themes and questions that are to be covered during the interviews. Additionally, an interview guide contributes to consistency amongst the interviews held, since each interview is held similarly. Furthermore, this adds to the simplicity of comparing and analyzing the information gathered from the interview and facilitates the process of identifying patterns and themes in the data collected. Overall, the development of an interview guide is an important step to ensure that the interview process is focused, comprehensive and generates high quality data that can be analyzed. Table 3.2.3 explains the process of developing an interview guide, complemented by a clarification of each step. The same process was applied when developing the interview guide in phase 3.

Table 3. 2: Development of interview guide

Steps in interview guide development	Explanation of each step
(1) Identify research questions	In the first round of interviews, the authors produced desired questions aimed at identifying the as-is state of the OEM with regards to the battery supply chain and to identify hurdles within the OEM. For the second round of interviews, the aim was to identify enablers and strategies, thus adjusting the questions accordingly.
(2) Determine topics to be covered	The topics to be covered were adjusted based on which round of interviews were held. Examples of topic covered are: *battery supply chain, current usage of nickel-cobalt battery chemistry, possible risks or concerns with the current & future battery supply chain.*
(3) Develop open-ended questions	The authors designed the questions in a way that would spark a discussion
(4) Develop probes and prompts *Probes is defined as follow-up questions whilst prompts is defined as an elaboration to a specific answer*	Probes and prompts were used to gain more in-depth insight from the interviewees. In some cases, the probes and prompts occurred mid-interview
(5) Pilot test the interview guide	A test on the interview guide was performed on a fellow thesis student at the PD, as the person was in the final stages of his thesis work and had conducted similar interviews on a similar topic. The same individual was used in the development of the second interview guide.
(6) Revise the interview guide	After the pilot session of the interview, the authors adjusted the guide where improvements were identified.
(7) Conduct the interviews	The authors conducted the interviews.
(8) Analyze the data	Applied thematic analysis

Step 1-6 were applied to develop the template for the interviews. Step 7 was where the interviews were performed and step 8 is where the data was analyzed using thematic analysis. Thematic analysis is defined as a qualitative research method used to analyze, identify and report patterns noticed in the outcome of the interviews (Bell, Bryman & Harley, 2018). The interview guide can be viewed in appendix A.1.

The interviews were held two-to-one, with both authors present at the interview. This structure was applied in order to ensure proper gathering of information, where both authors noted down points of interest. Thereafter, the notes were discussed to analyze if the gathered information was perceived and interpreted in a similar custom, meaning that, after every interview, a session of discussion was held to analyze the obtained data. To systematically analyze the data, the authors applied a thematic analytical strategy, which is a strategy that is used throughout the project. The methodology is explained further in chapter 3.7 - Data analysis. The participants for the first round of interviews are presented in table 3, alongside their position, interview date and interview duration.

3.2.3 Sampling

Purposive sampling is method which is which is defined by the authors Bell et al. (2019) as selecting respondents for interviews based on certain criteria selected by the researchers conducting the interviews. This is done in order to ensure that the characteristics align with the objective of this research project. The criteria used to select participants could be based on parameters such as knowledge, expertise or position within a particular industry or organization. The method is useful in this context since the aim of the thesis can guide the sampling (Bell et al. (2019).

3.2.4 Semi-structured interview I: Understanding challenges within the OEM

The first round of interviews was conducted once the literature review and the internal material provided by the industrial sponsor had been reviewed and analyzed. The purpose of the first round of interviews was to gain a deeper understanding involving challenges within the purchasing department and identify internal concerns related to the battery supply chain. The sample for this round of interviews was selected based on purposive sampling, which allowed the respondents to be chosen based on their knowledge and experience in the area. The candidates were selected based on their relevance to the topic and their willingness and availability to attend the interview. The interviews were conducted either face-to-face or via video calls. Job descriptions, interview dates and interview durations are presented in table 3. The semi-structured interviews were followed by a case study in the form of market data collection on the LFP and nickel-cobalt battery supply chain. This case study is further elaborated on in phase 2. To properly conduct an interview, an interview guide must be developed to guide the researchers during the session. For this interview session, the interview guide's development was based on the findings from (1) the literature review and (2) the internal reports provided by the OEM. The development is described in the section below.

Table 3. 3: Describes participants, with an ID given, their position, date and duration of the interview

Participant ID	Participants	Date	Duration
P1	Commodity and project manager	2023-01-30	90 min
RM1	Raw material specialist	2023-01-30	80 min
P2	Senior purchaser	2023-01-31	60 min
BA1	Business analyst	2023-02-03	60 min

3.3 Phase 2 – Mapping and Identification of vulnerabilities within the Nickel-Cobalt and Lithium-Iron-Phosphate battery supply chain

The authors Barroso et al., (2011) explains that in order to develop a supply chain that is resilient to disturbances and identify potential vulnerabilities, it is crucial to map out and understand the different processes in the supply chain. Hence, to answer the first research question, a supply chain survey of the geographical locations for the actors and processes involved in the battery supply chain must be conducted. By doing so, supply chain vulnerabilities based on the hurdles discussed, from the first round of interviews in phase 1, can be identified. Phase 2 was launched with a literature review, where the ambition was to identify vulnerabilities related to the battery supply chain in a general sense. The literature review is followed up by a case study on the current market of batteries, where information was gathered on the existing market of batteries with a main focus on nickel-cobalt and LFP cathodes. All findings from phase 2 were validated through a second round of validation interviews.

3.3.1 Literature review II: Identification of vulnerabilities for battery supply chain according to theory

Initially, a literature review was conducted in order to generate a holistic understanding of the current battery industry and the two battery compositions nickel-cobalt and LFP. At the launch of the review, the research questions had yet to be established, thus leading to a less systematic approach. However, after the completion of phase 1, the research questions that laid the foundation of the project had been established. Therefore, a second literature review was launched, in order to gain in-depth knowledge about the research topic. The five-step model developed by the authors Bryman & Bell (2011) was applied to conduct the literature review in a more systematic way, since the aim is now more tangible. The methodology is visualized by figure 3.1 below.

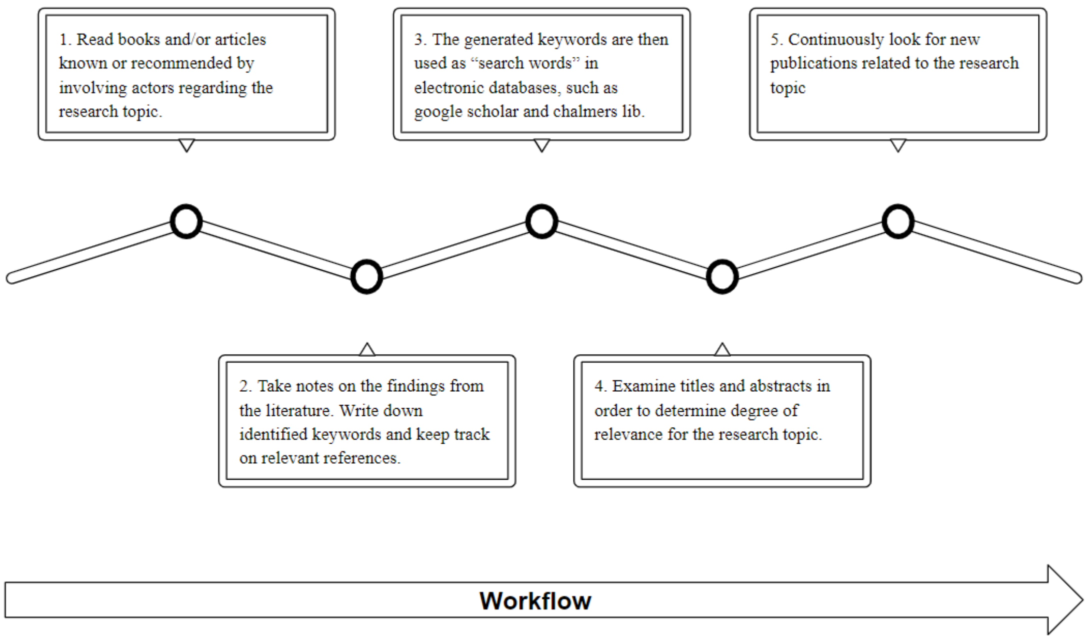


Figure 3. 1: Bryman & Bell five-step method for literature review

The five-step model by Bryman & Bell underlines the importance of having a structured way of working, this is done in order to maximize the efficiency of the literature review process, as well as keeping track of the relevant articles found. The model further simplified the process of finding new and relevant literature for the research topic by first *(1)* reading books and/or articles which were either recommended or where the authors had previous knowledge of. Once the reading is completed, and the keywords of interest have been identified *(2)*, the third step *(3)* was to use the generated keywords in electronic databases, finding relevant articles applicable in the context of the master thesis. The fourth step *(4)* was to analyze the article in order to determine the usefulness for the master thesis and the research topic and if they should be kept or screened out. When relevant articles were found, the last step *(5)* was to continuously check for updates or new publications, since the topic of batteries is a topic which is currently relevant for the automotive industry.

The aim of the literature review was to identify previously conducted research on vulnerabilities related to supply chain management and supply chain resilience, preferably within the context of batteries or scarce materials. Thereafter, an interview guide for the second round of interviews that included the identified vulnerabilities was designed so that the vulnerabilities were addressed when discussing the topic. Moreover, to obtain relevant and credible articles for the research topic, electronic databases were used, such as Google scholar, Chalmers library and research gate. The applied search words were, but not limited to, the following: *Supply chain resilience, supply chain resilience strategy, supply chain vulnerabilities, supply risks, battery supply chain, raw material criticality, supply disruptions, LFP supply chain, Nickel-Cobalt supply chain.* Once the literature review was finished, the case study was initiated.

3.3.2 Case study

According to Bell et al., (2019), a case study is appropriate for a theme when the aim is to generate a holistic understanding of a specific subject, context or phenomenon and gain deeper knowledge, a method which was deemed relevant for this project. The author Herring (2009) explains that there are two different types of labels for data collection, one being primary data collection and the other being secondary data collection. The difference among the two labels is that primary data collection is collected directly by the researchers, while secondary data collection is data or findings obtained from previous studies. In Phase 2, the secondary data collection method is applied to gather information, this is done through a market data collection study, where data was gathered by browsing different databases regarding the current state of the supply chain for batteries, but also to identify the concentration of the different actors in the supply chain. The data gathering started by identifying where companies that operate within the nickel-cobalt and LFP supply chain are geographically positioned. The case-study was divided into three layers. The initial step was to use internal data provided by the OEMs PD, which contained raw material suppliers of battery chemistries of interest, both in the mining and refining process. Thereafter, Bloomberg NEF was browsed in order to obtain data on precursor manufacturers and their geographical position. The website was able to provide data sets which had the option to filter based on five different parameters. It was therefore possible to only view the suppliers that manufacture the precursor material of interest. As for the cathodes and battery cells, Bloomberg were once again used, supplemented by material obtained from consulting firms such as Mckinsey and BCG and lastly academic journals.

The obtained data contained the following points: country of origin, manufacturing location and product produced. The gathering of market data is visualized in the figure below and supplemented with text explaining the process in-depth. In order to increase the validity of the information gathered, the data gathered was based on active manufacturing plants, i.e plants currently producing goods. Manufacturing plants that were to be launched in the coming

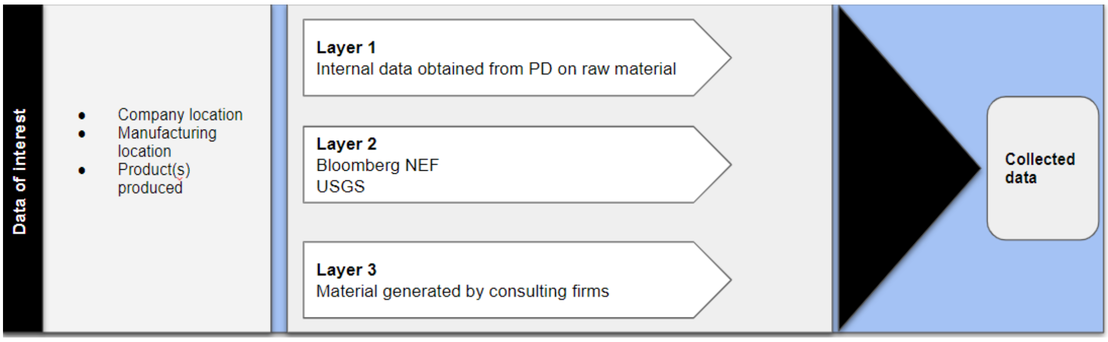


Figure 3. 2: Illustration of used method for case study

The content of layer 1 consisted of organizational news, investor presentations, company information and the own raw material analysis of the OEM. According to Bryman & Bell (2011), this type of data can be viewed as a valuable source of organizational information, thus increasing the probability of valid data. Subsequently, layer 2 acts as a supplement to layer 1. The website Bloomberg NEF provides valuable up-to-date market insights where the website's section “data & tool” provides consolidated data on different battery component manufacturers. The data set provided the option to filter based on five different parameters which were: plant status, manufacturer, component, battery chemistry and country of origin. The data sets provided information such as announced partnerships between actors, announced expansion plans and additional valuable information about the involvement of actors in the supply chain. However, to ensure the credibility of the thesis, these parameters were not included, since the aim was at only providing information on plants that are currently operating.

The third and final layer of data was collected from sources such as the consulting firms McKinsey & CO and BCG. The firms provide data regarding supply and demand estimates, but also provide information regarding the probability related supply chain disruptions. The data was gathered from the company’s own website. All of the information gathered for each actor in the supply chain was stored in a google drive folder, which was then categorized from the mining and refining all the way to the cell manufactures This aided in keeping track on the data obtained, whilst also streamlining the process of identifying the needed data points for the vulnerability parameter(s) identification. Once the description of the two supply chains and the market data process was finished, vulnerabilities related to the context of this project had been listed. To verify the relevance of these vulnerabilities in relation to the industrial sponsor and the automotive industry, validation interviews were held internally.

3.3.2.1 Assessment of critical raw material

In order to assess the criticality of the raw materials used to produce the cathodes of nickel-cobalt and LFP, the European raw materials criticality assessment was used to gather data. The methodology applied in the report involves a two-step process, whereas the first step in the assessment is a quantitative analysis which assesses the supply risk and economic importance of the raw materials. The analysis is based on data such as trade flows, price volatility and production volumes (i.e., mining capacity). The second step in the assessment is of a qualitative nature, where the environmental and social impact of the raw materials are considered. The assessment is further based on several criteria, such as the degree of production concentration and trade, degree of substitution, degree of recyclability and reuse potential, and lastly the level of governance in the production and trade of the raw materials. Figure 3.3 below visualizes the overall structure of the method that the European raw material criticality act utilizes (Europa.eu, 2023).

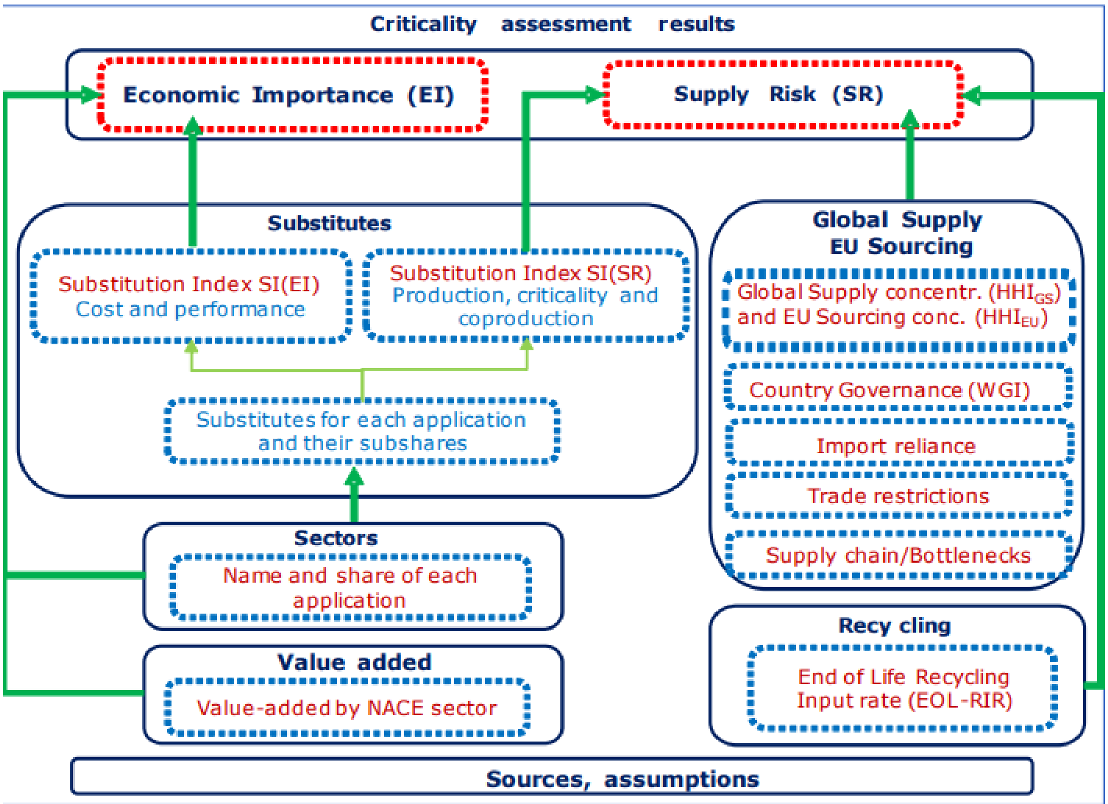


Figure 3. 3: European raw material criticality assessment structure (Europa.eu, 2023)

3.3.3 Sampling for validation interview I: Validating the findings from phase 2

To ensure the reliability of the data gained from interviews, it was deemed necessary to interview sourcing managers currently working within the purchasing department at the OEM. The participants were sampled based on their role at the department and their active part in procuring battery cells for the OEM, whether the involvement was direct or indirect. Direct involvement in this context is defined as the employees responsible for sourcing battery cells, whilst indirect involvement is defined as those employees which are responsible for the procurement or analysis of material related to batteries, e.g., raw materials. The criteria's applied in this sampling session was further based on how long candidates had worked in the department. Candidates who had less than 6 months of experience were excluded since they were still in the infancy stage of their role. It was also considered that the candidates who had primarily experienced problems in their daily work, related to the battery sourcing, were of interest. This is because the very purpose of the first round of interviews addresses the vulnerabilities of the supply chain.

3.3.4 Validation interview I: Validating the findings from phase 2

Once the identified battery supply chain vulnerabilities were found, the first round of validation interviews were held. The validation interview technique was held to verify that the findings were in line with what the OEMs purchasing department deemed relevant. In the validation interviews, the identified vulnerabilities from the case study were presented in combination with those vulnerabilities presented in the first round of the semi-structured interviews. The validation interviews were particularly helpful in enhancing the credibility and trustworthiness of the master thesis, but also to ensure that the project aligns with the ambitions of the OEM. This part of the process enabled the project to reach the next step, which was to identify relevant enablers, defined in section *2.1.2 supply chain resilience enablers,* and resilience strategies to address identified vulnerabilities.

3.4 Phase 3 – Supply chain resilience enablers and strategies - identification and pairing process

In phase 3, the purpose was to identify potential enablers and strategies that are related to the identified vulnerabilities. Semi-structured interviews were held with external industrial experts and practitioners related to battery supply chains, where the vulnerabilities from phase 2 were presented. After the interviews were finished and the obtained data was collected and analyzed, another round of validation interviews were held internally. The purpose of the validation interviews was to ensure that the findings were in line with the interest of the OEM.

3.4.1 Semi-structured interviews II: Identifying supply chain resilience enablers and strategies in context of battery supply chain

To capture the perspective of as many actors in the battery supply chain as possible, it was deemed it crucial to identify candidates active in as many parts of the supply chain as possible, both in a European context and a non-european context. Therefore, in order to ensure a diversified sample, the candidates were selected on criteria such as the geographical location of their employer, their business role (battery manufacturer, automotive OEM etc.) and their years of experience. The ambition was to target industrial experts and practitioners which were regarded as seniors. Moreover, it was desired to generate a sample in which the respondents had a diversified background, both in terms of working experience but also in terms of academical background, which could complement each other from a knowledge-based point of view. There were 11 participants from 6 companies. Their position, their role and the duration are presented in table 3.4 below.

Table 3. 4: Overview of the respondents form the second semi-structured interview round

ID	Company	Role	Date	Duration
A1	Automotive OEM A	Senior Project Buyer	2023-03-31	60 min
A2	Automotive OEM A	Global Category Manager	2023-04-03	60 min
A3	Automotive OEM A	Battery Buyer	2023-04-07	60 min
A4	Automotive OEM B	Procurement Specialist	2023-04-12	60 min
A5	Automotive OEM B	Global Category Manager	2023-04-12	60 min
AC1	Asian battery manufacturer A	Battery Component Buyer	2023-04-11	60 min
AC2	Asian battery manufacturer A	Global Commodity Specialist	2023-04-13	60 min
EC1	European battery manufacturer A	Battery Component Buyer	2023-04-11	60 min
RI1	Research institute A	Research and Business Developer	2023-04-03	45 min
RI2	Research institute A	Key Account Manager	2023-04-14	60 min
RC1	Battery recycling company A	Battery Recycling Specialist	2023-04-20	45 min

The interview guide, presented in appendix A.2, was designed to spark a discussion, but also to enable the respondents to provide personal experience from current or previous work experiences, in which their employer or department experienced disruptions along their supply chain. The participants were offered the option to elaborate on how these disruptions were managed, not only by themselves, but by the department and OEM as a whole. The interview structure was to initially provide the respondent to share information related to their work experiences and their day to day work, followed by the presentation of identified vulnerabilities. Once the vulnerabilities were presented, the respondents were given the chance to discuss said vulnerabilities and provide inputs of what they considered important aspects (i.e., enablers) to address the vulnerabilities and also supply chain strategies that could be considered in the context of battery supply chains. The transcripts of each interview were documented separately to facilitate the analysis during subsequent stages of the analysis process. The outcomes of this set of interviews will make a valuable contribution to addressing both research question two and three.

3.4.2 Validation interviews II: Validating enablers and strategies

To validate the findings related to enablers and battery supply chain strategies, a second round of validation interviews were performed. The goal of these interviews were to gather insights and validation from the respondents within the OEMs purchasing department and to ensure that the findings accurately aligns with the perspectives of those within the organization, whilst also providing the opportunity for the respondents to identify potential discrepancies in the data collected. Similar to the first round of validation interviews, the second round was constructed in a semi-structured manner. During the interviews, the respondents were presented firstly with the enablers identified previously and were asked to provide feedback, in terms of either confirming or denying the enablers and their relation to the topic. Thereafter, the consolidated strategies from the findings were presented, validated and paired with what the respondents believed were the required enablers to realize the strategy. The same respondents used in the first validation round were used again in the second validation round.

3.4.3 Workshop

According to Bryman and Bell (2013), a workshop can be utilized as a qualitative data collection method through focus groups for problem-solving sessions. Therefore, the findings generated from phase 3 were consolidated and presented in a workshop executed with the commodity and project manager, referred to as *P1* in table 3.3, for the purchasing department of the OEM. The purpose was to investigate how the identified strategies are realized through the identified enablers and the outcome was that each strategy was paired with the required enablers.

3.6 Data analysis

Analyzing data is a crucial step in any research project, since it allows the researcher to make sense of the information that has been collected and provides the opportunity to draw meaningful conclusions. Without the analysis of the data, the information gathered would just be a collection of unorganized raw data. The data analysis process furthermore ensures the validity and reliability of the findings and simplifies the communication of these findings to the readers. Therefore, a thematic analysis was applied for the data analysis process. Thematic analysis is a widely used approach to analyzing various types of data, such as qualitative, quantitative and mixed-methods data. However, in this thesis, the data which will be analyzed is of a qualitative nature, thus thematic analysis will be applied throughout the master thesis. In the following section, the key features of the analysis used, and the steps used will be described (Bell, Bryman & Harley, 2018).

3.6.1 Thematic analysis

The reasoning behind the choice of analyzing method comes from the flexibility of using thematic analysis. Unlike other methods, thematic analysis is not bound by a particular theoretical framework, nor is it tied to a set of assumptions. Instead, the method provides the opportunity to adjust it to fit the unique features of the information collected. Moreover, thematic analysis involves a systematic approach, ensuring the reliability and validity due to the ability to avoid subjective opinions and instead ensure that the analysis is based on evidence. The steps applied in the thematic analysis are explained below.

The steps for analyzing the data consist of (1) transcriptions, (2) coding, (3) categorization, (4) analysis and (5) interpretation. (1) *Transcription* is defined as creating a written record of the interview recordings. This was done and cross-examined in order to assure accuracy and completeness. (2) *Coding* is the process of categorizing and labeling the data gathered based on specific topics or themes, this involves identifying recurring topics, categorizing these topics and assigning them codes. Once the coding is completed, the data needs to be *(3) categorized*, the data can be organized based on key themes or topics, in this case, the data was categorized based on topics discussed. Once the data is categorized, the process of (4) *analyzing* the data begins, where the textual data is analyzed based on specific phrases, words, or topics within the scope of the master thesis, this is where specific patterns were identified in terms of recurring words, phrases, or themes. (5) *Interpretation* is defined as how the researcher(s) interpret the data and use it to develop insights and draw conclusions. (Bell, Bryman & Harley, 2018; Fontana & Frey, 2005; Guest, MacQueen & Namey, 2011). This way of analyzing data was applied throughout the master thesis.

The primary data collected was through interviews and the secondary data through a case-study and literature review. Before the data gathered could be presented in the master thesis, it had to be analyzed. The process of analyzing the interviews started off with transcription, where information which was regarded important and relevant was marked and categorized firstly according to research question and secondly according to themes and topic. There were also two sub-categories, one for the identified enablers and one for the potential strategies. This streamlined the process of analyzing the data, i.e., identifying patterns, correlations and similarities. For a more detailed view on the analysis, see Appendix B1 and B2. This approach was also applied in the validation interviews and workshop. As for the secondary case-study, the approach was similar to the one for the interviews, however, as there was no need for transcribing, this part was eliminated from the analysis process.

3.7 Research quality

Evaluating the research quality is an important step in order to ensure the trustworthiness of the study (Bryman & Bell, 2011). According to the authors, the research quality can be divided into three different parts, i.e., reliability, validity and generalizability. The validity in the research quality defines whether the results of the thesis measure what is supposed to be measured. In the master thesis, the mapping of the supply chain and the compiled data need to have proper validity. If this is not the case, meaning that, if the supply chain is mapped incorrectly or the data on the topic of battery supply chain and supply chain resilience are irrelevant for the context, it might lead to unfitting outcome of the conclusion and proposed framework for the OEM. To avoid undesirable consequences, a thorough data collection will be conducted in the shape of semi-structured interviews, case study and a thorough literature review.

3.7.1 Reliability, validity and generalizability

Reliability describes whether it is possible for an external actor to repeat the study and obtain the same results. Hence, it is of utmost importance to apply the same methodology for data collection so that an attempt to redo the study would results in the same outcome. Therefore, a structured data collection method was applied, which is explained in detail in section 2.1 (Bryman & Bell, 2011). To ensure the reliability in the master thesis, an approach using triangulation can be used. Triangulation is defined as the usage of several sources in order to certify statements. The method will increase the reliability in findings by verifying statements with other sources (Bryman & Bell, 2011).

Lastly, Bryman & Bell (2011) underline the generalizability of a research. This is defined as to what degree the findings of a research project may or may not be applicable beyond the scientific context of its research focus. In some scenarios, the research approaches are limited by nature in generalizability, often found in case study contexts. Other approaches might include quantitative characteristics that are designed to permit conclusions to be drawn beyond the samples of the data from which they have been selected (Bryman & Bell, 2011). For this project, the ambition is to provide the industrial sponsor with knowledge regarding alternatives and what required capabilities need to be in place to counter supply chain disruptions for their battery supply chain. This is done through investigating if the LFP battery supply chain offers conditions for what could be considered arbitrary supply chain resilience or an antifragile supply chain. Even though the focus is for a particular Swedish automotive OEM, the findings, and methods to counter disruptions are intended to be applicable for other European automotive OEMs that can be classified within the same industry and face similar challenges.

3.7.2 Ethical considerations

Before every interview, the interviewees were informed on the topic of discussion, so that there is no misunderstanding of the aim of the interview. The actors involved were also informed that the authors are conducting research for a master thesis and made aware that the thesis will be published. The respondents were also asked if they were comfortable with the authors taking notes of the meeting and also informing them to only answer questions that they feel content with. This was done due to the ethical aspect of the report, Bell et al., (2019) underlines the importance of ethical considerations when executing data collection in order to avoid any type of harm or discomfort. Concerning confidentiality, the interweaves were assigned aliases. The data collected was then placed in the industrial sponsor's own servers to ensure that only the authors had access to the confidential information. This was done so that no one can access the identities of the respondents, the companies where the respondents work, or any other confidential notes taken during the course of the interviews.

4 Empirical Findings

In this chapter, the main findings of the study are presented. The structure of the chapter is divided into two sections, where each section represents the first and second research question and the corresponding findings. For the first research question, the vulnerabilities of the two battery supply chains investigated are presented. For the second research question, the enablers and strategies identified from the data collection are presented and elaborated upon. Figure 4.1 below summarizes the empirical findings.

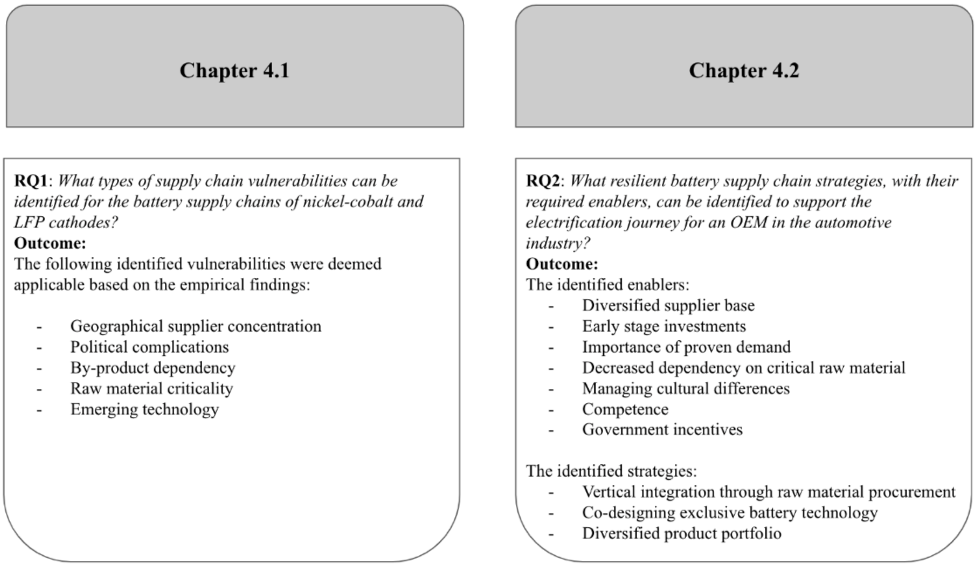


Figure 4. 1: Summarizes the content of the empirical findings in chapter 4

4.1 RQ1: Identified Vulnerabilities

LFP and nickel-cobalt are two types of battery chemistries for cathodes used in the EV industry. To provide a holistic view of what type of supply chain vulnerabilities these two battery chemistries have, the first research question that was formulated was "*What types of supply chain vulnerabilities can be identified for the battery supply chains of nickel-cobalt and LFP cathodes?",* which will be answered in this section. A total of seven vulnerabilities emerged from phase 2, however, this section will focus on the five vulnerabilities that were validated from the interviews in phase 2, which are the following: *Geographical supplier concentration, political implications, by-product dependency, raw material criticality and emerging technologies*. The remaining two vulnerabilities, *degree of recyclability* and *degree of substitutability*, are excluded from this section since the respondents did not discuss their relevance in the validation interview. The section starts off with presenting data for the geographical location of the suppliers and their geographical concentration in terms of market share. Followed by possible political implications for each chain, the by-product dependency for each material, the raw material assessment and how emerging technologies might affect the supply and demand for the materials used. Table 4.1 below summarizes each vulnerability addressed from the interviews in phase 3 and presents the key findings.

Table 4. 1: A summary of the 5 vulnerabilities that were addressed during the semi-structured interview in phase 3

Vulnerability	The consequence from each vulnerability
Geographical supplier concentration	• Chance of disruption if supplier countries suppress material to OEM • Potential impact on cost, quality, volume, customer satisfaction and reputation • Possible disruptions throughout the whole supply chain • Highly concentrated in Asia
Political implications	• Trade wars and taxes is a concern which is part of political implications • Political tensions affect the price and supply • Construction of manufacturing facilities might experience difficulties if not incentivized • The DRC is associated with social and environmental issues • The lack of incentives has been concluded to be a barrier for the European battery industry • Both LFP and Nickel-Cobalt face similar concerns in terms of political implications
By-product dependency	• Nickel-Cobalt is the only supply chain affected • If the demand for Nickel were to decrease, the supply of cobalt would be reduced
Raw material criticality	• All materials except iron ore are considered critical • Cobalt is the material considered the most critical • Higher degree of criticality leads to higher probability of disturbance
Emerging technology	• If the raw materials used in the batteries experience increased demand in other application areas, the supply and price might be affected. • Nickel: 70% of the supply are used in the stainless-steel production • Cobalt: application areas include the aerospace industry and electrical equipment such as motors and generators • Phosphate: 80% of the supply are used in the fertilizer industry

4.1.1 Vulnerability I: Geographical Supplier concentration

The supplier concentration vulnerability was identified partly through the literature review, where several academic articles emphasize the importance of having a dispersed network of suppliers, but also through the first round of interviews with internal management, who expressed concerns about having such a high clustering of suppliers in one area. Respondents explained that the risks around a potential blockage between the region and the OEM's manufacturing facilities could have devastating consequences, in terms of cost, quality, customer satisfaction but also the reputation as a premium vehicle manufacturer. In order to systematically break down what the concern is around the vulnerability identification of supplier concentration, this section presents the geographical market share of the different processes in the battery supply chain.

4.1.1.1 Lithium, Nickel and Cobalt supplier concentration - Mining & refining

For lithium, the mining stage is dominated by four different countries, which accounts for almost 90% of the total mining for lithium. Australia produces over 50% of the world's total demand. Followed by Australia are three separate countries which are responsible for the remaining 40% of the mining. Once the extraction of the mineral is completed, there is a need for the refining of the material in order to obtain the right chemistry blend before it reaches the cathode manufacturers. Like the mining process, the refining of the mineral is heavily dominated by four countries, however in this step of the process, Australia has been replaced by China as the major actor for the refining of Lithium. The remaining countries, i.e., Argentina, Australia and Chile are responsible for 30% of the refining process for lithium. Table 4.2 presents the data in percentage for the mining and refining countries.

Table 4. 2: Country concentration in the mining and refining process for lithium (data retrieved from Bloomberg NEF, 2023)

Country	Market share	Mining or refining step
Australia	52%	Mining
Chile	22%	Mining
China	12%	Mining
Argentina	7%	Mining
China	60%	Refining
Argentina	13%	Refining
Australia	9%	Refining
Chile	8%	Refining

As for nickel, the mining and refining stage is heavily dominated by Asia, where Indonesia accounts for a third of the global mining production and China for almost half of the world's refining process for nickel. However, the remaining countries responsible for the mining and refining for nickel are more spread out around the globe compared to lithium, table 4.3 presents the data for market share for nickel.

Table 4. 3: Country concentration in the mining and refining process for nickel (data retrieved from Bloomberg NEF, 2023)

Country	Market share	Mining or refining step
Indonesia	33%	Mining
The Philippines	12%	Mining
Russia	11%	Mining
New Caledonia	8%	Mining
Canada	8%	Mining
China	49%	Refining
Finland	17%	Refining
India	11%	Refining
Australia	6%	Refining

For the mining of cobalt, the Democratic Republic of Congo (DRC) accounts for approximately 70%, followed by Russia, Australia, Cuba and the Philippines. Even though DRC possesses the largest market share in the mining process, China dominates the refining process at 79%. Table 4.4 presents data on the exact market share.

Table 4. 4: Country concentration in the mining and refining process for Cobalt (data retrieved from Bloomberg NEF, 2023)

Country	Market share	Mining or refining step
DRC	70%	Mining
Russia	4%	Mining
Australia	4%	Mining
The Philippines	3%	Mining
Cuba	3%	Mining
China	79%	Refining
Finland	7%	Refining
Taiwan	3%	Refining
Cuba	1%	Refining

4.1.1.2 Lithium, Iron and Phosphate rock supplier concentration - Mining and refining

The mining and refining stages for lithium are unchanged, regardless of what type of battery chemistry it ends up in. Thus, the following section will only present the country's concentration for iron and phosphate. Since there is no data available on the refining process of neither iron nor phosphate, an assumption is that the refining takes place on the production site. For iron ore production, Australia, Brazil, China and India are responsible for 70%. As for phosphate, China, Morocco and the USA are the market leaders in the mining process, accounting for over 70% of the mining. Table 4.5 presents the data for the mining.

Table 4. 5: Country concentration of iron ore and phosphate rock (data retrieved from USGS, 2023)

Country	Market share	Mining or refining step
Iron ore mining		
Australia	36%	Mining & Refining
Brazil	19%	Mining & Refining
China	14%	Mining & Refining
India	8%	Mining & Refining
Phosphate rock mining		
China	39%	Mining & Refining
Morocco	18%	Mining & Refining
USA	10%	Mining & Refining
Russia	6%	Mining & Refining

4.1.1.3 Supplier concentration - Precursor

As for the country concentration of the precursor materials, China is the major provider of Precursor materials for the LFP and nickel-cobalt cathodes, being responsible for almost 100% of the precursor supply chains for both types of cathode active materials (Bloomberg NEF, 2023).

4.1.1.4 Supplier concentration - Cathode manufacturers

The cathode manufactures for both LFP and nickel-cobalt cathodes are heavily dominated by Asia in terms of country concentration. For LFP, Asia conducts 100% of the cathode manufacturing, split up between China, Taiwan and South Korea at 94%, 4% and 2% respectively. As for the nickel-cobalt cathodes, Asia is still the major producer, where China, Japan and South Korea stand for almost 70% of the production, whereas Europe accounts for the remaining 30%.

4.1.1.5 Supplier concentration - Cell manufactures

For the cell manufactures, China once again dominates the production in terms of country concentration, accounting for 76% of the total production of battery cells. The USA and Europe come in second and third place with 8% and 7% respectively. The remaining 9% of cell manufactures are located in Asia (Bloomberg NEF, 2023).

4.1.2 Vulnerability II: Political implications

Political implication was a vulnerability identified as a result of the geographical cluster of suppliers connected to the battery supply chain. Multiple factors were identified within the context of political implications, such as trade wars, the possibility of clustered battery business regions shutting down borders, thereby eliminating the supply of material, or the unwillingness of a country to trade to an OEM located in another country. The findings from the interviews and the case study revealed that the lack of incentives from the government and policymakers on international levels is a significant issue. With no lucrative agendas contributing to fully or partially localizing battery supply chains, the reliance on particular suppliers increases which implies a fragile supply chain. Political tensions were also brought up as a vulnerability in this context. For instance, the war between Russia and Ukraine caused a significant price increase on nickel, since Russia is a major supplier of nickel. Similar issues are related with the cobalt supply, which is largely concentrated in the DRC, where reports of human rights violations and child labor are issues. Even though some of the raw materials used, primarily nickel and cobalt, in the battery manufacturing process are susceptible to political implication, the remaining materials highlighted in this project, lithium, phosphate and iron, can also be affected by political implications to some extent. This is, again, mainly due to the geographically clustered battery supply chains for both LFP and nickel-cobalt cathodes.

4.1.3 Vulnerability III: By-product dependency

By-product dependency for raw materials that constitute a specific type of cathode is viewed as a vulnerability that increases the chance of disruptions in the supply chain. As for nickel-cobalt and LFP cathodes, it is the nickel-cobalt battery composition that is subjected to by-product dependency. This is due to cobalt being a secondary material, extracted through nickel or copper mining as primary materials. The LFP cathode, unlike the nickel-cobalt cathode, does not face this issue. Lithium, iron and phosphate all are considered primary materials. The mining process itself is not considered the only factor for the identified vulnerability, there are other scenarios that may cause disruptions in the supply chain due to the mining process. For instance, if the market decided to move away from nickel-cobalt batteries, the decrease in demand would result in decreased mining of nickel, which in turn would affect the supply of cobalt. Therefore, future scenarios for certain OEM´s still utilizing cobalt could result in harsh competition when securing the supply of cobalt, provided that the demand for nickel or copper decreases.

4.1.4 Vulnerability IV: Raw material criticality

The materials used in the manufacturing of nickel-cobalt and LFP cathodes are composed almost entirely of 100% critical raw material, with the exception of iron ore used in LFP cathodes. Lithium, which is essential for the production in both cathodes, is viewed as a critical raw material due to its wide usage in the manufacturing of batteries for electric vehicles, mobile devices and similar technological applications. Due to the increased demand for electric vehicles, in both the private and commercial sector, the demand for lithium has increased significantly. Moreover, Europe is dependent on imports for lithium, since approximately 90% of the supply for lithium comes from countries outside of Europe.

The most critical raw material is cobalt, which is also an essential component used to manufacture rechargeable batteries in electric vehicles and other similar applications. Similar to the case of lithium, the demand for cobalt has increased drastically due to the increased demand of battery electric vehicles. The assessment stems partly from the high import reliance on the supply of cobalt, whereas more than 90% of the metal being supplied from outside of Europe, and partly from the environmental and social challenges in the cobalt supply chain, which includes human rights abuses and the high share of environmental impact, such as water pollution and destruction of biological ecosystems. Therefore, cobalt receives the critical raw material label.

As for Nickel, Europe is once again dependent on imports in order to meet the demand, where more than 70% of the processed nickel supply originates from outside of Europe, especially now due to the Russian-Ukraine conflict. Phosphate rock, the raw material used in LFP cathodes, is also viewed as a critical material. This is mainly due to Europe being 100% reliant on imports of the material to meet the demand. The only material out of the ones discussed in this project which is not labeled as critical is iron ore. Even though iron ore demand relies on imports to meet demand in Europe, the countries that Europe receives iron ore from are not viewed as regions where increased or emerging supply risk exists. Figure 4.2 below visualizes the criticality based on supply risk and economic importance according to European critical raw materials act.

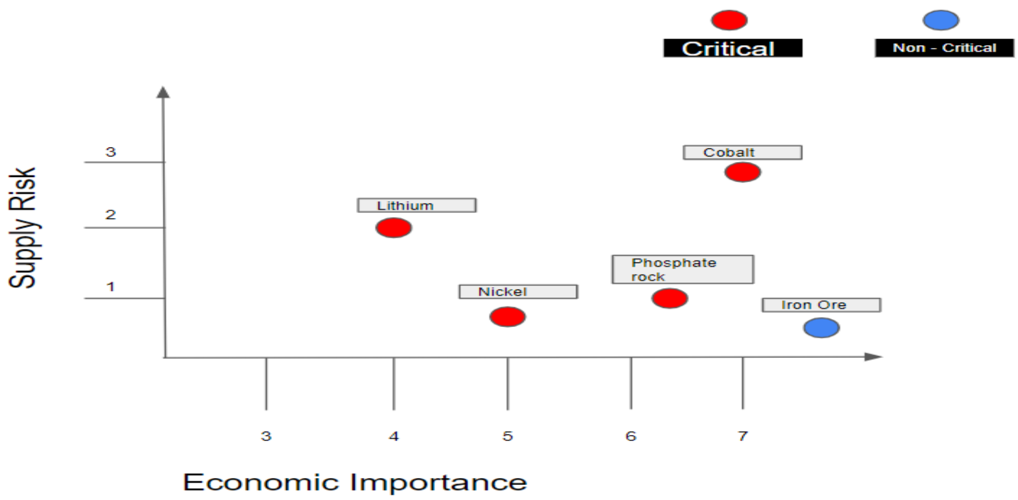


Figure 4. 2: Visualizes the supply risk in relation to economic importance of lithium, nickel, phosphate rock, cobalt and iron ore, where red indicates critical materials and blue indicate non-critical materials (adapted from European critical raw materials act)

4.1.5 Vulnerability V: Emerging technologies

There are multiple raw materials used to manufacture the cathodes in both nickel-cobalt and LFP. Throughout this project, there have been different angles in analyzing the possibility of disruption for the two different supply chains. However, this section explains what other applications exist for the raw materials involved. Due to lithium being a necessity in the manufacturing of batteries, it will be excluded from the analysis. Thus, only nickel, cobalt, iron and phosphate will be mentioned.

Nickel has been noted to have multiple application areas, the production of various alloys, different chemical applications and the stainless-steel production are a few. The stainless-steel production being the most dominant one, where approximately 70% of the nickel mined are accounted for by said industry. Therefore, even though there aren’t any disruptions currently due to the industry's high demand, if there were to be another industrial construction revolution, there could be serious consequences for nickel's supply chain, thus posing a possibility for disruptions.

As for Cobalt, besides the risks that stems from the mining phase and the high concentration, there are additional areas of use for cobalt. The aerospace industry applies cobalt-based alloys in aircraft engines and other high-performance applications, similar to nickel. Cobalt is also used in other electrical equipment such as motors and generators, which comes from the production of magnetic alloys. Therefore, there is a possibility of disruptions if these industries were to accelerate their usage of cobalt, besides those already mentioned.

Iron is one of the main components in the LFP cathode production, whilst there is an abundance of iron, the steel production industry accounts for over 90% of the iron demand. When only include the construction industry, the usage increases to approximately 95% of the global demand, thus posing a vulnerability if these industries were to experience a sudden increase in demand for iron ores. Phosphate also has other industrial application areas, particularly the fertilizer industry where phosphate is a key component that accounts for over 80% of the usage. However, for both iron and phosphate, there aren't any immediate chances of disruptions, i.e., sudden increases, which are deemed unlikely, would need to occur to affect the supply chain for the two materials.

4.2 RQ2: Supply chain resilience enablers and strategies for battery supply chain

In this section, the findings from the semi-structured interviews through the method highlighted in phase 3 will be presented. The findings aim at answering the second research question of this project which is "*What resilient battery supply chain strategies, with their required enablers, can be identified to support the electrification journey for an OEM in the automotive industry?*" The identified supply chain resilience enablers for the battery supply chain will be presented and explained in terms of their definition, context and motivated factors expressed by the respondents who raised them. Subsequently, the chapter is followed by compiling the data from phase 3 into supply chain resilience strategies for the battery supply chain that were raised by the respondents. Table 4.6 and 4.7 below summarizes the identified enablers and strategies respectively. Lastly, this section finishes by highlighting what enablers are required to realize each identified strategy, which was composed through the workshop explained in section *3.4.3 Workshop*.

Table 4. 6: Identified supply chain resilience enabler for the battery supply chain

Enabler	**Definition**	**Key findings**
Diversified supplier base	*"Multiple suppliers in multiple countries, eliminating clustering of suppliers"*	• Having multiple countries to source from enables a resilient supply chain • Reduces the impact of supply disruption by having several alternatives • Could lead to decreased cost • Could provide accelerated innovation
Early-stage investments	*"Being early on in investing in new technology"*	• Asian suppliers have been able to gain a competitive edge by investing in emerging technologies early on • By identifying and investing in new battery technology early on, the OEM gain the advantage of being prepared and thereby increasing the resiliency of the supply chain
Importance of proven demand	*"Providing proof of proven demand to suppliers"*	• Suppliers in the battery supply chain has multiple customers to choose from. Therefore, in order to be viewed as an attractive customer, the OEM needs to present a proven demand
Decreasing dependency on critical raw material	*"Reducing the dependency on material which is assessed to be critical"*	• To handle the concern with critical raw material, one must either decrease it drastically or eliminate it completely
Managing cultural differences	*"Managing cultural differences amongst Asian and European employee cultures. Work-culture differs significantly"*	• Asian OEMs have different ambitions compared to European OEMs, whereas Asian OEMs focus more on revenue, whilst European OEMs focus more on the environmental aspect • It's important to understand and address the cultural differences to achieve a resilient battery supply chain
Competence	*"Increased knowledge connected to batteries is identified as a facilitator to achieving a resilient supply chain"*	• There is a lack of competence connected to batteries in Europe • European OEMs needs to focus on increasing the competence through either recruitment or education
Government incentives	*"Government incentives contributes to the acceleration of the EV and battery industry"*	• In order for Europe to accelerate the battery industry, different government actors needs to contribute in terms of incentives

Table 4. 7: Identified supply chain resilience strategies for the battery supply chain

Strategy	Explanation	Key findings
Vertical integration through raw material procurement	“The act of procuring raw material and guiding the material to desired suppliers”	• The strategy generates increased visibility and control over where all the value chain processes occur after raw material extraction
Co-designing exclusive battery technology	“Designing a unique battery, exclusive for the applications of an OEM”	• Being a part of the design phase entails also participating in supplier selection • Increased upstream control in the supply chain • Production capacity of cell suppliers dedicated for the applications of the OEM
Diversified product portfolio	“Offering more than one battery technology, not everything has to be premium or high-end”	• Increased flexibility due to expanded product offering • Increased competitive edge • Decreased demand for critical materials

4.2.1 Diversified supplier base

Out of the 11 respondents, three highlighted the importance of having a *diversified supplier base* as a resilience enabler. The two respondents, RI1 and RI2, implied that the concentration of suppliers is in most cases a vulnerability for any supply chain, especially in a scarce material field such as the battery manufacturing industry. RI1 and RI2 mentioned that the diversification would potentially enable a resilient battery supply chain, since if one supplier were to experience production delays or quality issues, the purchasing actor, in this context the OEM, could shift their focus and increase the flexibility of their procurement to another supplier in their supplier base. This could reduce the impact of potential disruptions. This was further strengthened by the A5, which spoke about the importance of having a high yield rate on every manufacturing process of the battery supply chain.

"Multiple suppliers would facilitate the development of a resilient supply chain, since the OEM can be flexible when disruptions in the chain occur." - RI1

Besides securing supply, the respondents underlined that multiple suppliers could also lead to decreased costs, since the negotiation power would increase, similar to a hedging method. This would in turn increase the leverage which allows for the opportunity to gain supply chain advantages, thereby also playing a role in the competitiveness of the OEM. RI2 pointed out the importance of open innovation, which could be achieved by having more than one supplier, since multiple suppliers would generate a sea of ideas, which could turn the partnerships into more of a collaborative nature, stimulating the creativity within the focal company, further securing the competitiveness. This was also in line with RI1, which pointed out the lack of innovation in important industries, such as the battery manufacturing sector. By collaborating and exchanging knowledge, the two actors could benefit from one another whilst simultaneously generating profit.

However, the two respondents were clear regarding the fact that they did not have any practical examples of the advantages from having a diversified supplier base in the battery supply chain context. RI1 and RI2 pointed out that the proposed enabler is rather of a general guideline but can still be deemed important due to the complexity of the battery supply chain. A4 aimed more focus on the advantages from a sustainability point of view. For instance, by having multiple suppliers to choose from, an OEM could select suppliers based on their environmental performance, thus ensuring that the components used in the manufacturing of a battery is sourced sustainably. This is deemed by A5 to be of interest, since the battery industry has received criticism regarding partly the sourcing of batteries or its materials and partly due to the conditions from where the raw materials used are mined from, referring in this case to cobalt.

4.2.2 Early-stage investments

Respondents A1 and A2 highlighted the *early-stage investment* as a factor. Early-stage investment is in this context defined as investing a new technology early on before it reaches maturity or commercialization in the market. Both respondents used Asian suppliers as an example. The Asian suppliers had been actively securing supply all the way from the mining stage to the manufacturing of the actual battery. This had been done during a time span of approximately 30 years, thereby resulting in a solid market position. During this time, the battery supply chain actors have been securing close partnerships amongst each other, which respondents AC1 and AC2 pointed out. They elaborated on how Asian cell manufacturers had made strategic early investments in the industry, fostering partnerships that encouraged key players upstream in the battery value chain to establish production facilities for cathode processes near the Asian cell manufacturers. This joint effort was made possible through investments before the battery industry was fully established and is still continuously improving, making it harder for other actors downstream in the supply chain to gain control of supply.

Moreover, A1 stated that the current challenges for the automotive industry stems from a sort of panic purchasing strategy, where the ambition is to secure supply immediately, in order to minimize the probability of production stops. A1 explains that their automotive OEM was able to avoid these disruptions because the organization was quite early in the development of electric vehicle batteries. However, the respondent pointed out that if they had been even earlier, they could have secured capacity in a more "trouble-free" way, meaning that they would have managed to establish closer relationships with suppliers and perhaps even secured low-priced batteries. This would have further strengthened their market position and the resilience of their battery supply chain.

"Since we at this OEM were early on in recognizing the potential limited supply, we were able to avoid pausing the production due to the lack of batteries or cathode materials, increasing our competitive advantage". - A1

RI2 is on the same track, as the respondent also emphasized the importance of being an early investor in a new, emerging technology. RI2 believed that it is currently "too late" for OEMs to secure assets without taking the risks of disruption and they should therefore look at other types of battery technologies to invest in instead. RI2 argued that there are possible and new battery technologies for cathodes and referred to where TESLA, as a leading EV OEM today, is positioned today and how any of the global automotive OEMs ready to invest in new technologies could be in future scenarios. The respondent believed that TESLA does in fact have a resilient battery supply chain due to the company's long-standing presence in an industry that has just started to expand in the last two or three years. Moreover, RI1 and RI2 emphasized that early investments can help OEMs to establish a resilient supply and adapt to new market conditions. The reasoning behind this statement was that being an early investor and not lagging in new innovations increases the situation awareness of a market and benefits can be carved out early before competitors.

4.2.3 Proven demand

Six respondents highlighted the importance of *proven demand* as a key enabler for a resilient battery supply chain. In this context, proven demand is defined as an OEMs ability to guarantee volume for the supplier as proof which ensures the suppliers that doing business with the OEM will generate profit. A1, A2, A3, AC1, AC2 and EC1 underlined proven demand as a critical tool for a purchaser in the battery industry. All six respondents argue that Asian suppliers are mainly driven by profit and are acts accordingly.

"*Asian suppliers focus firstly on profit, and this is shown in their selection of customers. They have the option to choose who they do business with since there is such high demand. Therefore, if the customer can't guarantee that they will purchase a specified amount of product, they just choose to go with another customer, repeating this process until they are satisfied with the proposed volume capacity. Therefore, for a customer to have leverage in the discussion, the customer needs to be able to guarantee high volume." -AC2*

"The best weapon in a purchaser's arsenal is the promise of proven demand when dealing in the battery industry." - AC1

By ensuring proven demand, the OEM would also be able to make requirements in a completely different way, since they would be regarded as a more valuable customer to the supplier. This leads partly to the strengthening of the supply chain and partly to becoming more competitive as an OEM. For instance, if a European OEM has obtained a high level of negotiation leverage through proven demand, they can suggest that Asian cell suppliers start building production facilities in Europe, in other words localization which is proven to have a positive effect on supply chain resilience according to AC1 and AC2. Furthermore, A2 and A3 mentioned that proven demand also assists in the procurement process of batteries and battery material since battery cells are not items that could be stored during longer periods of time. This is not only due to highly costly material in the battery cathode being tied up, but also safety and quality risks that come with storing battery cells or cathode active materials, unlike regular metal or plastic parts that is usual for the automotive industry. Hence, with a verified demand in place, the OEM can confidently procure materials knowing that they will be utilized promptly, thereby streamlining the process of ordering new cells containing cathode active materials and eliminating any concerns about the previously acquired battery cells becoming obsolete. This also further strengthens the proven demand to the cell suppliers and improves the determination to continue producing materials for the customer, being the European OEM.

4.2.4 Decrease dependency on material mined through by-production and material assessed as critical

All respondents underlined the issue with the critical raw materials used in the manufacturing of cathodes for batteries, especially nickel and cobalt. Lithium was also highlighted as a critical material, but is currently regarded as necessary in the battery cathode production. However, only four respondents suggested decreasing the dependency on critical minerals by exploring alternative cathode compositions. RI1 suggested looking at chemistries completely eliminating cobalt, by increasing the concentration of nickel and adding manganese, but also exploring the possibility of using a chemistry consisting of iron-phosphate, i.e., LFP. This was further strengthened by RI2, A1, A2 and RI1. The respondents expressed that a possible enabler to overcome the complex supply issues regarding cobalt, but also nickel, would be to completely eliminate it through other battery technologies. A1 highlighted that even though the switch from cobalt and possibly nickel to other applicable materials would affect the performance and range of the vehicle, it would in theory result in a more resilient supply chain and potentially even reduce the cost of the vehicle, since the cathode active material is the main cost driver in a battery cell.

" If we were to proceed with other chemistries, preferably those that do not include cobalt and nickel, the set up for inquiring the needed material would be much easier, since iron and phosphate for example is not as critical as nickel and cobalt. It would just simplify the process a whole lot more." - A1

A1 continued with elaborating on the subject, stating that the issue with using cobalt, besides the sustainability aspect of it, has its roots in the mining stage. If the demand for nickel would decrease, the production volume of cobalt would follow, leaving the OEM vulnerable for disruption. A1 pointed out that the location of the OEM also is relevant for reducing the dependency, since the OEM is located in Europe, some of the raw materials used to manufacture the cathodes might be affected by their criticality, further increasing the difficulty of procuring them. This is strengthened by A2, RI1 and RI2, who claims that these materials hinder the ability to create a resilient supply chain.

4.2.5 Managing cultural differences

Several respondents highlighted how cultural aspects between European and Asian actors substantially affects the possibility to enable resilient battery supply chains. A1, A2, A3, A4, A5, AC1, AC2 and EC1 all expressed that the way of working in Europe differs significantly from the way of working in Asia and that this often leads to clashes in interests and agendas. A1 was specific with underlining how economic interest was the primary driver in the Asian industry, meanwhile the European actors may have several other agendas that might not be fully in line with capital gain as fundamental drivers. The Asian suppliers are well aware of what strategic level batteries and their respective commodities have reached as an item in the global Automotive industry. A1 continues by describing that Asian battery cell manufacturers will remain within the frame of short-term utilization of the production capacity and technology knowledge to gain as much profit as possible before battery manufacturing technology becomes accessible globally. A1, A2 and A3 mentioned that the cultural difference must be fully understood and special methods that address how to influence the development direction in accordance with the European context must be implemented.

"I would say that the large battery manufacturing corporations in Asia also have people from every corner in the world working there. We could utilize this in a smart way to influence the discussion so that cultural clashes are as minimal as possible." - A2

A4 and A5 also mentioned the importance of culture and how the differences add additional complexity to an already difficult scenario. However, the suggestions from A4 and A5 on how to handle this was more of a forceful nature, believing that if the dependency on Asia remains long-term, the OEM has to be strict and constantly change suppliers or invest in new suppliers that might have the required production capacity, but lack maturity which might still make it possible influence the culture according to European standards. This was also highlighted by RI2 that described how a way to succeed initially might require having arm's-length relationships with several suppliers and being unfaithful with companies that are difficult to handle. That way, the OEM can explore different actors and develop a solid supplier base that has learned the European way of working and could therefore minimize the possibility of cultural conflicts. Moreover, AC1 and AC2 also touched upon the cultural aspects when working with Europe and underlined how the the companies upstream in the value chain have a level of loyalty developed during their 30 years of partnerships with the battery cell manufacturers. Therefore, expecting to change these relationships in a short period of time to suit European standards due to the rapid growing electromobility industry, is unrealistic. Instead, AC1 and AC2 believe that a key to succeeding when it comes to culture is that European companies must work with policymakers in a way that facilitates the collaboration between Europe and Asia.

“If European firms work efficiently with policymakers to make it easier for Asia to collaborate, then Asian firms will surely change culturally and view Europe as a region with more possibilities than risks, thereby making local investments there more attractive.” - AC2

4.2.6 Competence

Competence and knowledge connected to batteries, battery manufacturing and battery supply chains were recurring terms during the interviews and mentioned by A1, A4, A5, AC1, AC2, RI1, and RI2. This is due to how battery manufacturing differs significantly from the traditional way Europe has been working in the automotive industry, where traditional component and vehicle assembly is described as a mechanical process, while the core of battery manufacturing is described as a chemical process. AC1 and AC2 describe how cathode active materials are blended together into a certain mix, depending on the technical properties requested by customers, requiring highly skilled staff to execute this process with the correct quality, as little material waste as possible and an arbitrary production yield rate.

“One could say that the experience of a senior technician when it comes to battery manufacturing, especially cathode manufacturing, is equal to at least 10 junior technicians. That is how much competence for me means in this industry” - AC2

Investing in an in-house battery manufacturing was seen by the A1, A2, A3, A4, A5, RI2 and EC1 as the ultimate goal when it comes to enabling the development of a resilient battery supply chain, however, the respondents also underlined several times the importance of competence. A1 described that local supply chain configuration is preferred, although not without a well renowned partner. AC1 and AC2 explained how Asian battery manufacturers must send large amounts of experienced workforce to Europe once they have established production sites there to ensure that the yield rate in the production is arbitrary and early lack of knowledge issues can be minimized or eliminated. A3, A4, A5 pointed out that investing in European startups can also be seen as a key to resilient battery supply chains, however, there are risks considering immaturity in battery manufacturing, therefore making them still rely on Asian companies until the competence is partially or fully developed in Europe. RI1 and RI2 described that in order to succeed with local supply setups for cathode active materials, recruiting battery manufacturing competence from well established Asian companies can be considered as key. However, RI2 highlights that relying on recruiting staff from other regions in the world is not sustainable long-term and that Europe needs to develop local competence for batteries, especially since they will not only be strategic for the automotive industry, but several other areas as well.

"We are incredibly good at collaborating on a European level with industries and educational systems. We have to show the European firms that they must partner up with research institutes and allow us to validate innovations and ideas related to battery technologies beyond critical materials that are controlled by certain regions in the world." - RI2

EC1 also highlighted how currently new startups and European battery cell manufacturers rely solely on competence from staff having previous experience in Asian battery companies. EC1 believed that without the guidance from personnel with such experience, the production would not have been operational at all, but that time is needed to allow this competence to be transferred and mature for European firms.

"It might take longer than we initially wished for, but I believe that we have to give this industry time and not allow investments to be made without clear plans and competence development." - EC1

4.2.7 Government incentives - Increase collaboration between OEMs and policymakers

Whilst discussing the success of Asian battery manufacturers, respondents A1, A2, A3, RI1, RI2 and EC1 all stressed that the progress stems mainly from the involvement of the Asian countries and their respective governments. Moreover, the respondents expressed their frustration with the lack of involvement at the political level, both local and EU level. The respondents argued that Asian battery manufacturers have been able to maintain their competitive business model through the support of their governments. A1, A2 and A3 explained that these suppliers have managed to pick up shares because of the cooperation between them and the government. Incentives have enabled them to expand and maintain concentration in the Asian region, partly contributing to the construction of facilities required to produce the products themselves, but also to secure raw materials from the mines. For example, the Chinese government has invested large amounts of money in building and developing refinery processes for the raw materials, the process before reaching precursor and cathode production. This has contributed to the strategic advantage where even if OEMs manage to secure raw materials themselves, a large proportion of the materials still have to go through Asia where approximately 70% of the refinery processes are located.

The respondents argued that if Europe is to catch up, larger and more frequent investments into the electromobility industry is required. Even if OEMs have regular dialogues, the respondents believed that it must be done in a way so that improvements are focused on the correct areas. RI1 and RI2 argued that this was in line with their own opinions and believe that even if support exists for research institutes, it is often slow and in need of collaboration from both OEMs and policymakers. RI2 emphasized that even if Asia has a 30-year head start, Sweden and Europe are much better at working collaboratively with open innovation.

*"**We** (Europe) are much better at working with open innovation, we collaborate with actors working towards the same goal. We can even collaborate with competitors, if that would mean getting one step closer to solving the problem." - RI2*

“Politicians need to get more involved in this issue, electrification can be crucial to achieving our environmental goals of being net-zero by 2050.” - RI1

According to AC1 and AC2, the Asian governments provide funds to accelerate electrification, thus strengthening the statements of previous respondents. However, the agenda with the investments might not necessarily be to reduce carbon emission, the government sees it rather as an opportunity to generate profit.

“The Asian governments provide incentives for companies which work towards electrification. However, the purpose of the funding is not primarily to reduce emission. The government sees it rather as a possibility to make money. My assumption is that the EU prioritizes the environmental aspect above the possibility to make money, which could be a reason for what some say “lack” of involvement.” - AC1

Thus, increased investments from the different levels of government are identified as an enabler, partly to overcome the advantage which Asian suppliers currently possess and partly addressing the identified vulnerability with political implications. A1 and A2 argue that incentives would promote innovation in the area. A5 also agrees that the government should be more involved in increasing the progression rate, however, the respondent emphasizes that more focus should be put on the development of infrastructure. A5 elaborates on the topic by stating that to meet cost parity with combustion engine vehicles, one must scale up production, i.e., pursuing economies of scale. However, this could be difficult since there is a lack of infrastructure which translates to consumers not willing to purchase EVs if governments still fall behind in charging infrastructure. Concluding that infrastructure will most likely lead to increased demand. Increased demand would be recognized by non-European companies as a possibility to generate revenue, by moving production facilities over to Europe.

4.2.8 Identified battery supply chain resilience strategies

The semi-structured interviews resulted in a compilation of three types of supply chain resilience strategies that the respondents deemed necessary to achieve a resilient battery supply chain. These strategies are presented below.

4.2.8.1 Vertical integration through raw material procurement

The first consolidated strategy is related to *vertical integration through raw material procurement* which was mentioned by A1, A2, A4, A5 and EC1. This strategy entails that the OEM is responsible for the first process of the battery value chain, which is raw material procurement, with a primary focus on the critical raw materials that the cathode is composed of. Thereafter, the OEM selects which supplier or suppliers to direct the raw material to, implying that the subsequent value adding processes of the battery value chain for the cathode is outsourced to the already established refineries, precursor manufacturers, cathode manufacturers and battery cell producers. The respondents believed that this type of approach to the battery supply chain allows the firms to gain control, visibility upstream and the possibility to design the battery supply chain in line with their own interests, which is deemed as a significant advantage due to batteries growing in strategic importance for the automotive industry. Other advantages highlighted was that by being in control of the first process, firms such as the ability to adapt rapidly and avoid potential supply chain disruptions that may arise from shortages of critical raw materials. Furthermore, A2 pointed out that by directing the raw material to suppliers of a firm's own choice in the battery value chain facilitates the process of ensuring correct quality and sustainability standards. A2 and EC1 underlined that when an OEMs focus on prioritizing raw material procurement, in time they will gain increased understanding and situational awareness of critical raw materials as well as experience in how such purchasing processes should be conducted. Subsequently, with that type of increased knowledge, firms are better positioned to identify the regions in the world where there is potential for incoming raw materials producers to emerge and be the first to invest and capture new options, thereby moving away from geographical clusters of critical raw materials.

Moreover, A2, A3, EC1 and RI2 believed that after initializing the process of raw material procurement for critical cathode materials, the opportunity to cultivate and establish strong relationships with raw materials producers arises. If this opportunity is seized in a correct manner where the raw material producers view the OEM as a trustworthy and valuable business partner, then the possibility to utilize those relationships for a future transition to a in-house battery cell production emerges, thereby increasing chances of reducing dependency on geographical regions where processes of the battery value chain are currently clustered. Additionally, AC2 described that depending on the size of the OEM and what type of global presence they have can also affect how well the firm can establish important relationships with raw material producers. For instance, if the OEM is active across multiple continents, the possibility to strategically utilize personnel from different regions in the world is a viable option when attempting to build important relationships. This can prove to be advantageous, especially if the OEM has production facilities in locations near raw material producers, since staff from each region possess a comprehensive understanding of their respective cultures and can facilitate the creation of healthy relationships to secure future supply of essential raw materials.

4.2.8.2 Co-designing exclusive battery technology

The second identified strategy is related to Co-designing *exclusive battery design*, meaning that the OEM decides, in collaboration with the primary cell manufacturer, how the battery technology is designed, i.e what materials the cathode is composed of. This strategy was mentioned by A1, A2, A3, AC1, AC2, RI1, and RI2. The respondents emphasized that the battery, as a core component of EVs, plays a critical role in differentiating the OEM from its competitors. Being a part of the battery design phase also entails that the OEM must inevitably be a part of selecting suppliers upstream in the supply chain that fulfill the requirements for the unique battery design, thereby giving the OEM a different type of control in comparison to when only sourcing complete battery cells.

To further extend on this concept, the design provides an increase in control over the upstream supply chain, providing the OEM with greater stability and flexibility in managing their battery supply, whilst ensuring a trustworthy source of batteries for their vehicles. This is mainly due to the strategy forcing the supplier to bind a certain amount of production capacity exclusively to the applications of the OEM, since a unique battery design is not intended for other applications. The responsibility and ownership of the unique cell design and the required supply chain remain with the cell supplier, however, the OEM is still able to partake in the supplier selection phase of all components, including critical materials. Moreover, the respondents emphasized that from a competence perspective, an OEM's own battery design could potentially lead to overall increased knowledge for battery cell manufacturing, specifically cathodes, and the corresponding supply chain. The reasoning was that during the design phases, important concepts and information can be extracted and distributed in the organization of the OEM.

Moreover, the respondents also highlighted that co-designing an exclusive battery technology could have strategic implications in supplier relationships, since being involved in the battery design process also implies that the firm is a part of the supplier selection for the foregoing processes in the battery value chain. OEMs could leverage their battery design capabilities to negotiate better terms with third-party battery cathode material suppliers, such as pricing, volume discounts, and intellectual property rights. Additionally, having their own battery design could enable OEMs to establish closer and more collaborative relationships with their battery suppliers, leading to improved strategic partnerships. This collaborative approach could nurture innovation, knowledge sharing, and co-development further upstream in the supply chain, resulting in improved product quality, faster product development cycles, and potential access to proprietary technology and expertise from battery suppliers. Such collaborative partnerships can contribute to the OEMs' innovation efficiency and enhance their competitiveness in the market while simultaneously improving supply chain resilience. Furthermore, the respondents pointed out that an OEM's own battery design could provide better visibility along the supply chain, leading to improved sustainability practices. By having control over the battery design, OEMs can ensure that the batteries used in their EVs meet their sustainability and environmental standards. This could include factors such as reducing the use of rare or environmentally harmful materials, optimizing the recyclability and circularity of batteries, and adhering to environmental regulations.

4.2.8.3 Diversified product portfolio

Respondents A1, RI1 and RI2 suggested the strategy of providing customers with multiple options when choosing the electric powertrain, thus having a *diversified product portfolio* strategy. This was compared to automotive manufacturers offering different engine alternatives which are run on either petrol or diesel, meaning the strategy would by that comparison, be feasible. The strategy improves battery supply chain resilience through offering customers different options, tailoring solutions. RI2 argued that not everything needs to be high end and top of the line. By offering different battery cathode compositions containing different raw materials for different uses, the OEM can provide high performance and increased range to those customers request such parameters and are also willing to pay extra, whilst still offering entry or middle level versions of the same vehicle, with decreased performance and range to customer that have other areas of use. RI2 provided an example with offering a nickel-manganese-cobalt (NMC) mix to those who seek higher energy density and longer range and LFP mix to those who prefer longer life span, at the expense of shorter range. RI2 continues by emphasizing that the OEM could then cater to customers with different usage patterns and needs.

A1 and RI2 argued that the point of strategy is increased flexibility and the possibility to reduce the impact of disruptions due to the multiple options provided, by using different cathode active materials for the battery composition. This entails that the OEM still has commercially viable options if either one of the battery supply chains for the cathode raw materials faces disruptions and production operation can continue, thus not severely impacting revenue streams. In addition, the diversified product portfolio can help the OEM stay competitive, since the electric vehicle market is a competitive one and OEMs need to find means to differentiate themselves from their competitors, which is further strengthened by A1 and RI1 as a way to impress Asian battery cell suppliers to continue supplying the OEM, which also strengthened the resilience of the supply chain.

Additionally, A1 and RI1 were confident that this strategy would further incentivize the OEM to actively seek alternative battery technologies that are beyond the reliance on critical raw materials. This, in turn, would pave the way for opportunities to explore fresh battery supply chain configurations in line with new battery technology. By doing so, they would acquire valuable knowledge and employ a supply chain design that can effectively bypass vulnerabilities comparable to the prevailing challenges. Additionally, by embracing a forward-thinking mindset and actively pursuing alternative battery technologies, the OEM can effectively address the current supply chain vulnerabilities while positioning itself as an industry leader in sustainable and innovative solutions. This proactive approach not only strengthens the OEMs battery supply chain resilience, but also drives progress towards a more sustainable and environmentally friendly transportation ecosystem.

4.2.9 Pairing enablers to respective strategies

Each strategy discussed in section *4.2.8 Identified strategies* require supply chain resilience enablers, as stated in the theoretical framework upon which this project is based. The results from the workshop will be presented in the sections below, followed by a summary of the pairing result in *4.2.10 Summary RQ2*.

4.2.9.1 Pairing enablers to: vertical integration through raw material procurement strategy

Regarding *vertical integration through raw material procurement*, P1 concluded that the success of the strategy would be dependent on all the identified enablers.

The reasoning was that firstly, since raw material producers were described as companies having a high level of loyalty to their current customers located in Asian countries, understanding their way of working and culture would be an essential enabler for this strategy. If the OEM plans on sourcing raw material, knowing how the relations have been built and what contributes to the loyalty is a critical factor. Proven demand was deemed as an enabler closely related to cultural differences and could be one way of approaching the issue. P1 underlined that it is significant to not be viewed as an OEM that wants to disrupt long and healthy relationships between raw material producers and their current customers, but rather show that there is a business interest with mutual benefits and new opportunities for the already existent raw material producers.

Furthermore, early investment and decreasing dependency on critical raw material were described by P1 as two closely related enablers for the long-term perspective of this strategy. The reasoning was that this type of strategy requires the OEM to learn and develop adequate raw material competence so that future investments in new battery technologies and the required raw materials can be done with proper foundations. Additionally, the focus of this strategy forces the OEM to constantly look for new and upcoming suppliers of critical raw materials, in contrast to only sourcing finished battery cells. Therefore, being early with new suppliers beyond the already established ones is essential for the success of this strategy, which also connects the diversified supplier base enabler which is highlighted as highly advantageous by the respondent as it gives the OEM several options for raw material producers. Moreover, collaborating with policymakers to facilitate the development of local or regional raw material producers was also underlined as relevant to succeed with this strategy. P1 mentioned that it is not beneficial to only focus on well-established raw material producers that are located overseas or in other continents, especially since sustainability and new local content requirements will affect battery supply chains. This indicates that the OEM is forced to involve policymakers to reduce entry barriers for future local or regional raw material producers to be in line with future battery manufacturing requirements.

Lastly, since this strategy involves directing raw material for the battery cathode into the value adding processes of the battery supply chain, a high level of competence related to battery manufacturing processes must be existent in the purchasing department. Otherwise, directing material to all the subsequent processes after material extraction without knowing how many and what suppliers have the correct quality, production capacity and yield rate, could result in wasting valuable and scarce raw material. Therefore, understanding how the battery value chain processes must be executed according to the correct standards is crucial as well as advantageous if transitioning to in-house battery cell production.

4.2.9.2 Pairing enablers to: Co-designing exclusive battery technology

Regarding *Co-designing exclusive battery technology*, P1 concluded that the success of the strategy would be dependent on four identified enablers which are *proven demand, competence, government incentives* and *early-stage investments.*

P1 highlighted the importance of having proven demand to verify to the cell suppliers that business will be profitable. This enabler is important, since the OEM needs to justify the large investments required for the design of the battery, otherwise the cell supplier would most likely deem this strategy unnecessary to proceed with. The appropriate expertise and competences is moreover emphasized by the P1 as a key to succeeding with the strategy, a team or multiplier employees with senior expertise regarding the design and manufacturing of batteries is a necessity to ensure the technical feasibility of the battery design, but also to ensure a high yield rate when the battery goes into production.

Furthermore, a recurring topic when discussing this strategy is the financial aspect which P1 highlighted as the amount of funds needed to realize this strategy. P1 pointed out the importance of having a greater collaboration with policymakers and how government officials could aid OEMs on their journey towards a more sustainable automotive industry. The support from governmental actors is a must in succeeding with this strategy, in terms of funding, incentives but also regulatory frameworks which enables and facilitates the collaboration with cell suppliers in other regions of the world. The incentives could include investments in research and development, both in terms of investing in the OEM, but also investing in research institutes. By doing so, the process for creating a new battery design can be done with multiple actors, increasing the chance of an innovative battery design that requires new supply chain configurations, where the OEM can be the first to establish these and secure the future of a new battery technology and its corresponding supply chain. This is also argued to be in line with the last enabler, which is the act of early-stage investments. P1 highlighted this as important to identify potential new chemistries and technologies for batteries, so that they can be first in fully commercializing such technologies, either by themselves or with new partners, thereby creating a resilient battery supply chain from start.

4.2.9.3 Pairing enablers to: Diversified product portfolio

For the strategy to be successful, P1 argued that four enablers are needed as foundation. These enablers were *to decrease dependency on critical raw material, early investments, competence* and *diversified supplier base*.

The respondents emphasized the need to avoid critical materials due to high supply risks and environmental risk that comes with cobalt and nickel. Therefore, to ensure a secure supply chain, other chemistries need to be explored. Once again, cathode composed of LFP were identified as a possible substitute or an addition depending on the context, for the strategy to be successful. However, the need for a more thorough understanding of different chemistries was identified as a requirement, thereby arguing for the need of an increased knowledge level. The OEM currently faces issues regarding the lack of experienced employees with regards to batteries in their supply chain, it is therefore essential to increase the knowledge level, something which has proven to be the case for the two previous strategies. This is considered to be the case for both the OEMs purchasing department, but also from a manufacturing and R&D point of view. By acquiring the right competence, either through recruitment or through internal education, the OEM can choose where to focus their resources in terms of investments. Leading to the third required enabler, early-stage investments. To ensure the feasibility of this strategy, the OEM must investigate different battery compositions more in-depth. The respondents identified the current state as a side-effect from being late when it comes to electrification generally. It is therefore of importance to ensure that the OEM does not find themselves in the same position again, hence the need of being early with investing is part of the foundation for the strategy. Moreover, by being early in the stages of investments allows the OEM to explore different suppliers, both well renowned and newly established, thus giving the possibility of having a diversified supplier base, resulting in many alternatives so that severity of disruptive events is reduced. By starting early on and diversifying the supplier base, the OEM is provided with the opportunity to strengthen the relationships with their suppliers, which in turn leads to a more resilient supply chain.

The result of how each identified enabler was paired with each strategy from the workshop is displayed in table 4.8 below. Noteworthy is that the relationships do not highlight if any enablers might contribute negatively to any of the identified strategies.

Table 4. 8: Summary of pairing enablers to each respective strategy. "X" marks required battery supply chain resilience enabler to realize any of the battery supply chain strategies

Supply chain resilience enabler	Vertical integration through raw material procurement	Co-designing exclusive battery technology	Diversified product portfolio
Diversified supplier base	X		X
Early-stage investment	X	X	X
Proven demand	X	X	
Decrease dependency on critical raw material	X		X
Understanding cultural differences	X		
Competence	X	X	X
Involving policymakers	X	X	

5. Analysis & Discussion

This chapter discusses the contributions and the limitations of this research work. The chapter is divided into three different sections, where the first section reflects on the methodology, the second section will analyze the research questions and the last section.

5.1 The utilized methodology

In this section, all data collection methods applied will be discussed and evaluated based on their contributions and their limitations. The scope of this discussion includes the challenges experienced in the data gathering process. The section emphasizes the complexity related to the research of EV batteries, which is characterized by its high confidentiality and competitive nature.

5.1.1 The literature reviews

The literature reviewed when initializing this project laid the foundation when formulating the research questions and the trajectory of the research. For instance, the first literature review conducted in this project aided in determining the research questions, whereas the second literature review partially contributed to the identified vulnerabilities which aided in answering RQ1. The results of RQ1 were subsequently used as the foundation and background in the data collection for RQ2. The vulnerabilities used in the project were considered the most important. This is due to the context of the project and the industrial sponsor as an automotive OEM located in Europe. Therefore, it is important to consider the vulnerabilities as preliminary, since not all vulnerabilities might be applicable in all contexts even though many European OEMs face similar supply chain vulnerabilities. Moreover, due to the accelerated innovation and development in the battery industry, several articles were considered outdated, even though they were only a few years old. Some articles that were less than 5 years old could have been contradicted by articles released in the last two years. Therefore, selecting articles was always made with relevance and credibility as focus. The selected articles provided a theoretical basis, which identified various vulnerabilities that were partly presented internally to the OEM, but also partly used in the development of the interview guide for the second round of interviews.

5.1.2 Primary data collection - Interviews

To gather useful data for the research topic, multiple interview rounds were held. Firstly, four semi-structured interviews were conducted in order to get an overview of the challenges faced by OEMs PD. The answers from this interview round contributed to the next step of the project, which was the identification of vulnerabilities. Once these were identified, they were presented in a validation round to the OEM, to ensure that the vulnerabilities were in line with the OEMs image of the issue at hand. Hence, the first round of interviews therefore affected the outcome of the project. The second round addressed RQ2, where 11 semi-structured interviews were conducted with respondents from six different companies active in the battery supply chain. These interviews consisted of individual opinions, knowledge accumulated over the years, challenges encountered and finally what the respondents as industrial experts believed were the most important supply chain resilience enablers and strategies to address the vulnerabilities of the battery supply chain. The answers are thus considered to have a form of subjective basis associated with the respondents' background. To improve the data collection, more people from the same company could have been interviewed to gain insight from different perspectives. Also, it would have been possible to interview people from other companies operating in the same industry that are spread across several countries. This is because the degree of maturity of battery manufacturing in Sweden, but also Europe as a whole, is lower than battery manufacturers in, for example, Asia. Therefore, it is assumed that the quality of the data collection may have differed if the number of companies and respondents was increased. However, even if leaving aside the fact that this project is carried out under a 20-week duration which implied unavailability of additional time for data collection, confidentiality was still often encountered as a substantial barrier in the data collection process. Therefore, stating that the result of this project would have had differences in outcome or validity is difficult to determine due to the strategic nature of this research topic and the unwillingness from respondents or companies to share decisive information. Nevertheless, the data collected from the respondents could still be deemed relevant to the research topic.

5.1.3 Case study

A case study was carried out to explore the current state of the industrial sponsor. The data collected related to the different parts of the supply chain, from raw material extraction to battery cell manufacturing following mainly the cathode part of a battery cell for the cathode compositions. Unlike the interviews, the case study was of a secondary nature derived from current market analysis. The data collected was considered valuable and also generalizable, as it presented information from a general level and was not limited to any specific context, firm or OEM. Hence, the outcome could not have been different, unless specific information related to the different OEMs in the supply chain was available. This part of the data collection also contributed to a more qualitative and objective source of information, as the remaining questions were answered by interviews and workshops, where the data may be affected by subjective opinions.

5.2 Discussion of the empirical findings

In this section, the results and findings of RQ1 and RQ2 will be discussed generally and placed in relation to the theoretical framework of the project.

5.2.1 RQ1

RQ1 did not necessarily contribute to any new findings in relation to the vulnerabilities that were all identified from the second literature review, which entails that during the remaining data collection, no new vulnerabilities were detected. However, the combination of the vulnerabilities within this specific context are new to the industrial sponsor and can be considered unique since the vulnerabilities were collected from different resources and not simply summarized from the same source (table 2.1 in theoretical framework can be viewed to see the different sources). It is likely that several other types of vulnerabilities beyond the ones included in this project could have been extracted from the alternative literature, however, the relevance of other observed vulnerabilities were deemed invalid to proceed with due to the lack of context. Moreover, some of the previously conducted research regarding the topic has been more specific in presenting supply chain vulnerabilities aimed at investigating one specific vulnerability in-depth. For instance, the authors Slack et al., (2017), Langhammer (2010) and Nasser, Gradel & Harper (2015) only mention how the by-product dependency of a desired mineral affects the supply chain in terms of price, cost and supply of the desired mineral, while failing to address several other relevant vulnerabilities. In contrast, Helbig et al., (2018) underlines more than one vulnerability to show how several factor can impact the supply chain. In this project, the industrial sponsor desired a more general and wider spectrum of vulnerabilities to investigate, which led to the result in RQ1 having an arbitrary level of generalizability that can be placed in the context of other European OEMs. Therefore, the vulnerabilities can be deemed as a suitable foundation for OEMs working with critical components or materials that need increased resilience levels for their corresponding supply chain, with a similar approach to Helbig et al., (2018) when studying supply chain vulnerabilities.

The validation interviews indicated that the vulnerabilities by-product dependency, raw material criticality and emerging technology aligned with the findings from the literature review. As for the remaining vulnerabilities, the majority of the respondents pointed out factors which were not brought up in detail by the literature in chapter 2. For the geographical concentration, the literature mentioned how the visibility is affected depending on the degree of concentration (Singhal et al., 2011; Azchet & Helbig, 2013), which the respondents from the validation interview briefly mentioned. The focus from the respondents was aimed at addressing the supplier concerns, rather than the insight into the supply chain system design, meaning the respondents acknowledged the existence of the vulnerability but in terms of the difficulties of having a more diversified supplier base in multiple regions and how that might affect the operational efficiency. Regarding political implications, the response revealed that almost all the candidates experienced political tensions and lack of incentives as a major part of the vulnerability. Whilst the authors Achzet & Helbig (2013) emphasized how regulatory measurements could potentially limit the trade of the origin country to another region. This lifts new findings from industry experts that extends the findings from the literature included in this project, which were related to taxes, trade wars and possible embargoes.

Moreover, for this study, noteworthy is that determining the level of importance of each vulnerability has not been made. While some vulnerabilities were directly and indirectly discussed more than others, the study is still of qualitative nature with no attempt at quantifying how important or on what level the vulnerabilities can be placed. However, the relevance of the vulnerabilities for the OEM and the corresponding battery supply chain context was in fact determined through the internal validation interview. Notable is that two vulnerabilities, *degree of substitution* and *degree of recyclability*, that were presented at the validation interview were not verified by the respondents from the industrial sponsor, thus not included when designing the interview guide for the data collection phase and the subsequent findings of RQ1. The degree of substitutability was currently regarded as difficult to incorporate in a limited and complex supply chain, however the authors Helbig et al., (2018) and Graedel et al., (2013) underlines the importance of having a substitutable process, component or product when dealing with critical material in a supply chain. The reasoning behind the exclusion was that battery cell suppliers with their different designs and cathode compositions require certain systems in EVs to be aligned with the technology. Therefore, substituting a battery cell supplier and expecting the vehicle to be operational without extensively reworking every other system in the EV is unlikely. Moreover, even though the degree of recyclability was in fact viewed as a vulnerability and acknowledged as an important aspect for sustainable practices and decreasing dependency on supply of critical materials, its implementation in the current supply chain context was limited since the industry for recycling battery materials is still in its infancy. As a result, the focus of the project remained primarily on the upstream supply perspective. While that reasoning can be deemed understandable from a supply point of view, it can be considered mandatory to include this as a vulnerability since the European Parliament (EuropaParlamentet, 2022) highlights that automotive OEMs must have proper recycling programs for battery materials.

As for the relations between the vulnerabilities, geographical supplier concentration can be deemed related to political implications, since supplier concentration in specific regions could be affected by upcoming political tensions or implications caused by regulatory measurements. The relevance is further strengthened through the mention of the two vulnerabilities by the authors Achzet & Helbig (2013). The same principles apply for critical raw materials and political implications, since policy makers could forbid the usage of critical raw materials, thus further affecting a supply chain containing critical components. By-product dependency and future technology demand – Emerging technology demand are moreover deemed interconnected to each other. Since if emerging technologies (such as EV batteries) increase drastically, minerals mined through by-production can lead to material shortages.

5.2.2 RQ2

RQ2, as it was based on primary data collection, contributed to new findings in relation to what enablers and strategies are significant to resilient battery supply chains. The central aspects of the findings are related to sourcing of scarce material, in this case for batteries cathodes, that have not previously been investigated in detail, thereby filling some knowledge gaps in the literature as well as the academy. Noteworthy is that all the enablers presented in this research project were identified by analyzing the data gathered from the second round of semi-structured interview from phase 3, therefore not being fully objective. However, the sampling of whom to interview was selected based on individuals who were relevant and could be considered as a credible source of information regarding the topic.

Moreover, the interview guide for phase 3 attempted to extract information from the industry experts with the theoretical framework of supply chain resilience described by Kamalahmadi et al., (2016), supply chain resilience enablers highlighted by Faisal (2010) & Birke et al., (2017) and tailored supply chain resilience strategies underlined by Cohen et al., (2022) as well as the vulnerabilities from RQ1 as the basis. To some respondents, the details of the theory was not fully recognized, but the understanding of for instance "supply chain resilience" as a topic was not an issue. Nevertheless, this affected where and what the respondents focused on during the interviews. While some tried to relate their answers back to the definitions of the theory, others angled their answers in other directions, but still within the topic of strengthening the supply chain of batteries to counter disruptions and addressing the supply chain vulnerabilities accordingly. Therefore, even though some of the retrieved data focused on company specific topics where the respondents worked, the core aspects that were extracted from the data could be considered generalizable and were still valuable in relation to the purpose of this project.

As for the empirical findings presented for RQ2, the supply chain resilience enablers presented can be viewed as subsets of relevant factors that must be used as building blocks when creating a strategy with the purpose to increase the battery supply chain resilience. The enablers can be viewed separately to address a specific vulnerability, or as a collective and thus encompassing a full strategy, which is in line with the theory from Birke et al., (2017) of how supply chain resilience enablers should compose a resilience strategy. While the respondents did not explicitly pair the underlined enablers with the vulnerabilities, having that type of summary to relate the enablers back to the vulnerabilities could be deemed relevant for this project. Therefore, table 5.1 below is an example of how the enablers could be related back to the vulnerabilities with the information extracted from the findings of RQ2.

Table 5. 1: Summary of how the enablers from the findings of RQ2 address the vulnerabilities of RQ1

Supply chain resilience enabler	**Vulnerability I: Geographical supplier concentration**	**Vulnerability II: Political implications**	**Vulnerability III: By-product dependency**	**Vulnerability IV: Raw material criticality**	**Vulnerability V: Emerging technologies**
Diversified supplier base	X				
Early-stage investment				X	X
Proven demand	X				
Decrease dependency on critical materials			X	X	
Managing cultural differences	X	X			
Competence	X				X
Government incentives		X		X	

Furthermore, the strategies compiled from the data collected in phase 3, which also were paired with the required enablers in the findings of RQ2, align with theory that efficient supply chain resilience strategies should contain enablers specific for their supply chain context and that address the corresponding vulnerabilities from Faisal (2010) and Birke et al., (2017). The enablers thus serve as an intermediate between the battery supply chain vulnerabilities and the battery supply chain strategies. Designing a supply chain resilience strategy without the subsets, in this case resilience enablers, that addresses the core challenges could be considered as an incomplete resilience strategy. Significant to note is that the enabler-to-strategy paring showed in table 4.8 only contributed to visualizing what enablers are needed to realize each strategy but does not show if any enablers might possibly prevent the strategy from becoming actualized. Also, the theory that was reviewed did not mention any type of counteracting validation, for instance suggesting that testing must be done to determine if any identified enablers were to oppose the identified strategies, and therefore verifying that was neglected for the results of RQ2. However, interesting would have been to obtain data regarding if any of the enablers might possibly reduce resilience rather than enhance resilience, thereby emphasizing negative aspects that might be implied directly or indirectly from the identified enablers.

Moreover, it is significant to address the focus of this study. The enablers and strategies are based on the vulnerabilities, which in turn are based on the specific supply chain context of this project. Therefore, the findings of RQ2 might not fully capture the width of vulnerabilities currently present in the whole battery supply chain. Furthermore, the impact of the enablers and compiled strategies on the vulnerabilities is based on the perspectives of the respondents from the interviews in phase 3, which most likely introduces biased opinions. Nevertheless, the suggested resilience strategies from the respondents are tailored to the supply chains of batteries, with a primary focus on the cathode material. This supports the idea that industry or company specific approach is necessary when designing supply chain resilience strategies from the theoretical framework from Cohen et al (2022) and Alicke & Strigel (2020). Furthermore, it was evident, based on the findings in RQ2, that generic supply chain resilience strategies would not suffice in the complex environment of the battery supply chain. For that reason, the compiled resilience strategies can be regarded as valuable for the industrial sponsor of this project while also filling a gap in the literature regarding resilient supply chains for scarce materials.

Further, assessing the effectiveness of different strategies and verifying whether the enablers that compose these resilience strategies effectively address the vulnerabilities identified in RQ1 is difficult to determine, as there are no viable means to simulate or empirically test the discovered insights. However, they can be categorized according to chapter *2.2 Supply chain resilience strategies - tailored to firms* from Cohen et al., (2022), which gives some direction to how effective they may be in real life contexts.

Vertical integration, which is connected to the strategy of *vertical integration through raw material procurement*, entails that companies perform the two or more, often capital intensive, processes of the value adding chain which also assumes a high level of supply chain integration. The processes or assets that are strategically significant are controlled by the company, since batteries due the cathode composition contain valuable and deceive material for the EV industry. Assuming that this strategy is successful and the OEM in question controls the raw material, the majority of the supply chain would be controlled from an end-to-end perspective, in the sense that the focal company controls the beginning and the end of the battery supply chain. This also makes all intermediary processes dependent on the OEM, rather than the OEM being fully dependent on actors upstream in the supply chain. Figure 5.1 below visualizes the control that the OEM has assuming the strategy of vertical integration.

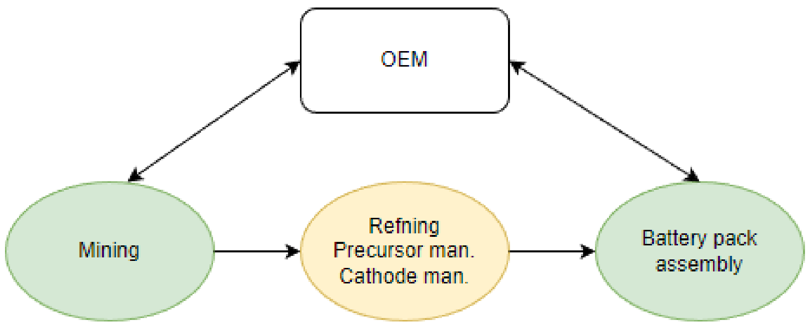


Figure 5. 1: Illustrates the processes of the battery supply chain that the OEM owns (in green).

As for *co-designing exclusive battery technology*, the OEM chooses the battery composition in collaboration with a battery cell supplier and tailors the design to their own applications. This is relatable to the collaboration level of integration from the theory from Cohen et al., (2022) viewed in table 2.3, which states that the collaboration level of integration is associated with companies being interlinked with goal alignment being strong to the extent that new product development is done in a collaborative manner. Joint design manufacturing was given as an example for this level of integration, which would entail that switching partners would be exceedingly costly. While most of the collaboration level of supply chain integration is in line with the strategy of co-designing exclusive battery technology, there is a notable difference. The primary objective of an exclusive battery technology is to compel the cell supplier to dedicate a portion of their production capacity exclusively to one customer. It could be considered that this arrangement deviates from the notion of a collaborative decision with mutual benefits and goal alignment. Instead, it can be deemed as a way of working that represents a more forceful contractual agreement aimed at exploiting and securing the supply. Therefore, depending on how this strategy is approached, it could either have a forceful foundation as intention or a path that cultivates innovation and long-term benefits for several involved actors.

When it comes to the strategy of *diversified product portfolio*, the focus is more on offering the market several alternatives with the motive that not everything needs to be premium and high-end with critical raw materials as the basis. The resilience of a battery supply chain could through this strategy be improved because the firm would have multiple supply chain configurations corresponding to a diverse product portfolio. Consequently, an automotive OEM would be able to maintain operations and offer alternative battery technologies in their EVs when disruptions occur in the supply chain for a particular cathode and its associated materials. However, it is essential to consider the theoretical framework presented in table 2.2 of chapter 2.2, which emphasizes that companies with a broad and varied product portfolio typically fall into the category of low supply chain homogeneity. This entails that the firm has several independently managed supply chains with limited resource sharing, due to variations in core components across different products. This could be viewed as an issue when aiming to establish a resilient supply chain if the company lacks the necessary ability to handle several supply chains simultaneously. Although the automotive industry has traditionally handled complexities associated with multiple engine and drivetrain configurations, it remains uncertain whether similar comparisons can be drawn for battery supply chains, given the complex nature of battery manufacturing and supply chains.

5.3 Discussion of the aim of the project

This section will focus on the aim of the project, which was to aid the sourcing managers in the OEM with the creation of a resilient battery supply chain. This section will therefore outline the combination of theoretical inputs from chapter *2. Theoretical framework*, empirical evidence from both RQs and section 5.1 and section 5.2 to provide key propositions for the company to support the aim. Additionally, this section will also focus on the academic contribution through addressing how the propositions complement the theoretical framework laid as foundation for this project.

5.3.1 How the identified strategies relate to the dimensions of preparedness, response, recovery

The aim of the project, in addition to providing the industrial sponsor with primary industry data of supply chain resilience enablers and strategies that addressed the identified vulnerabilities, was to make an academic contribution by filling literature gaps for supply chain resilience in battery supply chain contexts. Therefore, in this section the three identified strategies will be categorized according to the three different dimensions of supply chain resilience. Noteworthy is that the categorization can be done depending on how each strategy is viewed and that different angles of analysis may impact under what dimension each strategy falls under.

5.3.1.1 Co-designing exclusive battery technology - Preparedness

Co-designing an exclusive battery technology can be considered to fall under the characteristics categorized under the dimension of preparedness (Mahfouz & Arisha, 2017; Han et al., 2020; Chowdhurry, 2017), which is visibility, situation awareness, security and robustness, since it involves a number of proactive measures which need to be taken in order to ensure the success of the resilience strategy. By collaboration with the cell supplier and being a part of the design phase, which involves selecting suppliers for the other processes of the battery supply chain, the OEM obtains a level of visibility that reveals large parts of the supply chain. Through the increased level of visibility, the OEM also receives a raise in situation awareness, thus being able to identify potential vulnerabilities before they expand into disruptive events and utilize this knowledge to adjust the battery supply chain arrangement accordingly. For instance, the OEM could adjust the amount of critical material the cathode is composed of, before any of the materials are likely to experience supply constraints. The strategy also contributes to the characteristic of security since the OEM can design the supply chain configuration by selecting well renowned or proven suppliers with high quality in the foregoing processes from the primary cell supplier, in order to proactively strengthen the supply chain with the most suitable suppliers from an end-to-end perspective. Lastly the robustness of the supply chain and the ability to keep operations running is present since the primary cell supplier has already dedicated production capacity to the applications of the OEM and is bound to utilize the material exclusively constructed for the battery unique design when assembling the battery cells. This also assumes that the design is fully patented and not accessible to other external parties, eliminating the possibility for the primary cell supplier to utilize the cathode composition for other customers. Noteworthy is that this resilience strategy does not necessarily mean only having one single exclusive design, the OEM could do this for multiple designs intended for multiple applications.

5.3.1.2 Vertical integration through raw material procurement - Response

The strategy of *vertical integration through raw material procurement* can be considered to fall under the characteristics for the response dimension (Mahfouz & Arisha, 2017; Han et al., 2020). The reasoning is that it contains reactive characteristics that are beneficial in the dynamic environment of battery supply chains. By adopting this type of strategy and assuming that it is successful, the effect of raw material supply disruptions would not inflict the same amount of harm to operations, compared to when only sourcing finished battery cells. By having direct relationships with raw material suppliers, the OEM can be flexible in adjusting quantities and timing order in accordance to changes in demand, therefore making this strategy fulfill the characteristic of flexibility in the response dimension. Moreover, this strategy would contribute to the collaboration characteristic of the response dimension as it would facilitate working more closely with not only raw material suppliers, but also the remaining actors for the subsequent processes of the battery value chain. With that type of network contact, joint planning, improved forecasting and inventory management could be conducted to keep operations running in the event of disruption. For instance, the OEM could quickly share updated supply, demand or production information simultaneously with different actors without having to be limited to receiving information in a serial manner so that disruption can be countered quickly in battery value chain processes. This is also connected to the agility characteristic of the response dimension, since the velocity of responding to market shifts is improved substantially. In addition, the strategy would also encourage the OEM to look for opportunities related to local sourcing, which in time could prove useful from an agility perspective if the transition to in-house cell manufacturing becomes reality. Through that, the overall supply chain lead times would be reduced, giving an agile capability for the organization to respond to the dynamic environment of the battery supply chain.

5.3.1.3 Diversified product portfolio - Recovery

As for the strategy regarding *diversified product portfolio*, it can be considered to fall under the characteristics of the recovery dimension (Mahfouz & Arisha, 2017; Han et al., 2020). The reasoning is that the strategy is built on the knowledge of knowing that the battery supply chain, specifically regarding cathode materials, is prone to disruption depending on the cathode composition. Exploring alternative battery technologies and implementing these alternatives into their product portfolio can be viewed as proof that the OEM has utilized the concept knowledge management, meaning that past events have shown that disruptive scenarios hindered the OEM from keeping operations running. Therefore, the OEM has returned to not only the pre-disruption state, but also an improved state where sales can continue in the event of disruptions due to multiple battery technologies available. This strategy also encourages the OEM to continuously look for opportunities to incorporate while simultaneously assessing contingency plans for recovery. Lastly, the diversified product portfolio increases the presence on the market for the OEM. By having multiple options, the OEM can compete on several aspects and obtain a strong market position. Most OEMs only offer one battery technology, meaning a limited offer for consumers to choose from and therefore not a strong market position to restore and improve operations after disruptive events.

5.3.2 Complete combination of theoretical framework, RQ1 & RQ2 and discussion from section 5.1 and section 5.2.

Through the theory combined with the findings of RQ1 & RQ2 as well as the discussion from section 5.1 and 5.2, completing a full illustration of how what the project contributed with and the relation of all the aspects highlighted thus far, is possible. The result is shown in figure 5.2 below, which creates a relation network between the identified vulnerabilities, the identified supply chain resilience enablers and the compiled supply chain resilience strategies related to each dimension of supply chain resilience. Figure 5.2 therefore fulfills the academic contribution part of the aim, since it builds upon existing literature from an industry specific context related to battery supply chains, which can also be considered relatable to resilient supply chains for scarce material.

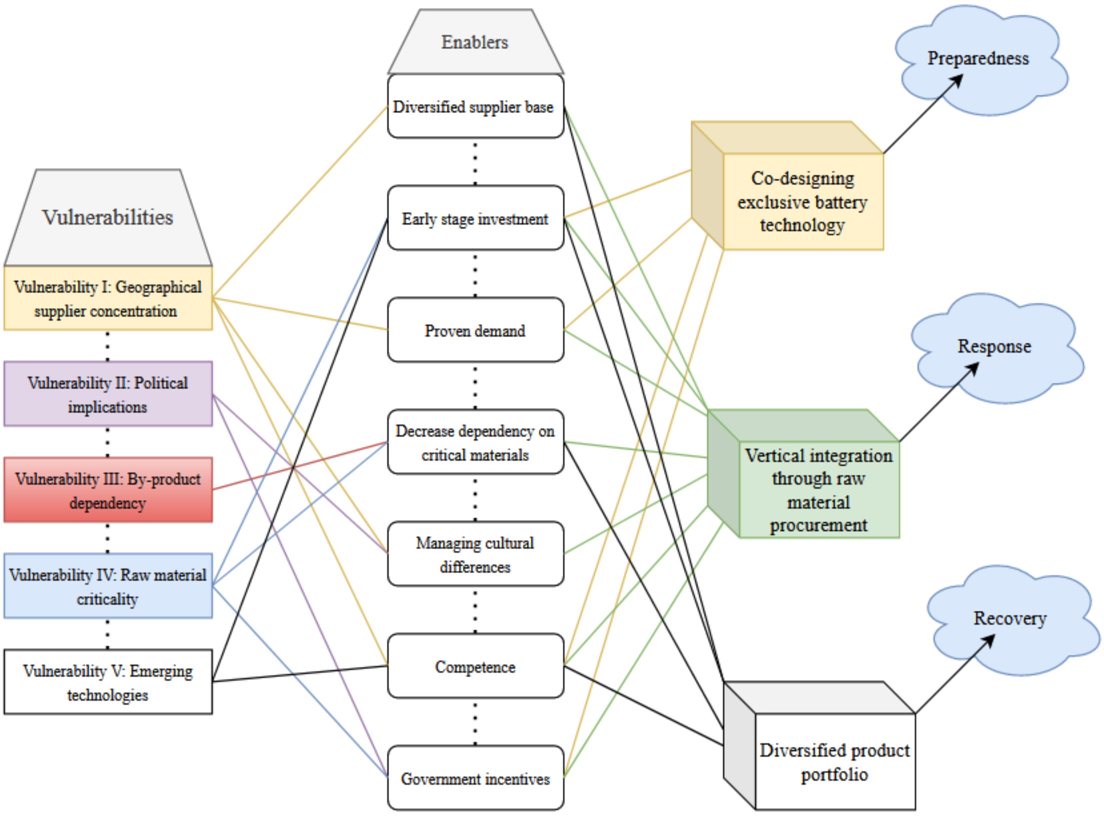


Figure 5. 2: Illustration of the combined findings from RQ1, RQ2, theoretical framework of the project as well as discussion from section 5.1 and section 5.2 for the battery supply chain. The colored rectangles to the left represent the vulnerabilities proceeded with in RQ1 and used as basis in RQ2. The white rounded rectangle positioned centrally represent the supply chain resilience enablers identified in RQ2. The cubes to the right represent the supply chain resilience strategies complied in RQ2. The colored lines are means to explicitly show how the network is connected between the vulnerabilities, enablers, and strategies. Each supply chain resilience dimension has been colored in blue to refer to the color used in figure 2.2 in chapter 2.

5.3.3 Key propositions - Aiding the OEM with their electrification journey

The second part of the aim was to aid the sourcing department of the industrial sponsor by investigating what supply chain resilience strategies are suitable to implement in order to support the creation of a resilient battery supply chain. The strategies identified supply chain resilience strategies of this project are based on the identified enablers, that in turn addresses the vulnerabilities of the nickel-cobalt and LFP cathodes. By considering the aspects from the findings, the OEM gains new insights regarding battery supply chain resilience and possible strategies based on both primary industry data with theoretical frameworks regarding the topic as foundation. In this sense, there are some propositions that can be made to guide future endeavors in this effort.

Firstly, as stated in the background of this project, the purchasing department of the OEM has a responsibility to source what can be considered a decisive and strategic product. Given the volatile nature of the industry and the presence of frequent market shifts, it becomes imperative to investigate if new challenges have arisen and to assess the effectiveness of existing strategies and capabilities concerning battery supply chain resilience while frequently updating new vulnerabilities or gaps that need to be addressed. The theoretical inputs of this project can be used in this sense.

Secondly, consider the three strategies identified in this project, either partially or fully depending on where and what the analysis from the first proposal directs the focus. Observe how the strategies aid in the dimensions of preparedness, response and recovery and evaluate where the focus needs to be allocated in these dimensions. Noteworthy is that these strategies are presented as unique to each dimension of supply chain resilience, however, this does not imply that they are mutually exclusive and could not be implemented simultaneously.

Thirdly, assess the strategies and try to highlight the potential impact. While this project highlights several benefits related to the battery supply chain, there are likely other areas of interest related to the strategies and even more specific and detailed when observing it from a sourcing manager perspective. Addressing the potential challenges or barriers that the OEM might face during implementation processes can also be considered significant.

Lastly, if the result of the foregoing three propositions partially or fully encourages the implantation of one, two or all three identified battery supply chain resilience strategies, design a roadmap for execution accordingly. This should include a timeline for the OEM to follow and break down every step and milestone to make the process manageable and measurable, so that assessment can be conducted afterwards, and reconfiguration or adjustments can be made respectively. Figure 5.2 below summarizes the key propositions.

Table 5. 2: Summarize the key propositions and deliverable in relation to the findings of the project

Proposition	Deliverable
1.Evaluate current state battery supply chain resilience	Assessment of new possible vulnerabilities and challenges
2.Consider the strategies identified in this project, either partially or fully	Knowledge of how the strategies may aid in preparedness, response and recovery within the context of battery supply chain
3.Highlight the potential impact of the strategies	Investigate how they might relate to other areas of interest not brought up in this project, while also addressing potential implementation challenges
4.Create a roadmap for implementation of strategies	Explicitly show every step of implementation

6. Conclusion

The aim of this study has been to aid an automotive OEM with their battery supply chain resilience by identifying supply chain resilience strategies and the required enablers that address the vulnerabilities. Firstly, 7 vulnerabilities were identified from a literature study and verified through a validation interview with the industrial sponsor. Secondly, supply chain resilience enablers, defined as capabilities, skills, actions or factors that enable firms to create supply chain resilience strategies were identified through primary data collection, in this case, semi-structured interview. The vulnerabilities were addressed by the highlighted enablers that subsequently were combined and compiled into three complete strategies related to supply chain resilience dimension of preparedness, response and recovery. Lastly, the aim of the project was discussed and derived from the findings from the first and second research question of the project. This three-phase methodology allowed the conclusion below to be drawn.

First, to provide a description of the vulnerabilities that hinder the OEM from achieving a resilient battery supply chain, it was concluded that a total of seven vulnerabilities based on the literature review were placed as baseline of this project. These vulnerabilities were the following: *Geographical supplier concentration, By-Product dependency, Future technology demand - Emerging technology, degree of substitutability, political implications, degree of recyclability* and *raw material criticality.* Through the validation interviews, it was shown that mainly 5 vulnerabilities were currently of interest. *Degree of substitutability* and *degree of recyclability* were left out when proceeding since they were not considered prioritized by the respondent at that time.

Second, 7 battery supply chain resilience enablers were identified that illustrate what capabilities, skills, actions or other factors that need to be existent to address the identified vulnerabilities. These supply chain resilience enablers were the following: *Diversified supplier base, Early-stage investments, Importance of proven demand, Decreasing dependency on critical raw material, Managing cultural differences, Competence* and *Government incentives*. These enablers in combination with further information from the primary data collection contributed to three resilience strategies compiled which were: *vertical integration through raw material procurement, co-designing exclusive battery technology* and *diversified product portfolio*. These strategies were connected to the dimensions of supply chain resilience with preparedness, response and recovery. Each strategy was concluded to be associated with one of the supply chain resilience dimensions and related back to the aim of the project.

A complete network was illustrated to explicitly show the relation between the vulnerabilities, enablers and supply chain resilience strategies, which concluded that the project remained within its aim. Thereafter 4 propositions were made to guide future endeavors and electrification journeys of the industrial sponsor. These propositions were made as follows; *Evaluate current state battery supply chain resilience, Consider the strategies identified in this project, either partially or fully, Highlight the potential impact of the strategies* and to *Create a roadmap for implementation of strategies*. Furthermore, it can be concluded that the project also fulfilled the academic contribution part of the aim, as the combination of theoretical input and findings from the first and second research question extended the current literature with industry specific contexts of resilient supply chains for scarce materials, specifically for the present battery supply chain which is a popular topic due to the sustainability agendas globally.

6.1 Further research

This project has been done with one single OEM connected to the automotive industry with a focus of two battery cathodes supply chains, which naturally affects the level of generalizability and validity of the results. To further extend on this research, which could be in the context of battery supply chains or possibly other supply chains related to scarce, rare or valuable materials, some future research suggestions can be done.

One aspect that could be considered important for the future research is long-term assessment of impact, which could be done by conducting a study where the aim is to evaluate the long-term impact of the proposed supply chain resilience strategy for the battery supply chain. Such a study could provide an arbitrary view regarding the effectiveness and sustainability of the strategies over a longer period, giving the possibility for improvements and adjustments based on new conditions. Secondly, an in-depth comparative analysis between several different automotive OEMs and their corresponding battery supply chains could possibly be a way to identify industry best-practices and aid a larger part of the European automotive industry as well as exploring variations of vulnerabilities across organizations. Moreover, technological advancements are frequently occurring and further investigating the potential impact of emerging technologies, such as blockchain Internet of Things and artificial intelligence with battery supply chains as background could generate significant findings related to how technologies can be incorporated to improve visibility, transparency or traceability which is related to managing identified vulnerabilities.

Furthermore, exploring the role of collaboration and partnerships more detailed between different automotive OEMs, either still in the European context or perhaps globally, battery manufacturers or raw material producers. Such a project could delve into exploring mutual benefits, cooperation challenges or best collaboration initiatives such as joint ventures, strategic partnerships or supplier development programs. Additionally, political implications could be investigated to further examine the influence of policymakers on battery supply chain resilience. Such a project could deliver an analysis of the impact of regulations related to raw material sourcing, environmental sustainability, and geopolitical factors on the vulnerabilities of the battery supply chain. Additionally, it could explore how governments can incentivize and support supply chain resilience efforts in the automotive industry. Further, to be able to assess whether a concept is in line with what a company desires, the aspects must be measurable. Therefore, conducting research with the intent to develop a supply chain resilience metric that allows firms to measure the levels of supply chain resilience, specifically for scarce material such as the ones found in battery cathodes. This could enable improved benchmarking and performance evaluation to capture key aspects or enablers of supply chain resilience. Lastly, circular economy initiatives, that also go in line with the degree of recyclability which was one of the neglected vulnerabilities of this project, can contribute to enhancing supply chain sustainability and resilience. Such a project could potentially contribute to strategies for optimizing battery life cycles which reduced dependency on supply of newly extracted material. It could also generate findings related to recycling and reuse materials while minimizing waste in production.

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Appendix A

A.1 Interview guide for Phase 1 - semi-structured interviews:

1. General information: first interview

(a) Introduction of the interviewers

i) We are two students from the master's program in Supply Chain Management at Chalmers University of Technology. We are currently conducting our Master thesis here at the OEM for the purchasing department.

(b) Aim of the project

i) The aim of our master's thesis is to investigate the battery supply chain of the OEM. Within the topic of supply chain. As of now, we have not been able to establish appropriate research questions.

(c) Purpose of the interview

i) Due to the lack of appropriate research questions, the purpose of this interview is to generate a discussion to identify possible challenges and hurdles which the purchasing department within the OEM faces. The preferred outcome from this interview is an aim of direction, followed by the establishing of research questions.

2. Introduction of the interviewee

(a) Could you please tell us your full name and current work title?

i) Would you like to be anonymous in our project? If the answer is yes, are we allowed to use your job title without mentioning your name?

(b) Are we allowed to record this interview? We will delete the recording once the project is finished.

i) Note*: The information obtained from this interview could be used in our master's thesis, which will be published for the public. Are you still ok with proceeding with the interview?*

(c) What educational background and/or past experiences do you have within the field of strategic purchasing?

(d) Could you briefly elaborate on your role at the OEM and what you are currently working with?

3. General questions regarding the role in the electromobility department

(a) The OEM is currently on an "electrification" journey, we assume that this journey has contributed to several challenges, due to a new material need. Do you experience any challenges? If so, could you explain them?

(b) What is your take on the current nickel-cobalt battery chemistry which the OEM are purchasing?

(c) What is your opinion on the current sourcing strategy?

4.More in-depth questions aimed at the battery supply chain

(a) There have been a lot of discussions regarding the scarcity of raw material, what is your opinion on the matter?

(b) What could the OEM, in your opinion, improve with the current battery sourcing strategy?

(c) What would be an ideal situation for sourcing the batteries?

A.2 General information: second interview

(a) Introduction of the interviewers

i) We are two students from the master's program in Supply Chain Management at Chalmers University of Technology. We are currently conducting our Master thesis here at the OEM for the purchasing department.

(b) Aim of the project

i) The aim of our master's thesis is to investigate the battery supply chains of automotive OEMs. The topic places a focus on supply chain resilience, specifically how to enable the development of resilient battery supply chains and the importance of how SREC strategies should be designed to support this.

(c) Purpose of the interview

i) *The purpose of this interview is to identify what aspects that industry professionals regard as enablers for supply chain resilience in the case of the very current electrification transition with batteries as the main energy storage system for the automotive sector.*

2. Introduction of the interviewee

(a) Could you please tell us your full name and current work title?

i) Would you like to be anonymous in our project? If the answer is yes, are we allowed to use your job title without mentioning your name?

(b)Are we allowed to record this interview? We will delete the recording once the project is finished.

i) Note: The information obtained from this interview could be used in our master's thesis, which will be published for the public. Are you still ok with proceeding with the interview?

(c)What educational background and/or past experiences do you have within the field of strategic purchasing?

(d) Could you briefly elaborate on your role at the OEM and what you are currently working with?

3.Challenges and hurdles within the purchasing of batteries/cathodes/raw material

(a) The automotive industry is currently on an "electrification journey", we assume that this journey has contributed to several challenges, due to a new material demand with a limited supply. Do you experience any challenges? If so, could you explain them?

(b)What are, in your opinion, the most important enablers to facilitate a more resilient supply chain based on the presented vulnerabilities?

i) Definition: *A supply chain resilience enabler is for instance capabilities, skills, actions or factors that enable firms to develop an antifragility for their specific supply chain context. The goal is to strengthen the competitive* *advantage of a firm by building supply chain resilience strategies that are based on relevant enablers. Note: It can be both very concrete on a value chain level, but it can also be on an organizational plane*

(c) What vulnerabilities do you believe are crucial for firms to address? What enablers do you think would best solve it?

Table A:1

Supply chain vulnerabilities	**Description**
Concentration risk	*The formation of suppliers in a single or few countries*
By-product dependency	*Production of a mineral which comes from the production of a "main" mineral.*
Future technology demand	*Raw material which has other industrial application areas besides battery usage*
Political implications	*Supply chain disruptions caused by the implementation of political regulatory measurements or the lack of it, i.e., lack of infrastructure (example)*
Raw material criticality	*The criticality of a raw material used in the manufacturing of batteries, more specifically the cathode material.*

4.More in-depth questions aimed at the battery supply chain

(a) There have been a lot of discussions regarding the scarcity of raw material, what is your opinion on the matter?

(b) From your point of view, how should supply chain resilience strategies be designed to support the creation of a resilient battery supply chain? Do you have any examples of successful scenarios of this?

5.General questions regarding battery supply chain

(a) In your view, what does the future of the battery supply chain within the automotive industry look like? Feel free to elaborate on this from a geographical, supply and demand etc. point of view.

- **Follow up question:** What development direction do you feel that companies should aim for?

(b) What type of emerging trends and technology do you feel the OEM should be aware of and take into consideration when choosing battery type? Since there are possibilities of raw materials used in batteries facing demand from other industries. (in relation to current state)

Appendix B - Thematic analysis for enablers and strategies

B.1 Thematic analysis: supply chain resilience enablers

Theme	Code	Quote/Data	Respondent
Diversifying suppliers	Reduced chance of disruption by diversifying suppliers	Having multiple suppliers in a diversified geographical area contributes to a more resilient supply chain. This is mainly due to the increased flexibility. Since if one supplier experience disruptions in their supply chain to the geographical concentration, you can use the other supplier	RI1 RI2
	Increased flexibility and higher yield rate	*"If you have multiple suppliers and you experience a disruption amongst one of the suppliers, you can shift to the other one, not compromising the delivery and increase the flexibility. However, it's important to have a high yield rate in every step of the supply chain"*	A5
Early-stage investments	Early recognition of limited supply	*"Since we (OEM) were early on in recognizing the potential limited supply, we were able to avoid pausing the production due to the lack of materials (i.e., batteries), increasing our competitive advantage".*	A1
		"Europe needs to accelerate their presence in the electrification journey, similar to how China did, resulting in securing supply"	A2
	Supplier relationships	Asian suppliers have been working actively for the past 30 years, securing supply all the way from the mining process to the cell manufacturing stage. By being early with their investments, they have been able to secure supply whilst also establishing close relationships with their suppliers.	AC1 AC2

Proven demand	Strong negotiation position	*"Asian suppliers focus firstly on profit, and this is shown in their selection of customers. They have the option to choose who they do business with since there is such high demand. Therefore, if the customer can't guarantee that they will purchase a specified amount of product, they just choose to go with another customer, repeating this process until they are satisfied with the proposed volume capacity. Therefore, for a customer to have leverage in the discussion, the customer needs to be able to guarantee high volume."*	AC2
		"The best weapon in a purchaser's arsenal is the promise of proven demand when dealing in the battery industry"	AC1
	Ability to purchase large amount of product	The Asian cell suppliers are able to choose who they want to sell to, as there is such a high demand. If an OEM in the automotive industry is interested in buying from these Asian suppliers, they must be able to show that they can buy high quantities of products. Thus, you have to prove that the demand exists at the OEM to ensure that you buy the volume being discussed.	A1 A2 A3
Decrease critical materials	Alternative chemistries	It's difficult to create a robust supply chain if you are dependent on materials that can be considered critical. Hence, it is important to consider other battery chemistries that do not rely on that type of material.	RI1 RI2
Lack of competence	High experience	*"One could say that the experience of a senior technician when it comes to battery manufacturing, especially cathode manufacturing, is equal to at least 10 junior technicians. That is how much competence for me means in this industry."*	AC2
		"The reason why it's so hard for European battery companies to compete with Asian companies is mainly related to the lack of competence. We (meaning Asian companies) have been working in this industry for more than 30 years and developed key competence in the area"	AC1
		Lack of the right skills is considered a major problem. Even if you get all the investment you want and have all possible factories, it is still difficult to start production and deliver good quality without having the right skills. There is considered to be a shortage of good knowledge in batteries in Europe.	A1 A4 A5 RI1 RI2 EC1

	Recruiting the right competence	Whilst a solution to the concern regarding lack of competence is to recruit people from asian battery manufacturers are suggested, it's still not considered enough	Ri2 EC1
	Investing in an in-house battery manufacturing facility	In order to reach a truly resilient supply chain, investing in an in-house battery manufacturing facility is a must. The reasoning being that it allows for more control, more visibility and can have local supply of a core-material.	A1 A2 A3 A4 A5 RI2 EC1
Increased Collaboration	Progress of Asian companies	Involvement and incentives from the government in the affected Asian countries has contributed to the progress and establishment of their strong presence in the battery industry. Therefore, significant identify governmental actors as an important element in order to accelerate electrification in Europe.	A1 A2 A3 RI1 RI2 EC1
		"The Chinese government provides incentives for companies which work towards electrification. However, the purpose of the funding is not primarily to reduce emission. The government sees it rather as a possibility to make money. My assumption is that the EU prioritizes the environmental aspect above the possibility to make money, which could be a reason for what some say "lack" of involvement."	AC1
	Political involvement	*"Politicians need to get more involved in this issue, electrification can be crucial to achieving our environmental goals of being net-zero by 2050."*	RI1
	Stronger collaboration in Europe	*"We (Europe) are much better at working with open innovation, we collaborate with actors working towards the same goal. We can even collaborate with competitors, if that would mean getting one step closer to solving the problem."*	RI2

B.2 Thematic analysis: Supply chain resilience strategies

Theme	Code	Illustrative data/quotes	Respondent
Securing material	Raw material procurement	By securing material in the beginning of the supply chain allows for increasing the visibility and traceability.	A1, A2
		When an OEMs focus on prioritizing raw material procurement, in time they will gain increased understanding and situational awareness of critical raw materials as well as experience in how such purchasing processes should be conducted	A2, EC1
	Strengthening supplier relationships	After initializing the process of raw material procurement for critical cathode materials, the opportunity to cultivate and establish strong relationships with raw materials producers arises	A2, A3, EC1, RI2
Increased control over battery supply chain	Having own cell design	*"By having your own cell design, you are able to increase your competitive advantage"*	AC1
		"For an OEM to have their own cell design, would be a huge advantage, it's so hard to duplicate for outside actors."	AC2
		"The best option for an OEM would be to have their own battery design. You can tailor the design according to the vehicles desired specifications whilst simultaneously gaining more control over the supply chain"	RI1
	Increase control	To increase the control over the up-stream supply chain, significant is to have more parts of the chain in-house. By "owning" more steps in the supply chain, an OEM can increase the total control of the chain.	A1, A2, A3
Multiple option offering	Decrease the amount of cobalt	*"A desire would be to reduce cobalt, we could for example you another chemistry. However, we offer only high-performance vehicles, there aren't currently any other chemistry that is applicable in our current situation"*	A2
	Increase product offering	*"Surely not all consumers need the highest specifications on their vehicle, or the longest range. Therefore, it would only be reasonable to offer another, cheaper battery chemistry, to those consumers."*	RI2
		"One option to at least reduce the need of nickel and cobalt could be to expand the product offering"	RI1

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