UNDERSTANDING THE TENSIONS IN THE LITHIUM RECYCLING INDUSTRY IN EUROPE: AN INTEGRATION BETWEEN PARADOX THEORY AND CIRCULAR ECONOMY PERSPECTIVE

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ABSTRACT

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The European Union (EU) has set very strict goals for 2030 and 2050 regarding carbon emissions and carbon neutrality, aligned with the European Green Deal, United Nations Sustainable Development Goals and the Paris Climate Agreement. Transportation and mobility are the main polluters and users of fossil fuels contributing about 25% of the CO2 emissions in Europe (EEA, 2023). Electric vehicles play an important role in the decarbonization of the economy. However, the manufacturing of electric vehicles requires enormous amounts of critical materials, which currently mostly come from outside the EU. This research aims to identify and understand the tensions in the lithium recycling industry in the EU by applying the paradox theory and the circular economy perspective. This study combines semi-structured interviews with experts and industry leaders that are triangulated with secondary data. The analysis includes the output of conflicting elements of the lithium recycling industry enabling the organizations to come up with better responsive strategies to the complex raw material dependency. The findings of this study contribute to paradox theory and the circularity of the lithium industry in the EU.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

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Anssi Kannisto

Litiumin kierrätysteollisuuden jännitteiden ymmärtäminen Euroopassa: Integraatio paradoksiteorian ja kiertotalouden näkökulman välillä

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Euroopan Unioni on asettanut erittäin tiukat tavoitteet hiilidioksidipäästöille ja hiilineutraaliudelle vuosille 2030 ja 2050, jotka ovat sopusoinnussa Euroopan vihreän kehityksen ohjelman, YK:n kestävän kehityksen tavoitteiden ja Pariisin ilmastosopimuksen kanssa. Liikenne ja logistiikka ovat suurimmat saastuttajat ja fossiilisten polttoaineiden käyttäjät, joiden osuus CO2-päästöistä Euroopassa on 25% (EEA, 2023). Sähköajoneuvoilla on tärkeä rooli talouden hiilestä irtautumisessa. Sähköajoneuvojen valmistus vaatii kuitenkin valtavia määriä kriittisiä materiaaleja, jotka tällä hetkellä tulevat enimmäkseen EU:n ulkopuolelta. Tämän tutkimuksen tavoitteena on tunnistaa ja ymmärtää Euroopan unionin litiumin kierrätysteollisuuden jännitteitä paradoksiteoriaa ja kiertotalouden näkökulmia soveltaen. Tämä tutkimus yhdistää semi-strukturoidut haastattelut asiantuntijoiden ja alan johtajien kanssa tietoihin, jotka on kerätty toissijaisista lähteistä. Analyysi sisältää litiumin kierrätysteollisuuden ristiriitaisten elementtien tuotoksia, minkä ansiosta organisaatiot voivat kehittää paremmin reagoivia strategioita monimutkaiseen raaka-aineriippuvuuteen. Tämän tutkimuksen tulokset edistävät paradoksiteoriaa ja litiumteollisuuden kiertotaloutta Euroopan unionissa

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This master's thesis has contributed to the EU Horizon research project RELiEF - Recycling of Lithium from Secondary Raw Materials and Further (Grant Agreement No. 101069789), in which SCI-MAT Platform - LUT University participated. I am especially thankful for the chance to be part of the SCI-MAT platform and I wish all the best for the future research the platform has ahead of it.

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Anssi Kannisto

ABBREVIATIONS

CE	Circular economy
CVC	Circular value chain
EOL	End-of-life
EV	Electric vehicle
IRA	Inflation reduction act
ICE	Internal Combustion Engine
LCA	Life-Cycle Assessment
LFP	Lithium iron phosphate
LIB	Lithium-ion battery
SCI-MAT	Sustainable Circularity of Inorganic Materials
SDG	Sustainable development goal

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1 Introduction

Europe is moving towards climate neutrality and one way to do it is by decarbonizing the transportation industry. The European Union (EU) deal to end the sale of new CO2 emitting cars by 2035 was agreed on October 27th, 2022, and it was one of the first major laws towards the EU strategic goals (European parliament, 2022). On 14th of February the agreement was formally approved by the European Parliament and therefore put into action. The agreement to ban the sale of new combustion engine vans and or cars is a big change in the European car industry. The ban is part of the European Union's climate change package called *Fit for 55* (European Parliament, 2022), aiming to reduce climate-damaging emissions by 55% by 2030, when compared to 1990 levels. Additionally, '*Fit for 55'* aims to reach climate neutrality by 2050 in alignment with the European green deal's goals (EU Commission, 2022).Batteries are required for powering EVs and critical materials such as Lithium, Copper, Nickel and graphite are used in the manufacturing of LIBs. Therefore, Li plays an important role due to the expected exponential increase in EV demand, huge amounts of Li are needed to manufacture those batteries (Yamasue *et al.*, 2022). As a result, different efforts are focused on optimizing the recycling of lithium from the future EOL batteries of electric vehicles. Increased use of electric vehicles and, at the same time, critical raw material prices such as the case of lithium, have increased 11-fold in the past 2 years (Statista, 2023). Lithium metals demand (Ali et al., 2021a; van Bommel, 2018 will continue to increase and despite lithium recycling being an established process, an estimated 27% of the current global lithium production still turns into waste (RELiEF, 2023). European Union has now realized the importance of independency in sourcing the lithium within the EU countries rather than being dependent on other countries such as China that has been leading most important production value chain, while the lithium resources are in Australia, Chile, Bolivia and Argentina, Australia and Chile are contributing close to 90% of the total production of lithium and their reserves are the main source for lithium in the future (USGS, 2022).

The EU agreement to stop combustion engine vehicles sales puts very high pressure on EV producers to obtain the needed Li-ion batteries for the cars and therefore pushes the battery manufacturers to secure massive amounts of the battery raw materials. To support this goal,

many regulations such as the EU green deal, the EU battery act and the Fit 55 initiative, have been implemented by the EU (EU Commission, 2022).

To tackle the supply-demand challenges in the future, the EU has funded many projects that are aimed at solving this exact problem. This thesis is part of an EU-funded project called RELiEF (Recycling of Lithium from Secondary Raw Materials and Further) under the program HORIZON-CL5-2021-D2-01-01 - Sustainable processing, refining and recycling of raw materials (Batteries Partnership. The project is participated by LUT University through the SCI-MAT (Sustainable Circularity of Inorganic Materials) research platform. RELiEF project (7.2022-6.2025) aims to reduce lithium waste by more than 70% by recovering Li from potential secondary sources and transforming recycled Li into high value battery-grade material. In this way, RELiEF aims to contribute to the decrease of EU dependency on importing raw materials and battery chemicals from outside EU countries.

The demand of Lithium can be estimated based on the current policies scenario where the annual lithium demand forecast would be 164Kt and 276Kt by 2030 and 2040 respectively (IEA, 2022). Whereas, in a sustainable development scenario, where Paris agreements and EU Green Deal goals would be met, the forecasted annual demand for lithium would drastically increase to 378 and 904 Kt by 2030 and 2040 respectively. (EU Commission, 2022; IEA, 2022). The global goal is that ICE vehicles must be substituted with EV and Hydrogen Fuel cell powered (H2-Cell) vehicles (EU Commission, 2022). Most of the EV's are to be powered with lithium-ion batteries. To reach these goals, the demand for lithium will be much higher than for the stated policies scenario. EU is starting to question whether there are enough lithium primary and secondary source in EU to support this EV substitution, sustainable and circular transition. The clean energy transition is the main factor in the massive increase of demand for critical minerals.

The increase of demand is significant and to avoid shortages, the supply needs to match the growth. Currently the global capacity for Li-ion battery recycling is around 180 kilotonnes per year (kt/yr), from which China accounts for almost 50% of this capacity. China is expected to retain its dominant position given the large amount of additional capacity it has announced, amounting to 1 000 kt/y (IEA, 2022). This increase would be sufficient even for the need in the sustainable development scenario but as mentioned, China is dominating the industry and therefore in the European Union, when most likely the EV industry will become

the largest in the world due to the policies, the EU needs recycled lithium. Most of the companies involved in lithium recycling today are independent refiners, but a broad spectrum of players from battery manufacturers, original equipment manufacturers, miners and processors are beginning to show interest in entering the competitive EV and lithium recycling markets, especially in Europe.

The demand and supply mismatch is not the only tension in the lithium recycling industry. When there are multiple stakeholders involved, with different targets and priorities, there will likely be tensions arising from the clashing interests. Tensions arise from these targets and priorities related to the economic, environmental, and social aspects of business (Hahn *et al.*, 2014). Technological advancements and regulations are needed to improve the industry but at the same time, those innovations and regulations can be creating tensions among some stakeholders that would not have implemented those regulations or that people are losing jobs due to the new innovations/regulations taking jobs elsewhere.

Green innovations are not free from the waste management and sourcing paradoxes either as communities are being affected from the EV boom. (González and De Haan, 2020; Yamasue *et al.*, 2022) Therefore, the aim of this study is to identify and understand the tensions in the lithium recycling industry in Europe. The focus is on the empirical research on the EU lithium recycling industry and market creation. The theoretical framework is based on the combination of the paradox theory and the circular economy perspective.

1.1 Thesis Background

LI-Ion batteries (LIB) have evolved during the last 20 years as have the needs and requirements of the batteries. Li-Ion batteries are suitable for multiple uses where a high energy-weight ratio is needed (Thompson *et al.*, 2020). There are different variants of LIB, which affect the composition of materials. Even though the chemistry types have changed in popularity, the main components for LIB have not (Mohr *et al.*, 2021). There are eight primary materials used for LIB which are: lithium, cobalt, nickel, manganese, aluminum, iron, graphite, and titanium. While lithium is the main element in rechargeable LIBs and is used as cathode for all LIB batteries, cobalt is more costly and rare. Cobalt mining has been

in the news lately due to its main source being in Democratic Republic of Congo where there are political and ethical concerns due to the way it is extracted (Ali *et al.*, 2021a)

Lithium-ion batteries are complex products with materials that can be harmful for humans, but there are multiple recycling methods for end-of-life batteries. There are three basic process types: pyrometallurgy (smelting of the material in high temperatures), hydrometallurgy (leaching and separating materials in aquatic solution) and direct recycling (physical process to dismantle or crush batteries) (Gaines, 2018). These process types can be combined based on the quantity and characteristics of the recycled material. Historically, the main objective of Li-ion battery recycling was to recover cobalt due to its high value but due to increased lithium content in the batteries and the regulations for recycling rates, companies have started to increase their efforts and investments into recovering other materials such as lithium in its many forms (Gaines, 2018). Secondary lithium raw materials can be used to create new battery packs after the recycled materials are processed. There are different requirements for materials' quality where secondary raw materials coming from end-of-life batteries or other sources like slag or wastewater might have market potential.

This thesis focuses on understanding of the LIB recycling industry. Two main corpuses of literature were selected to the study: circular economy and paradox theory. There is a significant amount of past research done on sustainability and circularity. Sustainability paradigms and lithium-ion batteries circular economy (Eisenriegler, n.d.; Geissdoerfer et al., 2017; Ghisellini et al., 2016; Korhonen et al., 2018; Mayer et al., 2019; Mossali et al., 2020; Rizos and Bryhn, 2022). These studies have researched circular economy and the concept of circular economy in lithium recycling while there are other studies which have used circular economy to explain circular business model (CBM) barriers and enablers (van Keulen and Kirchherr, 2021; Lewandowski, 2016; Witjes and Lozano, 2016).

While there is no abundance of studies on these topics, there are not that many studies related to the tensions that create challenges and barriers circular economy models might face, but there are studies that focus on managing the tensions in sustainable business models (van Bommel, 2018; Porter and Kramer, 2011.; Zehendner et al., 2021 and mainly connected to EV and li-ion batteries. When a new business model innovation is being thought of, there is always the need to understand the value creation and the stakeholder's perspective and role in all of it and there are few studies that have done exceptionally well in explaining the

frameworks in a closed loop value chain. (Freudenreich *et al.*, 2020; Hofstetter *et al.*, 2021; Schenkel *et al.*, 2015).

1.2 Research question and objectives

This study focuses on the sustainability of lithium recycling industry in Europe through linking paradox theory and circular economy to understand the key threats, barriers, opportunities, and drivers for the industry. The focus is on lithium recycling industry in Europe, even though Asian influence on the industry In Europe is not overlooked. Based on the information gathered in this research, strategies and measures for the industry actors will be presented, to mitigate the effects of the tensions affecting the industry.

The main research question therefore is as follows:

What are the main tensions and opportunities for the growth of the sustainable and competitive lithium recycling industry in Europe in the next decade?

This main question is answered by dividing the question into 3 sub-questions that support the reasoning for the main answer.

RQ1: What kind of tensions can be identified in lithium recycling industry?

The main idea is to map out the main tensions in the lithium recycling industry by introducing the key components that are behind most of the tensions.

RQ2: How these tensions create barriers and/or challenges for the competitive EV battery recycling industry in Europe?

With this answer, the goal is to take the results from the previous research question and make sense of the barriers and challenges for the EV recycling industry in Europe, based on these identified tensions.

RQ3: How can industry actors respond to these tensions to compete in the global markets?

Here, the key is to, based on the previous answers, try to give some recommendations for the actions and strategies on how to address these tensions in the industry.

By preliminary mapping out the industry stakeholders this thesis will give an overview to help with the other research questions. Before discussing the strategies and solutions, it is important to first answer in detail, what are the main causes of tensions in the industry.

Lastly, this thesis will map out the main business models that currently work on the circular economy perspective around the world.

1.3 Theoretical framework

To be able to understand the results and the discussion, it is important to first lay down the foundation, namely the theoretical frameworks. In this thesis the study is based on the theories of circular economy and the paradoxical tensions in sustainable business. I apply them to the context of LIB battery circularity that is based on two main global policy goals, the Paris Agreement and the Sustainable Development Goals (UN Agenda 2030). Both have been adapted and integrated by the European Union of the main policy European Green Deal. These global and EU policies are driving the transition to EV and the need for LIB recycling industry. therefore, this study will also utilize frameworks such as sustainable development goals, European green deal and the Paris agreement.

This thesis is constructed on the circular economy and paradoxical tensions theories where circular value chain, circular value creation and circular business models are used to connect lithium recycling and circular economy. Paradoxical tensions in lithium recycling are linked together by combining paradoxical tensions, paradoxical thinking and paradoxical actions and strategies as shown in figure 1.

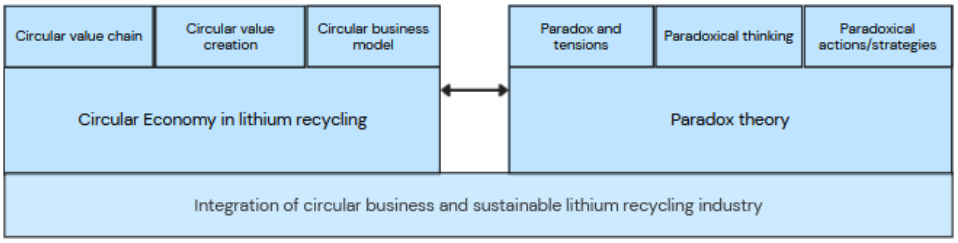

Figure 1. Theoretical frameworks

In reality, circular economy and the paradoxical tensions theory are overlapping while creating the integration of circular business, sustainable lithium recycling industry and the tensions.

1.4 Research Limitations and Boundaries

One of the limitations of the research is that even while being focused for the interviews, it was not easy to get many interviews with industry leaders, which could be because of the competitive nature of the RELiEF project goals, in the minds of the industry actors but eventually, a couple of important industry actors agreed to be interviewed. Even though the goal is to find European value chain proposition and to identify the challenges and opportunities in the economic block, the lack of Chinese company's evaluation in this research could be seen as limitation as currently China is dominating the recycling and reuse market of lithium and other battery materials. Giving that this is a qualitative study, another limitation is that this research is based on the expert's interviews and secondary data regarding perceptions and vision on the future of the industry. Nevertheless, the lithium industry is changing very rapidly, and, as a consequence, the comments from the experts are likely to be outdated with the upcoming technological advancements. This is the matter of fact in most of research studies but lithium and the EV industries are changing much more rapidly than most industries that have already been established.

1.5 Structure of the thesis

The thesis will consist of seven chapters and the first chapter is meant for research questions, research gap and overall background of the thesis.

The second chapter introduces the literature review and the theories that work as a foundation for this research. The focus is on explaining circular economy and paradoxical tensions in sustainable lithium recycling. In the third chapter the context of the research is given by explaining the analysis of the main actors, technologies and regulations in the lithium recycling industry in Europe. In the fourth chapter the research will analyze the interviews and the validity of the chosen research method.

In the fifth chapter the findings are presented, and the results are combined with the geographical illustration and industry landscape of lithium recycling and the use of secondary raw materials. In the sixth chapter the research will analyze the results and answer the research questions. In the last chapter the research will give conclusion, implications

and learnings from the thesis. This will be done in the manner of discussing the key findings and future research opportunities in the topic. Structure of the thesis is shown in figure 2.

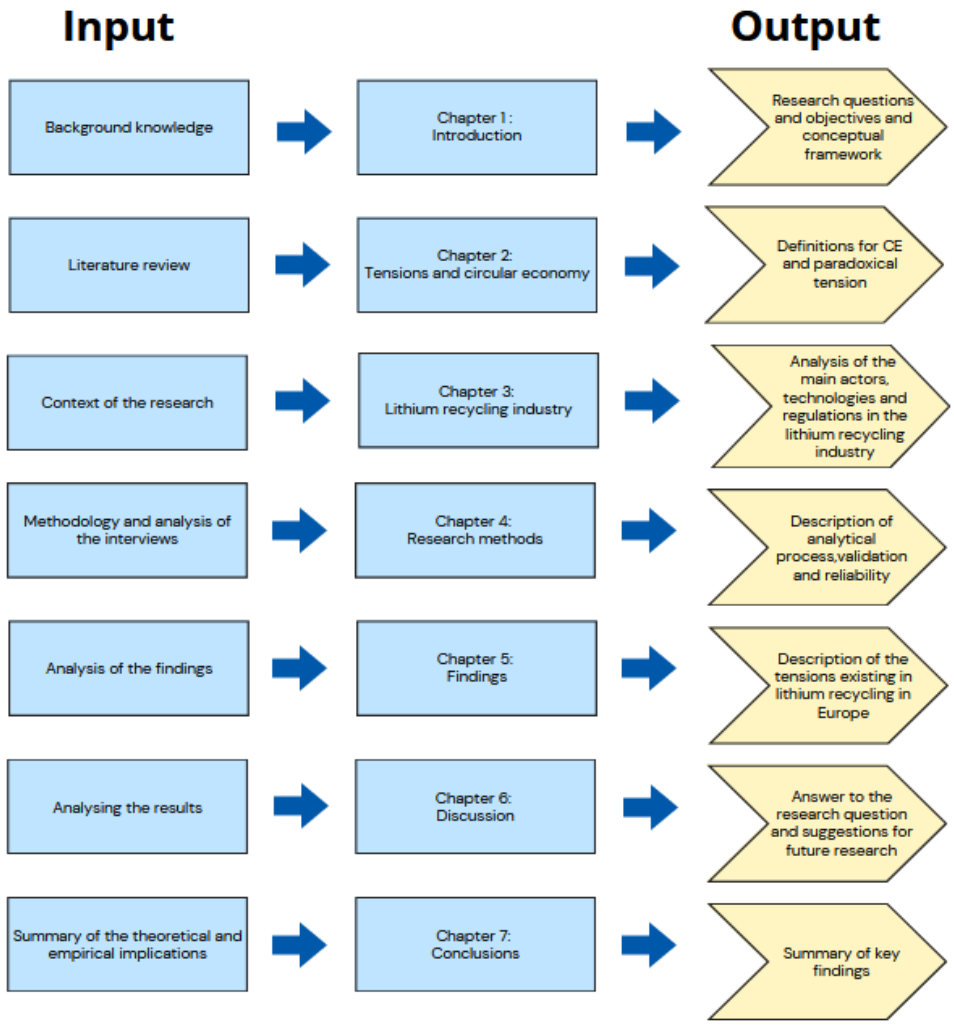

Figure 2. Structure of the thesis

2 Literature review

In this section I present the literature review. This thesis utilizes two literatures: The green transition connected to circular economy and secondly the tensions and possible paradoxes in lithium recycling industry in Europe.

2.1 Circular Economy of Li-Ion batteries

This chapter introduces the concept of circular economy and differentiates linear economy from it. It will also discuss circular business model and the drivers and barriers for circularity in lithium recycling industry with the focus on recycling of EOL batteries. Three main elements are explained in this section, circular value chain, circular value creation and circular business models. The structure of this theoretical chapter is shown below in figure 3.

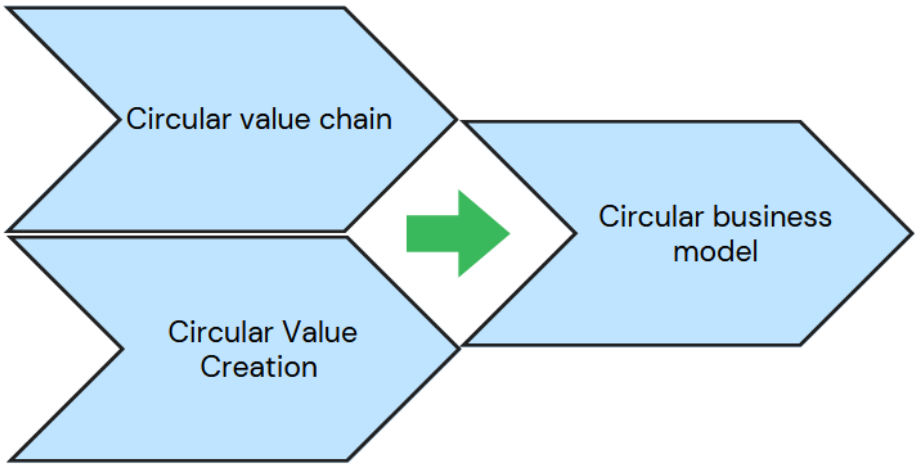

Figure 3. Structure of the theoretical chapter

2.1.1 The Concept of Circular Economy

Circular economy thinking is not new. The circular economy concept has gained momentum since the 1970s. The idea of circular economy was first brought up by Stahel and Ready-Mulvey in 1976 who described CE as "closed-loop economy" and they invited researchers to contribute to the study of CE (Merli *et al.,* 2018) A circular economy is an economic system that is regenerative and restorative by design (Ellen Macarthur foundation, 2013). It is based on the principles of preserving and enhancing natural, human, and economic capital. In a circular economy, waste and pollution are designed out of the system and resources are kept in use for as long as possible, extracted and processed in a way that minimizes negative impacts, and are recovered and regenerated at the end of each service life (Witjes and Lozano, 2016).

The circular economy model contrasts with the traditional linear economy, in which resources are extracted, used, and then disposed of. The linear model has a "take, make, use, dispose" waste-based approach, whereas the circular model aims to keep resources in use for as long as possible and minimize waste (Antikainen and Valkokari, 2016).

There are several key elements to a circular economy. These include designing products and systems that are resilient, resource efficient, and regenerative; using renewable energy to power the economy; and creating economic, social, and cultural incentives that support the transition to a circular model (Geissdoerfer *et al.,* 2020).

Adopting a circular economy approach can help to reduce environmental impacts, create economic opportunities, and improve social and human well-being. It has the potential to create new jobs, stimulate innovation, and enhance economic competitiveness.

The concept of a circular economy has been around for many years and has evolved over time. It has roots in various fields, including economics, industrial ecology, and environmental science. There is no lack of different circular economy model visualizations but one of the most well-known is the Ellen MacArthur Foundation's circular economy diagram.

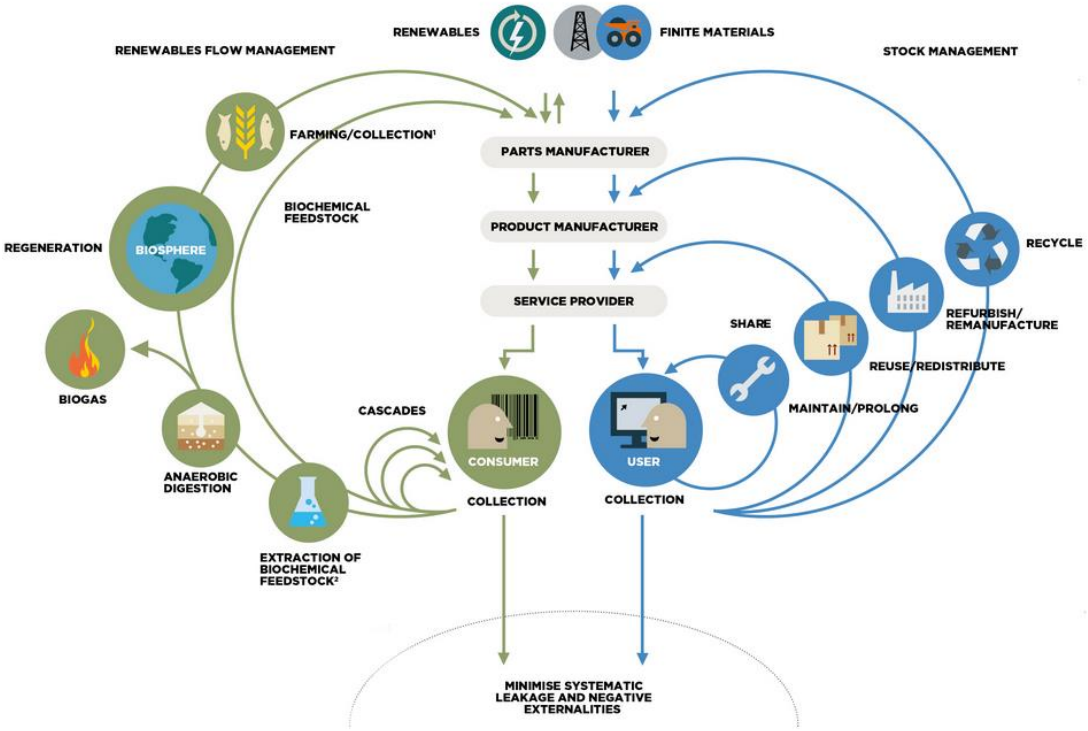

Figure 4. Circular economy based on Ellen MacArthur Foundation, 2013

The diagram presents the main target for circular economy which is to reduce waste and increase resource efficiency. The model describes two different cycles which are biological and technological. In the biological cycle the diagram presents the life of a non-toxic waste that becomes part of the biochemical feedstock. This is done by collecting the finite materials in various stages of the life cycle of the resource that has been turned into a product. Circular economy is based on three activities: Reduce, reuse, and recycle.

Reduce – reducing the waste by prolonging the lifetime of a product by maintaining it properly.

Reuse – Reusing the materials by introducing them back to the service provider to be put back into the system.

Recycle – Give a new life to end of life products by recycling the parts and sending them back to the manufacturer.

Producers and wholesalers play a large role in circular economy and so do the governments. Collecting the used products and scrap from the consumers is probably one of the most important parts of the whole process and is an expensive part of the value re-creation from the used materials. The classical linear economy model where renewable and non-renewable

resources are used to produce products for consumers who then dispose of the products which end up in a landfill or are incinerated. Our world has been dominated by this traditional linear business because it has been profitable and successful (Mathews and Tan, 2011). This could be coined as the traditional economy model where we "take, make and dispose." (Ellen MacArthur Foundation, 2013). The other model is circular economy where there is a closed loop of recycling of the resources from usage back to the producers to give the product a new life.

Circular economy business models can be divided into two groups (Hofstetter *et al.*, 2021). Firstly, the model that encourages reuse and the extending of service life through repairing, remanufacturing, upgrades, and retrofits and secondly to those models that turn old goods into new resources by recycling the materials. While it is very important to increase the lifetime of products, the end-of-life date will eventually come to every man-made product. Therefore, it is important to create the products so that it is possible to recycle the raw materials from the end-of-life product (Hofstetter *et al.*, 2021).

2.1.2 Circular Value Chains and Circular Value Creation

In this section I will discuss the circular value chain and the circular value creation and how these concepts have been presented. Like discussed earlier, the value creation and how value chains are build has changed rapidly. The biggest problem is that companies are still trapped in an out-dated approach to value creation where there is only short term strategic plans to create profits for the shareholders (Porter and Kramer, 2011). This sort of thinking is changing though, companies are becoming more aware of their supply chain and how to create sustainable value throughout their value chain. Circular value creation thinking comes from the triple bottom line thinking and also from the pressure from stakeholders who require sustainable business practices. In simplest method, circular value creation and circular value chains mean closed loop supply chains (Schenkel et al., 2015. Another indicator for circularity in value chain is how well the value chain retains the value of the resources throughout the value chain.

2.1.3 Integrating the circular economy into lithium supply chains

Even though metals have been recycled for a long time, and 400 million tonnes of metals are recycled annually, in the United States, only 5% of the lithium was recycled in 2018 (Church and Wuennenberg, 2019). Circularity in the supply chain starts after the end user has seen the end-of-life with their battery and is about to permanently dispose of the waste. Instead of this permanent disposal of critical raw materials, in circular economy, the batteries are collected by third parties and sent to the processing plants to be recycled. At the processing stage the batteries are dismantled and sorted for recycling processes. The metals are then recovered through multiple of different recycling processes and restored to a concentrated volumes for manufacturers processes (Atia *et al.*, 2019a; Gaines, 2018; Mossali *et al.*, 2020). The loop closes when manufacturers get secondary raw materials from the recyclers, and they use the secondary raw materials to manufacture end-products such as EV-battery packs.

In its simplest form, the whole life cycle is: mining, international trading houses, smelters and refiners, manufacturers and then the end user. Most of lithium ends up in a landfill for a permanent waste disposal and it will be the end of life of that lithium. Circularity brings another layer of value chain by introducing the end-of-life lithium back into the system by established collection system that provides lithium for processing and the waste/scrap for metal recovery.

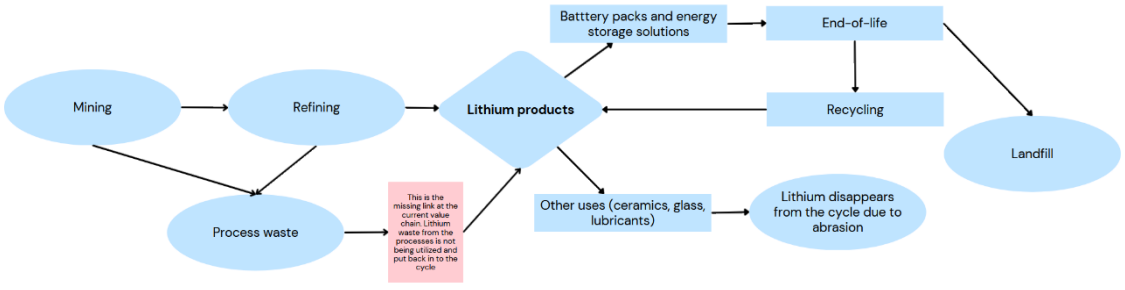

Figure 5. Conceptualization of the missing link in the lithium recycling industry, Author

In the figure 5, I explain how the current value chain works and what is missing from it. In the life cycle of lithium, from mining to the end-product, there are multiple of stages where lithium is getting wasted. Especially important part is the process waste that is currently not being used. Process waste is often overlooked by the companies due to the price of the virgin

material and relatively low quantities of lithium in the process waste, but once all the process waste streams are combined, it can become a significant amount.

2.2 Paradox theory and sustainability of lithium recycling

In this section the thesis conceptualizes the second main theory used to, the paradox theory in reflection with the sustainability of lithium recycling. It is important to understand the paradox theory and how it is linked to the tensions that are affecting the industry. Not all tensions are paradoxical, most are not, but it does not mean that understanding the paradoxicality of the tensions would not be necessary, as there is clear difference between paradoxes and tensions, of which the latter can be solved. The aim of this sub-chapter is to make clear what are the differences between paradoxes and tensions, so that in the latter part of the thesis, there will be no misconceptions. Paradoxical tensions in lithium recycling are linked together by combining paradox and tensions, paradoxical thinking and paradoxical actions and strategies as shown in figure 1

2.2.1 Conceptualization of tensions and paradoxes in lithium recycling

Paradox refers to the contradictory features that exist in organizations simultaneously and create tensions between due to the mismatch of the goals and targets. Paradoxes differ from contradictions in that they create situations of almost impossible choice, hence the seemingly irrationality or absurdity of the situation (Smith and Lewis, 2011). They are often linked to unexpected outcomes and inconsistencies, for example, situations that lead to inefficient efficiencies, equity programs that legitimate discrimination, and democratic systems that inhibit participation (Putnam *et al.*, 2016). Paradoxes can also be interdependent and mutually exclusive opposites that reflect on and impose on each other (Putnam *et al.*, 2016). This can occur through the ways that contradictions and dialectics from the building blocks of paradox as it persists over time and makes choice difficult (Smith and Lewis, 2011). Tensions should not be left unmanaged and there are different strategies of how to tackle these tensions in a manner that resolves them prior to having to deal with the consequences (Putnam *et al.*, 2016). I will next discuss some of the strategies and solutions on how to

embrace the paradoxical tensions emerging from the supply chains and business models utilized in sustainable business of lithium recycling.

Sustainability tensions emerge from the mismatch of short-term and long-term sustainability goals of different stakeholders and the more diverse the stakeholders are, the stronger the tensions might be (González and De Haan, 2020). Tensions can be experienced as stress and as difficultness of moving forwards with decisions. (Putnam et al., 2016).

First, it is especially difficult when there are governments and economic blocs such as the European Union involved in sustainability discussions as the EU has a lot of power to regulate the industry where the company is operating. The short-term goals of a certain business are not usually aligned with the long-term goals of the EU commission. When a company or project such as RELiEF is thinking about different business models and value creation concepts, it is important to understand the possible threats that might hinder the functionality of the suggested model or value creation concept. As any project that aims for sustainability, we are facing the same threats as any company that functions within the strict goals and legislations of the European Union.

Managing sustainable supply chain and sustainable business can be difficult because of numerous tensions and conflicts. Paradox refers to a contradiction between interdependent elements, while tension represents the negative side of business relationships that arise from multiple different sources (Hahn *et al.*, 2014).

Tensions usually arise from divergent elements that conflict with the realization of social-ecological objectives in supply chains (Zehendner *et al.*, 2021a). Many scholars have said that organizations should embrace tensions instead of avoiding contradictory and interrelated demands. Managers should therefore acknowledge the interconnectedness and interdependence of economic, environmental and social concerns (Zehendner *et al.*, 2021a). This paradoxical tension concept has similarities with triple bottom line concept and stakeholder theory as they all show the importance of understanding that there are different stakeholders with different needs and expectations (van Bommel, 2018). In table 1 the categories are explained with examples from the lithium recycling industry.

Table 1. Categories of tensions in lithium industry, authors adaptation (Van Bommel, 2018)

Tensions	Examples
Tensions emerging from multiplicity of stakeholders and goals	Bottom-line thinking, financial vs triple bottom line. In lithium recycling industry this is very evident as the likeliness of being able to accommodate all of the bottom lines is impossible.
Tensions emerging from individual and collective conflicts around identity and values	Focus on sustainability versus business logic. Value of protected land versus profits from a mining site.
Tensions emerging from intra EU dynamics	EU sustainability targets versus core business models of lithium recycling companies.
Tensions emerging from multiple time horizons as growth, change and flexibility are pursued	Short-term business focus vs. Long-term sustainability goals of European Union.

Tensions operate between as well as within these categories. Learning and performing spur tensions between building capabilities for the future while ensuring success in the present (Smith, 2011). This means that while companies are trying to survive in the present, many sustainability actions only bear fruit later in the future and are considered more of an investment, therefore creating paradoxical tensions balancing between surviving the present economic situation and preparing for the challenges in the future.

Learning tensions usually arise from change in systems, renewing strategies or innovations and therefore the tension is usually described as old versus new and very much present in the times of transition and change. In sustainability the new innovations and operation methods usually mean more sustainable business practices, but these changes are also the cause of many paradoxes (Smith and Lewis, 2011).

Belonging tensions are often driven by different and often divergent identities, values and views of actors in certain industry (Putnam et al., 2016). Belonging tensions and paradoxes arising from these tensions often come from stakeholders having different values and views regarding the environmental and social factors and are more visible in global trade and global supply chain due to so diverse cultural and legislative backgrounds of foreign stakeholders (Zehendner *et al.*, 2021a).

Organizing tensions are created from competing structures and processes utilized by organizations and supply chains to achieve desired outcomes. The integration of social-ecological into the organizations core strategy often creates organizational tensions (Yamasue *et al.*, 2022). The paradoxes arise from the need to create fully integrated sustainability strategies into the business strategy while also trying to maintain the economically viable business strategy.

Performing paradoxes arise from the multiple stakeholder problem as many stakeholders have different goals and strategies, often contradicting with other stakeholders. Many of these performing paradoxes are caused by double bottom line thinking when financial and social goals override the environmental goals (Yamasue *et al.*, 2022)

2.2.2 Strategies to overcome tensions

Based on paradox theory, to manage the tensions there are several strategies: *Acceptance, separation and synthesis* which have different outcomes that can also be divided into 3 different categories: trade-off, win-win and integrative (Smith and Lewis, 2011). By accepting the tensions as they are, one will utilize trade-off or integrative outcome to incorporate the tensions in their business. Win-win is rarely a realistic opportunity but by synthesis strategy a company could work around the tensions and try to achieve a win-win situation with other stakeholders affected by the tension. Table 2 will provide the list of strategies and the context for each strategy.

Table 2. Strategies for managing tensions and the outcomes. Synthesis by the author

Strategy:	Context
Acceptance	In acceptance strategy companies try to find ways to simultaneously consider contradictory aspects without emphasizing one pole of the tension as the best way (Beech *et al.*, 2004; Clegg *et al.*, 2002). With regard to tensions between international agreements, regulations and organizational sustainability agendas, acceptance strategies embrace divergent inter- or intranational and organizational agendas and allow for diverse views on corporate sustainability within the industry. By accepting the diverse agendas, companies can, though in a costly manner, embrace the international sustainability goals.

Separation	A separation strategy aims for the management of tensions by separating the tension creating poles either by spatially or temporally (Clegg *et al.*, 2002). A temporal and spatial separation of company and economic area sustainability agendas can be achieved through the creation of permanent or temporal separation of the sustainability actions, if they do not interfere with each other. In reality it is not really easy to separate sustainability agendas especially in an economic bloc such as the EU.
Synthesis	Synthesis strategy seeks to accommodate the opposing poles of the tensions in a mediating way. With the synthesis strategy, companies in an economic bloc can manage their sustainability agendas by participating in the broader sustainability agendas and aligning their own goals and targets with the, for example, EU goals and targets. The main idea is to create the participation in a common goal thriven approach (Beech *et al.*, 2004)
Outcome:	Context
Win-Win	In a Win-win outcome approach, the companies or industry actors do not attempt to find solutions to the tensions rather they seek to adapt and align the objectives with the other stakeholders by trying to achieve an equilibrium with the economic, environmental and socials aspects (Van der Byl and Slawinski, 2015). In reality, this approach usually does not work in terms of creating value for each and every stakeholder.
Trade-off	Trade-off approach is based once again on the three layers of evaluating success of a company and in the trade-off approach a company is willing to trade one or two layers in promises of gaining more value for the remaining ones (Van der Byl and Slawinski, 2015). It is impossible to achieve success in all of the dimensions when creating large wins in the economic and social aspects usually means losses in the environmental aspect and vice versa. Companies are usually willing to sacrifice short-term financial goals to pursue long-term environmental goals but in reality, companies will maximize their efforts for profitability over social and or environmental goals.
Integrative	There are recent studies in the field of sustainability that claim that companies can address tensions simultaneously and not only in terms of win-win or trade-off. Integrative approach assumes that the goals

	can be balanced without having to trade-off by giving more focus on any of the three dimensions (Van der Byl and Slawinski, 2015; Smith and Lewis, 2011). This approach that would not prioritize or favor any of the three dimensions is a goal worth achieving and there have been some companies in lithium recycling industry who are seemingly trying to utilize the integrative approach, such as Li-cycle. They focus on social, environmental and profitability aspects seemingly simultaneously.

As seen from table 2, there are multiple of strategies but most likely companies would be utilizing some version that utilizes a combination of a set of strategies, but this creates the problem of not knowing what the most likely outcome might be.

3 Contextualisation of lithium recycling industry

This section introduces the context of analysis, the lithium recycling industry. To be able to understand the origin of a problem we need to first contextualise it. In this chapter, the research creates an overview of the industry by introducing the main actors, regulations, and technologies in the lithium recycling industry in Europe.

3.1 Drivers for sustainable lithium recycling industry

U.N Sustainable Development Goals

One of the main drivers for circularity and sustainability in the European Union and the whole world is The United Nations Sustainable Development Goals (SDGs). The SDGs are a set of 17 global goals adopted by the United Nations General Assembly in 2015 as a reviewed and extended version of the Millenium development goals (United Nations, 2023). The MDGs were focusing on the developing countries and the new SDGs focus both the developing and developed countries which is a very big difference especially considering how these goals are now the supportive backbone of the actions in developed countries. The SDGs comprise of 17 goals and 169 targets and are intended to be a guideline to achieve a

better and more sustainable future for all. The list of these goals is very extensive, and each goal has several targets that are measurable and monitored. In the figure below, we have all the goals set by the U.N. and we can see that not all are relevant for critical minerals usage and recycling (United Nations, 2023).

Figure 6. Sustainable development goals, (United Nations, 2023)

For circular economy and to understand the reasoning behind the need for circularity in the raw materials sector, we would need to focus on several goals that are the most important for solving the critical raw material dependency:

Goal 7. Affordable and Clean Energy

This goal is obviously very important and the target 7.2 of SDG 7 for affordable and clean energy aims to increase substantially the share of renewable energy in the global mix by 2030 (United Nations, 2023). Lithium is critical to the development and deployment of green energy technologies such as electronic vehicles and energy storage. Securing the sustainable and affordable supply of lithium and other critical minerals through the improvements in mineral recycling processes contributes to the target.

In the case of EV business models and Li-ion battery circular economy, this SDG affects the policies and funding that is available through EU and other sources and as mentioned, the energy efficiency comes from second use materials. Mining and processing primary raw materials take a lot of energy and therefore decreases the energy use to produce energy storage systems needed for this goal.

Goal 8. Decent Work and Economic Growth

Engaging in enhanced lithium and cobalt recycling services could contribute to SDG 8 for Decent Work and Economic Growth by generating sustainable jobs, improving the safety of waste treatment and creating chances for economic. Specifically, Target 8.3 aims to promote policies and projects that formalize and grow micro-, small- and medium-sized enterprises (MSMEs), including through access to financial services (United Nations, 2023). Secondary processes are labor-intensive, and entail additional employment creation for collection services, dismantling, processing, metal recovery, manufacturing and sales operations. Target that are important for recycling of critical materials are for example 8.4: Increase resource efficiency. 8.6: Take immediate action towards stopping child labor and child soldiers in the conflict areas, which is not at the moment the problem areas for lithium but rather for cobalt, but we can be sure that these problems could arise lithium production too.

Goal 9. Industry, Innovation and Infrastructure

Targets 9.4 and 9.5 of SDG 9 aim to promote sustainability through retrofitting industries for increased resource-use efficiency and enhancing the technological capabilities of industrial sectors in all countries, respectively (United Nations, 2023).One of the key advantages of mineral recycling is that, if operators work proficiently, the minerals can be reused almost endlessly, thereby extending resource-use efficiency.

Goal 12. Responsible Consumption and Production

Targets 12.4 and 12.5 of SDG 12 for Responsible Consumption and Production aim to reduce waste generation and ensure the sound management of chemicals and waste (United Nations, 2023). Primary extraction—or mining—can be associated with higher levels of waste production when compared to recycling processes. The levels of waste can be very significant; in the European Union (EU), for example, mines have generated more waste than households (Johansson, 2016). If poorly managed, lithium and cobalt mining, like other forms of mining, can also cause environmental and health problems related to the waste generated. Beyond waste, mining can also place considerable demands on the local resource base.

Goal 13. Climate Action

As discussed in the introduction, climate change mitigation measures are essential to accomplishing the commitments set out by both SDG 13 for Climate Action and the Paris Climate Agreement. Renewable energy sources like solar and wind, will contribute greatly to mitigation by providing options for lowering greenhouse gas emissions from the overall energy system, while still satisfying the global demand for energy, but these solutions require a large quantity of energy storage units, for example lithium battery packs, therefore boosting the demand of lithium battery solutions.

Goal 16. Peace, Justice and Strong Institutions

Increased mineral recycling could fulfill some of the goals of the circular economy by reducing reliance on finite resources and mitigating permanent waste disposal. It could also directly contribute to SDGs 7,8,9,12,13 and 16 among others. Each goal has specific targets that are intended to be achieved by the year 2030. The SDGs are meant to be universal, meaning they apply to all countries around the world, and they are integrated, meaning that they recognize that economic, social, and environmental goals are interconnected.

The Sustainable Development Goals are necessary because they provide a framework for addressing some of the most pressing challenges facing the world today. These challenges include poverty, inequality, climate change, environmental degradation, and a range of social and economic issues. By setting specific, measurable, achievable, relevant, and time-bound goals, the SDGs provide a way to track progress and hold governments and other organizations accountable for their actions.

The SDGs also recognize that these challenges cannot be addressed in isolation. Instead, they require a coordinated, holistic approach that considers the interconnected nature of economic, social, and environmental issues. By working towards the SDGs, countries and other actors can help to create a more sustainable and equitable future for all people around the world. SDGs should therefore be seen as a catalyst to innovate the energy sector, rather than hinderance to it.

Climate agenda: UN Paris Agreement

Sustainable development goals work as the blueprint on how to build a better planet for all of us by giving us concrete goals. One agreement that is very important in securing the success of multiple SDGs is the Paris agreement, which is an international treaty on climate change that covers climate change mitigation, adaptation, and finance, negotiated by the U.N

(United Nations Climate Change, 2015). The Paris agreement is especially important for the Climate change goal. The Paris agreement was adopted by 196 countries at COP 21 in Paris, on 12 December 2015 and it entered into force on 4th of November 2016 (United Nations Climate Change, 2015).

The Paris agreement aims to limit global warming to well below 2 degrees Celsius compared to the pre-industrial levels. The Paris agreement is a unique agreement in climate change actions that is for the first time bringing together all nations to tackle the looming problems caused by climate change. The Paris agreement puts developed countries to take the lead in providing financial assistance (United Nations Climate Change, 2015). It's vision to reduce the GHG emissions help with obtaining funding for EV technologies and circularity of the needed materials for the EV.

Legislation in a strongly controlled economic bloc is another influencer when it comes to funding and being a driver for sustainability. One such legislative package is the European Green Deal. The European Green Deal is a set of policies and actions proposed by the European Commission, the executive branch of the European Union (EU Commission, 2022), to make the EU's economy more sustainable and climate-neutral in the future. The main goal of the European Green Deal is to achieve climate neutrality, which means that the EU's overall greenhouse gas emissions are reduced to a level that is net zero or negative, by 2050. To achieve this goal, the European Green Deal aims to (EU Commission, 2022)

- Reduce greenhouse gas emissions across all sectors of the economy, including energy, transportation, agriculture, and industry.
- Promote the use of renewable energy sources, such as solar and wind power, to meet the EU's energy needs.
- Green Deal aims to improve energy efficiency in buildings, vehicles, and industrial processes to reduce energy consumption and greenhouse gas emissions.
- Protect and restore natural habitats such as forests and wetlands, to help absorb carbon dioxide from the atmosphere and provide other environmental benefits.
- Promote sustainable and circular economy, which reduces waste and resource use, and encourages the reuse and recycling of materials.

The European Green Deal is likely to have a significant impact on EV and battery businesses in Europe, as it will require them to change the way they operate in order to reduce their greenhouse gas emissions and contribute to the EU's goal of climate neutrality. The Green deal will increase regulatory requirements and it is expected to lead to the development of new regulations and standards that will require businesses to reduce their greenhouse gas emissions. This may require businesses to make changes to their operations, such as adopting new technologies or changing the way they produce and sell products and services. This is especially critical for EV business as they are reliant on the regulations and policies supporting the green energy wave.

There are opportunities for innovation for sure, as EU is investing in new green innovations. The transition to a more sustainable and climate-neutral economy may create new opportunities for businesses that are able to develop and offer innovative products and services that help reduce greenhouse gas emissions.

The European Green Deal is likely to lead to changes in consumer behavior as people become more aware of the environmental impacts of the products and services they purchase. This may create new market opportunities for businesses that are able to offer environmentally friendly services and operate sustainably. Businesses that are unable to meet the new regulatory requirements or that fail to adapt to changing consumer preferences may face costs, such as fines or reputational damage.

The European Union Green Deal includes the Circular Economy Action Plan as one of the main building blocks of the deal. It is the new agenda for Europe’s sustainable growth and driver for transition to a circular economy that will reduce the pressure on natural resources and will create sustainable growth and jobs. It targets how products are designed, promotes circular economy processes, encourages sustainable consumption, and aims to ensure that waste is prevented, and the resources used are kept in the EU economy for as long as possible (EU Commission, 2022).

Overall, the European Green Deal is likely to have both challenges and opportunities for businesses in Europe. It will require businesses to adapt to a new regulatory environment and changing consumer preferences, but it may also create new opportunities for innovation and growth.

The EU Green Deal affects directly to EV business models and Li-ion battery circular economy. First, it is not only the driver for change and the driver for funding for circular economy, but it also works as a guideline for the regulations and recommendations from EU. Business models need to be aligned with the EU Green Deal goals as otherwise a company could be blind sighted by EU's regulations. By understanding the Green Deal and actively looking to integrate the goals in the business model, a company is securing its investments as there is much smaller chance of a new regulation that would hinder their business. Even better, a company that is integrating the Green Deal in their business model can take advantage of the extra funding and possible business opportunities coming from the Green Deal policies.

PESTEL framework and the drivers arising from it

It is important to understand what the drivers and barriers are for entering the industry. A good way to analyse the industry is to utilize a PESTEL framework. PESTEL framework is a multifaceted approach to assess big-picture forces to better understand the strategic orientation of an organization and to assist in making considered and informed decisions about organizational activities (Song *et al.*, 2017). The PESTEL framework primarily concerns six factors: political, economic, social, technological, environmental and legal. Pestel provides an overview of the macro-environmental factors the company needs to consider in its decision-making (Song *et al.*, 2017). Table 4 will show the PESTEL analysis for lithium recycling industry

Table 3. PESTEL analysis of the lithium recycling industry in general

Driving factor	Drivers for circularity in lithium recycling	Barriers for circularity in lithium recycling
Political	Targets and regulations: SDGs, European Green Deal, carbon neutral Europe 2050 Government support	Government policies Political instability Tax policies
Economic	Financial capability New economic potential	High costs Difficult to specify the business model

	Opportunities for cost savings and efficiency Increased funding	Uncertainty of future of the business environment Fluctuating prices of raw materials
Social	Environmental consciousness Potential to create jobs Changed consumer attitudes Ideological values	Weakness of public consciousness Lack of support from the supply and demand network Lack of expertise
Technological	New Technologies Technology incentives Digital innovations	Lack of technology Lack of recyclable material
Environmental	Resource constraints Reducing environmental impact	Hazardous material regulations Environmental policies Pressure from NGOs
Legal	Protectionism inside EU Import bans	Labour laws Health and safety laws Export bans

Political drivers and barriers can be the same but with a mirrored effect. For example, some policies that are meant to help European Union to become more independent and less dependent on foreign minerals, can be also harmful for the industry players in Europe. SDGs are one of the main drivers of this change but at the same time these policies can hinder some technological opportunities of recycling of lithium.

Economic factors are probably one of the most important drivers and or barriers to the recycling industry. Without economic viability, there is no business to be done. It is important to balance sustainability with economic stability. Most of the sources of lithium from secondary sources might not be economically viable, but it is important to calculate and estimate each of these sources to make sure.

Social factors include for example environmental consciousness which means increasing awareness and concern about environmental issues, including resource depletion and waste management, drives the need for sustainable practices like lithium recycling. Lack of public awareness and understanding about the importance and benefits of lithium recycling may hinder its adoption. Educating the public about the environmental and economic advantages of recycling lithium can help overcome this barrier.

Technological drivers are related to the technological advancements in lithium recycling processes, such as hydrometallurgical and pyrometallurgical methods, which can improve the efficiency and cost-effectiveness of the recycling process. Innovation in techniques like mechanical sorting, leaching, and selective extraction can drive the development of more sustainable recycling solutions. While technological barriers are complex battery chemistries, battery handling safety, scalability and costs and limited infrastructure.

Environmental factors include drivers such as investments towards sustainable mining and production and resource constraints that increase the prices and therefore create financially viable opportunities for companies. Barriers include the pressure from NGOs and environmental groups and hazardous material regulations and other environmental policies.

Legal drivers are for example import bans and other sorts of protectionism such as the policies included in the inflation reduction act in the USA which forces American battery and car manufacturers to use lithium sourced from mines in USA or recycled lithium from American companies.

3.2 Lithium recycling industry

LIB have evolved during the last 20 years as have the needs and requirements of the batteries. Li-Ion batteries are suitable for multiple uses where a high energy-weight ratio is needed. There are different variants of LIB, which affect the composition of materials.

Cathode materials:

Lithium cobalt oxide – LCO

Lithium manganese oxide – LMO

Lithium nickel manganese cobalt oxide – NMC

Lithium iron phosphate – LFP

Lithium nickel cobalt aluminum oxide – NCA

Anode materials:

Lithium titanate - LTO

Even though chemistry types have changed in popularity, the main components for LIB have not (Ali et al., 2021b). There are eight primary materials used for LIB which are: lithium, cobalt, nickel, manganese, aluminum, iron, graphite, and titanium. While lithium is the main element in rechargeable LIBs and is used as cathode for all LIB batteries, cobalt is more costly and rare (Ali et al., 2021b).Cobalt mining has been in the news lately due to its main source being in Democratic Republic of Congo where there are political and ethical concerns due to the way it is extracted (Ali et al., 2021).

Lithium-ion batteries are complex products with materials that can be harmful for humans, but there are multiple recycling methods for end-of-life batteries. There are three basic process types: pyrometallurgy (smelting), hydrometallurgy (leaching) and direct recycling (physical process). These process types can be combined based on the quantity and characteristics of the recycled material (Atia et al., 2019; Lemougna et al., 2019). Historically, the main objective of Li-ion battery recycling was to recover cobalt due to its high value but due to increased lithium content in the batteries and the regulations for recycling rates, companies have started to increase their efforts and investments into recovering other materials such as lithium in its many forms (Gaines, 2018). Secondary lithium raw materials can be used to create new battery packs after the recycled materials are processed.

Based on a survey made by the United States Geological Survey (USGS), 74% of lithium is used for batteries while ceramics and glass take 14% and lubricating grease 3% (USGS, 2022). The trend is that lithium usage for batteries will increase dramatically and could therefore push ceramics and glass producers to look for other solutions to replace the use of lithium in their processes. Problem with these smaller streams of lithium is that most of it is really costly to collect and would require a large campaign to make consumers to understand that they need to recycle glass and ceramics in a specific way.

Lithium waste is coming from multiple sources, namely air treatment, pharmaceuticals, rubber, battery recycling, lubricants and greases, catalysts and other uses. The quantities of from these material flows are not very significant, but RELiEF-project is researching on how we could utilize these waste flows. Recovering the lithium from very small content percentages is not sustainable as the logistics costs and emissions from the recovery processes would be higher than the benefits. Lithium from the waste generated from Li-alloy production (from pyrometallurgy process) is worth investigating in the business modelling stage.

3.3 Value chain in the lithium recycling industry and the main actors

3.3.1 Circular Business Model

Circular business models are a growing field of research especially in the mining and rare earth minerals industry. The demand for electronic vehicles has created the demand also for circular business models for production of the batteries and the precursors. This is especially important for lithium-ion based batteries where the demand is expected to be 20-fold in the next 20 years or so, when we are closing to the European Union targets of carbon neutrality by 2050. Currently the research is focusing mostly on technical and economic issues based on recycling and second use of batteries (Bocken *et al.*, 2018; Wrålsen *et al.*, 2021)

Business models describe the way business is done. The value proposition, or product or service offering, is at the center of the business model. In the case of a collaborative business model, collaborators should search for a value proposition that creates value for a network of multiple stakeholders, rather than just the customer or consumer (Freudenreich *et al.*, 2020). Value creation and delivery are the activities, resources, channels and partners to create and deliver value, while value capture is about cost and revenue streams. More broadly, value capture also includes the business model's wider benefits to society.

Conventional business model innovation focuses on economic value creation by satisfying customer demand. Shared value creation or creating a collaborative business case, is about creating value for a wider group of stakeholders (Porter and Kramer, 2011). Circular business models are not about satisfying the customer demand or trade-offs where one group

benefits to the detriment of another stakeholders through deforestation or society through harsh working conditions.

Circular business models are built on the concept of creating shared value. Similar to sustainable business models, circular business models are economically competitive while contributing positively to the environment and society (Eisenriegler, 2020). A micro-level circular economy system can exist within the current economic system by means of collaboration. To enable this, the company needs to consider the key stakeholders according to the stakeholder's perspective.

There are at least 6 different business model strategies which utilize circularity or at least sustainability in their strategy, that fit the lithium recycling industry. (Bocken *et al.*, 2018)

Table 4. Business strategies, authors adaptation of the Kraaijenhagen et al. 2016

	Business model strategies	Definitions and examples
1	Extending product value	Utilizing residual value of products – from manufacturer to the consumer and back to the manufacturer, to close the cycle. For example, a EV battery company that buys back your old battery and sells it to a stationary energy storage manufacturer
2	Classic long-life model	Business models focused on delivering long-life products through design for durability and repair.
3	Encourage sufficiency	Solutions that actively seek to reduce end-user consumption through principles such as durability and efficiency. The focus has been changing to efficiency and range instead of speed of acceleration, which reduces the size of the battery.
4	Extending resource value	Exploiting the residual value of resources. Collection and sourcing of wasted materials or resources to turn these into new forms of value such as the old mining waste that is now being utilized due to the increased raw material prices.
5	Industrial symbiosis	A process-orientated solution concerned with using residual outputs from one process as feedstock for another, which benefits from geographical proximity of the businesses. This is yet to be utilized but for example

		a LAS glass producer that would take the non-battery grade lithium from the EV battery recyclers as the glass is not so dependent on the quality of the lithium.
6	Maximize material and energy efficiency	Doing more with fewer resources and generating less waste, emissions and pollution is the goal of European Union but as long as the green transition requires massive amounts of critical materials, the focus must be on building up the recycling industry and only after, start to focus on the efficiency once the loop is closed.

It is important to understand how many different strategies there is to apply for a business model to become more sustainable. These strategies are not meant to compete with eachother, and a company could utilize multiple strategies from this list. For battery manufacturers that utilize secondary sources of lithium, understanding these strategies is critical. It is though, a balance of cost of production and how big of an influence the company gets from their sustainable business model. Utilizing secondary raw materials that have been left unused is a business model that would mean maximizing material and energy efficiency.

Firstly, we need to understand what and where are the primary sources of lithium. Lithium supply is becoming a critical thing for many economic blocs and especially in Europe. Mining businesses and lithium reserves are scattered around the world, but the main players are dominating the field. Australia, Chile and China cover over 95% of the production in the world (USGS, 2022).The economically viable sources of lithium as the estimated total worldwide resources are about 88 million tonnes. Only 1 quarter of the resources are financially viable to mine, but it is still enough for the EV and electricity storage revolution (USGS, 2022), but without a smart and efficient recycling, it will not last forever, as we will witness happening to oil in the relatively near future.

Currently, most of the waste from these processes goes untreated or is otherwise used by the producer themselves. The research done by RELiEF project estimates that there is not enough material available to be used as a secondary raw material source for lithium from the smaller streams.

3.4 Regulations in Europe and other economic regions

European Union legislation can be frustratingly slow to change but sometimes some regulations and legislation changes come very rapidly. It is very important to stay up to date with all the changes in legislations and therefore it is worthy of research to understand what are the main legislations and regulations that could affect lithium recycling and logistics currently and in the future. One current example from the U.S is a recently published federal hazardous material regulation (Federal Register, 2022):

- Prohibiting the transport of lithium-ion cells and batteries as cargo on passenger aircraft.
- Requiring that rechargeable lithium-ion cells and batteries on cargo-only aircraft be at no more than a 30% state of charge "when not packed with or contained in equipment."
- Restricting the use of alternative provisions for smaller cell or battery shipments to one package per consignment.

These kind of changes for example would harm or even destroy companies that were utilizing air freight in their business model of recycling/processing lithium batteries. Therefore, it is important to communicate frequently with the regulatory agencies and try to understand the changes and how to influence the decisions.

France submitted proposal to add lithium carbonate, lithium chloride and lithium hydroxide to the list of hazardous materials due to scientific evidence of carcinogenicity, germ cell mutagenicity and reproductive toxicity. RAC opinion from 16th of September 2021, was that there is enough evidence of how harmful lithium in breast milk is (CLH, 2023).

The European Union is moving towards a sort of paradoxical tension here. At the same time, the EU has adopted these goals to become carbon neutral by 2050. There is a very concerning legislation that is currently going through the review and commenting phase in the European commission. EU is planning on making lithium salts, which are essential for battery production, and lithium itself a hazardous material (CLH, 2020), which would hinder the profitability of many business models related to recycling lithium for second use. 7th of November was the last day of submitting comments to the proposal. The final solution is yet

to be released. There has been multiple of public complaints about this proposed legislation from big players in the lithium industry such as Albermarle. The proposed legislation would hurt the industry heavily and seriously harm Europe's chances to become independent from relying on Chinese lithium. Recycling processes are heavily reliant on logistics, especially when the processing plant is designed to be centralized in one location in Europe. Demand for EV battery sets will most likely increase the price of lithium and other battery materials, but it is hard to estimate if profitability of lithium from secondary raw material sources will ever be enough.

REACH is another set of regulations of the European Union meant to protect human health and the environment from hazardous chemicals and materials. REACH stands for Registration, Evaluation, Authorization and restriction of Chemicals. REACH places the burden on companies to manage their responsibilities regarding to the substances. At the minimum, REACH enforces companies to register their processes and chemicals they use, and they are required to manage the risks involved (ECHA, 2023).

New battery directive 2023 was published on the June 14th, 2023, and which came to force on the 17th of August 2023 (European Commission, 2023). The idea of the new battery regulation is to reduce the dependency of foreign battery material, to reduce the waste coming from batteries, increase the recycling rate of critical materials and require the battery producers to utilize recycled material in their new products (European Commission, 2023). This regulation is reflecting the inflation reduction act in the USA. The biggest difference between these two regulations is that the IRA is much more protective for the American companies and American manufacturers are required to utilize only material that is from the USA or recycled material from the USA. One of the most interesting regulations in the new act is the mandatory minimum level of material from recycled sources for the new batteries. For lithium these minimum levels will be 6% and 12% for the years 2031 and 2036 respectively (European Commission, 2023). This is very important for the RELiEF-project and for any recycling company in the EU in the future. This regulation gives the recyclers a massive opportunity as the lithium demand is forecasted to be 400000 tonnes by the year 2030 in Europe alone. If the 6%/12% requirements are calculated, just in Europe, the battery producers are looking to source at least 24000 tonnes by 2031, or 48000 tonnes by 2036. If we assume that the price of lithium ton would be around 40000€ it is averaging in 2023 (Statista, 2023), then the recycled lithium demand for the battery manufacturers would be

around €1-2 billion and this estimation is based on the 2030 demand which is close to the €25 billion estimates for the global lithium recycling industry. The only challenge with the current regulation is that it categorises the recycled lithium that can be used for this 6%/12% mandatory level as battery production scrap. Currently it looks like other secondary sources of recycled lithium are not accepted for the mandatory level requirements. Therefore, this portion of the battery material is going to be hard to obtain. Author has given the European Commission a suggestion on how to change the regulation to better utilize the projects that are currently being worked on in Europe. Author's recommendation is to allow all recycled lithium from secondary sources to be accepted and to make sure that no foreign companies are taking advantage of this regulation, for example a Chinese company selling black mass or recycled lithium. We could never be sure what is the source of this recycled material as there is no distinguishing chemical fingerprint of the source of lithium whether it is from a mine or recycled battery packs.

3.5 Lithium recycling technologies

There are different recycling methods for LIB, which can be used for other secondary raw lithium sources too. The three recycling methods are hydrometallurgy, pyrometallurgy and direct recycling. The most common processing method is the pyrometallurgy but there are relatively high number of companies who utilize hydrometallurgy side by side with pyrometallurgy processing method (Ali *et al.*, 2021a).

Hydrometallurgy process uses a reagent to filter various metals from the cathode of LIBs (Khan, 2021). This process is called leaching. Hydrometallurgical recycling utilizes water-based solvents to retrieve lithium from ores and concentrate and is often utilized in LIB recycling due to its relatively low cost and the benefit of not having to deal with toxic gases. Hydrometallurgy has high recovery rate of metals and good purity of the end-product, and it requires much less energy than for example pyrometallurgical process (Ali *et al.*, 2021a). Hydrometallurgical process does not create toxic fumes but instead it produces a lot of wastewaters that needs to be treated and although it is overall very efficient method to recover different recycled metals, it is only partially able to recover lithium and lacks the anode material recovery ability (Ali *et al.*, 2021a).

Pyrometallurgy process utilizes furnaces to create high temperatures, that reach 800-1000 degrees of Celsius. In common language the process is often referred to as smelting process. Metal scrap and concentrate is turned into an alloy of different metals (Atia *et al.*, 2019a). This 'black mass' of metallic alloys and slag is then put through hydrometallurgical process to separate the metals. Even though pyrometallurgy process is the most used in the industry, it is not able to recover lithium salts, that comprise 50% of the LIB wight and it also is not able to separate and recover plastics and other parts of the batteries. Pyrometallurgy is efficient in recovering cobalt, nickel and copper but is not efficient in recovering lithium. Pyrometallurgy also needs gas treatment due to the toxic emissions from the process and it is highly energy intensive process (Ali *et al.*, 2021a).

Direct recycling, as defined by its name means mechanical shredding of the LIBs and separating the materials. This process usually requires the LIBs to be discharged before scrapping. This process is the least efficient as it can destroy the usable lithium even before the next stages of recycling which are needed. Direct recycling does not offer advantages to the recycling process as it requires pyrometallurgy and hydrometallurgy processes after the primary shredding.

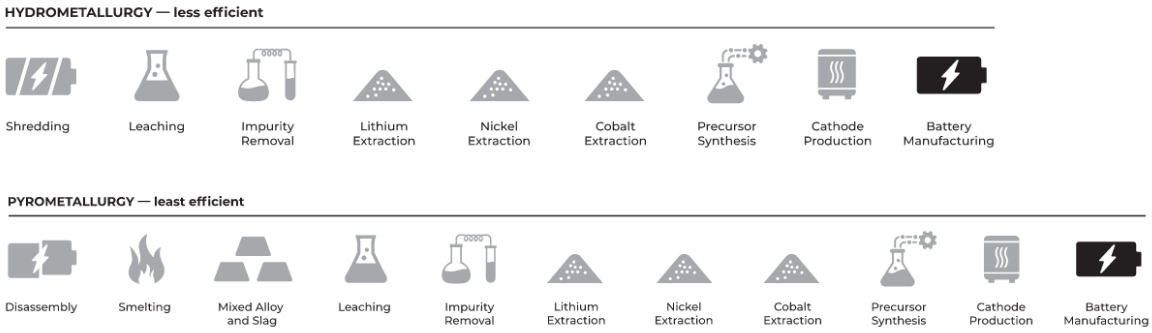

*Figure 7. Hydro and pyrometallurgy processes (*Ascend elements, 2023)

In the figure above we can see that pyrometallurgy process is an extension to the hydrometallurgical process and what it offers is slag from the smelting process which can be used to build roads and used for other applications.

Most of the companies studied for this thesis are working on improving these methods. Increased energy prices have hit industry and the pyrometallurgical process being very energy intensive and not the most environmentally safe, there is an incentive for the recycling companies to find other solutions. All of the new technologies claim to be more energy-efficient and environmentally friendly with a higher recovery rate.

There are several of these promising recycling processes, for example electrohydraulic fragmentation technology. In this process the LIBs are made into a form between liquid and solid and then fragmentation treatment breaks the materials only with a shockwave (Khan, 2021). This process claims to be very energy efficient and would lower the cost of recycled LIBs significantly. Another promising method by Tan and Li (Tan and Li, 2015), where valuable materials are extracted from waste through a mechanochemical process. By mechanically decreasing the particle sizes, increasing the surface area and breaking the bonds, the research claims that through extended milling time, nearly 100% of the lithium could reach the leaching process (Tan and Li, 2015).

Third promising process improvement is already in place and utilized by Ascend elements. By their patented hydro-to-cathode process they can skip the extraction of different metals (nickel, cobolt, lithium) and directly move to the synthesis of precursors for cathode production as shown in the figure 9.

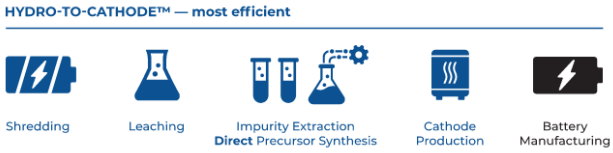

Figure 8. Ascend elements hydro-to-cathode process (Ascend elements, 2023)

As seen from the figure 9, Ascend element utilizes so far the most efficient method of recycling EOL batteries without the pyrometallurgical process which is not very efficient for lithium. And by extracting impurities from the hydrometallurgical process they can go straight to the cathode production without refinement of the recycled material.

4 Research method

This chapter explains the chosen research and data analysis methods.

4.1 Inductive qualitative view

This study is based on an inductive qualitative view. Inductive qualitative view means collecting and analysing data without preconceived categories, creating the flexibility that allows the data to guide the analysis to identify the themes and patterns (Aspers and Corte, 2019). I adopt Grounded theory, that is a research approach that involves the development of theories directly from the data collected during research (Glaser, 1978). This approach is often used in social sciences to explore novel and complex phenomenon and to generate new theories and concepts, as in this case (Charmaz, 2014).

The grounded theory approach typically involves collecting data through various methods such as interviews, observations, and document analysis. As data is collected, the researcher uses constant comparison to analyse and interpret the data, identifying patterns and themes that emerge from the data (Charmaz, 2014; Corbin and Strauss, 2008)

The iterative nature of the grounded theory approach allows for the development of theories and concepts that are grounded in the data, rather than relying on pre-existing theories or hypotheses (Charmaz, 2014). The resulting theory is then tested through further data collection and analysis, leading to the refinement and development of the theory (Charmaz, 2014).

In summary, grounded theory is a research methodology that involves the development of theories directly from data, through a process of constant comparison and iterative refinement. This approach can be particularly useful for exploring complex phenomena and generating new theories and concepts.

To codify the data, I have used the methodology proposed by (Gioia *et al.*, 2013). With the methodology introduced by Gioia, the prior information from the technologies and tensions are not given too much influence so that novel ideas are can be achieved from the interviews and secondary data sources. Data analysis is focusing on the main theories represented in this study, rather than previous theories and data analysis done by other researchers in their studies.

4.2 Qualitative data and inductive reasoning

This thesis proposes a mixed method approach to gather data with a qualitative research method which were used in form of semi-structured interviews, secondary data, and analysis of business models of the companies in LIB recycling. Then, I adopted inductive reasoning which starts with the observations and pattern recognition which are then used to identify and categorize the topics for the interviews. As for any good quality qualitative research, in this research multiple data sources are used but the core of the study will eventually focus is on the semi-structured interviews. In a mixed method research, qualitative data is used alongside with quantitative data to support the research objectives. This mixed method helps the researcher and the reader to make a more comprehensive understanding of the research questions and the findings.

Inductive research approach is a research method that starts with the collection of observations and data, and then uses this information to generate theories or hypotheses. This approach involves moving from specific observations to broader generalizations and theories (Corbin and Strauss, 2008; Gill *et al.*, 2008).

According to (Creswell 2014), inductive reasoning is a process of discovery, where the researcher "collects data, forms theories, and revises them based on the data." In this approach, the researcher does not start with a pre-existing theory or hypothesis but rather allows the theory to emerge from the data.

Inductive research is commonly used in qualitative research methods such as ethnography, grounded theory, and case study research. It can also be used in quantitative research, particularly in exploratory studies.

4.3 Data sources and data collection

4.3.1 Sampling strategies

In order to defend their findings, authors of qualitative studies must persuade the reader that the sample they used were adequate and sufficient. The author should at the very least describe the sample selection process, the number of participants or observations and the justification for that number, as well as the participant characteristics. If the author mentions data saturation, they must show proof of how they came to that conclusion (Gill *et al.*, 2008). To understand the challenges and opportunities of the industry and to have an extensive knowledge about the technologies and future implications of the field of study, extensive interviews were conducted. The goal of a qualitative research is to find experienced professionals who can share up-to-date knowledge about the subject (Gill et al., 2008).

There are numerous of different sampling strategies for selecting the interviewees for the research. It is important to identify participants who can provide information regarding the research questions or give perspective of the phenomena. Most commonly used strategies are: convenience, snowball, purposive and theoretical sampling (Isaac, 2023). Convenience sampling provides the easiest access to the interviewees but often do not supply the best information as the strategy is based on volunteering rather than a targeted sampling. Snowball strategy is where current interviewees recommend other people with relevant information regarding the topic and is one of the most useful strategies as it also opens the dialogue with the possible interview able person (Isaac, 2023). Although very efficient, the strategy also has some problems as the quality of the referred persons may vary as it is subjective to the perspective of the referrer. Purposive strategy means that the interviewer purposedly chooses the persons to be interviewed through their own contacts or networks whom they know are knowledgeable about the topic. It is hard though, to find the knowledgeable people if the networks are not broad enough to include such people. It is a common practice to utilize more than one sampling strategies (Gill *et al.*, 2008). Sample size in this study is relatively small but as we will discuss the research methods further, it is explained that in this case it was a particularly difficult task to obtain useful data from certain sources.

In this study convenience and snowball strategies were utilized. As the project aims to deliver a business model that most companies working in the industry might see as a competitor, it was hard to obtain interviews from the industry leaders. Also, the recycling of secondary raw materials from other than end-of-life batteries is not very researched or utilized field, so it became clear that interviewing academics in the field of lithium recycling and future technologies was the smartest and most efficient way to go. Industry leading companies are not willing to share useful information as the industry is changing so fast and new technologies are being developed at a rapid pace.

The interviews started at the beginning of the year 2023 and continued throughout the year and this came with a realization of how fast the industry changes. If possible, the interviews would have been better to be redone after a 6-to-8-month period to go through the answers and what has changed since the initial interview. Before the interview, some meetings were held with couple of other participants of the RELiEF project to gather more information about the progress of the project and what questions have arisen from the other work packages. It is important to first gather the knowledge about the key players and key questions regarding the topic to be able to make the interviews as fruitful as possible.

4.3.2 Interview protocol

The interviews were held in English as it was seen as the most efficient method and most of the interviewees were not native Finnish speakers either. The interviews were conducted in Microsoft Teams and recorded with approval of the interviewees. One of the interviewees chose to answer the questions in a written form through an email. The interviews were then transcribed by the author by meticulously going through the interview's multiple times and at the same time memorizing the recordings for future references. The interviews lasted 40 minutes to up to 2 hours. The transcriptions were then transferred to NVivo to be coded and processed as there was so large amount of data to go through. The expert interviews were the most useful as the research was on tensions affecting the industry. The interviewees were kept anonymous during the analysis of the results to comply with GDPR standards and to promote good faith between the interviewees and the interviewer.

The experts are some of the leading researchers in the field of battery technologies and battery recycling innovations from Aalto University, LUT University, KTH Royal institute

of technology and the University of Padova. The industry actors represent most parts of the value chain from mining industry to battery cell manufacturing and recycling of EOL batteries. The questions were modified slightly to accommodate the interviewees expertise and to avoid questions that are not likely to be answered by the interviewee.

Table 5. List of interviewees

Interviewee	Category	Length	Strategy
A	Expert	75 min	Purposive
B	Expert	69 min	Purposive
C	Expert	88 min	Snowball
D	Expert	85 min	Snowball
E	Industry	84 min	Convenience
F	Industry	120 min	Convenience
G	Industry	58 min	Convenience
H	Industry	30 min	Snowball
I	Expert	85 min	Snowball
J	Expert	69 min	Snowball
K	Industry	Written	Snowball

4.4 Data analysis

The objective of this study is to find out the tensions and paradoxes on the development of LIB recycling industries. The analysis also found opportunities and challenges of a business model for secondary raw material sources of lithium to be used in electric vehicles and other applications. It is important to identify the key actors in the recycling industry to understand the existing business models and recycling processes. There is not a single company in the world that has come forward with a plan to utilize lesser-known secondary raw material sources, meaning anything other than end-of-life batteries from used electric vehicles. That is the reason why it has been very hard to identify existing companies so rather than focusing on the companies, I chose to identify the key academics and NGO's who are more willing to discuss the topics that are almost treated as trade secrets by the large multinational lithium recycling companies.

In this study, it was recognized that there are 4 different dimensions that create tensions among the lithium recycling business in Europe. The dimensions are Cooperation, profitability, technology, and regulations.

The interview data was analyzed by utilizing codification of the transcriptions. I utilized the (Gioia *et al.,* 2013)method utilizing grounded theory to simultaneously use inductive and deductive process of data. The theoretical background from circular economy and paradoxical tensions were taken into account during the coding process. There was not enough prior literature on the tensions revolving around lithium recycling and the tensions to create comprehensive hypotheses, but the prior theories worked as guidance throughout the codification process.

The interviews were done through Microsoft teams and there is an option to make an automated transcription from the interview, but the automated transcription was of a very bad quality therefore I had to carefully go through all the interview recordings and make corrections to the transcriptions. This helped me to gain a very good understanding of the interview recordings and helped me to start codifying the topics that were coming up repeatedly. The number of first-order categories was very significant in the beginning, but I went through the first-order categories three times and every time reduced the amount and finally there were only 100 first-order categories. The second-order categories were then formed from these categories based on the 4 dimensions of tensions, which were the backbone of the whole study. The figure 11 below shows the different themes and layers of the data to help visualize the topics better.

Figure 9. Data structure of the study

4.5 Reliability of the research

The study is always only as reliable as the methods used by the researcher. All measures to minimize hindering the research results and to make the research duplicable have been made. To avoid the mistakes in sampling strategies for the interviewees, discussion with the supervisor was conducted and the interviews were selected carefully, and snowball strategy was utilized with sufficient screening of the suggested interviewees. Many comments related to the EU regulations, IRA or the battery act were double checked from the official sources to make sure that there is mutual understanding of the current changes in the rapidly evolving lithium recycling industry. In research where the information is changing rapidly as new technologies were coming up during the thesis writing process almost monthly, it has to be

taken into account that some of the information coming from the experts can be and is speculative in nature.

The research data, interviews and transcriptions have been stored to LUT cloud provider and are only accessible by SCI-MAT researchers.

5 Findings

This chapter discusses the findings of the empirical research, and it has 5 sub-chapters. First one covers the technological and innovation mismatch between the current needs lithium recycling industry considering the tensions arising from barriers and challenges, purity and quality of the recycled material and logistical tensions. The second sub-chapter discusses the organizational and management mismatch with the current industry needs considering the sustainability versus profitability tension and policies that create uneven playing ground for companies and competitive landscape. The third sub-chapter will discuss the empirical findings of the disconnect of the regulatory bodies and the lithium recycling industry needs though combining the interviewees views on the different economic bloc's regulatory advancements in the field of batteries and the recycling of lithium.

The fourth and fifth subchapter present the comparative analysis between LIB battery recycling business models. In the fourth sub-chapter discussion is moving towards the existing business models in the lithium recycling industry with comparison with the interviewees comments and the comparative analysis of companies operating in the industry. The fifth sub-chapter will discuss the viability of these business models through identifying the and challenges and opportunities. The last sub-chapter will then cover the issues of secondary raw material sources of lithium to be used for electronic vehicles.

To be able to build a financially viable business model for lithium recycling from secondary raw material sources, companies need to first understand the challenges and the factors behind the tensions arising from, in some cases even paradoxical mismatches between the needs of the industry and the current situation.

5.1 Technology and innovation mismatch with the current needs of the supply of the LIB recycling industry

In this sub-chapter the most mentioned technological tensions are discussed. This sub-chapter is also the opener for the discussion and helps the readers to understand the current tensions in the recycling industry to better understand the next sub-chapters. There needs to be a clear distinction between paradoxical tensions and tensions as paradoxical tensions are impossible to be solved due to the nature of the paradoxicality. In this thesis the focus is on the tensions that emerge from outside and inside the lithium recycling industry, that can be solved or worked around.

5.1.1 Tensions arising from barriers and challenges from technological demands of the industry

In the data we can find different types of tensions:

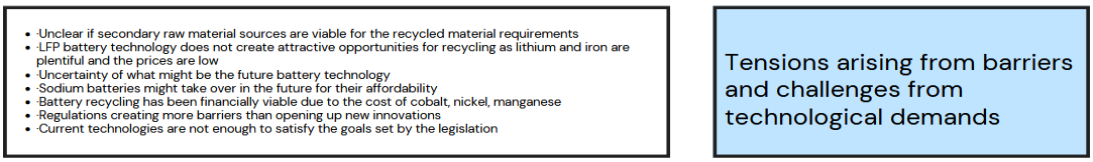

Figure 10. Data structure for second order theme

The first tension arises between the profitability of the recycling industry with the current recycling processes. There is unclarity if secondary raw material sources are viable for recycled material requirements, the tension between demand with the supply, Current technologies are not enough to satisfy the goals set by the legislation, for example the goal to de-carbonize the automotive industry, . In most of the interviews the interviewees raised up the topic of the technological demands needed to be satisfied to make the industry better and more profitable. Lithium itself has seen a massive drop in the price and battery pack recycling has been profitable due to the batteries high content of cobalt and manganese. The new battery technologies utilizing lithium iron phosphate composition do not possess the same amount of value as the older MNC battery technologies for example. Lithium is the only valuable mineral in the composition as iron and phosphate are plentiful in the industry and the prices reflect to that.

"Well, at the moment I would say that companies are making no value because they are not recycling lithium. In my understanding the main reason is that the price of virgin materials has been low enough that it has not been a business to recycle lithium. Maybe now that we are in a changing situation and lithium metal prices increasing, so the even smaller amounts of lithium might start to be feasible to be recycled, but so far, the quantities have been so small that the and the lithium price so low that it has not been a business to recycle lithium"
(Interviewee A)

Therefore, there is a tension between the profitability of the recycling industry with the current recycling processes. Lithium price has seen a drastic drop in its price in the past couple of years, from October 2022 to October 2023, the price has dropped to 25% of the highest price. Pyrometallurgical recycling process is not as suitable for lithium as it is for cobalt, manganese and other rare elements in battery packs and hydrometallurgical processes are not utilized yet by most recyclers. There have been some companies such as Li-Cycle that has utilized hydrometallurgical process where there is no need for dismantling that has been one of the main costs, but with the current lithium prices, recycling of lithium from battery packs and other scrap is not yet financially feasible in smaller scale, at least.

"In a pyrometallurgical process, where you essentially burn the battery to remove the plastics and what not, is less sustainable because those processes typically only recover up to 50% or less of Li. So, huge amount of lithium is actually lost in pyrometallurgical processes. So, that is the starting point."
(Interviewee H)

One other main raised tension was the unclarity if secondary raw material sources are viable for recycled material requirements at all.

Final tension is that current technologies are not enough to satisfy the goals set by the legislation, for example the goal to de-carbonize the automotive industry.

The technology that will prevail in the future also is detrimental to understanding where and how the governments and economic blocs are investing the funds to research and innovate.

Many of the interviewees were saying that with the current projections of lithium production and battery manufacturing, there is no realistic way to match the demand with the supply. The goals are set way too strict for the European Union for 2035 to ban the sales of new combustion engine cars. As of now, there are also 9 states in the USA that have decided to set the similar target as the EU. This will of course increase the price of lithium in the short

term, but the investments take time to flourish. We are living in a very uncertain era when it comes to the future of mobility as people are not seeing the real reason behind the need to change the norms.

5.1.2 Purity and quality versus profitability

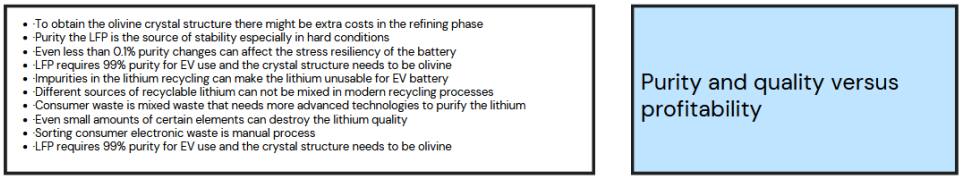

Figure 11. Data structure for second order theme

There are very strict purity requirements for the lithium in the batteries as even a slight impurity can decrease the recharge cycles or efficiency of the battery especially in the colder environments. LFP has an olivine crystal structure, and the profitability problems arise from the demands of the purity as different sources of lithium scrap do not have the same structure and as mentioned above, even a slight impurity can affect the battery performance drastically. For profitable recycling process of secondary raw materials, there would need to be a process where all different sources of materials could be recycled simultaneously but this is not the case with the current technologies. All the different sources of lithium from secondary raw material sources need to be recycled separately. Even small amounts of certain elements in the recycled material can be harmful for the recycling process or even destroy the output of the whole process. For example, fluoride-ion batteries from the earlier era of the lithium batteries are not easily recycled and cannot be placed together in the same processes as other sources of lithium scrap.

> *"Purity is a source of stability over time, and impurity is a source of failing, especially in hard conditions." (Interviewee I)*

> *"I think that you need to recycle together only the same kind of batteries, and this is a big problem because every company, has its own recipe and sometimes there is little addition, one percentage, two percentage of this or that. And I think that this is a source of problems or issues about recycling and secondhand materials, not the dominant material, but all these additives that every company adds." (Interviewee I)*

To get high quality, battery grade lithium from recycled material, it is very important to understand the demands of the EV battery industry. Some industries such as CAS glass producers manufacturing glass cooktops do not require such a specific olivine structure and therefore are competing for poorer quality lithium.

5.1.3 Logistics tensions arising from sustainability targets

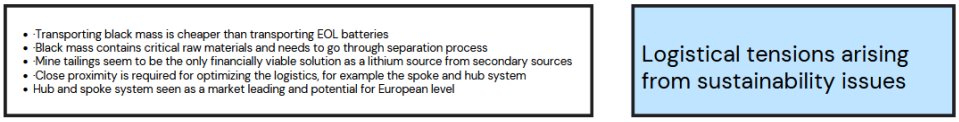

Figure 12. Data structure for second order theme

The first tension is connected to the location for the new factories. In the interviews it became clear that location is very important for recycling business. Unnecessary logistical costs and emissions are creating tensions since, based on the interviews, there is not enough material to recycle, especially locally.

A second main tension is where to set up the hub and spoke as logistics solutions. In the EU level, some distances between the source of the recyclable material and the recycler can be even a couple of thousands of kilometres.

European Union is 4 233 000 square kilometres, about half of the size of the USA. Recycling and air transportation industries have a thing in common, both could rely on hubs that are fed by the spokes, because it is not financially feasible to have the largest plane models flying from every airport. It is better to have smaller planes to transport people first to the main hubs that are connected to other main hubs around the world and only use the largest plane types between the hubs, where there are enough passengers to fill the planes and make the flights financially feasible. Close proximity is required in order to make recycling profitable.

> *"For a logistic provider, It's the same as for the rest of the value chain, for us to have enough material we need to make sure there is manufacturing and demand in the given geography. "(Interviewee H)*

> *"You do not want to be transporting huge batteries between Finland and Hungary for example, which many pyrometallurgical companies are relying on. That is a huge distance, very costly and hazardous and of course contributes to the carbon footprint." (Interviewee H)*

5.2 Organizational and management mismatch with the current needs of the competitiveness of the LIB recycling industry

5.2.1 Competition tensions arising from Chinese companies influence

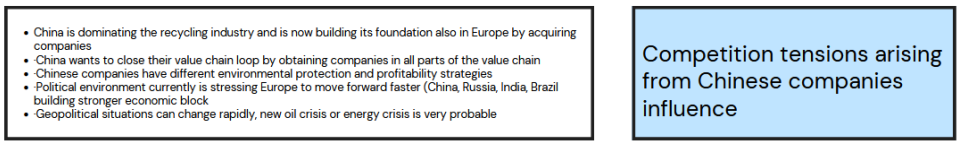

Figure 13. Data structure for second order theme

Chinese companies can be seen as saviours or disruptors of the raw material recycling industry in Europe. Geopolitical situations are changing rapidly as we have seen and while Chinese companies are bringing in large investments, the political stability in Europe and dependency on foreign raw materials will not change unless the European companies are taking over their industry. Chinese companies have specialized in the recycling of lithium and often, European companies have been sending their black mass or battery scrap to China to be recycled over there. Cooperation with Chinese companies is seen almost as a necessary step for European companies to obtain investments and technological knowledge. Specialization is one way to make a market entry as companies in the target market are in need of the technology and knowledge. This knowledge is being spread into EU by joint ventures with Chinese companies and European companies. If EU wants to compete in the recycling industry, we need to make sure that we have all the parts of the value chain taken into account, otherwise the missing part of the value chain will be lost to foreign companies taking advantage of the business opportunity.

> *"I think the second big thing we need to think about is that we need to make sure that these batteries that are manufactured and used in Europe need to be recycled here in Europe. Often times what can happen is that second life of battery is in East Europe and the third life somewhere in Africa and then they eventually get dumped somewhere in landfills" (Interviewee H)*

Numerous of lithium battery gigafactory projects face delays even though announcement by Chinese battery recycler CATL of their second gigafactory on European continent was released. It has been claimed that 70% of the planned gigafactories face delays now (Energy storage news, 2022), due to multiple reasons but competition and the decreasing price of lithium carbonate equivalents has been the main reasons. This will only make European

lithium recycling industry more careful and probably lead into less investments in the near future until clearer future estimations come along.

5.2.2 Sustainability goals versus profitable business

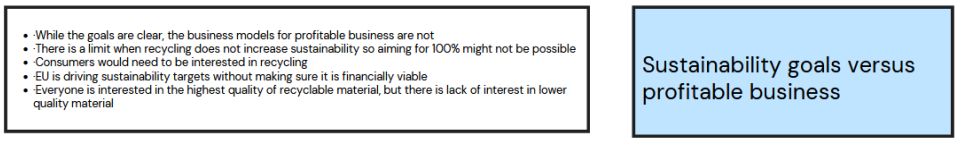

Figure 14. Data structure for second order theme

The second set of tensions emerged based on the conflicts between sustainability versus profitability. It became obvious during the interviews that profitability is the main contributor to the tensions arising from recycling when it clashes with the other dimensions. Sustainability and profitability are very important but also the toughest dimensions to match. Sustainability can not be done half-heartedly, meaning that some operations and processes would be done in a sustainable way and if it comes too costly, sustainability in other processes would not be considered. As the transportation fleet electrifies as EV industry advances, the sustainability factors will get better simultaneously but without these technological advancements, the sustainability factors will be the main hinders of the profitability of the industry. Each process, let it be hydrometallurgy or pyrometallurgy, utilizes energy, but so does the mining industry. As long as mining for pristine raw materials is relatively more efficient, the recycling industry will need to advance technologically to match and to overcome the profitability issues compared to mining.

> *"Mining is an extremely resource-intensive process, mining of lithium is extremely carbon intensive, water-intensive, has significant community impacts, environmental impacts. So, a process that is able to maximize the recovery of these metals, has to be considered the most sustainable. And here, hydrometallurgical processes are extremely valuable (Interviewee H)*

5.3 Mismatch between the actual developments of the industry versus the ideal sustainable and circular business models

5.3.1 Cooperation-collaboration tensions between recycling industry actors

Figure 15. Data structure for second order theme

These set of tension emerge between actors in the LIB recycling industry that are competing and collaborating. There were multiple of tensions raised by the interviewed industry actors and the author also joined a seminar discussing the cooperation tensions between different actors in the industry. In the seminar, industry actors could vote on what is the main problem in the industry and there were some comments regarding funding but most of the votes were pointing at the competition being the main reason for hindering innovations and wasting resources. Cooperation seems to only happen when there are no overlapping interests. Vertical cooperation happens with the companies when they are working together with upstream or downstream actors in the different parts of the value chain. Horizontal cooperation seems to be very limited, there are though, joint-ventures and strategic alliances in the industry but most companies keep their business to themselves.

Protectionism in different economic bloc is creating the tensions between companies who would likely to work together if the protectionism laws would not be affecting their business. For example, the new legislations in the Europe and in the USA drive towards protectionism. In the USA the legislation is forcing companies to choose the geographical location based on the markets as new EV batteries need to be manufactured from material mined or recycled in the USA. European Union is seemingly also moving towards similar regulations that would hinder companies from outside of EU to do business with manufacturers inside Europe. It is critical to understand where and how companies could source the lithium and therefore critical to look further than their closest suppliers. Like in the case of aircraft manufacturers:

5.3.2 Policies contradicting with industry practices

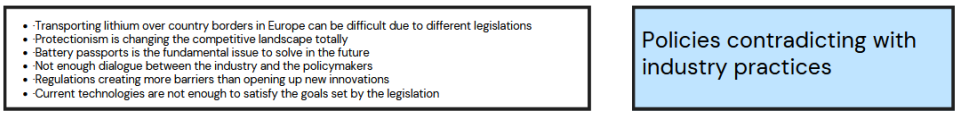

Figure 16. Data structure for second order theme

These set of tensions in the competitive sphere emerge dure to the conflict between policies and industry practices: lack of dialogue between policymakers and industry actors,

Most of the interviewees raised the issue of new EU legislations and battery act. The main issues seem to be that there isnot enough dialogue between the policymakers and the industry actors. Current technologies and lithium supplies are not enough to satisfy the need of what the 2035 de-carbonization of mobility in Europe would require.

Meanwhile, European Union is pushing for legislation that would make certain lithium salts hazardous and many interviewees saw that as a massive challenge not just due to the increasing logistical costs but intra-European transportation of the materials as country borders are crossed and the demands for the logistics would be very strict, if the legislation passes as it is suggested.

Some interviewees see the suggested battery passports to be the game changer in the industry but at the same time they are doubting on how it can be controlled and how the battery passport can be made transparent and trustworthy. As lithium being a metal, can be smelted back to the original chemical composition regardless of where it has been mined for example.

5.4 The disconnect between regulatory bodies and the current needs of the of the industry

In this chapter the main focus is on the interviewees comments on the how the regulatory bodies and the current needs of the lithium recycling industry are not matching and that is creating a tension between the strategic goals of different stakeholders. European lawmakers

have been very active in 2022 and 2023 as the decarbonization targets and the climate neutrality goals are fast approaching.

5.4.1 New EU regulations changing the rules of the game

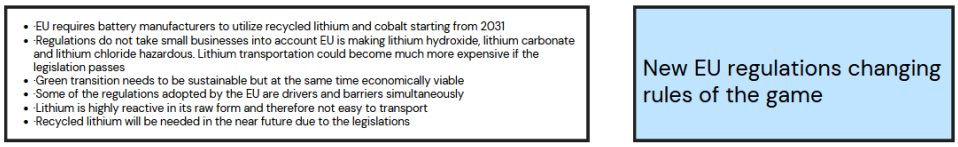

Figure 17. Data structure for second order theme

In the latest interviews, the new EU battery legislation had been published and the industry is now seeing some changes that are pushing the legislation towards the right path. EU will require battery manufacturers to utilize recycled lithium and cobalt starting from the year 2031, but it is yet unclear, if the recycled lithium share could be bought from outside Europe. This is a move to the right direction since it allows companies to invest money with higher security that their investments will not be in vain. One of the concerns though, is that the new legislations do not take smaller businesses into account and are more supportive towards companies which operate in all different parts of the value chain. For example, a battery manufacturer is much more likely to obtain the battery scrap through contracts made with the downstream companies and users of their batteries, therefore closing the loop but at the same time making the competition really hard for the same material that is needed by the other recycling companies. Such a situation will lead into very large companies dominating the whole market and eventually running the smaller businesses out of business. Therefore, the green transition, while needed to be sustainable, can create barriers for some companies and loss of EU jobs.

5.4.2 USA –IRA targets affecting EU regulations and investments

Figure 18. Data structure for second order theme

EU has been updating its regulations to close the lithium value chain to make the closed loop system more sustainable, but as the interviewees have remarked, the companies have had hard time to stay up-to-date with the regulations due to lack of communication between the regulatory bodies and the companies. It is seen as a very positive that companies are soon required to recycle even higher percentages of their lithium but many companies are at the same time facing the financial struggles due to high investments needed to match the demands from EU and the competition coming from the USA due to their own regulatory advancements. Many actors in the industry still see the effects of the USA IRA-act as a main influencer for the European regulatory counters, but the changes are so rapid and the demands so high that it is hard for the companies to be able to obey the new requirements. EU battery act and the regulations were expected to make it viable for foreign companies to move to Europe, which they have done through acquisitions and joint ventures but in reality we have seen many companies moving to USA due to their regulations. The regulations are required to bring clear incentives and goals for the companies working in EU. Even though it on paper looks like Europe is growing it's independency of critical raw materials, actually Europe is still vulnerable for geopolitical turmoil.

> *"The regulations need to set high incentives for transparency, disclosure and traceability of the materials. Battery regulations and critical raw materials act as well, which sets clear intentions for the domestic recycling of EV batteries and the recovery of lithium, cobalt and nickel among other critical minerals."*
> *(Interviewee H)*

> *"Europe is not really generous for the industry as the U.S is with their new inflation reduction act. Even though if there are subsidies, the problem in Europe is the energy cost, they can't compete with the with USA right now."*
> *(Interviewee D)*

5.4.3 The competitive landscape of EU companies arising from regulatory uncertainties

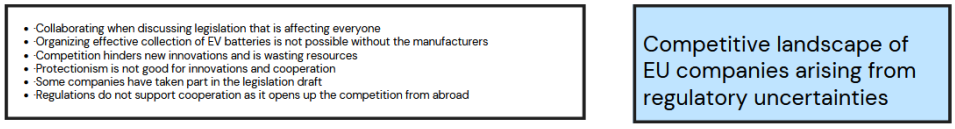

Figure 19. Data structure for second order theme

The interviewees said that the regulatory uncertainties in Europe are pushing major companies to rethink their global strategies and especially Europe's role in it. There is some cooperation between European and for example Chinese companies when the collaboration is related to discussing legislation that is affecting everyone equally. Many industries and companies will be competing for the same raw materials and it is no different when it comes to pristine, virgin raw material and secondary raw material sources, through recycling. China is currently dominating the lithium recycling industry and is rapidly building its foundation also in Europe by acquiring companies and closing the value chain loop. As far as the interviewees were aware, Chinese companies have much more relaxed environmental protection and profitability strategies implemented, compared to the European counterparts. Many interviewees raised the concern that organizing effective collection of EV batteries is not possible without the manufacturers and they will most likely organize their own collection process through joint-ventures or by themselves.

5.5 Implication of the tensions for circular business models in the lithium recycling industry

5.5.1 Profitability as the main tension creating dimension

Based on this study, it became clear that most of the tensions are related to the profitability dimension and how profitability does not overlap with other dimensions. Profitability is conflicting with technological, cooperative and regulatory dimensions due to the fact that in the end, without profitability, there is no business. There are clearly 4 dimensions that are especially relevant, regulations, collaboration and cooperation, profitability and lastly, technology. These dimensions provide the explanation of the main tension creators in the industry. These dimensions work on three different levels of which each one is different in scale and on how difficult it is to find solutions for the tensions between the dimensions. Organizational level is the lowest level followed by the regional level, leading to the systemic level that is the hardest one to have effect in.

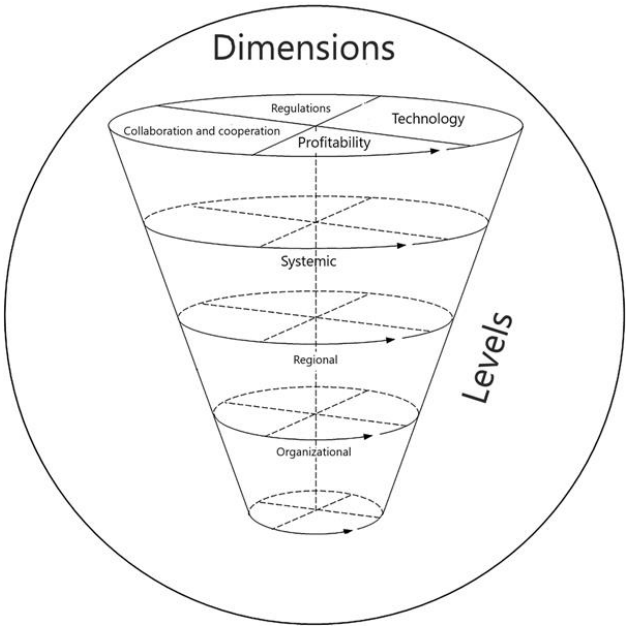

Figure 20. Dimensions and different levels of tensions illustrated by author based on (Zehendner et al., 2021)

In this study, the main focus was on the 4 different dimensions, but it is necessary to understand that there are different levels where these dimensions are conflicting. The dimensions are the same on every level but how they contradict with each other is different. For example, on the organizational level the conflicts can be solved by legislative measures or by investments targeted to minimize the conflicts. This could be done by government fund that would offset the negative effects of the conflicts. In systemic level, there are no such measures as the geopolitical situations and the competitive landscape of the lithium industry would not be affected by these compensations, in a global level.

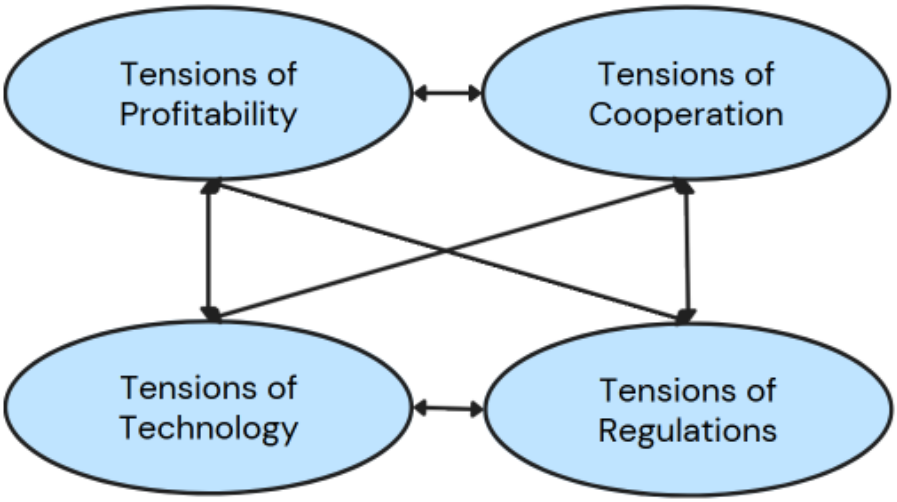

Figure 21. Main tensions interaction with each other by author

Profitability – Cooperation

There are many tensions between profitability and cooperation as mentioned earlier, cooperation happens mostly on vertically and through joint ventures where both companies are hoping to increase their profitability. The margins in the recycling business of lithium have been cut down due to the price of lithium dropping dramatically.

Profitability – Technology

Profitability is tightly linked to the technological advancements and innovations, which create more profitable processes. Technological advancements though, can have negative impact on profitability of older technologies which creates a tensions that is related to the investments and expected returns of those investments. It is a paradoxical situation as new innovations are needed but at the same time new innovations might deem the older technologies useless. For example, new battery technologies are being innovated and the industry is changing rapidly.

Profitability – Regulations

Regulations are meant to improve the attractiveness of the industry by creating opportunities but at the same time some regulations are creating barriers and challenges for the companies. As mentioned earlier, the legislator bodies have been creating more and more protectionist regulations to help their own economic bloc become independent from other countries or economic blocs.

5.5.2 Key challenges

The data structure presented the challenges and the aggregate themes and their subsequent themes. Data structure is presented in a confined figure here to present a clearer image to illustrate the data arising from the interviews.

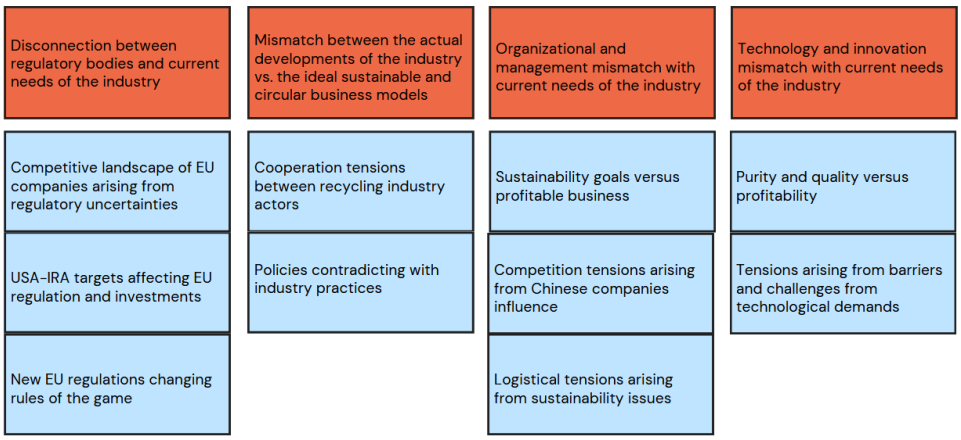

Figure 22. Main data structure components, aggregate themes and second order themes author

The challenges can be divided into technical, economic, environmental and market demand challenges.

Technical challenges

There are multiple of technical challenges in recovering lithium from mine tailings such as low concentrations of lithium in the tailings, limited supply of sources of the tailings and co-occurrences with other elements.

Economic challenges

Economic challenges are quite straightforward as the costs and the price of the lithium need to be working together. As the price of lithium has crashed recently, the costs have become more important factor for the recyclers.

Environmental challenges

There are many environmental factors that affect the viability of the use of tailings for lithium sourcing. There are always environmental issues arising from any project that uses

material from earth as it needs to be processed with chemicals and toxic materials. Also, the toxicity of lithium salt itself, can be harmful to human health.

Supply chain, lack of partners and low availability of materials, high dependency on external partners, low virgin material prices, lack of consumer interest in CBM, resistance from supporters of linear business models

Market

Lack of financial resources, high up-front investment costs, higher cost, unclear future, lack of technical know-how and expertise,

Key challenges identified during the interviews summarized in table 11.

Table 6. Challenge categories and descriptions with possible solutions

Challenge category	Challenge description	Possible solution
Missing actors in the value chain	Profitability issues have created a vacuum in some parts of the value chain	Incentives needed to provide viability to these processes
Investments uncertainties	Without knowing what the legislative changes are coming, companies are not willing to invest money in expensive plants	Clear 10-15-20 year plans need to be put in place in Europe to help the companies to make plans for the future
Scarcity of recyclable material	Lithium from secondary sources are inferior to any other primary method of producing lithium, with very low quantities	There is no easy solution here until the primary material prices grow over the limit to make these sources financially viable
Logistical and technological challenges	Hazardous metals, long distances to the recycling plant and large amount of unusable material is needed to be transported which creates the financial viability problems	As mentioned before, spoke-hub system could also work in Europe to release the logistical tensions

5.6 Existing business models for Lithium from secondary sources

In this sub-chapter I will present analysis of 14 companies that are some of the most relevant companies working in the EV battery industry, either in the recycling industry or working

throughout the value chain. Before a business model is considered, it is important to understand what the competitors are doing. These companies have created different solutions for tackling the EV battery material scarcity. These companies in this analysis were selected from a larger set of companies that were selected based on the market shares, global presence and geographical distribution. All of these companies are the some of the leading in the industry in their home markets and abroad. It is important to have a broader perspective of the industry before doing an analysis of selected few companies. Secondary data was sourced from company websites, articles and financial listings of the companies in the industry.

Table 7. Comparative table of key industry actors in lithium recycling categorized based on the value chain, author

Company	Primary source	Raw materials refining	Cell component	Battery data	Sustainability and recycling
Sungeel					
GEM					
DOWA					
Duesenfeld					
Umicore					
Accurec					
Nickelhutte					
Cirba solutions					
Ganfeng					
Li-cycle					
Ascend elements					
CATL					
Rio Tinto					
Eti Maden					

As discussed earlier, the secondary sources, if excluding the EOL batteries, do not contain high amounts of lithium. Business model innovation for lithium recycling from secondary raw material sources should start with discussing the logistics. Business models can be philanthropic or aimed for profitability, but regardless, a viable business model must make money, otherwise there will not be a long journey ahead. Logistics and decentralised

production/processing plants is the key to make the business model work. Although I have introduced some companies which utilize EOL battery pick-ups and other services to make it easy for consumers to get their e-waste sorted, these models do not work with waste that has low concentration of the precious metals. EOL batteries such as Tesla's LFP battery pack has 10-15% concentration of lithium and e-waste from secondary raw materials could have as low as 0.01% concentration. This means that to get the 10% concentration Tesla battery pack has, we would need 1000 times the weight of a tesla battery pack to theoretically obtain the same amount of lithium. Tesla battery pack is about 500kg, so we would need 500 tonnes of waste to get the same amount of lithium.

One of the main technological barriers to the cost-effective recovery of vital minerals is the low concentration of essential minerals in mine tailings and other secondary sources. This is primarily due to the fact that current methods are made for primary ores, which often have greater grades than mine tailings.

One solution could be a mobile pre-processing plant if the available technology allows it. This process would be a phase in the recycling where the e-waste is going through a primary selection process where the concentration of target minerals is increased. The model in table 15is based on the spoke-and-hub concept which is currently used by Li-cycle company in the U.S.

Table 8. author's own contribution on the existing business models

Proposal	Novel benefit	Process
Pre-processing at the customer location	Increase the lithium content of the waste	Mobile pre-processing unit
Localized secondary processing plants	Increase the lithium content of the waste	Localized processing plants, per country, region, city depending on the calculations and supply
Optimized logistics	Increase the profitability of the business model	Consolidation of pick-ups to optimize the logistics and easiness to follow the hazmat regulations with specialized logistics chain

Centralized processing plant to make battery grade lithium salts	Efficiency, environmental issues are taken into account	One location helps with human resource issues of finding the required professionals and also helps with funding and co-operation with different stakeholders

There are multiple of different technologies for lithium extraction that do not include the primary mining sources. One of the most promising opportunities is the unused waste rocks from tens of years of mining, for example waste from boron mining. The only downside to this process is that once the mining waste has been depleted, there will not be enough to supply the processing plant as the technology has improved to the level that there is not that much waste in today's process.

Rio tinto and Eti Maden source their battery-grade lithium in the US from nearly a century's worth of mining waste rock at their Boron operations in California (Rio Tinto, 2023)

Their process involves roasting and leaching waste rock to recover lithium. Since it involves separating lithium from waste rock that has already been mined, this breakthrough process is a more sustainable alternative to other sources of lithium supply.

Rio tinto's demonstration plant in California has a design capacity of 10 tonnes per year of battery grade lithium. Priorities in 2021 include optimising the process to inform their feasibility assessment for progressing to a commercial scale plant. This plant would have an initial capacity of at least 5,000 tonnes per year of lithium, or enough to make batteries for approximately 70,000 electric vehicles. Eti Maden opened their lithium carbonate production plant in December 2020 and is expected to be able to provide 50% of the lithium need of Turkey (Rio Tinto, 2023). They produce battery grade lithium carbonate that meets the strict quality assurance standards required by the electric vehicle industry.

5.7 Tensions that are likely paradoxical

Some tensions are paradoxical by nature and some paradoxes are so contradictory that they cannot be solved even while we understand the background and the reason of the tensions. Based on the research in this thesis the most important paradoxes are between profitability and sustainability (SDG, Paris Agreement goals), the global competition between EU and China and USA, and the lack of recycling of lithium in Europe. It is important to understand the difference between tensions and paradoxes, because if we are putting efforts, money or otherwise, in solving paradoxes, we are not only wasting our resources but delaying the industry growth and competition with other economic blocs. Paradoxical tensions are tensions that can not be solved by regulatory, technological, or cooperative actions.

Competition between USA, China, and Europe for the same resources is a very important tensions affecting the industry globally. And seemingly, it does not matter how far technological, regulatory, and sustainability advancements can go in the future, the tension will most likely stay paradoxical as all the economical areas are struggling to obtain enough material to recycle while the regulations are becoming more and more protectionist. Cooperation that is happening currently between these global strongholds shows that also on that front, there is seemingly no easy solution even though all actors are aiming for similar goals.

Lack of recyclable material and infrastructure for sustainable and profitable lithium recycling in Europe is another tension that is most likely already paradoxical. Even with increased investments and technological advancements it is likely that there will be a lack of recyclable material for everyone as most of the companies will close their value chain loops by taking care of their own EOL batteries. In EU level the best option would be to create a special economic zone where the companies working with the lithium industry would be focused and the cooperation would be highly promoted.

Profitability and sustainability tensions would need to be closely observed and worked with as these tensions can easily become paradoxical due to the regulations focusing too much on the sustainability and not on how to make the sustainability actions lucrative option in terms of profitability. For years, sustainability has been promoted almost as a marketing strategy for large companies. There is no easy solution for these tensions either, that is why it is very

likely that these tensions will become paradoxical. Profitability in the end, is the main driving force of any company that wants to survive in the very competitive landscape of lithium recycling industry.

6 Discussion

In this section, the author will discuss the main contributions of the study and the findings relation to the literature on the topic. It is challenging to evaluate the findings as the relationship of circular economy and tensions in the lithium recycling industry is not yet well studied. In practicality, these tensions are discussed and managed daily in any given industry, but the academic side of it has been missing. This study is also one of the first ones trying to create a comprehensive understanding of the tensions affecting a specific industry.

6.1 Discussion about the Main Challenges and Paradoxes on the Growing of LIB Recycling Industry in Europe

The main paradox is competitiveness vs. sustainability and SDG and Paris Agreement goals. EV battery industry will only grow in its attractiveness and popularity as more and more consumers are becoming tired of the current prices of battery packs and the life-expectancy of their electric vehicle depending on the lifetime of the battery. Safeness of the electric vehicle battery packs is one of the main factors that influence the public image of the electric vehicles. In the beginning of the electrification of cars, one of the main problems was and has been the uncontrollable fires that might occur in the battery packs but with the recent changes and the future plans for the battery compositions are going to diminish these problems and create much better public image for the electric vehicle industry.

The toughest challenge or paradox that EU faces is the lack of lithium from secondary sources excluding the EOL batteries. As this research has pointed out, the lack of available secondary raw material is going to be a big challenge as China and other regions will fight to source the EOL batteries and other streams of secondary raw materials to recycle. LAS from the glass industry will be a big source of lithium but to organize a circular business

model where the glass cook tops for example are collected, is very far from being organized with financial viability. As the lithium required for the LAS glass is of much lower quality than the battery quality, there is no need to refine the material and therefore the market is very different from the battery quality recycled lithium market.

A growing tension that might become a paradox is how to sustain EU-based investments in the next years. To be able to meet the 2050 goals of carbon neutrality or carbon negativity in the European Union, there needs to be more investments into battery technologies and battery charging infrastructure for electronic vehicles. Therefore, there will be a massive need for raw battery materials such as lithium as many countries are trying to push away from cobalt that has been struggling with its reputation. One problem that European Union has in its investment activities is that the lithium and EV industries are changing so rapidly that the governing bodies have realized that it is somewhat easier to sit back and watch what is happening rather than having invested money go to waste as the new technologies are introduced. This mindset is unfortunately very common and harmful for new innovations and there is no easy solution to this as the money EU is investing is the money out of the pockets of European citizens who care about where the money is going and most of the citizens do not yet understand the massive demand of EV production materials needed in the near future.

When we are discussing industry stakeholders and actors that need to be taken into account when thinking of the tensions and competitive advantages, NGO's and governmental bodies are important to not to leave out. Governments and economic blocs create legislations that can support or hinder business opportunities in their area. As mentioned, protectionism is on rise especially now, when we have very flammable geopolitical situation around the world. Most parts of the world are thinking about how to secure their share of the critical raw materials and how to achieve the goals set by the U.N for example.

Nevertheless, the most important part is to understand the competition and business actors in different parts of the value chain to recognize potential joint-venture possibilities and the reasoning behind tensions among the industry.

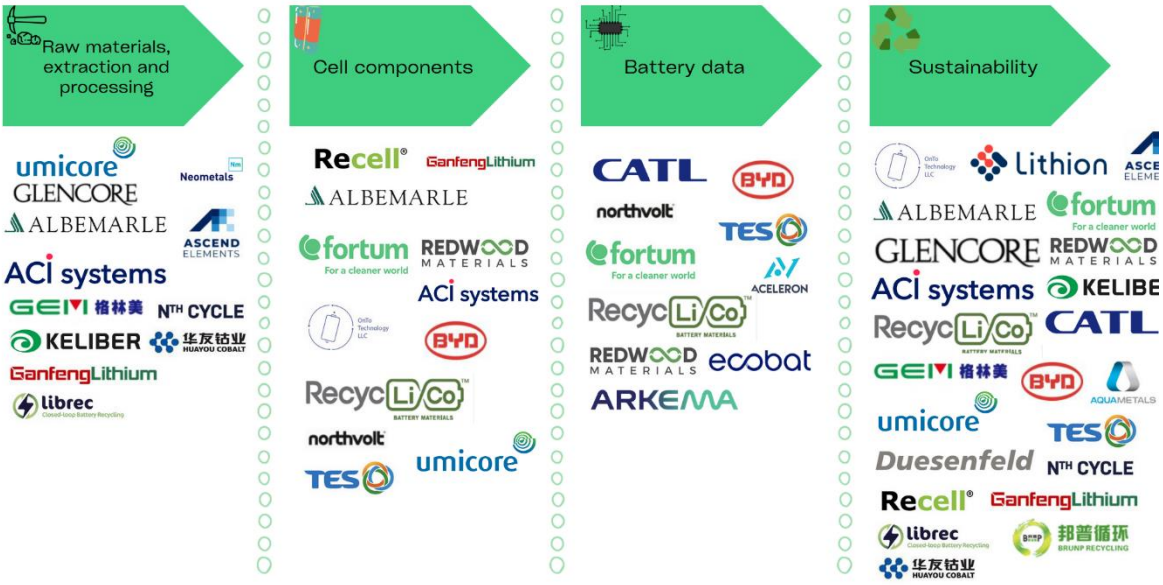

FIGURE 23. AUTHORS VISUALISATION OF THE CURRENT LIB INDUSTRY, 2023

We can see from the figure that even though there are companies which operate in most of the different parts of the value chain, the most competitive part of the whole chain is the recycling sector. We can also see from the selected companies that only one of them is involved in battery data technologies. There is therefore clearly no lack of recyclers but rather there is a discrepancy in the battery producers and sourcing of the waste and battery scrap for the recycling facilities. Clearly companies are focusing on their strengths rather than providing services in every part of the value chain. Chinese companies are utilizing the specialization strategy where business is focused on very specific area of expertise to improve the efficiency and scalability. Specialization can provide comparative advantage and it has been clear in the lithium recycling that Chinese companies have achieved such comparative advantage through massive investments in their recycling industry.

There are many policies that support the idea of utilizing the secondary raw material sources but currently the funding is not supportive enough to make the business models viable. Like discussed, there supportive policies such as the European green deal, Paris climate accord, EU battery recycling directive. Most of these policies and directives are meant for recycling end-of-life batteries and improving the efficiency of the process. But as mentioned above, the world is changing towards protectionism and Europe as a whole, needs to think about becoming more independent from others as the world only seems to become more politically unstable. Some of the policies that have recently been introduced, for example a policy that would make lithium salts hazardous materials, are hindering the lithium recycling industry.

In Europe we are going to have logistical challenges similar to the ones that the USA has currently, but as we are a union consisting of tens of different countries with different policies regarding transportation and recycling, we would need to make all the regulations universal as soon as possible. Essentially the biggest influence comes from the new EU battery regulation that came to force in August 2023. It sets the mandatory levels of recycling and the mandatory levels of recycled materials to be used in the production of new batteries.

There currently is no business model that is involving the use of lithium's secondary raw material sources other than the end-of-life batteries. As discussed earlier, the quantities in the other secondary sources seem to be so limited, that there is no financially viable business model in utilizing those sources. What we have seen though, especially in the USA where the inflation reduction act only allows lithium from the USA to be used in the cars manufactured in the USA. Even recycled materials need to be recycled in USA and we will probably see something similar happening in Europe in the near future which would probably make the secondary sources of lithium financially viable. In Europe we therefore need to be ready for the changes that can happen rapidly and build the needed infrastructure and technologies to have them ready when the methods become viable. That is what the RELiEF-project is essentially about, finding out what we will need in the future. It is important to show what is possible with the right regulations and subsidies to help the industry grow.

Proposal to overcome these challenges and paradoxes: Spoke and Hub system as a mean to solve the logistical problems. With the rapid development of the logistics processes there was a need for an efficient model to help the companies to overcome their logistics challenges. The model that was developed is the hub-and-spoke logistics network which ultimate goal is to reduce the inefficiency of the logistics chain.

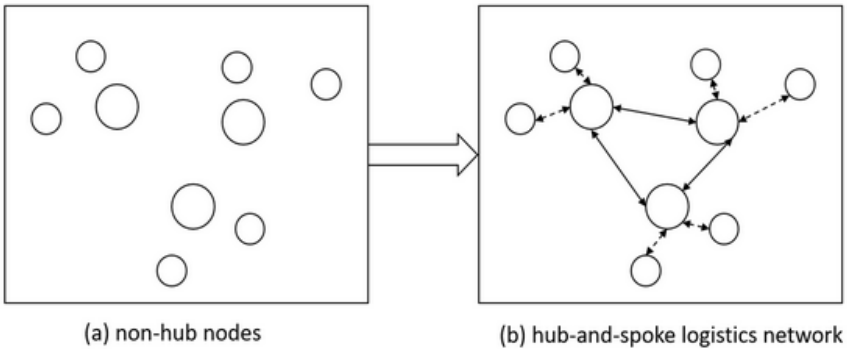

Figure 24. Zhou 2021

From the image above we can see the difference between a non-hub nodes and hub-and-spoke logistics network. This idea can be utilized for example with a recycling business model where there are multiple of sources and only a small number of hubs that then lead to the main processing plant. Logistics is all about optimizing (minimizing) the costs while maintaining efficient logistical functions and it is especially important for lithium recycling industry where the margins can be extremely low and in many cases the recyclers are not making any money out of solely recycling lithium. Li-Cycle company is already utilizing this model in North America and soon also in Europe. In spokes end-of-life lithium-ion batteries from cars and other sources are shredded and turned into black mass in a inert setting where there is no need to discharge the batteries. There is no risk of fire or other risks for the employees as the batteries are recycled under aquatic solution. From spokes, the black mass is then transported to the larger hubs where hydrometallurgical process is being used to separate the metals and other materials. This process minimizes the waste and logistics costs. Instead of moving heavy battery packs around, this process focuses on long distance transporting only for processed material, this process is therefore more sustainable and safer to the workers and the communities these operations are located.

6.2 Theoretical contributions and managerial implications

The main contribution of this thesis is that it ties together the circular economy in lithium recycling and the challenges arising from different sources such as policies and financial viability. I have created a framework which will help to understand the secondary raw material sources opportunities and challenges compared to virgin, mined minerals. By describing these challenges and opportunities, this thesis contributes to the literature on circular value chain and circular business models for these, currently unused secondary material sources and therefore creates a platform where future research direction could build its foundation. The relationship between circularity, paradoxical tensions and lithium recycling were expanded in this thesis and these relationships can be used to understand the needs of European self-sufficiency with Lithium raw material in the future.

To sum up, here are the 5 main opportunities and 5 main challenges for the recycling industry

Opportunities:

1. Positive direction of the new legislations in Europe regarding EV and the batteries
2. EU wide support for most of the new legislations regarding EV and the batteries
3. Demand for lithium will be increasing, if the sustainability targets are taken seriously
4. Investments from abroad and intra-European union are increasing
5. EU is investing heavily on the green technology research

Challenges:

1. Price of lithium is very volatile, and the new unknown technologies have the potential to dismiss lithium, but the trend is still that lithium is the future
2. Cooperation is lacking and that is hindering the innovations
3. Logistics inside Europe, especially if lithium salts are labelled hazardous
4. EU targets are set so high that there might be backlash from the public, if those targets are not met
5. Any large market disturbance or new technology could mean major changes in the industry

6.3 Policymaking implications

Policymakers play one of the largest roles in how we are going to achieve the U-N sustainable development goals, EU Green deal and other targets set by different organizations. Policymakers also have a big role in helping Europe become independent from foreign raw materials by helping the recycling industry to close the loop on the critical raw material supply chain. Policymakers need to keep on funding projects that are aimed to build European companies owned full value chain of lithium EV batteries from the raw minerals to recycling and closing the loop. Europe needs to be promoted as the critical raw material centre of the world with participation in all the parts of the value chain. By competing with USA for Chinese investments, while keeping the companies independent from the control of foreign entities.

Policymakers need to make the communication a two-way process. I have been trying to get in touch with the policymakers through the EU communication channels but have not gotten any proper answers and it seems that there is a roadblock in every direction. Only the largest companies have enough resources to lobby for their own agendas but smaller companies and European citizens who might have some ideas on how to resolve the issues are not being heard currently. But as mentioned above, the world is changing towards protectionism and Europe as a whole, needs to think about becoming more independent from others as the world only seems to become more politically unstable. Some of the policies that have recently been introduced, for example a policy that would make lithium salts hazardous materials, are hindering the lithium recycling industry. In Europe we are going to have logistical challenges like the ones that the USA has currently, but as we are a union consisting of tens of different countries with different policies regarding transportation and recycling, we would need to make all the regulations universal as soon as possible. Essentially the biggest influence comes from the new EU battery regulation that came to force in August 2023. It sets the mandatory levels of recycling and the mandatory levels of recycled materials to be used in the production of new batteries.

6.4 Limitations of the study and suggestions for future research

This study's aim was to find out the tensions and paradoxes that affect the implementation of lithium recycling business in Europe and to identify the challenges and opportunities arising from these tensions. The study will hopefully help to understand the reasons behind these tensions but the limitations for this study were obvious as one of the main contributors for the tensions is the competitive landscape of the industry. The study still lacks the input from companies operating in the different parts of the lithium recycling value chain.

In the future researchers have plenty of different opportunities in the field of lithium recycling and the tensions around the different targets and goals. One could research for example how the different technological advancements are affecting the investments in the short term and long term as based on this study, while the technological changes are expected, it seems to hinder investments in the technology at hands. The industry is changing so rapidly that the tensions and topics related to the lithium recycling industry need

continuous research to support the European Union legislators to make the best choices for the future.

7 Conclusions

The objective of the study was to find out, and to understand the tensions and paradoxes between different dimensions in the lithium recycling industry in Europe. this study aims to identify what are the causes of the barriers and challenges the relatively young industry is facing currently, and in the future. It also aims to give some solutions to these tensions and signal main unsolvable paradoxes. The key findings should be useful for managerial and policymaking decisions. The key findings were a comprehensive description of the tensions that are relevant to the lithium recycling industry and how the different business models are working around these tensions currently. The main giveaway from this study is that collaboration is very important for the industry in European and international level. Without collaboration, the goals that have been set by the organizations and governments, are not going to be met as the demand for these critical raw materials, of which lithium is just one example. The learnings from this study can be used for other critical materials such as graphite and manganese for example. It is critical for the future of the industry to ensure that communication platforms and cooperation are created with vertical and horizontal perspectives. The transformation towards greener future is evident but without the right corrective moves, it will be almost impossible to achieve according to the schedule proposed in the agreements.

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