The reverse logistics of electric vehicle batteries

Challenges encountered by 3PLs and recyclers
Acknowledgements

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Abstract

Background: The growing number of electric vehicles gives rise to a whole new reverse supply chain. Once the electric vehicle batteries reach their end-of-life, societal and governmental pressure forces automotive manufacturers to set up a network for disposing the hazardous batteries. Although, the volumes of returned batteries remain low, volumes will increase in upcoming years. Current networks and processes related to the return flow of electric vehicle batteries are not well established, nor well defined. Thus, creating an urgency to develop efficient collection networks.

Purpose: The purpose of this study is to investigate how reverse logistics networks are currently set up and to provide an overview of how the different actors and processes are connected. In addition, this thesis aims to identify challenges encountered by logistics providers and recyclers. By doing so, we hope to contribute to the research gap of which factors that constitutes a bottleneck for further development of the reverse logistics chain of electric vehicle batteries.

Method: The thesis conducts an interview study and is qualitative in nature. Semi-structured interviews generated empirical data, which was analysed through cross-case analysis incorporating a thematic analysis. Through this analysis we were able to achieve new theoretical understandings in connection to institutional theory.

Conclusion: Through empirical findings a detailed framework of the reverse logistics chain of EVBs is portrayed. Furthermore, different challenges span over the processes illustrated in the framework. This presents an overview which is not found in current literature and extends current research on this topic.
List of Abbreviations
Accord Dangereux Routier – ADR
Closed-Loop Supply Chain – CLSC
Electric Vehicle – EV
Electric Vehicle Battery – EVB
Internal Combustion Engine Vehicle – ICEV
Lithium-ion Battery – LIB
Original Equipment Manufacturer – OEM
Reverse Logistics – RL
Supply Chain – SC
Third Party Logistics Provider – 3PL
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1 Introduction

The introduction chapter is intended to familiarize the reader with the background to the fundamental concepts addressed in this study, namely, reverse logistics (RL) and electric vehicle batteries (EVBs). Moreover, the main problem is described, providing the reader with further understanding of the importance of the study. Finally, the research questions and the purpose of the study is outlined.

1.1 Background

The global concern of growing greenhouse gas emissions is threatening to negatively affect individuals, both economically and physically (Sierzchula, Bakker, Maat & Van Wee, 2014). Particularly the emissions of CO$_2$ have led automotive OEMs (original equipment manufacturers), governments and individuals to consider more eco-friendly alternatives (Verma, 2018). In 2016, the transport sector alone accounted for 27% of the total CO$_2$ emissions in Europe (EEA, 2018a). In order to reduce the dependency on internal combustion engine vehicles (ICEVs), the automotive industry continuously aims to provide more sustainable alternatives (Grandjean, Groenewald & Marco, 2019). The most predominant alternative for sustainable technology in the transport sector is the electric vehicle (EV). EVs have the potential to reduce the consumption of non-renewable energy sources such as coal and oil (Cui, Zhao, Wen & Zhang, 2018). Instead, EVs can be powered by renewable energy sources, such as wind and solar energy, without producing any tailpipe emissions (Andwari, Pesiridis, Rajoo, Martinez-Botas & Esfahanian, 2017). By powering EVs with renewable energy sources, CO$_2$ emissions from the transport industry can be considerably reduced (Zackrisson, 2017).

The electrification of the vehicle fleet has received some criticism since EVs are only as environmentally friendly as the electricity powering them. The greenhouse gas emissions and energy use related to production of EVBs is a trending topic (Clarke, 2017). The European Environment Agency released a report showing that emissions are higher when producing EVs than conventional ICEVs, however, these numbers are offset by the potential energy efficient way of operating EVs. In total, the report showed that EVs in Europe generally emit 17-30% less emissions than ICEVs during their lifetime (EEA, 2018b). Nonetheless, two of the greatest barriers for the wider adoption of EVs are the
high purchasing prices and short driving range (Hosseinpour, Chen & Tang, 2015). These barriers are forecasted to be reduced in the near future since technological advancements in EVB technology are being made in a high pace (Pelletier, Jabali & Laporte, 2016).

In 2017, over 1 million EVs were sold worldwide, a one-year increase of 50% from 2016 (International Energy Agency, 2018) and there are no signs that this increase will lose momentum. Bloomberg New Energy Finance (2018) forecasted that the numbers from 2017 will increase to 11 million by 2025, and 30 million in 2030 as production costs decrease. Automotive OEMs such as Volvo, Volkswagen, Audi, BMW, Mercedes and Land Rover have confirmed that they will introduce new electric models in the upcoming decade (Dia, 2017). Simultaneously, more experienced electric carmakers like Tesla, Chevy and Nissan are planning on lowering prices and optimizing performance in order to outperform their petrol and diesel counterparts (Randall, 2016). The following illustration shows the increase in new sales of EVs between the years 2017 and 2018.

![Graph showing EV sales and growth](adapted from Irle, 2019)

EVs are powered by energy stored in internal energy storage systems i.e. electric vehicle batteries (EVBs). The most common type of battery employed in EVs are lithium-ion batteries (LIBs) (Grandjean et al., 2019). Compared to other types of batteries, LIBs provide high energy and power density, fairly long life and are the most environmentally friendly option available (Lu, Han, Li, Hua & Ouyang, 2013). These characteristics have proven favourable in other areas. Thus, LIBs have had a leading position in portable electronics for many years, mainly in cell phones, laptops and digital cameras (Lee,
Yanilmaz, Toprakci, Fu & Zhang, 2014). However, EVBs lose capacity over time, which eventually make them unsuitable for powering an EV (Berecibar et al., 2016; Klör, Monhof, Beverungen & Bräuer, 2018). In general, EVBs should be replaced once their capacity is reduced to 80% of their initial capacity (He, Williard, Osterman & Pecht, 2011). This point is considered to be the final level of degradation (Knowles & Morris, 2014).

Traditional supply chain management generally focuses on the forward supply chain (SC), without considering the end-of-life (EOL) management of products (Govindan & Soleimani, 2017). The authors also point out that companies have recently become more concerned about the environment than ever before, which has redirected their attention to the backwards SC i.e. reverse logistics (RL). Thereby, creating a “closed-loop supply chain” (CLSC), a CLSC integrates both the forward and the backward SC (Govindan & Soleimani, 2017). RL can be defined as moving goods from its final destination with the intention of capturing value from EOL management and acting sustainable (Bouzon, Govindan & Rodríguez, 2015). By doing so, companies improve their corporate image and social legitimacy (Wong, Lai, Shang, Lu & Leung, 2012). When handling EOL products, there are several green options available, such as recycling, remanufacturing, disassembly, repairing and disposing (Soleimani & Govindan, 2014). RL is part of the cross-disciplinary field of Green Supply Chain Management, which due to an increased environmental awareness has led to a greater emphasis on the environmental aspects of the SC (Govindan, Kaliyan, Kannan & Haq, 2014). In developed countries, certain industries and companies consider RL to be a key process in the SC due to their positive effects on society (Heydari, Govindan & Jafari, 2017).

1.2 Problem Description

Many believe that EVs are one of the solutions to reduce the dependency on fossil fuels in the transport sector (Rezvani, Jansson & Bodin, 2015). Therefore, governments have enforced policies to facilitate the spread of EVs (Li, Long, Chen & Geng, 2017; Sierzchula et al., 2014). Through these incentives, sales of EVs are predicted to increase rapidly (International Energy Agency, 2018). The growing volumes will complicate the reverse flow of EVBs, thus making it a global concern (Adler & Mirchandani, 2014; Grandjean et al., 2019).
Automotive OEMs are responsible for collecting their spent EVBs with the purpose of repurposing or recycling them (Ramoni & Zhang, 2013). However, capabilities connected to the transportation of dangerous goods, storage, recycling and repurposing are not considered to be amongst the core competencies of automotive OEMs (Hoyer Kieckhäfer & Spengler, 2015; Klör et al., 2018). Therefore, the responsibility is often transferred to external actors or third parties (Ramoni & Zhang, 2013), which collectively form the RL network. RL is considered to be an effective way of improving the business and environmental performance of a company (El Korchi & Millet, 2011). However, RL can be complicated as environmental initiatives and RL initiatives are often driven by customer requirements (Álvarez-Gil, Berrone, Husillos & Lado, 2007) and competitive factors (Lewis & Harvey 2001). Another major influence on RL processes are external regulations (Lai & Wong, 2012). These regulations mainly emerge from governments who are increasingly promoting sustainability and environmental protection (Das & Chowdhury, 2012).

LIBs do not have a standardized design, which will significantly complicate the RL processes. Furthermore, EVs and EVBs constitute an evolving technology, which further complicates the development of a long-term standardized solution (Hendrickson, Kavvada, Shah, Sathre & Scown, 2015). Additionally, the RL network must make sure that no LIBs are left landfilled, since landfilling could have serious consequences due to their hazardous nature (Heelan et al. 2016). Spent LIBs are classified as dangerous goods and include toxic materials such as heavy metals and organic chemicals (Zeng, Li & Liu, 2015). Therefore, LIBs require acid-proof packaging and storage during transportation and throughout the entire RL process, because leaking batteries are considered a health hazard and a threat to nature (Klör, Bräuer & Beverungen, 2014). Improper handling of LIBs can result in fires, explosions and the release of toxic materials due to their corrosive, flammable explosive and toxic characteristics (Huo et al., 2017). Currently, the industry is lacking adequate policies and technology for handling LIBs in their afterlife (Zeng, Li & Singh, 2014). Due to the aforementioned reasons, the development of RL plays a crucial role in reducing negative environmental impact and raw material consumption.
Unfortunately, the business and management research done in the area of RL combined with used EVBs is highly limited. Our research did not discover any substantive work discussing how actual business systems are set up in order to collect and recycle EVBs. Moreover, a gap was identified regarding basic RL activities connected to collection, such as transportation, packaging and storage of EVBs. This gap also transfers to the EOL activities of recycling and second use. Consequently, research of how third-party logistics providers (3PLs) and recyclers will be involved in the RL process has been neglected in previous research. As pointed out by Klör et al. (2018), most previous research has focused on technical feasibility on second use of EVBs, rather than investigating actual business models. Currently, the majority of popular research simply focuses on the technical perspectives related to either recycling or repurposing. For instance, Shokrzadeh and Bibeau (2016) and Heelan et.al. (2016) investigated whether specific repurposing techniques were possible to realize, while Dunn, Gaines, Sullivan & Wang (2012) and Busch, Steinberger, Dawson, Purnell and Roelich (2014) examined the technical feasibility of recycling batteries.

Ramoni and Zhang (2013) state that the automotive industry is undergoing a fundamental change that calls for an urgency to develop sustainable EOL strategies. According to Zeng et al. (2015), the main bottleneck for EOL activities of used LIBs are the lack of developed collection systems and recycling technologies. Furthermore, regulations concerning used EVBs are neither fully implemented, nor fully developed (Grandjean et al., 2019; Mayyas, Steward & Mann, 2019). The current European Parliament Council (2006) Battery Directive 2006/66/EC prescribes targets for collection and recycling efficiencies. The directives state that at least 50% of the average weight of a LIBs must be recycled, while stating a minimum collection rate of 45% for all batteries and accumulators. However, the directives are currently being revised (Romare & Dahllöf, 2017). The uncertainty of how directives and legislations will be strengthened in the future makes it crucial for the automotive industry to develop a closed loop system that is able to meet future requirements of recycling. Additionally, the process of reusing EVBs in second life applications is not well defined and requires additional investigation (Yazdanie, Noembrini, Heinen, Espinel & Boulouchos, 2016).
It is necessary to develop sustainable processes for the EOL management of EVBs. Especially due to their hazardous nature and because there are opportunities to capture additional value from the batteries, either through recycling or by second use. Specifically, it is important to research the set-up of the RL flow and to investigate how 3PLs and recyclers are involved in the process. While also identifying challenges encountered by actors in the RL process. In doing so, we aim to pinpoint the reason why developed collection systems and recycling technologies are presenting a barrier for efficiency in EOL activities. Moreover, we find it necessary to close the literature gap and contribute to existing literature by examining and comparing the practical approaches adopted by actors in the RL chain of spent EVBs. By doing so, we hope to bring clarity in how challenges are approached by 3PLs and recyclers, while providing insights into what makes the situation complex.

1.3 Purpose & Research Question

We believe that one reason for the current gap in literature could be that the amount of returned EVBs still remain low. However, our standpoint is that this will be a highly discussed topic in the near future. Therefore, the purpose of this study is to gather insights from recyclers and 3PLs in order to develop a framework on how a RL flow can be set up. By doing so, we provide an in-depth view of the structure of the reverse flow of EVBs. In connection to investigating the setup, our study will present challenges within it. Consequently, our study aims to prepare actors in the network for the rising volumes of used LIBs.

This leads us to two research questions we want to answer in this study:

**RQ1a:** What is the set-up of the reverse logistics process concerning electric vehicle batteries?

**RQ1b:** Which challenges are 3PLs and recyclers encountering regarding reverse logistics of electric vehicle batteries?
2 Theoretical background

This chapter will present the theoretical background of the thesis through examining and combining existing literature in fields related to the research questions. Firstly, the concept of reverse logistics will be presented together with specific characteristics applicable to the study. Thereafter, electric vehicle batteries and the possibility to prolong their life time will be investigated. It ends with similarities drawn from the sector of lead-acid batteries and the applicability of institutional theory to our study.

2.1 Reverse Logistics

RL have received a lot of attention in both academic and practitioner fields in recent years. Furthermore, RL is an essential part in a company’s effort to achieve a CLSC (Olugu & Wong, 2012; Shankar, Bhattacharyya & Choudhary, 2018). RL must be seen as an integrated part of the SC, not a stand-alone aspect managed independent from other aspects of the SC (Seitz & Peattie, 2004). However, as Aitken and Harrison (2013) indicated, this has not been the case in the past, since RL has received inadequate attention on how to deal with used products.

In principal, RL is nothing else than the reverse flow of goods from the customer back to the manufacturer of the product, meaning that used products move upstream from the customer (Cruz-Rivera & Ertel, 2009). However, initially the product or raw materials need to proceed from the manufacturer or supplier to the point of use, before a reverse flow can start (Aitken & Harrison, 2013). Figure 2 shows a simplified SC in order to get a better understanding of the forward and reverse flow.

![Figure 2. Reverse flow (adapted from Fleischmann et al., 2000)](image)

As seen in Figure 2, the reverse flow arises at the customer level with the collection of the used product. Fleischmann, Krikke, Dekker and Flapper (2000) explain that collection
incorporates activities from transportation, purchasing as well as storage. In the phase of selection, used products need to be evaluated for further purposes and are sorted with regard to their reusability. Further, the authors describe that after the successful evaluation of the product, it will either be disposed or potentially re-processed. If the product should not have an adequate market value, costs for repairs would be too high, and recycling would not be economically feasible, it will be disposed. On the other hand, in the re-processing stage the product will either be recycled to gain value from resources or materials in the product, be repaired in order to be used again, or it will be remanufactured to use in a different way than it was initially intended for. In the final phase redistribution, the products will be guided into an appropriate market so that they can be reused (Fleischmann et al., 2000). Therefore, the definition by Rogers and Tibben-Lembke (1999) “the process by means of which goods are transferred from their final destination to the point of origin with the aim of recovering value or of reducing waste” fits best with the above given description of RL.

As mentioned in the beginning of this part, RL has become the subject of a lot of research in recent years. This attention stems from three aspects companies usually consider when they introduce a reverse flow for their products. In the following paragraphs the drivers will be thoroughly observed.

2.1.1 Economic Aspect

Logically, a main condition in implementing a new strategy is that it must have an economic value for the company. This could be reflected in several ways. Firstly, a company performing remanufacturing activities is potentially able to reduce manufacturing costs up to 60% since they can reutilize components from the recovered product (Aras, Aksen & Tanuğur, 2008). Secondly, recycling helps many firms to recover scarce raw materials and through that enables them to save money. This is possible because of reduced procurement cost, since consumption of new raw materials is not as high as before recycling (Chan, Chan & Jain, 2012; Lee & Dong, 2008). Thirdly, reselling a product after the initial life-phase ended is another strategy that allows companies to generate value after recovering the product. Through repairing, cleaning, or refurbishing, companies are able to prepare the old product for an appropriate aftermarket, which is a common strategy in e.g. the copier or mobile phone business (Schultmann, Zumkeller &
Rentz, 2006). Finally, companies have realized that the practice of RL became an opportunity to gain additional revenue and not just a cost optimization approach (Govindan, Soleimani & Kannan, 2015). However, Sheriff, Nachiappan and Min (2014) mention that incorporating a reverse flow into an existing SC can only be done if the reverse flow is managed in a cost-efficient manner. Meaning that all stages in the reverse flow are subject to optimization purely due to the fact that revenue is generated at the end of the chain.

2.1.2 Social Aspect
Besides the economic aspect, social aspects are also a big driver for implementation of RL into the SC. Through legislations directed by the EU or governments, companies are now forced to incorporate take-back policies for their EOL products and producers are responsible for their final disposal (Daaboul, Le Duigou, Penciuc & Eynard, 2016; Ferguson & Browne, 2001). All the legislations or directives from the EU start with Extended Producer Responsibility and make the manufacturer accountable for the whole life-cycle of the product till the EOL disposal (Le Blanc, Krieken, Krikke & Fleuren, 2006). A rather interesting legislation in that regard, is the End-of-Life Vehicle directive. This directive forces automotive OEMs to recover 95% of a vehicle's weight, excluding the battery, which need to be reused or recycled and only 5% of the weight is allowed to be disposed (Kumar & Putnam, 2008). With such legislation, manufacturers now bear the responsibility to implement RL in order to comply with laws and demonstrate the significance of RL (Sbihi & Eglese, 2010). All these legislations display the societal concern corresponding to environmental aspects of the waste disposal by firms (Seitz & Peattie, 2004).

2.1.3 Environmental Aspect
Lawmakers are not the only party becoming more environmentally conscious. Resource depletion results in higher prices, which has led firms to take new approaches in doing their daily business (Abdulrahman, Gunasekaran & Subramanian, 2014). Furthermore, with an activity like remanufacturing, a company can save up to 85% of energy, 86% of water, and 85% of material compared to the production of a new product (Kumar, Chinnam & Murat, 2017). This can be an economic driver; however, since sustainability
and using natural resources in a more responsible way became increasingly important, it is included in the environmental aspect.

In summary the three above mentioned aspects not only reflect drivers of implementing RL, but also reflect the three sustainability components of the term triple bottom line which was coined by John Elkington (Wilson, 2015).

2.1.4 Third party logistics provider
A 3PL, in general, is a firm which carries out different logistics related services, which another firm outsourced to them (Aguezzoul, 2014; Cheng & Lee, 2010; Ko & Evans, 2007). The main reason for this, as mentioned in a study, is because of increasing cost and the possibility to reduce these through a 3PL (Govindan, Palaniappan, Zhu & Kannan, 2012). However, the authors also mention that the reduction of cost is not the only factor in choosing a 3PL for his services. Strategic reasons, process effectiveness and the lack of capability are the other crucial factors to consider when firms are using 3PLs (Govindan et al., 2012). Cheng and Lee (2010), also add that the absence of resources to control the complex network of actors in RL processes is a reason for dealing with 3PLs. 3PLs offer firms solutions for a variety of different logistic processes ranging from transportation, distribution, warehousing, or RL as a whole (Aguezzoul, 2014). Jayaram and Tan (2010) also explicitly acknowledge RL as a function 3PLs are willing to perform, because of the value this function possesses. Furthermore, Aguezzoul (2014) mentions that when 3PLs take care of RL, reuse, recycling, remanufacturing, and disposal are amongst the things a 3PL will handle. Additionally, firms which are doing business with 3PLs have the benefit of using the specialized infrastructure of the 3PL to manage the backward flow in an efficient manner (Ko & Evans, 2007). Min and Ko (2008) state that product returns were the key offering in a 3PLs service portfolio. However, the authors add that product returns are also responsible for a big part of costs through activities related to product returns, especially transport, and successfully handling these activities can be a differentiator to other 3PLs in the business. Therefore, the next paragraph will address the logistical challenge of picking up products.

2.1.5 Vehicle Routing Problem
An issue which has great impact on RL as well as EOL activities is the vehicle routing problem (VRP) and the effects it has on the economic efficiency on the reverse flow of
recovering products (Schultmann et al., 2006). In principal, the VRP is concerned with finding the most cost-efficient routes from start to the end of collection facilities, while also taking the optimal number of vehicles into account (Le Blanc, Flreure & Krikke, 2004). Since the VRP is unique for each firm, a few conditions have to be identified. Meaning that a firm needs to know the availability of its vehicle fleet, capacity of its inventory, and other specific conditions depending on the industry or product (Qiu, Ni, Wang, Fang & Pardalos, 2018).

2.2 Electric vehicles

In 2012 the transportation sector was responsible for 20% of the global energy consumption, and for 25% of energy related greenhouse gas emissions (Shokrzadeh & Bibeau, 2016). Further, the authors mention that the International Energy Agency (IEA) has set up a goal, stating that the global average temperature increase should be limited to 2 degrees Celsius by 2050. In the scenario set up by the IEA, the transport sector should account for 21% of the global CO2 reductions by 2050. In order to achieve this goal, many believe that electrification of the vehicle fleet is a necessity.

Richardson (2013) state that EVs are considered as an environmentally friendly and energy efficient alternative, which reduces the dependence on fossil fuels. Consequently, reducing emissions of CO2 and other pollutants such as nitrous oxides (NOx) and sulphur dioxide (SO2). EVs are likely to phase out and eventually replace conventional ICEVs in a foreseeable future (Ramakrishnan, Hiremath & Singaperumal, 2014). Apart from a decrease in emissions, EVs outperform ICEVs in several safety aspects by providing a lower centre of gravity and increased crumple zones (Matteson & Williams, 2015). Furthermore, EVs spread less operating noise than ICEVs and require less maintenance due to less moving parts and that no oil changes are needed (Pelletier et al., 2016).

EVs can be categorized into three types: hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) (Richardson, 2013). The EVB installed in an HEV is the smallest and has the lowest impact on performance, these EVBs purpose is to optimize the performance of an internal combustion engine (Pelletier et al., 2016). Meaning that the HEVs are still powered by gasoline (Yazdanie et al., 2016), while the battery is powered by the internal combustion engine and generative braking
PHEVs have larger batteries than HEVs that can be connected to the power grid; however, PHEVs still have an internal combustion engine (Richardson, 2013). Hence, PHEVs can be operated both as a BEV and as an ICEV (Peiro et al., 2013), making it possible to power PHEVs both on electricity and gasoline, either combined or separately (Yazdanie et al., 2016). BEVs do not have an internal combustion engine and are fully powered by grid electricity that is stored in the battery pack (Richardson, 2013). Naturally, BEVs have the largest batteries (Pelletier et al., 2016), which they solely rely on (Yazdanie et al., 2016).

The stakeholders in the EV market are automotive OEMs, governments, companies in the electric power sector and consumers (Shokrzadeh & Bibeau, 2016). Many governments have implemented favourable policies and incentives for purchasing EVs in order to increase their market penetration (Pelletier et al., 2016; Shokrzadeh & Bibeau, 2016). Yazdanie et al. (2016) state that policies are needed to maintain the market growth, leading to technological advancements and developments in infrastructure. Further, the authors provide examples of countries with preferential policies towards EVs, amongst them are the US, Japan, Norway, and France. All these countries offer subsidies when purchasing EVs, for instance, the US government covers 10% of the total price of an EV (max. 4000USD). Moreover, these countries offer tax reductions, e.g. Japan halves motor vehicle taxes, commodity taxes and license taxes. Lastly, Zhang and Qin (2018) present non-monetary incentives that have been introduced in France, where EVs are offered free parking and some road sections are exclusively intended for EVs. While in Norway, EV owners are offered exemptions from various road tolls (Yazdanie et al., 2016). The main reasons why governments across the world are offering such incentives when purchasing EVs, are the benefits related to protecting the environment, developing energy technology and maintaining a sustainable society (Matteson & Williams, 2015). EVs are still an emerging technology with rapid technological developments, therefore the EV industry is viewed as a market with great potential of improvement and maturity (Yazdanie et al., 2016). The market share for EVs is still very small on a global scale, however Norway and the Netherlands are two exceptions where EVs make up for a significant amount in the vehicle fleet (Pelletier et al., 2016).
It is important to remember that an EV is only as environmentally friendly as the electricity that is supplied by the power grid (Matteson & Williams, 2015). Therefore, it is important that there is enough capacity of renewable resources to be able to satisfy the future demand (Palencia, Furubayashi & Nakata, 2012; Shokrzadeh & Bibeau, 2016). Shokrzadeh & Bibeau (2016) reported that both wind and solar power capacity are increasing but are restrained by technical and economic limitations. According to Notter et al. (2010), the biggest threat to the environment by using EVs are realized if the electricity powering the vehicle is not produced from renewable sources. Furthermore, using EVs purely powered by renewable energy can reduce the total greenhouse gas emission by more than 50% compared to ICEVs powered by gasoline (Yazdanie et al., 2016). However, even if EVs would mitigate some of the environmental issues present today, they would also bring new environmental issues with them, such as scarcity of metals included in EVBs in case of a large EV fleet (Andersson & Råde, 2001).

2.2.1 Lithium-Ion Batteries
LIBs were first commercialized in 1991, since then the market share has increased drastically, particularly in portable electronics, such as laptops and cell phones (Matteson & Williams, 2015). In 2014, there were over 1500 million cell phones using LIBs, compared to 300 million in 2000 (Heelan et al., 2016). Apart from laptops and cell phones, lithium batteries are used in e.g. tablets, power tools, e-bikes, cameras, toys and video games. Generally, the lifetime of a LIB in other applications than EVs are between two and ten years (Peiro et al., 2013).

LIBs are currently the leading technology when it comes to EVBs and are the most widespread technology used in EVs (Pelletier et al., 2016; Yazdanie et al., 2016). EVs are powered by secondary batteries. In comparison to primary batteries, secondary batteries are rechargeable while primary batteries are not (Peiro et al., 2013). EVs are heavier than ICEVs, with the main difference being the weight of the battery (Palencia et al., 2012). The market for EVs is growing at a rapid pace and technology advancements for batteries are being made with short time intervals. Simultaneously, the price for EVBs are decreasing (Pelletier et al., 2016), which gives rise to complexity of how the increased flow of EVBs are going to be handled (Pelletier et al., 2016; Shokrzadeh & Bibeau, 2016). The already decreasing prices can be illustrated as followed. In 2012, Hein, Kleindorfer
and Spinler (2012) reported that batteries account for approximately two thirds of the total production costs of EVs. Later, in 2015, Matteson and Williams (2015) expressed that batteries in many cases account for up to 50% of the total cost of production. Lastly, in 2018, Klör et al. (2018), stated that EVBs account for between 20-40% of the total cost of manufacturing an EV. According to Matteson and Williams (2015), the reason why LIBs are so expensive to produce are the lack of economies of scale together with high material costs.

There are several different EVBs that are currently available on the market, the most common ones are nickel-metal-hydride batteries, sodium-nickel-chloride batteries (i.e. ZEBRA batteries), lead-acid batteries and LIBs (Pelletier et al., 2016). Compared to the competing rechargeable battery types on the market, LIBs have some outstanding advantages. For instance, LIBs weigh 50% less than the other battery types and can be 20% to 50% smaller, while offering the same capacity. Moreover, LIBs offer three times higher voltage than the other battery types (Peiro et al., 2013). The combined strengths of LIBs offer an unmatchable combination that makes them highly suitable for EVs (Ellingsen, Hung & Strømman, 2017). Strengths have been widely discussed in literature, Ramakrishnan et al. (2014) and Pelletier et al. (2016) point at the advantage of a relatively long service life, while being an environmentally justifiable alternative (Ordoñez, Gago & Girard, 2016). Additionally, LIBs have a high energy density, resulting in a large storage capacity (Ellingsen et al., 2017; Heelan et al., 2016; Notter et al., 2010; Ramakrishnan et al., 2014; Xiao, Li & Xu, 2017), high specific energy and power (Pelletier et al., 2016), low memory effect (Notter et al., 2010; Pelletier et al., 2016) and the fact that LIBs require minimal maintenance (Notter et al., 2010). Negative operational aspects have not been discussed to the same extent, Ramakrishnan et al. (2014) explain that even though less maintenance is required, it is significantly more expensive once it is necessary. Additionally, LIBs are negatively affected by cold weather, which decreases the performance of the vehicle (Jaguemont, Boulon & Dubé, 2016).

The total length of a LIBs life can be affected depending on how it is used and stored (Pelletier et al., 2016), which is directly associated with the driving range of the vehicle (Hein et al., 2012). It is hard to fully explain what causes EVBs to age, however, it is certain that driving patterns, extreme temperatures and charging rates are influential
factors (Klör et al., 2018; Pelletier et al., 2016). Furthermore, when capacity fades, other factors such as, acceleration and fast charging capabilities are reduced (Klör et al., 2018). Furthermore Pelletier et al. (2016), state that high speed, quick acceleration, carrying heavy loads and upwards slopes causes the battery to lose capacity as well. These factors lead the EVB to eventually enter the RL flow. Shokrzadeh and Bibeau (2016) present parameters that potentially impact the life time of LIBs, for instance, charging rate and depth of discharge. Moreover, the maximum age for LIBs is often estimated to be between five and ten years, i.e. when the total capacity of the battery has been degraded to below 80% (Hein et al., 2012; Klör et al., 2018; Pelletier et al., 2016; Yazdanie et al., 2016), or when the vehicle has been powered for about 100,000 km (Klör et al., 2018) to 150,000 km (Notter et al., 2010). Furthermore, LIBs might enter their EOL due to battery failures or damages caused by accidents (Chiang, Sean, Wu & Huang, 2017). Peiro et al. (2013) state that it can take up to 15 years from the purchase of an EV before the LIB is returned, depending on how the vehicle is used and stored. According to Pelletier et al. (2016), there is a possibility for future lithium batteries to improve significantly in terms of specific energy and driving range through further developing existing technologies.

As previously mentioned, LIBs are changing and developing at a rapid pace (Notter et al., 2010). While the chemical compositions differ, the constellation in the battery pack is mainly the same. The battery pack is modular (Klör et al., 2018), which means that cells, that provide electric power, are assembled together to create modules (Pelletier et al., 2016). These modules are then put into the battery pack. Apart from the modules, the authors state that EVBs have a battery management system (BMS) that manages quality and safety aspects within the battery. Klör et al. (2018) explained that the battery pack also consists of a thermal management system and a battery casing. Additionally, every LIB requires an anode, cathode, separator, and an electrolyte (Heelan et al., 2016; Ordoñez et al., 2016). In general, LIBs are composed of 5-20% cobalt, 5-10% nickel, 5-7% lithium, 7% plastics and 15% organic chemical products (Ordoñez et al., 2016).

Heelan et al. (2016) explain that the cathode is the most inconsistent and variable part. As an example, the authors state that the first EVs used lithium cobalt oxide (LiCoO2). In 2008 more than 60% of all EVs used this composition, in 2012 the number had decreased to around 37% and is expected to fall even more (Heelan et al. 2016). Further, they explain
that cobalt recently has been replaced with nickel-manganese-cobalt (NMC) due to its high-power density. Nowadays, this composition is often changed in order to maximize the desired characteristics of the battery.

Yazdanie et al. (2016) state that currently, the composition and the specific technologies used in LIBs do not significantly affect the total greenhouse gas emissions from EVs, it is rather the primary energy source e.g. the use of renewable energy that makes a difference in overall emissions. However, Dunn et al. (2012) conclude that the fact that LIBs are not bound to a specific setup of materials is one of the main reasons why recycling and repurposing become problematic. Further, the authors mention that the varying compositions and accompanying characteristics related to performance problematize the way LIBs have to be handled in their EOL. Moreover, the authors conclude that recovery and recycling of metals such as cobalt, lithium and manganese could be highly profitable, as well as crucial for the environment.

2.3 EOL activities

After reviewing EVs and LIBs in general, it is also crucial to examine the prevailing activities that are used for recovered products. Such activities include reuse, recycling, refurbishing, remanufacturing, repair, cannibalization, incineration, and landfilling which are commonly connected to RL (González-Torre, Alvarez, Sarkis & Adenso-Díaz, 2010; Thierry, Salomon, Van Nunen & Van Wassenhove, 1995). The upcoming section will present the EOL activities of collection, recycling and repurposing. Even though previous literature on collection is limited, it is a prerequisite for the widely researched activities of recycling and repurposing.

Even though many scholars have researched the environmental impact of LIBs in their EOL, the results have been widely diverse, making it hard to predict the actual environmental impact on LIBs (Ellingsen et al., 2017). Batteries are considered to enter their EOL once their capacity no longer meets the requirements of the EV in terms of distributing energy. By efficiently using EVBs in their EOL, they can become valuable assets that do not alter the actual purpose of powering an EV (Hein et al., 2012). Recovery and recycling of lithium from LIBs is the most crucial factor for the long-term viability of the metal (Peiro et al., 2013). The role of retired EVBs in second life application still
requires investigation and development because as it of today, this process is not well defined (Yazdanie et al., 2016). The choice of either repurposing or recycling is based on economic motivation, environmental responsibility and legislation (Klöer et al., 2018).

Heelan et al. (2016), presents three reasons why no standardization of LIB-recycling has become eminent. Firstly, it is stated that the business model for recycling must be further developed as the current profit margin is too low, while recycling technologies do not extract all valuable components. Secondly, LIBs are constantly evolving, making it hard for a standardized model to be set up, instead recycling companies have to try to adapt to new compositions and consequently use new techniques. Thirdly, several countries lack governmental control and do not enforce legislations towards recycling. As previously mentioned, the EU directives require LIBs to be recycled to at least 50% of the average weight.

2.3.1 Collection

The collection process is the step that takes place before treatment, disposal and distribution. Today, large volumes of lithium batteries from several industries are being stored for no apparent reason instead of being recycled or repurposed, which in turn negatively affects the environment and society (Heelan et al., 2016). Therefore, it is important to establish a proper EOL process that allows the industry to take care of used EVBs. Zeng et al. 2015 explain that the growing volumes of LIBs will require efficient collection systems to be set up. Collection activities related to LIBs are highly influenced by regulations and legislations. For instance, the European agreement of International Carriage of Dangerous Goods by Road (ADR) and the battery directives causes transportation to be very expensive (Grandjean et al., 2019). Further, the authors explain that the most expensive activity is transporting damaged or defective batteries, since these must be transported in explosion proof boxes that can cost around €10,000. As mentioned by Dehghani-Sanj, Tharumalingam, Dusseault and Fraser (2019), collection is one of the main challenges of recycling. Additionally, the authors state that collection is highly dependent on public support, governmental incentives, businesses and other social organizations.
Collection activities are crucial, since a scenario where the majority of LIBs would remain landfill after retraction from EVs would imply serious environmental consequences and cause harm to animals and humans (Ordoñez et al., 2016). Unmonitored LIBs cause a significant risk of catching fire (Heelan et al., 2016; Kang, Chen & Ogunseitan, 2013). Grandjean et al. (2019) explained that many reports state that LIBs have started combusting in storage, which illustrates the unpredictability of the chemistry. Moreover, used LIBs have to be properly handled in order to avoid contamination of soil and groundwater (Gao et al., 2018; Ordoñez et al., 2016). Heelan et al. (2016) also talks about the risks of lithium reaching the ground water, stating that LIBs might emit hydrogen fluoride formations if exposed to water e.g. rain. Kang et al. (2013) conducted a study on how landfill lithium batteries for cell phones affect the environment. The authors discovered that the metals Cobalt, Copper, Nickel and Aluminium, which are all commonly used in EVBs, leached significant concentrations that would cause high levels of dangerous chemical waste to humans and the environment.

2.3.2 Reuse

Reuse can be divided into two separate categories. The first category is direct reuse, meaning that the product is reused with the same purpose it had before. The second category is indirect reuse (repurposing), where the product or component is applied in a different setting (Bobba et al., 2018). Therefore, this part is split up into direct reuse and repurposing. Before the EVB enters its second life, it must be remanufactured in order to avoid future quality issues (Ramoni & Zhang, 2013). Reuse and repurposing of EVBs are gaining more interest due to their ability to assist in second life applications (Heelan et al., 2016). However, Klör et al. (2018) explain that repurposing of EVBs is a problem since there is no solution or guidelines on how to approach it. The authors state, that this originates from the complexity that stems from reusing EVBs and that these activities are not in the automotive OEMs core competences. Moreover Klör et al. (2018) explain that the most complex part of managing EVBs in their EOL are the uniqueness of modern battery technology and their diverse properties. Busch et al. (2014) also addressed the complexity and emphasized that the differences in LIB chemistries is the largest barrier. Lastly, the first real wave of used LIBs is still to come and therefore no commercialized second life use for EVBs have been presented (Heelan et al., 2016). The authors also
indicate that it is very likely that this will be an attractive market for used EVBs, nevertheless reused EVBs will ultimately need to be recycled.

As reported by Klör et al. (2018), EVBs can be repurposed in either stationary or mobile applications. In stationary applications, the battery is permanently installed e.g. as extra energy storage in windmills. Regarding mobile applications, EVBs can be installed in devices that require less energy than cars, such as forklifts. The most common area of reuse discussed and investigated in literature are the use of spent EVBs in stationary energy storage systems (ESS). Several studies investigate this approach (Ahmadi et al., 2014; Foster, Isely, Standridge & Hasan, 2014; Klör et al., 2018). Examples of ESS functions that spent EVBs can be used for are: peak-shaving and load-following functions (Ahmadi et al., 2014). As stated by Klör et al. (2018), some automotive OEMs (e.g. BMW, Chevrolet and Nissan) have developed proof-of-concept projects, demonstrating that it is possible to repurpose EVBs in ESSs from a technical perspective. According to Hein et al. (2012), ESS operators are generally interested in buying used EVBs due to the possible value that they still possess. Furthermore, Hein et.al. (2012) state that it is the ESS operators' market, meaning that the market is constrained to what they are willing to pay, which in turn is affected by the value that the used EVB is expected to generate.

Moreover, Klör et al. (2018) refer to several other potential areas of repurposing, some being energy storage in smart homes, residential load levelling and for energy grid stabilization. Hein et al. (2012), also discuss the possibility to connect spent EVBs to the energy grid. In this scenario, used EVBs would work as a “bank of used batteries” with the function of an energy reserve in grid level storage devices. Moreover, Hein et al. (2012) investigated the economic feasibility of such a system and concluded that there is potential value in this area. Yazdanie et al. (2016) also mention that EVBs can be used to integrate renewable energy into the grid.

2.3.3 Recycling

Recycling has been identified as one of the earlier adoptions in product recovery management and as more and more legislations were put in place, companies were forced to follow the legal guidelines (González-Torre et al., 2010; Le Blanc et al., 2004). However, even with legislations, the economic considerations have been an early driver in adopting such an activity that cannot go unnoticed (Klör et al., 2018). Therefore, it is
not surprising that both the forward and reverse SC needs to be organized together. By doing so, actors within the supply chain are able to react to uncertainties of quality, quantity of EOL products, and the scarcity of natural resources (Das & Chowdhury, 2012; Keyvanshokooh, Ryan & Kabir, 2016). With recycling as a recovery option for raw materials, the whole design and appearance of the product is lost and starts with the disassembly of a specific part. Recovered material can then be reused in manufacturing of new products. In case of the ICEVs, 95% of a vehicles weight need to be either reused or recycled (Kumar & Putnam, 2008; Olugu & Wong, 2012).

Already in 2006, non-recycled lithium batteries started to stack up in developed countries (Heelan et al., 2016). Moreover, the authors explain that the largest market for LIB recycling is for laptop batteries, while cell phones are less recycled due to their low mass. Andersson and Råde (2001) state that a closed loop system is crucial when it comes to battery recycling, the main reasons for this being environmental awareness and not to drain the material depots of resources included in the batteries. Dunn et al. (2012) discovered that wrought aluminium accounts for approximately half of the emissions and energy consumption of producing an EVB. They also stated that recycling all aluminium used in an EVB could potentially minimize the energy consumption of producing new EVs by 33%. In regard to lithium, it is primarily recovered from the cathodes (Peiro et al., 2013). Another major driver for recycling materials is the global scarcity of nickel and cobalt (Larcher & Tarascon, 2015). The authors also argue that further spread of LIBs will require a new recycling process for recovering cobalt and nickel, otherwise the materials have to be replaced.

Dunn et al. (2012) explain that the battery recycling could be made more convenient through standardization of the battery shape, size and design. Standardization would be even more efficient if it would imply easy disassembly and separation of the different materials. Heelan et al. (2016) also advocate that design is an essential element for facilitating the recycling process. For instance, the recycling process itself could become standardized and eventually automated. Moreover, Heelan et al. (2016) criticize how LIB manufacturing has been handled until now and state that issues of recycling should have been considered by engineers already at the manufacturing stage, instead of leaving it as an afterthought. The concentration of lithium in LIBs is relatively small, Notter et al.
(2010), explain that 1 kg of LIBs consists of 0.007 kg lithium. Busch et al. (2014) explain that if policies are adapted that ensure that a recycling system infrastructure is in place for LIBs by 2025, there is a possibility to reduce the primary lithium demand by 40%. In contrast, Swain (2017) reports that the supply of lithium for automotive LIBs cannot be guaranteed by the year 2023 since less than 1% of lithium is currently recovered through recycling. Furthermore, only 3% of all LIBs are recycled at the moment (Dehghani-Sanij et al., 2019). Only with a 100% recycling rate of LIBs and a recovery rate of at least 90% of lithium, the future lithium demand can be met (Swain, 2017). However, even with the possibility of recovering lithium from recycled LIBs, the quality of such lithium might not meet requirements for reuse in battery production (Ziemann, Müller, Schebek & Weil, 2018).

As explained by Xiao et al. (2017), China is the leading producer of LIBs and holds the largest amount of lithium resources. However, China is not the only country with natural occurrences of lithium. Countries like Argentina, Bolivia and China also possess large deposits of this raw material (Peiro et al., 2013). Xiao et al. (2017) state that as the popularity of LIBs continues to increase, China's lithium reserves are likely to be emptied. Therefore, the authors believe that recycling of lithium becomes crucial for recovering lithium and keeping the existing lithium in circulation. Peiro et al. (2013) came to the same conclusion, explaining that by recovering lithium from LIBs, the production and market for LIBs would be even more satisfied. By improving and optimizing recovery, the authors mention that it is possible to keep lithium as a viable source in the long term. Furthermore, it is stated that recovery processes for batteries are still not sufficient and have to be improved.

2.4 Reverse logistics of lead-acid batteries

RL of EVBs represent an immature market, with some similarities to the developed and highly successful RL market of lead-acid batteries. Lead-acid batteries have been used as starting lighting ignition batteries in regular ICEVs for decades. They are another type of rechargeable battery, which is installed in almost every ICEV driving on the roads today. As a result of the developed market, the RL processes in Europe are standardized, thus creating a closed-loop system (Davidson, Binks & Gediga, 2016; Heelan et al., 2016). The developed closed-loop system allows for secondary lead (recycled lead) to account
for more than 50% of the material for producing new batteries in the world (Sasikumar & Haq, 2011), and 56% in Europe (Davidson et al., 2016). The main driver for collecting lead-acid batteries is that it is cheaper for battery OEMs to use secondary lead than importing lead from primary sources (Subulan, Taşan & Baykasoğlu, 2015). In order to make money out of the used lead-acid batteries, battery OEMs provide customers with discounts for the purchase of a new battery if they return an old one (Sasikumar & Haq, 2011). Another factor that pushed for efficient collection and recycling was social pressure to lower environmental impacts that improper handling of these batteries might have (Ellis & Mirza, 2010; Zhang et al., 2016).

Similar to spent LIBs, used lead-acid batteries are labelled as dangerous goods and are even more toxic and hazardous than used LIBs (Dehghani-Sanj et al., 2019). By efficiently recycling these batteries, the toxic materials will be kept from the environment (Subulan et al., 2015). Therefore, the recycling rates are extraordinarily high and have been stable for many years (Ellis & Mirza, 2010). In Europe and in the US, the recycling rates amount to 99%, and between 95-99% in total for the OECD countries (Dehghani-Sanj et al., 2019). The main reason for the high recycling rates, are the chemical properties and product design of lead acid batteries, which make the collection and recycling both feasible and profitable (Davidson et al., 2016; Sasikumar & Haq, 2011).

Used lead-acid batteries enter the RL chain through retailers or local garages (Ellis & Mirza, 2010), usually without being separated or dismantled (Tsoulfas, Pappis & Minner, 2002). Afterwards, the batteries are collected by 3PLs or other actors in the collection network of the battery OEMs who do not want to perform these activities themselves (Sasikumar & Haq, 2011). The batteries are then transported to the recycling plant (Sasikumar & Haq, 2011), since the collector does not store the batteries (Daniel, Pappis & Voutsinas, 2003). The major uncertainty for the collection networks is that the batteries can be disposed at anytime, anywhere (Tsoulfas et al., 2002). Even though the RL processes are well defined, the main challenge of today is to strategically locate collection centres to lower transportation costs (Subulan et al., 2015).

The toxic nature of the batteries forces the collection network to take certain safety measures in storage and transportation activities. During storage, the batteries have to be
inspected for cracks and leaks regularly (Tsoufias et al., 2002). Further, the authors explain that cracked or leaking batteries must be stored in special closed packaging that is acid-resistant and leak proof. They also describe that batteries can be stored either inside or outside, where outside storage is risky, because they might contaminate the soil or groundwater. Additionally, transportation holds the same requirements, since dangerous goods regulations apply, and the batteries should be charged to avoid short circuits, damage and acid leaks (Tsoufias et al., 2002).

After transportation, the battery arrives at the recycling facility. The recycling steps are basic and have not changed for decades (Zhang et al., 2016). The basic recycling includes: separation of components through breakage, smelting of lead material, shredding of plastics, purification of the electrolyte and treatment of remaining waste (Dehghani-Sanj et al., 2019). However, pyrometallurgical methods for recycling have been developed in the last couple of years (Zhang et al., 2016). Due to the importance of secondary lead, lead-acid batteries are not subject to reuse.

2.5 Institutional theory

The applicability of institutional theory in our study became apparent amidst the process of gathering data. Therefore, this section was added in retrospect as it emerged during the process of examining our empirical findings.

Institutional theory provides an understanding to identify how external factors support the legitimacy as well as the survival of business practices of a firm (Glover, Champion, Daniels & Dainty, 2014). Furthermore, DiMaggio and Powell (1983) state that firms need to comply with guidelines and belief systems which are predominant in their institutional environment in order to be successful and protect their position in the market. The authors also identified three elements which create isomorphic tendencies between different firms in the same industry. DiMaggio and Powell (1983) named these elements coercive, normative, and mimetic isomorphisms.

Firstly, coercive isomorphism deals with the influence either formal or informal institutions are applying onto others in their respective environments (DiMaggio & Powell, 1983). Firms therefore need to tailor their business practices to the regulations or
legislations that governments and professions are applying onto them (Glover et al., 2014). This kind of pressure can be observed in the EU, as the EU passes legislations which make it necessary to recycle electronics, batteries, or a specific percentage of a car (Sbihi & Eglese, 2010). As the authors state, this leads firms to adopt RL practices as they will be held accountable if they are not complying to these legislations. Das & Chowdhury (2012) even regard legislations as the biggest influence on a company’s reverse flow activities. Therefore, governmental bodies apply high coercive pressures on firms to implement RL (Ye, Zhao, Prahinski & Li, 2013).

Secondly, normative isomorphism results in firms showing that their business practices or activities are legitimate (Sarkis, Zhu & Lai, 2011). Customers, the market and society in general greatly influence the legitimacy of a firm due to the growing interest for environmentally friendly processes (Govindan, 2018). As EVBs are of hazardous nature, landfilling could cause serious health issues (Heelan et al. 2016). Thus, the normative pressure drives firms to legitimize their business practices in the eyes of others. Furthermore, RL activities fosters the retrieval of used products and increases the product life as well as material usage (Thierry et al. 1995). Leading to improved relationships with stakeholders and in return legitimizing a firms’ RL activity (Sarkis et al., 2011).

Thirdly, mimetic isomorphism is the consequence of firms facing uncertainty (Govindan, 2018) and focuses on how firms cope with this challenge (DiMaggio & Powell, 1983). The low and unpredictable return volumes of EVBs (Hein et al., 2012; Klör et al., 2018) give rise to mimetic pressure. Mimetic pressure describes a firms’ effort to imitate advanced business practices of competitors (Glover et al., 2014). Parallels can here be drawn to the matured industry of lead-acid batteries where RL has remained the same for years (Zhang et al., 2016). However, companies are also exposed to mimetic pressure in order to be successful in the market (Govindan, 2018). A firm will mimic the RL process of a successful competitor, so they may gain access to the competitors’ advantages (Ye et al., 2013). Further, companies are likely to mimic competitors that are implementing new strategies or concepts, such as RL (Narver & Slater, 1990).

Above aspects show that institutional theory is highly relevant for our study as it incorporates pressures, which influence the challenges we encountered during our
empirical findings. Since the industry of RL regarding EVBs remains immature, institutional theory presents the possibility to link the set-up of a RL chain to the encountered challenges. Figure 3 provides a framework of the institutional theory in order to get a picture how coercive, normative, and mimetic pressure are interrelated with business practices of a firm.

Figure 3. Institutional Theory Framework (own illustration)
3 Methodology

In the following chapter, our overall research approach will be presented through discussing and presenting philosophical and methodological considerations. These considerations are expressed in both broad approaches and more specific techniques and methods that represent the structure and design of the study. Further, an explanation of the process of sampling and collecting empirical data is presented. Followed by how the data was analysed, how quality is ensured, and finally ethical considerations are presented.

3.1 Research Philosophy

In order to assure quality in business and management research it is necessary to understand and be aware of the relationship between data and theory, thereby making research philosophy a key concern for any researcher (Easterby-Smith, Thorpe, Jackson & Jaspersen, 2018). Research philosophy in management and business research can be divided into two philosophical assumptions, namely ontology and epistemology. These assumptions create a bridge between philosophy and research (Tsang, 2016), and will lay the foundation of the research by affecting strategies and methods adapted by the researchers (Saunders, Lewis & Thornhill, 2009). Further Blaikie (2007), explain that ontological and epistemological assumptions represent “particular ways of looking at the world as well as their ideas about how it can be understood”.

Ontology represents the core of any researchers’ philosophical assumptions and portrays the philosophical assumptions about the nature of reality (Easterby-Smith et al., 2018). Ontology in social sciences are mainly concerned with three positions, namely: nominalism, internal realism and relativism. Nominalism advocate that there is no truth and that social reality is solely constructed by individuals through language and discussion (Cunliffe, 2001). Internal realists on the other hand, argue that there is one reality, but “accepts both a scientific realist ontology and an internalist theory of truth” (Ellis, 1988). However, this study follows a relativist ontology, implying that there are many truths and that facts are dependent on individual perceptions of the observer. The objective of this research is to investigate the RL of EVBs and challenges encountered by recyclers and 3PLs. Hence, relating to the subject ontology, illustrated by our goal to gather diverse pieces of information on the same topic from similar sources. We believe
that both internal and external factors influence the perceptions of our interviewees, thereby, suggesting that there is no single truth and that truth indeed is a consequence of the viewpoint of the observer.

The second category of philosophical assumptions is epistemology. According to Easterby-Smith et al. (2018) epistemology mirrors the nature of knowledge and approaches to questioning into the social and physical world. Further, epistemology assists researchers in providing the foundation for obtaining knowledge and making it comprehensible (Johnson & Duberley, 2000). Within epistemology, there are three different views, namely positivism, interpretivism and constructionism, whereas interpretivism and constructionism are compatible with qualitative studies (Punch, 2013). Interpretivism focus on the meaning that individuals assign to behaviour and situations, and how they use these to understand their world (O'donoghue, 2006). For this study, a constructionist approach is applicable, meaning that reality is determined and constructed by people, which is affected by their everyday life and their interactions (Blaikie, 2007; Easterby-Smith et al., 2018; Guba & Lincoln, 1994). Our study is based on the assumption that 3PLs and recyclers have different views on a specific situation. Knorr-Cetina (1983), described that it is likely that the “closure” of scientific debates is influenced by business politics and commercial resources. In relation to this, we believe that the diverse viewpoints are a consequence of their organizational environment, thereby aligning our assumptions with the social constructionist epistemology.

Moreover, Easterby-Smith et al. (2018) state that there is a solid link between ontology and epistemology, not the least between the two assumptions used in this study; social constructionist epistemology and relativist ontology. This combination is usually represented by studies based on questions, comparison and theory generation. Making this combination a perfect match for our study where we carefully choose interviewees and compare the results from these in order to develop a theory of a topic with limited transparency.

3.2 Research Approach

It is important to assign research approaches to the applied research philosophies, because these approaches will be reflected throughout the entire study. According to Creswell
(2014), “Research approaches are plans and the procedures for research that span the steps from broad assumptions to detailed methods of data collection, analysis, and interpretation”. Research approaches can be divided into three separate approaches, namely deductive, inductive and abductive (Bryman & Bell, 2015; Saunders et al., 2009). A deductive approach is based on theory testing in the real world by confirming or denying hypotheses (Blaikie, 2007; Dubois & Gadde, 2002). The inductive approach is focused on building theory from collected data in order to understand how people perceive their social world (Saunders et al., 2009; Thomas, 2006). Strauss and Corbin (1998) explained the inductive approach by stating “The researcher begins with an area of study and allows the theory to emerge from the data”. The abductive approach could be considered a combination of the two previous approaches. Further the abduction aims to examine an existing phenomenon from a new perspective, thus developing a theory instead of generating it (Kovács & Spens, 2005). An abductive approach allows researchers to have a perceptive view and create own interpretations towards the research and not limiting them to previous research (Bryman & Bell, 2015). As previously presented, the phenomenon and field of research related to RL in regard to EVBs is still in its infancy. Consequently, the range of prior research on the subject is underdeveloped. Our study will include institutional theory and aims to modify the existing RL framework (see Figure 2). Thus, rectifying an abductive approach. Abduction includes interpreting or re-contextualizing a single event and tries to gain understanding from a new standpoint (Danermark, Ekstrom & Jakobsen, 2005; Dubois & Gadde, 2002). This research will focus on developing theory based on interviews by analysing and reflecting upon the data gathered in order to obtain new insights and contribute to existing literature. Further, Dubois and Gadde (2002) explain that an abductive approach, in comparison to inductive and deductive studies, continuously modifies a framework “as a result of unanticipated empirical findings, but also of theoretical insights gained during the process”.

Moreover, the research approach is connected to the methodological choice between qualitative research, quantitative research and mixed methods (Locke, Silverman & Spirduso, 2009). Where mixed methods are combinations of qualitative and quantitative research. According to Newman, Benz and Ridenour (1998), qualitative and quantitative research can be viewed as each other's polar opposites. Easterby-Smith et al. (2018) explain that quantitative research is closely related to statistics, where large sample sizes
with pre-coded questions are used in order to identify relationships between variables (Easterby-Smith et al., 2018; O’Leary, 2017). Meaning that quantitative research is more appropriate when testing theory (Zikmund, Babin, Carr & Griffin, 2013).

On the contrary, qualitative research conclude any research that produces findings that are not derived from statistical methods, and where the analysis is interpretative (Strauss & Corbin, 1998). As pointed out by Håkansson (2013), qualitative research is focused on understanding individuals’ meanings, behaviours and opinions. Therefore, the main concern for qualitative researchers is how the data is perceived and interpreted (Finn, Walton & Elliott-White, 2000). Another determent of the quality of qualitative research is the researcher’s interaction with the subject (Silverman, 2013). With regard to the explorative nature of this study, we deem qualitative research to be the most suitable methodological approach. By conducting a qualitative study, we aim at nuancing the topic of this study by exploring a new field of research, that in our opinion requires further investigation.

### 3.3 Systematic literature review

The first step towards approaching the literature review was to generate appropriate keywords for our initial keyword search. Although the original string of keywords “(batter* AND “electric vehicle*” AND (repurpos* OR recycl* OR reus* OR “closed-loop” OR disposal OR “reverse logistics”))” yielded 324 matches, only 18 were in accordance with the requirements of the ABS-list as well as proved to be beneficial for the purpose of a literature review. These keywords were used in three data sources, namely Web of Science, Google Scholar and the Jönköping University online database (Primo). It became clear that most articles addressing the issue of the after-life of EVBs originated from engineering journals, thereby presenting an obvious gap in existing business and management research in the topic. After analysing the articles, the final number was narrowed down even further and had to be complemented with keywords such as “lithium-ion batteries”. In order to increase the number, citations were being traced continuously, also referred to as “snowballing” by Easterby-Smith et al. (2018). When all articles had been reviewed, the final number added up to 18 articles relevant for the EVB-part of the literature review. Moreover, none of the articles examined used EVBs in the context of RL specifically. Therefore, two separate keyword searches were
conducted for the second part of the literature review, including “reverse logistics” AND (automotive OR car OR vehicle), yielding 210 results. Eventually, this number was narrowed down to 24 relevant articles used in the literature review. As well as "reverse logistics" AND "third party logistics provid*", which concluded a total of 15 results, with six relevant articles. Lastly, two additional search queries were made for the latest contributions to the theoretical background i.e. reverse logistics of lead-acid batteries and institutional theory.

As briefly mentioned in the above paragraph, the literature review was divided into two separate categories: EVBs and RL. These categories were then merged and divided into a logical and systematic manner, making it comprehensive and easy to understand. The literature review is intended to work as a guidance and should be reflected in the empirical findings, moreover the objective of the literature review is to contextualize the research questions and the topic of research.

3.4 Research Strategy
The research strategy has been divided into three components. First, the choice of using an interview study will be explained and justified. Second, the sampling strategy will be examined and lastly, the collection of data will be presented.

3.4.1 Interview Study Research
In order to resolve our research questions, we decided to undertake an interview study approach. An interview study, allow researchers and participants to gain mutual discovery, understanding and reflection upon our research questions (Tracy, 2013). Qualitative interviews constitute a guided conversation that revolves around a predetermined and specific topic (Lofland & Lofland, 1984). As we investigate the reverse logistics set-up and challenges of EVBs, interviews with companies in the related field yield the best option to gather data. Accordingly, Rowley (2012) state that interviews are a legitimate way to gain access to the understanding of processes. Furthermore, an interview study is justified since the interviewed companies are quite similar. Therefore, differentiation into multiple cases according to Yin (2018) proved difficult and would be inconclusive.
To compile valuable data, the decision about the right form of an interview needs to be made. Interviews can be classified into three different structures, namely structured, unstructured, and semi-structured interviews (Edwards & Holland, 2013; Gill, Stewart, Treasure & Chadwick, 2008). In a structured interview questions are formulated rather short and the environment can be rather tense which can lead to unjustifiable answers (Adhabi & Anozie, 2017). Additionally, the authors mention that researchers need to keep the order of their question. While Stuckey (2013) emphasizes the importance that interviewers should not respond to answers with agreement or disagreement as well as imply answers. The unstructured interview can be characterized that no pre-planned questions from the researcher are present (Adhabi & Anozie, 2017). However, they also mention that today an interview can be classified as completely unstructured. Similar to the structured interviews are the semi-structured interviews, because questions are also predetermined (Stuckey, 2013). Nonetheless, questions do not need to be followed as stringent (Adhabi & Anozie, 2017), therefore offering flexibility, which allows the researchers to adapt to contextual differences between interviewees (Mason, 2002). Therefore, the semi-structured interview poses as the ideal form of conducting our interviews. Since our study depends on the knowledge we gather through the empirical data, it is crucial to have the possibility to adapt questions, as well as asking additional questions.

3.4.2 Sampling strategy

According to Eisenhardt and Graebner (2007) theoretical sampling is connected to the development of theory and that companies are selected because they are specifically suitable for the desired variables in the study. Hence, the companies chosen for this study will aim at extending an emerging theory. Saunders et al. (2009) makes the distinction between two techniques for selecting samples, namely probability sampling and non-probability sampling. Probability sampling is associated with research connected to surveys, which is not the case in this study. Instead, non-probability sampling is used as the primary data collection. Non-probability sampling does not include random samples, but rather carefully evaluated decisions where a limited number of companies for interviews are selected. These companies should be able to provide the authors with theoretical insights and help to answer the predefined research questions (Saunders et al., 2009). In order to increase accessibility and connection between the interviewees, a
certain degree of ad hoc sampling is applied. Easterby-Smith et al. (2018) describe this phenomenon as snowball sampling, which means that cases are collected through recommendations from people. Snowball sampling is especially useful since we are planning on collecting information from both 3PLs and recycling firms. For instance, one interviewee refers us to another reliable and relevant source for a potential interview.

For non-probability sampling there are no rules regarding sample sizes, instead the authors must deem what they think seem logical and what number seem relevant for answering the research questions (Saunders et al., 2009). For this study, we considered an initial sample size of six to ten companies, which eventually resulted in eight participants.

3.4.3 Collection of data
All interviewees were approached either via email or phone, according to Tracy (2013) approaching potential interviewees by email is perfect when contacting busy professionals. Furthermore, most participants were open for follow up interviews and questions via email, which made it convenient to gather additional information in retrospect. All interviews were conducted in English. In order to facilitate the transcription process, all interviews, besides one, were recorded with the permission from the interviewees. In total, 40 companies were contacted, including both recyclers and 3PLs managing EVBs. According to Håkansson (2013), qualitative researchers gather sets of reliable data until saturation has been reached. In our study, data saturation was reached after 8 interviews, meaning that we had gathered the amount of data that we needed.

Prior to conducting our first interview, we developed two sets of customized interview questions that emerged from taking part of literature, one for 3PLs and the other for recyclers. Some interview questions were applicable to the entire industry, hence allowing us to use the same specific questions in both interview guides. Other questions were more open ended and company specific, thus allowing us to adapt the interview questions depending on the nature of the company.
During the interviews, the researchers undertook specific roles that are in line with a tactic presented by Eisenhardt and Bourgeois (1988). The tactic comprises that one researcher handles the interview questions, while the other researcher is responsible for recording and taking notes. Easterby-Smith et al. (2018) state that it is crucial that interviewees create a setting that allow interviewees to open up and provide insights, by doing so, superficial conversations can be avoided. Therefore, the researcher taking notes was responsible for asking in-depth questions on what the interviewee mentioned during the interview. In Table 1 each company will be briefly presented followed by the specifics of the interviews.

**Table 1 Interview Respondents**

<table>
<thead>
<tr>
<th>Company</th>
<th>Industry</th>
<th>Position</th>
<th>Date</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company A</td>
<td>Recycling &amp; logistics</td>
<td>Research &amp; Development</td>
<td>27th March 2019</td>
<td>77 min</td>
</tr>
<tr>
<td>Company B</td>
<td>Third party logistics</td>
<td>Account Manager</td>
<td>2nd April 2019</td>
<td>60 min</td>
</tr>
<tr>
<td>Company C</td>
<td>Third party logistics</td>
<td>Upper management</td>
<td>3rd April 2019</td>
<td>86 min</td>
</tr>
<tr>
<td>Company D</td>
<td>Third party logistics</td>
<td>-</td>
<td>10th April 2019</td>
<td>41 min</td>
</tr>
<tr>
<td>Company E</td>
<td>Recycling &amp; logistics</td>
<td>Customer relations manager</td>
<td>11th April 2019</td>
<td>52 min</td>
</tr>
<tr>
<td>Company F*</td>
<td>Recycling</td>
<td>-</td>
<td>12th April 2019</td>
<td>79 min</td>
</tr>
<tr>
<td>Company G</td>
<td>Recycling &amp; logistics</td>
<td>Managing Director</td>
<td>17th April 2019</td>
<td>74 min</td>
</tr>
<tr>
<td>Company H</td>
<td>Third party logistics</td>
<td>-</td>
<td>18th April 2019</td>
<td>75 min</td>
</tr>
</tbody>
</table>

* Company F did not want to get quoted in the thesis

- No position was mentioned by the interviewee

In our study, 87.5% of the interviews were conducted via Skype. Skype is a free software that enables people to have audio or video conversations wherever they are (Deakin & Wakefield, 2014). Skype offers a range of advantages for both the participants and us as researchers and was therefore chosen as the predominant method for interviews. Since our participants were located in different countries, traditional face-to-face interviews would have been difficult to conduct as geographical boundaries are recognized as a problem in literature (Deakin & Wakefield, 2014; Easterby-Smith et al., 2018; Janghorban, Roudsari & Taghipour, 2014; Lo Iacono, Symonds & Brown, 2016; Tracy, 2013). Skype allowed us to perform the interviews regardless of geographical restrictions and seemed to be preferred by all interviewees. In addition, carrying out the interviews saved us substantial cost and travel time in order to being present at the choice of location from our interviews (Seitz, 2016). Besides the advantage of minimizing locational constraints, scheduling Skype interviews is also not as troublesome since interviews can more easily be rescheduled (Hanna, 2012; Seitz, 2016). While conducting the interviews
it was only needed to reschedule interviews two times, once because of an unforeseen business trip and the other time because of technological issue, however this issue will be picked up in the later part of this paragraph. Nonetheless, both participants were sending us a new time and date. Another benefit is the flexibility of times for the interviewee in regard to the time the interviews is scheduled as well as run over time with the interview (Lo Iacono et al., 2016). This was a very positive aspect for us since, as some interviews took longer than the anticipated time and interviewees were willing to extend the scheduled time frame.

Even though using Skype as a method for conducting interviews pose some advantages, there are also some disadvantages. This becomes evident when the video function was unwanted or of bad quality. Since non-verbal gestures are important to interpret the answers from respondents and in order get a feeling if there is more to ask (Seitz, 2016; Weller, 2017). Additionally, even when the video function was of good quality, the camera captured only the upper body or the head, which also makes it hard to read the complete body language of the respondents as stated by Lo Iacono et al. (2016). As mentioned previously, one interview had to be rescheduled because of technical issues. Seitz (2016) states that researchers and participants should both have updated to the latest version of Skype in order to not face any difficulties. In our case, the problem was that we used the business version of Skype while the participant only had access to the normal version of Skype and could not take part at the scheduled time. The interview had then to be rescheduled and a phone interview had to be conducted without the possibility of the video function. However, in order to decrease the loss of non-verbal gestures it is even more important to carefully listen to the participants voice (Seitz, 2016).

Concluding, the advantages of Skype interviews, in our case, outweighed the disadvantages and was therefore chosen as the method of choice. Furthermore, we gave all our participants the option to select between face-to-face and Skype interviews and all of them chose the latter.

3.5 Data Analysis

In order to analyse our data, we chose to use a thematic analysis approach within our interview study. Since we are taking an abductive approach, it is possible to identify,
analyse and report qualitative data and organize themes and patterns (Braun & Clarke, 2006). The themes and patterns commonly emerge through coding the findings (Saunders et al., 2016). In order to be transparent and as comprehensive as possible in our coding process, we decided to adapt the framework provided by Braun and Clarke (2006), which includes six steps.

The first step as proposed by Braun and Clarke (2006) and Saunders et al. (2016) is to get familiar with the qualitative data collected. In our case this was done through transcribing the interviews and reviewing each transcript individually. This led us to reading and re-reading the transcripts multiple times and getting acquainted with the data.

In the second phase, it was necessary to generate codes for specific data segments. Generating these codes helped to organize data with comparable meaning as each code summarizes the meaning of the extracted data (Saunders et al., 2016). In Table 2, examples from our data are given. Once we created codes for all the interesting data segments, we moved to phase three of the thematic analysis framework.

Table 2 Example of initial codes with data segments

<table>
<thead>
<tr>
<th>Quote</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>For transportation the so-called ADR requirements apply</td>
<td>Transport regulation</td>
</tr>
<tr>
<td>All truck that are driving has to be ADR trucks</td>
<td>Special trucks for transport</td>
</tr>
<tr>
<td>You need to define on which ADR regulation you are doing the transport</td>
<td>Transport specification</td>
</tr>
<tr>
<td>ADR requirements defines packaging</td>
<td>ADR packaging</td>
</tr>
<tr>
<td>Provide special packaging material that meets the dangerous goods regulations</td>
<td>Dangerous goods packaging</td>
</tr>
<tr>
<td>ADR requirements defines packaging, […], and defines what needs to be done if you would like to do a transport</td>
<td>ADR defines packaging</td>
</tr>
<tr>
<td></td>
<td>ADR defines transport</td>
</tr>
</tbody>
</table>

In the third phase the generated codes should be grouped together into appropriate themes (Braun & Clarke, 2006). However, as Saunders et al. (2016) states, themes already start to emerge in the two stages before the third phase. This was no different for us, as we experienced similarities in data segments or recurring codes, which were then noted down in order to connect these ideas of themes to other codes we generated. In Figure 4, an example of initial codes from the table above with the first theme is portrayed.
The fourth phase of the analysis incorporates the need of reviewing found themes in order to build a consistent group of themes which then contributes to a well-structured analytical framework (Saunders et al., 2016). For our case this can be observed on the next page. Figure 5 shows that initial themes are now grouped into more coherent themes.

After the previous phase Braun and Clarke (2006) describe that the themes should be refined for a final time. Therefore, in the fifth phase, we cross-check the data with the
themes and re-evaluated themes if necessary. Themes were renamed if it was not instantly clear what the theme wanted to express. The final themes with sub-themes can be found in the beginning of the analysis part, where they are covered in more detail. Thematic analysis concludes with the sixth and final step, producing the report of the analysis which can be found in chapter five (Braun & Clarke, 2006).

3.6 Research Quality

This section will illustrate what actions and considerations that we applied to our findings and conclusions. More specifically, we want to assure that our study generates results that are of high quality in terms of credibility and trustworthiness. According to Saunders et al. (2009), qualitative studies has to have validity and reliability. In order to achieve high validity and reliability, we applied the criteria presented by Guba (1981), which includes credibility, transferability, dependability, and confirmability. However, we begin with explaining how transparency is incorporated into our research.

In order to be able to replicate our research, the principle of transparency as an indicator for quality is very important to us. However, as Rohleder and Lyons (2014) state, the description of research is always vulnerable to the information transmitted by the researchers. In our case, replication of the literature review can be done rather easily, since we provide our keywords in connection with Boolean operators and the value criteria for potential articles. Still, the data sources will change over time, since new articles will be written and can then also be found in connection with our keywords. For the interview part, replication is more difficult. Even if other researchers would interview the same person, it is likely that the interviewee would provide different answers due to possible new insights. Regarding the analysis, it is possible that the background of the researchers reflected the codes extracted from the findings. However, through including our codes in the thesis, researchers can partly follow our thoughts.

Credibility is a criterion that is closely related to “truth value”, which concludes how convinced the researchers are with the findings, research design, context and interviewees (Krefting, 1991). Lincoln and Guba (1986) stated that the purpose of the researcher is to accurately represent the realities presented by the interviewees. There are numerous strategies addressing how to enhance the credibility of a study. Krefting (1991), identifies
concept, interpretation and informants as main factors affecting the credibility of the research. To maintain high credibility in our research, we spend a considerable amount of time in analysing and interpreting the gathered data. By individually analysing the empirical data, we then compared the results in order to minimize the risk of misinterpretation. Furthermore, we try to extend our engagement with each interviewee by sharing the transcription and analysis with them. By doing so, the interviewees have the opportunity to interfere and correct any potential mistakes.

Dependability is directly related to how consistent the findings are, therefore, each specific method used for data gathering, interpretation and analysis must be explained (Krefting, 1991). In our study, we put a lot of emphasis on consistency. We use the same interview guides for each company depending on their main industry, meaning that the base for each interview is the same. These interview guides are illustrated in the appendices. Additionally, all companies and interviewees were approached and treated the same way. Moreover, all interview recordings, notes, transcriptions and email conversations are accessible and safely stored.

Confirmability could mainly be achieved through auditing, meaning that another researcher takes part of the unfinished study in order to make sense of why certain decisions were made (Guba, 1981). Guba (1981) also explains that the purpose of the audit is for the auditor to try to derive similar conclusions from the same material and context as the original authors. For our study, confirmability is achieved through a continuous peer-review process that is organized by the university, where we mainly discuss methods and strategies. The peer-review group consist of a supervisor and six other students, constituting three teams. Each team were dedicated two peer-reviewers from separate teams, resulting in two auditors for each occasion plus the supervisor. These meetings allow us to share our thoughts and results with colleagues that are also in the same process of writing their thesis, which provides us with valuable insights. Furthermore, the content of our study is internally discussed on a daily basis. We are also sharing our ideas and findings with people that are not directly related to the research in order to gather more diverse perspectives.
Transferability is concerned with the extent a qualitative study can be transferred to other situations (Anney, 2014). Guba (1981) states that in order to have the chance of transferability three factors need to be considered. First, a purposive sampling approach needs to be at hand. This means that interviewees are chosen who might have a different point of view from each other about the topic in research. Second, researchers need to collect rich data, which allows to make correlations from one situation to other possible situations. Last but not least, once the study is conducted an impenetrable description of the context needs to be established. Through the description, suitable situations besides the one studied can then be identified.

3.7 Ethics

From the beginning till the end of this research we need to consider ethical considerations in order to ensure quality of our research, as well as to protect research participants and the integrity of the research community (Easterby-Smith et al., 2018). With that in mind, we will adopt some of the ten key principles of Bell and Bryman (2007) in our research. Table 1 shows the key principles we endorse and in the next paragraph we will then show how they are applied in our research.

<table>
<thead>
<tr>
<th></th>
<th>Ethic principles (Bell &amp; Bryman, 2007)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ensuring that no harm comes to participants</td>
</tr>
<tr>
<td>2</td>
<td>Ensuring a fully informed consent of research participants</td>
</tr>
<tr>
<td>3</td>
<td>Ensuring the confidentiality of research data</td>
</tr>
<tr>
<td>4</td>
<td>Protecting the anonymity of individuals or organizations</td>
</tr>
<tr>
<td>5</td>
<td>Avoidance of any misleading or false reporting of research findings</td>
</tr>
</tbody>
</table>

In order for us to ensure that no participant will be harmed, participants were informed about our study and how their interviews will be used in the remaining part of our research. Furthermore, no personal data besides their professional position will be published so both privacy and anonymity of the individual are guaranteed. In order to assure the privacy of the company, neither name nor details about the company are shared in the interviews. Therefore, transcriptions of the interviews are sent to the interviewees, that they may check if no link to them or the company can be made. We will also ensure confidentiality of research data through encrypting data from the interviews which are
then kept in a safe location. In order to prevent any form of misleading in our research findings, we will let our interviewees audit our findings so there will be no misinterpretations of any kind.
4 Empirical Findings

This chapter will present the empirical findings that were collected during the interviews. The findings are structured based on three phases, within these phases there are certain process steps. For each process step, accompanying challenges and relevant data is presented.

In the findings it could be observed that handling EVBs is a complex activity with no clear guidelines regarding how the RL is supposed to be set up. However, the identified RL processes of all companies were of similar nature. The challenges identified also had some similarities, however they did not share the same conformity. In order to provide a clear overview of the findings, they are structured according to the similarities discovered in the process steps. Within each process step, factors associated with complexity in the RL are contextualized and exemplified. The structure of the empirical findings emerged from the interviews and is consistent with the research questions. The process steps constitute the setup, and the challenges are encountered within these steps. Additionally, the process steps are divided into phases, these phases are somewhat disconnected from each other in the RL network, while the process steps within the phases are closely connected. The overarching phases consist of 1. Pre-collection Phase, 2. Collection Phase and 3. Recycling & Repurposing Phase. While the RL process steps are divided into seven different categories, namely 1. Battery reaching EOL, 2. Assessment of battery, 3. Packaging, 4. Transportation, 5. Storage, 6. Recycling and 7. Repurposing. Before introducing the phases and steps, an overview of the current market situation will be presented. In order to emphasize the main challenges presented in the findings, they will be highlighted.

4.1 Current market

The volumes of EVs sold are steadily increasing every year, entailing that there will be a huge business opportunity for handling EVBs in their EOL. However, since the approximate life-time of an EVB is 8-10 years (Company A), or 5-10 years (Company B), the EVBs entering the RL chain remain very low. This creates uncertainty and makes it hard for recyclers and logistics providers to develop functioning business models, because they are based on predictions. Therefore, Company A plans to “follow the
development [...], learn and expand with the batteries” (Company A). It was also made clear that the low volumes are affecting the entire industry. Company B mentioned they are part of an expert network of logistics providers, who are all facing the same issues related to volume.

Company H problematized the challenges related to **low volumes** by stating that “The thing is if there's no volume, you are able to do less consolidation and the overall costs are a lot higher. And this is not only transportation, this is also for recycling facilities and so on.”. These **high costs** in combination with low volumes makes the RL market for EVBs “a niche market” (Company B). Statistics over how many EVs that have been sold in certain regions makes it possible to forecast how many EVBs that will be returned in the short term. For instance, Company A provided some statistics over EVs sold in Sweden. From 2010 to 2013 the EV sales had a tenfold increase every year and in 2015 the EV sales reached the thousands (Company A). It was also around this time most companies started looking into the business of handling EVBs in their afterlife. Most interviewees agreed that the volumes of returned EVBs will reach critical mass by 2025, or even sooner. Company D explained that “[...] it's going to be a couple of years until large amounts of batteries will come back”, while Company B described that the first wave of outdated batteries will arrive in three to four years.

According to Company C, there will be 30 million EVs driving on the roads all over the world in 2025. While also stating that the current global RL does not have the capacity to handle such volumes. Therefore, actors are taking certain measures to be prepared and gain more knowledge about the industry. Company E mentioned “For this business you have to plan for the future”. Company D stated that “this is not only sending a truck that will pick up the battery and delivered to some recycling facility [...] for example, provide special packaging material that meets the dangerous goods regulations [...] there's a lot of special paperwork, in order to transport them, that has to be prepared”. Company A is in the recycling business and has been taking part of several research projects in the last couple of years to learn and prepare for the expected volume increase. Further, Company A explained that “the first three four years it was mainly like following and the learning but what's happening now the last year is going from more research to action or business”.

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The majority of the participants in this study have previous experience from either recycling, collecting or transporting lead batteries. For instance, Company E stated that “We started with lead batteries that mostly from start batteries from the cars. So that is still our biggest area”. Since the industry is shifting from lead-acid batteries to LIBs, many companies want to be a part of the transition. This was exemplified by Company H, who stated “[...] the whole industry is shifting to this direction [...] it's clear that you need to be part of that.”. According to the interviewees the background of handling lead-acid batteries gives them an advantage in handling LIBs since they already have established networks for battery logistics. Company G addressed that even though EVs would be considered as additional quantity to ICEVs and lead-batteries or if EVs would be a substitution, their system would still be able to cope with the volumes. Due to their current capacity of battery logistics, Company G mentioned that “if people think of used batteries, they think of us and this [...] led to the case when we said, okay, we need to develop a solution for the lithium collection”. Furthermore, Company A has been recycling ICEVs for several years and explains the transition from ICEVs to EVs, and LIBs, was a natural step as they follow the industry trends. Moreover, Company A thinks that more actors will enter the RL process once the volumes go up, “I wouldn't be surprised if there are others also that are at least looking into this”.

Apart from the fact that it was obvious that EVs is starting to take over the automotive industry, many interviewees experienced that external parties approach them and ask for their solutions. An example is provided by Company E that mentioned “we have daily phone calls about if we can help companies to take care of these lithium batteries”. Furthermore, Company A shared that “everyone talks about lithium-ion batteries today and it's a huge interest both internally, but also from other companies, car companies ask us what our solutions is”.

Logistics providers participating in this study highlight the importance of know-how and offering value adding services in the form of a value chain. Today, automotive OEMs are targeting service and logistics providers for a full solution for the RL of EVBs. Their incentives are to establish a SC network that is capable of handling increasing numbers of returned EVBs. According to Company D, a service provider would be able to facilitate
the process for automotive OEMs by providing a “one stop shop service”, where the entire RL chain is centralized. Such a solution would remove many complex steps that the automotive OEM otherwise would have to deal with themselves. Furthermore, Company D stated that providing full solutions gives them a huge advantage in comparison to pure logistics and recycling providers. Company C also provides a similar service which started when automotive and battery OEMs contacted them saying “nobody can fulfil our requirements”. That was when Company C started developing their RL processes described as a “sophisticated boutique solution” (Company C).

4.2 Pre-Collection Phase
The pre-collection phase is greatly influenced by the state of the current market situation as it is correlated with how and when EVBs enter the RL flow. The upcoming section will provide insights about the first two activities within the RL setup.

4.2.1 Process Step 1 – Battery reaching EOL
An EVB can enter the reverse flow in several ways, mainly depending on the nature of the company. Also, due to the early nature of the topic, there are not many practical examples of how the process starts. Company C explained that the start of the process can be very unpredictable and provided some examples. For instance, defective batteries, product recalls and accidents are common triggers of the RL process today (Company C). Further, Company B expressed that a possible trigger could be that the automotive OEMs do not accept a battery received from the battery OEM.

The orders for spent EVBs can be divided into spot businesses and contract orders. According to Company G, spot business works like this “batteries occur somewhere and people say okay, I need a solution, and we say okay, we come to pick it up”. Furthermore, Company E describes their process by stating “customers are calling or emailing us and order the transportation, that's the way it works. Then of course, if they are non-critical we have to plan for our transportation so they can use the trucks in the most economical way”. Contract orders are straight forward, the contract is based on negotiations, often with automotive OEMs. As reported by Company G, agreeing on a contract with automotive OEMs can be cumbersome, “negotiations with OEM are not always very easy”. Apart from normal collection contracts, Company G offers their regular customers
packaging which they can store and once they have an EVB available they can put in the battery themselves and then Company G can pick it up.

Basically, RL providers are contacted by dealerships or automotive OEMs asking for a solution to get rid of the EVB. According to Company H, each order differs depending on the specific customer requirements, which forces the actors in the RL chain to be flexible. When an order is being placed, certain details have to be stated, some examples are: the collection address, volume, weight, if the battery is packed and if the battery has been classified by a dangerous goods expert (Company H). The classification is the most important part, because if the batteries are already classified by a dangerous goods expert the normal procedure can start. Otherwise the battery has to be classified and, in some cases, transported to a warehouse, Company B stated that “Which is let's say kind of a grey-zone because basically we are only allowed to transport dangerous goods when it's certified. So, most of the cases, it's checked locally at the place, and then we exactly know what to do and we have to transport or to store it.”.

4.2.2 Process Step 2 - Assessment of batteries

Batteries can enter EOL in different ways but mainly through accidents or that they naturally have reached the approximate capacity limit of 80%. Due to the hazardous nature of LIBs, battery assessment is an important step. These batteries have to be categorized in order for the involved RL partners to know how they have to be handled. Company C, Company F, Company G and Company H agreed on the same classification: namely critical and non-critical batteries. While the remaining companies classified EVBs as either damaged or not damaged, but the principle is the same. Non-critical batteries can be either damaged or not damaged, while critical batteries are severely damaged, and their state is considered not to be stable. Company G clarified this by explaining “So if that cannot be really classified as undangerous, they are classified as so-called critical batteries, critical for transport, or unsafe for transportation. And then you need a special approval for those batteries”. Critical batteries must be handled with caution, they require special packaging, storage and transportation, which will be further presented in the upcoming process steps. Even though non-critical batteries have less restrictions, they still require special handling. Non-critical batteries have to be transported as dangerous goods and are considered as waste; therefore, they also require
special UN-approved packaging, transportation and storage. Regarding the future volumes of critical batteries, Company C estimates that approximately 2% of all returned batteries will be critical, while the remaining 98% will be non-critical. Even though non-critical batteries are far less dangerous, they still pose certain risks since they are labelled as dangerous goods. Critical batteries are usually transported directly to the recycling facility, since they no longer have the possibility to serve a purpose in any vehicle or in their afterlife.

Many EVBs being returned today are in fact damaged, defective or critical since almost no EVB has reached their EOL naturally i.e. the 80% capacity limit. Company G explained this by stating “I would say 50 to 60% of the batteries coming back now are damaged or even critical due to having an accident or having a production issue”. For instance, a great deal of batteries entering the RL process have been used in test productions or R&D projects. Company H simply described the current situation by explaining “if a battery is defective, we take it back”. Regarding critical batteries, Company C explained that every battery implies a significant administrational process which must be organized. Further, it was elaborated that it “it’s very easy if you have to ship one battery per week. But when we know that there are gonna to be a few million electric vehicles on our roads in the few years from now, you can also count together when the big wave of reverse logistics will kick in. So today we can sit organize this you know, it's manageable. In five years, you need [...] ultimate systems to manage it because it will be no longer possible to administer this from a manpower perspective, it's just it's just too big, too large and too complex” (Company C).

Misjudging the state of an EVB can have severe consequences, therefore technical expertise about the battery chemistry is necessary for all companies involved in the RL chain. During the interviews it became clear that it is a challenge to determine the status of an EVB. Company B mentioned that “in reverse logistics the situation is more complicated as there are different types of damages which are tough to identify”. Even though some companies in this study mentioned that they do not handle critical batteries, Company H explained that “You can have the batteries on the shelf for half a year and nothing happens and when you take them out, then because of the movement of the batteries this could start already a reaction”. The complexity of initially assessing the
physical state of an individual battery is illustrated by Company H, stating that “[…] if this person cannot decide or he's not sure that there could be a reaction of the could be no reaction. Then it's definitely critical […] this is not an easy one because, basically he needs to be an expert […], secondly, he needs to know what has been done in the normal use of the batteries. Normally a person cannot decide it”. Company C addressed the importance of accurately assessing batteries and determining whether they are critical or not by stating “[…] because if this is a critical battery that means during transportation there can be a chemical reaction within the cells, there can be a short circuit and everything, this truck is catching fire and not only the truck goes on fire and the truck goes in flame”.

Every EVB must be checked and approved by a certified dangerous goods expert (Company B). Even if an EVB has been classified as non-critical by either internal or external experts, certain safety measures are still needed, which presents a challenge. According to Company B, classification is the most decisive factor for the RL of spent EVBs, since it determines to which extent the battery is damaged and under which UN-numbers the logistics must be done. Further Company B mentioned that this is one of the most important aspects in the future, more specifically that a “certified dangerous good experts which is easy accessible which is fast there and which gives you quite a fast go or no go or declaration what can be done and what has to be done with the battery”. Company H also raised the same concern, stating that “One major issue how to decide on the physical state of batteries, because right now there's nothing out where you can have a simple diagnosis”. Company E explained that their customers often times have a safety advisor who makes the assessment of the state of the battery, then Company E receives documentation stating whether the battery is critical or not. However, Company E also states that “But then there might be batteries in which you are doubtful […], these assessments are always done by us as well, especially when we can't know for sure that the batteries are non-critical.”. Other companies do not transport or handle critical batteries at all due to the high risks associated with it. However, the uncertainty and the difficulties in properly assessing their status have led Company G to take certain safety measures anyway, because “Of course, you never know what is happening”.
4.3 Collection Phase

In order to collect (e.g. store and transport) used LIBs, special permissions are needed. This was reflected in the interviews, as every participant mentioned the importance of complying with regulations and getting special permissions. “So, you have to match both worlds of regulations, the waste transport regulation and the dangerous goods transport regulation” which was stated by Company D. Furthermore, all companies specified the challenge that regulations differ from country to country. Thus, forcing firms to adhere to every country’s regulations and not only the one which it is transported into. Company B explained that “[…] it's really highly complicated, because of the different regulations, country wise”.

A vital role in why there are permissions needed is the declaration of LIBs as dangerous and hazardous goods. Furthermore, all companies dedicated a great deal of their time in explaining the dangerous nature of these batteries in order to make clear that these transports are not out of the ordinary. While for most parts interviewees always mentioned fires or explosions as big dangers, Company G was the only one to mention “a really underestimated risk, is the risk of electric shocks”. Another company expressed the notion that a high voltage expert has to be involved when extracting the battery from an EV. Risks related to packaged batteries are fires and even explosions, which could be a consequence of a short circuit within the battery. Short circuits could occur when an EVB leaks hydrofluoric acid. This is especially important as lithium fires are not able to be extinguished and poses a challenge for every firm working with LIBs. People working with damaged LIBs need to take other precautions as well in order to get them ready for collection. Company C stated that “you’re working with gas masks […] because there may be fumes […] evaporating from the battery because it is damaged”.

Another point in the collection phase is the discussion of a unified design for LIBs. This was a highly discussed topic in the interviews with very diverse aspects from the interviewees in the field of 3PLs as well as actors in the recycling industry. While for Company B “the main issue with the constraints are the weight issues. So, lithium-ion battery for cars are comparable heavy with around 400 - 600 kilograms […] So it's a limited capacity when you transport this […] on the road” and explicitly mentioned that there were no problems size wise another interviewee had a different opinion. “The sizes
of the full electric vehicle batteries are so awkward with regards to transportation that I always have to use loading meters instead of pallet positions” (Company C) shows the disagreement in the industry about a favourable design of LIBs. Though most of our interviewees recognized that a unified design will be favourable since “It's always easier if you have just one type, one design” (Company H). However, they acknowledged that the chances of actualizing a unified design will be almost impossible. This is well represented by a statement from Company D “they (battery OEMs) do not want to let anybody look into their technology. [...] So, I don't think it's possible to establish a unified battery design”.

4.3.1 Process Step 3 - Packaging

While the previous paragraphs talked about general aspects of the collection phase which are applicable for all steps, the packaging step incorporates facets of findings for both critical and non-critical LIBs. As the previous paragraph stated, batteries weigh approximately 400 – 600 kilograms. Therefore, this weight also poses challenges for the packaging step. Special equipment is needed in order to lift and move these heavy batteries and pack them into the appropriate boxes. While non-critical LIBs are easier to handle and arrange packaging for, firms still “have to [...] provide special packaging material that meets the dangerous goods regulations” (Company D). Critical LIBs are subject to more sophisticated packaging. This packaging consists of a fire extinguishing system, which is quite costly depending on the size of the box, further “you must by law, [...] you have to transport the critical battery in this box” (Company C). It is therefore essential to have the right packaging in order to transport the batteries without having to worry about any reactions which could occur during the transport. Since packaging is quite costly “we are also sharing boxes [...] in order to drive the overall logistics costs down” (Company C). The option to share such boxes is a creative way to overcome the binding of capital. Additionally, as explained in the beginning of this chapter, volumes of LIBs are still quite low and sharing these boxes helps to utilize their potential use. This is particularly interesting since “we're happy to buy it for our customer, but we would like to charge the customer back for that” (Company C). So, utilization of these boxes is another aspect 3PLs are working on in order to deal with the low volumes on the market at the moment.
4.3.2 Process Step 4 - Transportation

In the collection phase an interviewee made it clear that it is important to note that they distinguish between transports to a consolidation point, transports from the consolidation point to a recycling facility, and a direct transport to a recycling facility. The set-up is described by Company H as “Primary collection is the leg from the collection point to the consolidation point. [...] then you have a so-called secondary logistics, which is then from the consolidation point, [...] to the recycling facility. If already a collection point has lots of batteries there could be direct transport to the recycling facility [...] and with the critical batteries you need to do a direct transport”. Other interviewees mentioned transports to and from consolidation points as well, though did not distinguish them explicitly in the interviews. It was however expressed that LIBs cannot be transported from customers to consolidation points or EOL facilities at their own free will. There are time slots the 3PL has to acknowledge and plan accordingly. Furthermore, transportation is a rather expensive part of the reverse flow. The low volumes cause limitations for consolidating EVBs, Company C explained “If I were to pick up an empty battery in Sweden, and have to bring it back to Germany, my cost is probably around 5000 Euros [...] But the moment I have three batteries [...] I can cut the cost by three. But we don't have the critical mass yet”. This was confirmed by an interviewee who mentioned that cost for logistic operations are often undervalued (Company E). However, Company G expressed that “logistics is a big cost issue [...] still recycling is the more expensive part” which has to do with the different steps during the recycling process.

As all interviewed companies operated in Europe and rely on road transport, the ADR requirements for transporting dangerous goods apply and constitute a challenge. These requirements “defines packaging, means of transportation, [...] and defines what needs to be done if you would like to do a transport order transportation with waste” (Company H). So, all firms are bound to the legislation of the ADR for the transport of LIBs and for LIBs there are pages which state exactly the proceedings on how to handle LIBs. It was also brought to our attention by another interviewee that people often do not know about the specialized handling of LIBs because their main business is not with these batteries. However, firms are dedicating valuable personnel to ADR as these requirements are updated on a constant basis that is why “we have three people studying these regulations, all the time” (Company C). Additionally, the different legislations from individual
countries are coming into play as well. For transporting LIBs, especially critical ones, local authorities need to be notified and the authorities will then tell the firms the route they are able to take. This is done to ensure safety, not just for drivers of the truck, but the general public should an undesirable event happen during transportation.

4.3.3 Process Step 5 - Storage

Storage is another vital part in dealing with LIBs. Requirements related to storage usually differ depending on the responsible local authority. As Company C mentioned “the segregation and a standard distance to the next row of pallets, which can be anything between two meters up to six meters, depending on [...] requirements [...] you're allowed to store these goods but you can only stack two high, and you need to have a distance of 1 meter 20 cm in between the layers”. This already shows the difficulties in handling LIBs for storage with acquiring adequate facilities for them which is a new challenge with the new LIBs from the automotive aftermarket. Furthermore, storage of LIBs also needs to consider the possibility of batteries changing from non-critical to critical. Safety measures for such events need to be taken in advance. These measures depend on the status of the batteries but range from personnel controlling the heat of the LIBs, putting them into determined quarantine zones to “have a box with wheels, which they then bring to the fresh air [...] and you just let it burn and try to make damage as small as possible” (Company G). These safety measures need to be aligned with the legislations about dangerous goods in the respective countries.

As mentioned before the LIBs provided a new kind of challenge and 3PLs “take the advantage for this storage, because every additional requirement is increasing the profitability” (Company B). Though a lot of firms mentioned that storing these batteries is rather troublesome activity and a direct transport to the recycler would be preferable or as Company A put it “storage is just costing money and it's a safety risk”.

4.4 Recycling & Repurposing Phase

Recyclers have their own logistics network and cooperate closely with 3PLs. 3PLs work closely with recyclers through joint ventures and close relationships in order to form an effective collaboration effort for spent EVBs. Therefore, 3PLs have insights in recycling. Moreover, this section will present uncertainties and challenges in repurposing today, to
what extent the companies participating in the study are involved in repurposing and their thoughts about the future of repurposing. During the interviews the terms ‘second life’, ‘reuse’ and ‘repurposing’ were used interchangeably.

4.4.1 Process Step 6 - Recycling

As mentioned before, most EVBs entering this part of RL, currently come from test projects or accidents. Moreover, the recycling Company A explained that “what we see now is then that also batteries from industrial lithium-ion batteries like from cars, trucks, forklifts [...] most of them maybe from fires or something that's wrong but you can see those small flow of batteries coming you know”. Company C, Company G and Company E described that critical batteries have to be transported directly to recycling facilities, while non-critical batteries are often stored until a big batch can be consolidated and transported to the recycling facility (Company E). Company C noted that recyclers will not accept single batteries to be delivered unless it is critical and stated that “You need at least one tonne”. Company H adds that if there is no consolidation, the costs will rapidly increase, especially for recycling facilities. Another challenge related to coordination was presented by Company D, who stated that “half of the job to get the different companies together, because there's different time slots where we can deliver to the recycling facilities. There are only certain time slots where the logistics company can drive to the pickup location [...] these two have to match”.

Currently, there is a challenge related to what materials that recyclers are able to recycle from an EVB. Company H explained that “Right now it is just the major metals that gets recycled, which is copper, cobalt and nickel. Everything else is gone, [...] right now, this is not in an industrial stage”. Company E also confirmed this by pointing out that “it's only a small part of lithium-batteries that you can recycle, there is cobalt for example, [...] this is not so easy to make money off [...] it costs a lot to money”. Company A mentioned that “everybody recycles cobalt, also copper, nickel and aluminium is recycled in most facilities”. Recycling of lithium for instance, is very complicated. According to Company A, “what always comes up is the question about lithium, today is very few companies who recycle lithium”. Further, Company A thinks that there are two options for recycling of lithium to take off, namely, governmental directives requiring a recycling rate of e.g. 80%. Or that the price levels go up, Company A believes that “if you can buy...
virgin lithium cheaper than recycled. I think most company will buy the virgin. [...] I think it's also a question about quality”.

The EVB market is very uncertain and requires recyclers to wait for the volumes before they can expand their businesses. Especially since different materials and set ups for new types of EVBs are constantly being researched and tested. Consequently, recyclers play a passive role, Company A explained this by saying “it's difficult to foresee how the market will develop and what will happen”. Company D stated that recycling facilities usually are specialized in specific materials but due to the low volumes of EVBs, no recycler can solely focus on them. Therefore, recyclers are forced to focus on several materials, Company D expressed that “usually facilities that can operate different materials, for example, small household device batteries, and also at the same time, large industrial lithium-ion batteries”. Additionally, Company A mentioned that recyclers should be aware of LIBs being replaced in the future by stating “the people who research this [...] they don't do anything on lithium-ion anymore [...] that is the past for them, so when they look for the future, they look at the sodium, calcium, zinc, aluminium, potassium”. However, if another composition or type of EVB would become predominant, it would not be in the RL chain until approximately 2040 (Company A).

Since far from every country has a recycling facility that is capable of recycling LIBs (Company H), they have to be transported across borders, which adds to the complexity of recycling all EVBs. The costs of EVBs are declining and Company B described that “the cheaper the battery gets the more interesting it gets to have a waste management or a recycling management local company, which is focused on that.”. Company E is worried about the capacity of the recycling companies today, especially since many countries do not have their own facilities. Company A provided an example of this by stating that there is no final battery recycler that is treating battery cells in Sweden, meaning that parts of every EVB must leave the country. Since recycling facilities are so rare, it is important for recyclers to establish networks of collection points where the batteries are consolidated and then transported to the facility. Company G mentioned that their aim is to have at least one consolidation point in each country. Company A also talked about their plans for the future where they would like to expand their business and open up a more centralized battery centre.
One of the major challenges in recycling of EVBs are the **cost of recycling and dismantling** batteries, together with the question of who is going to pay for it. According to Company H, “they have a problem because who pays for it would like to have a solution which will just not cost anything, right now we are not there, not by far. There are no signs of that it will not cost anything in the end”. Company E also acknowledged the problem of high costs related to recycling of LIBs, “it is very expensive to destruct LIBs and the amount of material that could be extracted from the batteries is too small for it to be economically justifiable”. Additionally, Company G confirmed that recycling is the most expensive part of the RL process. Company C provided some insights of the high costs of recycling in Europe, stating that non-European automotive OEMs are asking Company C for solutions to transport EVBs to their home countries because recycling prices in Europe are too high. Company C also pointed out that “the person who makes the most money out of it is a recycler”. In comparison to recycling of lead-acid batteries, recycling LIBs is seen as a challenge, rather than an opportunity. As stated by Company H, the process for recycling of lead-acid batteries is always the same since they have only one chemical component, “regardless whether it’s a big traction battery a forklift, or a little one from whatever like a starter battery from a car”. LIBs on the other hand have a **large variety of chemical compositions**, as reported by Company H there is none that can handle them all. For instance, “It's so diverse this market right now, so, in the end, you may not have only hundreds of different types and sizes, you have thousands” (Company H). In order to get information of the exact materials included in a specific battery, recyclers often have to sign a non-disclosure agreement (Company H). Another big difference between LIBs and lead-acid batteries that is also related to cost is “We pay money for those batteries (lead-acid batteries) [...] when you look at lithium batteries, now people have to pay for those batteries to get rid of them” (Company G). According to Company C, the industry for recycling EVBs is changing. Today, automotive OEMs have to prove to the government that the EVB was disposed according to the respective recycling requirements per country. Further Company C explained that only when there is proof of proper recycling, the automotive OEM gets money back for the battery.

The process of recycling an EVBs can be divided into two different levels, one level is collection, dismantling and discharge, while the second level is final material recycling.
(Company A). Company D explained that discharging an EVB means to “take out remaining energy”. Afterwards, the EVB is dismantled, either to module level or cell level. The difference is explained by Company A, “you have the cell level, that's just the battery cells, and then you put them together to their module level”. Further, Company A explained that one module typically weighs between 10-15 kilograms. Normally the modules are attached to each other with screws, glue or in some cases they are welded together (Company D). Moreover, dismantling includes removing cables, electronic parts and the battery management system (Company D). Company A described that once the EVBs are dismantled, only 40-50% of the weight of the entire battery pack remain, which facilitates transportation. Company A clarified that “we try to collect, disconnect or dismantle as long as we can and then we sell the different materials”. Meaning that Company A does not participate in the final material recycling, instead they dismantle the EVBs into module level and sell the modules to recyclers all over Europe. According to Company D, “those are the first two steps that pretty much every recycling process has in common”.

Standardization of EVBs could not only facilitate the collection phase, but also the recycling process. Company A stated that they advocate a “common marking system for batteries”. Such a system would assist recyclers in operating in an optimized way since they nowadays are not aware of the chemistry within the battery once they receive it. Further, Company A stated that this marking would be favourable either on a module or cell level. Company A exemplified this by expressing their common thoughts “Is it Lithium-Cobalt-Oxide, Lithium-Manganese-Oxide, or Lithium-Iron-Phosphate”. Company H also mentioned the difference in chemistry, but also mentioned that EVBs come in different sizes and weights. Which leads to a manual decision about how to proceed in the recycling process for every battery, Company H affirmed that “it's always easier if you have just one type, one design”.

4.4.2 Process Step 7 - Repurposing

Repurposing is not something that is among the core competences of the participants of this study, however, it became clear that very few companies are actually involved in this process step. Currently the vast majority of the industry is simply discussing and researching its possibilities. For instance, Company D is part of the value chain, meaning
that they collect the batteries and deliver them to engineering companies who decide what to do with them. However, the participants of this study have great insights in the EOL of EVBs, thus also for repurposing. Company G has their own “[…] refurbishing and recycling programs, but also on a R&D level, on a pilot scale”. Most interviewees indicated that collaboration is necessary in order to establish proper alternatives for second life applications, Company A stated that “No company can do it by themselves, it has to be a group of companies that develop these concepts together”. Nevertheless, battery OEMs will have to be involved in the process due to their knowledge with the battery management system. Also, automotive OEMs will have to be involved due to their responsibility to dispose the EVBs.

All companies mentioned that there is a lot of research that is currently being made on how to provide a second life for LIBs. Further, the interviewees agreed on that repurposing of EVBs would make sense in the future. According to Company G “[…] this will take several years until the quantities in technologies are there where we would say that this makes sense”. The main limitation for repurposing is currently the low volumes and the speculative nature, which could be illustrated by a quote from Company H: “[…] everybody is talking about second life, but right now, there is not any, at least I do not know, any project where this is really done on a major scale”. Further, Company A provided the same perspective, saying that “three years ago, most people say that this was the most stupid thing that ever heard that second use will never happen […], two years ago, it started to change […] now most people say that second use of course, will be very important”. Company H stated that even though there is a lot of talking, “[…] nobody has come up with a viable solution or which really makes sense”. However, Company A is under the impression that the few EVBs that are currently being returned are being picked up by research institutions, which is positive. Further, Company A explained that “[…] there is a lot of uncertainty about the future for second life, but it has big potential”.

When it comes to repurposing there are several uncertainties, Company A expressed that “It's not easy I would say, I think most people underestimate the difficulties”. One fact is that if second use would happen on a large scale, these batteries will likely operate for an additional ten years. Consequently, the last phases of EOL would be delayed and greatly
affect planning for both logistics and recycling. Company A also shared that many researching institutions are looking into third and fourth use for these batteries, which would further delay the EOL activities. Company H also recognized the same problems, stating that if the EVBs would be reused, they would still have to be transported and recycled, which would require specific projects to be set up. Additional challenges that limit the development of strategies for repurposing are mostly on detail level. Both Company A and Company E mentioned that one restriction is that it is currently very expensive to reuse EVBs, which makes it difficult to make it economically justifiable. According to Company A, the reason for the high costs is the high diversity in chemistries available on the market. Due to the earliness of the technology and the uncertainty of whether the LIBs will remain the predominant technology, no business models have been fully developed. Simultaneously, there are many variations regarding the existing technology, therefore Company B stated that “The technology is improving, so, I think there will be some business model, but not on the base of today's technology”. Company H addressed that “[...] certain volumes of identical batteries are needed, otherwise it's difficult”. Batteries that have naturally reached their EOL by reaching or surpassing the 80% capacity limit are mainly subject for repurposing. Meaning that damaged batteries or critical batteries will not be considered for repurposing. As reported by Company C “[...] the decision whether this is end of life or second life can only be done in a test centre [...]”. Even though it is often known exactly how much capacity that has been reduced from the EVBs life time in an EV, Company H concluded that it is still hard to know exactly for how long such a battery would be able to serve in another application.

The companies presented slightly different views regarding what they consider to be the most promising areas of reuse. Most companies mentioned that it is likely that spent EVBs will be used in stationary applications or mobile applications. Company C advocates the extraction of modules in order to use them as mobile energy providers by explaining that “[...] they take out the modules, not the cells, but the modules, and they repack this and we build it to become a mobile energy provider”. Company G also thinks that extraction of the modules is the way to go, thereafter the modules of the highest quality could be reused in new EVs. Further, Company G believes that the modules of lower quality will be used in stationary applications, such as “servers for, solar panel, for those windmills, for people who are operating a network like the transportation or telecommunication
networks, they always need stationary power devices”. Company D thinks that the main field of second use will be in stationary applications where uninterrupted power supply systems are necessary, for instance in server facilities or in hospitals, where emergency power supply is crucial. Repurposing EVBs in stationary applications as energy reserves was also suggested by Company C and Company H.
5 Analysis

The structure of this analysis has emerged from the data coding conducted from the empirical findings. From these codes, common patterns related to challenges and process steps were discovered. These patterns were then used to develop overarching themes that will be the basis of the subsequent analysis.

The findings highlighted that the investigated market is still in its infancy, thus entailing an uncertain environment for the actors involved. As a result, the RL processes for EVBs are more complex than for other products. Additional factors contributing to the complexity are the current low volumes, the hazardous nature of LIBs and the differences in technological composition. This forces the actors to be prepared, responsive and adaptable in a constantly changing environment. As institutional theory helps to explain how external pressures and factors affect the involvement of actors in the RL chain, it will be applied throughout the analysis. In order to answer the research questions, the structure of the analysis is twofold. Firstly, the RL setup is analysed and illustrated based on the process steps, together with relevant information extracted from each step. Secondly, the main challenges encountered in the findings will be further elaborated on. These challenges are divided into general challenges and new market challenges, with the main difference being the probable perseverance of the challenge. Additionally, as the research questions are interconnected, the first two steps of the analysis will be merged and presented in a framework. For the general challenges, the main variables are risks in transportation, bureaucracy and lack of standardization. While the main variables for the new market challenges are costs, uncertainty and evolving technology.

5.1 Reverse logistics chain set-up

As mentioned in the beginning of the previous chapter, the overall structure emerged through the gathered data. However, institutional theory was also applied to our study, which highlighted the importance of business processes. Consequently, additional business processes were incorporated into our framework, such as packaging and storage. This is contrary to Fleischmann et al. (2000), as they saw these processes as a link between the different phases.
The initiation of the RL flow comes in form of a customer order for an EVB as the interviewed companies claim and is set in the pre-collection phases. The succeeding step is the battery assessment, where the LIB has to be evaluated by an expert (Company B), to determine if a LIB is either critical or non-critical (Company H). Depending on the assessment, the LIB will either be directly transported to recycling after it is packaged, or it can be consolidated to accumulate more batteries. In the following two phases, institutional theory has the most impact on the necessity of processes. In the collection phase, coercive pressure in the form of ADR regulations impact packaging, and transport. These coercive pressures were discussed in both literature by Grandjean et al., 2019, and in the findings by Company H. Additionally, transportation is also influenced by regulations from municipalities if the transport of a critical battery is necessary, as well as normative pressure as accidents with critical LIBs can have substantial consequences for society (Company C). Storage processes are also affected by regulations of local authorities and determine different aspects as mentioned already in the previous chapter by Company C and Company G.

During the recycling and repurposing phase the pressures from institutional theory impact both processes. Coercive pressure is imposed through the EU battery directive; thus, recycling became a mandatory process in the set-up of an EVB RL flow. As described by Heelan et al., (2016), recycling technologies must be further developed in order to make it profitable to recycle all components of an LIB. The consequence of the underdeveloped recycling technologies could be extracted from our findings. Company A stated that very few recyclers are capable of recycling an entire EVB. Thus, giving rise to multiple recycling steps. Repurposing activities are impacted by normative pressures from customers as EVBs are able to support second life applications (Heelan et al. 2016). Such an application can be a stationary ESS used in power plants (Company H). The potential downside with repurposing is that EVBs would greatly delay the recycling process. As mentioned by Heelan et al. (2016), every EVB eventually has to be recycled, even after its second life. Meaning that once the EVB has reached its EOL in a new application, a completely new RL flow is triggered (Company A; Company H). However, as repurposing is not yet commercialized, it will not be illustrated in our figure. The set-up of the RL of EVBs can be found in Figure 6.
Figure 6. Electric Vehicle Battery Reverse Logistics Chain (own illustration)
As could be seen in (Figure 6) a CLSC is not illustrated, even though Andersson and Råde (2001) considered it necessary for battery recycling due to environmental awareness connected to the hazardous nature of LIBs. The specific hazards were further elaborated on by Gao et al. (2018), Heelan et al. (2016), Kang et al. (2013) and Ordoñez et al. (2016). Thus, the basic explanation that RL processes is the upstream flow of goods from the customer back to the manufacturer (Cruz-Rivera & Ertel, 2009), is not valid for EVBs. This is mainly a consequence of the diversity and the low quality of secondary raw materials that can be extracted from LIBs. Instead, recycled material is sold on public or special markets depending on the nature of the material (Company D). For instance, Company A stated that recycled lithium is currently being used in lower level applications due to the low quality of secondary lithium, compared to primary lithium. Hence, disallowing the material to move all the way upstream to the battery OEMs. Consequently, battery OEMs influence on the RL activities are limited. In comparison to the RL of lead-acid batteries, the automotive OEMs are responsible for collection and recycling, which is also the case for EVBs. However, the battery OEMs are highly involved in the RL activities. The reason for this is that secondary lead, which is cheaper than primary lead, goes into manufacturing of new batteries (Sasikumar & Haq, 2011). Thereby, facilitating network structures since it makes it profitable for battery OEMs to actually recycle the batteries themselves. What partly makes the business for lead-acid batteries so profitable is that the recycling steps are quite simple (Zhang et al., 2016), in contrast to the ones for LIBs. For LIBs, new recycling technologies are continuously being investigated with the purpose of recovering more of the scarce materials. For example, new recycling processes must be industrialized in order to keep cobalt and nickel in EVBs (Larcher & Tarascon, 2015).

5.2 General challenges

General challenges are concerns that are encountered in the RL chain of EVBs, but that are not considered a consequence of an uncertain nature. Hence, representing challenges that are likely to persist in the market. In Figure 7 the aggregate dimension as well as the 1st and 2nd order themes are represented as portrayed by Gioia, Corley and Hamilton (2013).
5.2.1 Lack of standardization

In literature, the need for standardization of EVBs is a recurring topic. Both Dunn et al. (2012) and Heelan et al. (2016) emphasize that standardization of EVB design, shape and size would facilitate RL activities, such as collection and recycling. The lack of standardization was also a highly discussed topic in the findings, thereby presenting one of the main challenges in the RL set up. The struggle of non-standardized EVBs first present itself in the transportation step. Literature criticises the EVB design, Heelan et al. (2016) state that battery OEMs should have thought about EOL activities when they designed the batteries. The same was expressed throughout the findings, for instance, EVBs are not compatible with standard pallet sizes, thus leaving unused space in trucks (Company C). This is a problem since utilization in the logistics sector is of high priority in order to work in a cost-efficient way. As a result, 3PLs are in discussions with battery OEMs in efforts to reach a unified design (Company B). Thus, applying normative pressure on battery OEMs.

Similar challenges were encountered in the Recycling & Repurposing Phase. Whereas recyclers need to deal with the constant change in material composition in LIBs (Heelan
et al., 2016). Currently, the different EVB types are in the thousands (Company H), however, the real problem is that recyclers do not know the exact chemistry structure (Company G). Proper marking or labelling of EVBs would allow recyclers to choose the best recycling process for the specific EVB (Company A), in order to regain valuable material. Similar to 3PLs in the collection phase, recyclers are in discussions with battery OEMs in order to achieve unification regarding labelling EVBs with their composition. However, in both cases, 3PLs and recyclers do not expect to see any changes towards a more unified design as their impression is that battery OEMs are not willing to openly share such information regarding EVB design and composition. An example could be drawn from the market of starter batteries. Company G mentioned that efforts have been made in order to mark starter batteries in different colours according to battery types e.g. LIBs or lead-acid batteries. However, this was never actualized by the battery OEMs. Hence, making it hard to believe that battery OEMs will make any changes without them being exposed to coercive pressure.

5.2.2 Risks in collection phase
LIBs are classified as dangerous goods (Klör et al., 2018), through chemical reactions within the battery they are prone to start burning or to explode (Heelan et al., 2016; Kang et al., 2013). Even after months without any incidents or after the battery assessment was conducted a reaction can occur (Company H), as was also mentioned by Grandjean et al. (2019). Such a reaction can damage the mode of transportation and can have serious consequences for the general public (Company C). Therefore, LIBs constitute challenges for the processes in the collection phase, namely packaging, transportation, and storage. In order to be prepared for incidents like fires or explosions, certain safety measures need to be met by law. Thus, regulations and legislations add coercive pressure onto firms in order to legitimate their business practices. Firms are therefore bound to use special packaging with in-built fire extinguishing systems and acid proof casing (Company G). For the transportation of critical LIBs, firms need to adhere to instructions from the municipalities, to carry out the transportation. Such instructions include the avoidance of roads which the municipalities deem as too dangerous for the general public (Company C). As for storage local authorities, have a range of demands to ensure safety. These can be sprinkler systems, continuous observations, or disclosed quarantine zones should a LIB start to burn (Company C; Company G). Furthermore, literature also displays that
LIBs can contaminate the groundwater (Gao et al., 2018; Ordoñez et al., 2016) and in return harm the environment (Kang et al., 2013). As recyclers often do not accept volumes below a certain weight (Company C), critical LIBs or of uncertain state are stored outside for safety (Company E) and leaking acid can reach the groundwater. Therefore, the public exerts increasing pressure onto firms to operate legitimate processes to not harm the environment or society in general (Seitz & Peattie, 2004).

5.2.3 Bureaucracy

Connected to the social aspect of reverse logistics, bureaucracy in the shape of following legislations and regulations are a cumbersome activity for the actors in the RL chain. As presented in literature, the EU implements legislations in the form of take back policies for the producers in order to ensure proper disposal (Daaboul et al., 2016; Ferguson & Browne, 2001). The European directives require EVBs to be recycled to at least 50% of their weight and the collection rate to be minimum 45%. The directives constitute the minimum requirements for each country (Company H), meaning that each European country, in theory, could enforce different regulations. Romare and Dahllöf (2017) stated that the minimum directives are being revised. Showing that coercive pressure is a factor for actors involved in collection and recycling activities, as they constantly have to adapt to the changing legal environment.

The collection phase is greatly affected by external pressures. Literature showed that collection is affected by the ADR regulations and the battery directives (Grandjean et al., 2019). The findings showed that the main challenge related to regulations and legislations stems from complying to several requirements simultaneously. Every 3PL mentioned the complexity of both the ADR requirements and waste regulations. Company E mentioned that it is difficult to find a 3PL that is capable of offering both waste and dangerous goods transportation because the regulations are completely different. Literature stated that collection is highly dependent on public support and governmental incentives (Dehghani-Sanj et al., 2019). Although, no governmental incentives could be derived from the findings. Company A mentioned that they receive public funding for extending their collection network, showing a clear normative pressure from society to dispose the hazardous batteries. Due to the limited infrastructure for retrieving EVBs, many 3PLs must cover bigger areas and cross-country boundaries. Coordinating these regulations are
a major challenge (Company B), further the complexity was exemplified by Company C, who described that they have 3 people continuously studying European waste regulations. Moreover, if a 3PL plans to operate cross European boundaries, they need a “notification”, which is a permit from the authorities of each individual country that they pass during the transport (Company H). However, even domestic regulations require significant effort in specialization. For instance, Company E and Company C mentioned that they require licences and permits for every single transport of a battery that is considered critical.

Further, the recycling step is highly influenced by the European directives. An EVB can weigh between 150-500 kg (Company A), or 400-600 kg (Company B). Meaning that at least 75-300 kg have to be recycled. But due to increasing environmental awareness (Verma, 2018), the recycling legislation is likely to be strengthened. Company A, Company E and Company H explained that only a small part of the EVBs are currently being recycled, among these are copper, cobalt, nickel, and aluminium. However, literature showed that current recycling technologies are not able to recover the relatively scarce metals nickel and cobalt (Larcher & Tarascon, 2015), further lithium has to start being recycled in order to keep it a viable source in the long term (Xiao et al., 2017). The issue of not recycling lithium also emerged in the interviews. Company A stated that lithium would start being recycled if recyclers were required to do it. Thus, indicating a need for coercive pressure that will keep scarce material circulating in the market.

Company E explained that understanding the complex regulations will present a high entry barrier for new entrants in collection and recycling. While this presents an entry barrier, it also shows the need for mimetic isomorphism for either companies entering the RL chain, or unsuccessful ones. Firms will require personnel to stay up to date with regulations in their region of operation and therefore adopting similar business practices. A tendency of mimetic isomorphism presented itself during the interviews. As both recyclers and 3PLs are taking part in expert networks, conferences and meetings, where information and best practices are shared amongst the participants (Company A; Company B).
5.3 New market challenges

The challenges presented in this section are mainly problems that might be mitigated when the industry matures. These challenges are reflected by several factors, mainly related to uncertainty. What these challenges have in common is that they all represent entry barriers for actors involved in RL activities, even though the quantities of returned EVBs still remain low. In Figure 8 the different new market challenges can be found.

5.3.1 Evolving Technology

The findings showed that the rapid technological advancements in the automotive sector may lead to new types of EVBs entering and outcompeting the current dominating technology of LIBs. As a result, the technology for producing LIBs is constantly changing (Ordoñez et al., 2016). This represents a challenge affecting the processes of recycling and repurposing, while recycling additionally needs to deal with material specific
recycling processes. Through the change in technology, chemical composition within the LIBs differ (Peiro et al., 2013). This makes it hard for recyclers to treat EVBs with a specific chemical structure in an optimal way (Company H). This is portrayed by Swain (2017) since the recovery rate of lithium is less then 1% and could lead to uncertain supply of lithium for automotive OEMs in the next decade. Mimetic pressure is therefore a high driver in the recycling sector. Recyclers will try to imitate recycling processes of competitors once lithium will be able to be recycled with a higher rate. Furthermore, as no recycler is specialized for treating EVBs as only a small portion of LIBs can be recycled (Company E). Company A believes that legislations from the EU could change that, if a higher recycling rate for LIBs becomes mandatory and recyclers need to abide to these legislations. Showing that the coercive pressure today is not high enough and that recyclers must develop solutions which result in a higher recycling rate.

Regarding repurposing of EVBs, Company B stated that there will be a business model developed in the future, but not with the current state of technology. This is reflected by Klör et al. (2018), as the uniqueness of technology make it hard to manage for repurposing. Furthermore, identical batteries of a certain amount are needed for repurposing, as it is quite difficult to repurpose different batteries because of the distinct technology across LIBs (Company H). Therefore, firms in the repurposing sector exert a significant amount of pressure onto manufactures in order to create a business model where EVBs can be used to build stationary applications in form of ESS or reuse in other mobile applications like forklifts (Klör et al., 2018).

5.3.2 Costs

Throughout the interviews, a common theme was the non-standardized way of operating a reverse chain of EVBs. In turn, expenditures for transportation, storage, packaging and recycling are high. As described by Sheriff et al. (2014), RL should only be incorporated into the supply chain if it can be managed in a cost-efficient manner. Which is generally the case, but due to the immaturity of the market, the costs are outweighing the benefits. The successful RL processes of lead-acid batteries, where 99% are recycled in Europe and the US (Dehghani-Sanij et al., 2019), showcase the possibilities of developing an efficient RL chain. Every company participating in this study has had experience with lead-acid batteries before entering the market of EVBs, thus allowing them to make use
of their already existing networks. Ko and Evans (2007) also stated that 3PLs have the opportunity to use their special infrastructure for RL. However, even though these networks may lower the costs for operating such a RL chain, they do not mitigate all cost factors, such as special packaging and consolidation issues.

The cost of special packaging was extensively discussed in the interviews. Such packaging is used throughout the collection phase. Packaging was also covered in literature, Grandjean et al. 2019 explained that special packaging for critical EVBs can cost up to €10,000, while Klör et al. (2014) stated that non-damaged EVBs have to be transported in acid-proof packaging. Company C expressed that special packaging can range from between €8,000 - 20,000. Obviously, external pressure forces 3PLs to comply with these packaging requirements, which in turn, is a result of the increasing environmental awareness described in 5.2.2. The current low volumes make it hard to justify an investment of special packaging (Company C). Additionally, it is impossible to predict how large the share of critical LIBs will have. Therefore, 3PLs are sharing, pooling (Company C) and renting (Company E) these transportation boxes. Sharing and pooling transportation boxes constitutes a challenge due to complex coordination and dependency on other actors. Throughout the interviews it became clear that most actors use the same supplier for safety packaging intended for critical batteries. This special packaging was not originally produced for transporting EVBs specifically (Company C), thus showing that 3PLs have started to mimic best practices of each other. These transportation boxes are considered a scarce resource (Company C). Therefore, a tendency of normative pressure presents itself as the special boxes are indispensable when transporting critical batteries that have the potential to significantly harm the environment and individuals. Therefore, packaging has to be made more affordable and convenient for 3PLs and recyclers.

Additionally, costs for RL processes are high since there is a limited infrastructure due to the immaturity of the market. The limited infrastructure makes it challenging for 3PLs to consolidate EVBs, thus requiring single EVBs to be transported (Company C; Company G; Company H). In literature, this challenge is closely connected to the vehicle routing problem. The vehicle routing problem is concerned with the utilization of the truck fleet and that logistics providers must optimize the coordination of these trucks (Le Blanc et
al., 2004). Since truck utilization is in direct correlation with cost efficiency (Schultmann et al., 2006), transporting one EVB at the time is extremely inefficient in terms of costs (Company C). Referring to Sheriff et al. (2014), the low consolidation levels makes it impossible to make RL of EVBs cost efficient. According to Company E, logistics costs are often underestimated. Thus, a normative pressure is present in the market as 3PLs are facing high monetary expenditures.

5.3.3 Uncertainty

The challenge of uncertainty expands over all processes in the reverse flow of EVBs and encompasses the factors of low volumes, return of EVBs, and state of EVBs. During the interviews most of the companies stated that the current volumes are low and the first real wave of EVBs will occur in the future. This is in accordance to Heelan et al. (2016), as they mention that no substantial amount of EVBs have been returned through a continuous flow. However, Company E expressed that larger numbers already need to be handled. Nonetheless, all interviewed companies indicated that with rising volumes, adaption needs to be made in order to manage the increased volumes. So, firms need to adjust their storage facilities regarding the capacity as well as improve safety measures in handling the increased volumes (Company B; Company G). This shows that the actors in the RL chain plan to expand along with the EVBs due to the incertitude of what the future will look like, in terms of regulations and volumes. This gives rise to imitation in the different phases of the RL as firms want to stay competitive (Govindan, 2018). Company A mentioned that even though the volumes are quite low, automotive OEMs are approaching and asking to provide solutions for RL of EVBs. This indicates the rising pressure of firms in the industry to comply to the ambitions of automotive OEMs to support the future demand. Since automotive OEMs need to prove to the government, that EVBs are actually disposed according to the respective requirements in order for the automotive OEM to receive money for the EVB (Company C).

Furthermore, the actors of the RL chain cannot be certain of the state of batteries entering their EOL. As stated by Company G, the state of batteries is highly diverse and approximately 50-60% of the returned batteries today are either critical or damaged. As presented in the findings, the state of the battery determines the type of safety measures that need to be applied, the uncertainty of the state of returned EVBs presents an
additional challenge. Therefore, 3PLs have to be prepared to transport any type of battery, no matter its condition. As previously mentioned, automotive OEMs exert pressure onto the 3PLs handling the EVBs as they are accountable by law.

Figure 9 concludes the analysis with incorporating the set-up of Figure 6 and the challenges discussed in the analysis. As it can be seen below, only uncertainty affects the complete RL chain, while cost and bureaucracy influence the Collection and Recycling & Repurposing Phase. risk in collection phase, as the name suggests only impacts the Collection Phase and evolving technology shapes the processes of recycling and repurposing. lack of standardization also influences the processes of recycling and repurposing, but additionally poses as a challenge in the transport activities.
Figure 9. Electric Vehicle Battery Reverse Logistics Chain and Challenges (own illustration)
6 Conclusion

In this chapter, the main results and insights of the thesis are outlined. Hereby, conclusions are drawn, and the research questions are answered.

In this study we wanted to model and examine the RL setup for EVBs and identify which challenges 3PLs and recyclers encounter within the RL process. Through conducting an interview study and interviewing eight European 3PLs and recyclers, we were able to answer the following questions.

1a. What is the set-up of the reverse logistics chain concerning electric vehicle batteries?
1b. Which challenges are 3PLs and recyclers encountering regarding reverse logistics of electric vehicle batteries?

Regarding the first question we were able to portray the set-up of the EVB RL flow by identifying and connecting the individual RL processes. Furthermore, we divided the processes into the three phases pre-collection, collection, and recycling and repurposing. Through applying institutional theory, we discovered that coercive pressure is a major driver of how the RL is structured. Coercive pressure in the form of regulations and legislations determine the set-up and decide whether LIBs need to be taken directly to the recycler or if they can be consolidated.

Our study was also successful in providing an answer to our second research question. We present and analyse the identified challenges faced by both 3PLs and recyclers in an immature market. Not only are we highlighting six challenges, we also put them into perspective to the set-up of the RL flow. This made it possible to connect the challenges to individual process steps and show how they impact the processes. The challenges we discovered impact several processes, thereby illustrating the importance of establishing a collaborative RL network. Comparatively, cost and uncertainty both impact the recycling and repurposing phase. However, the challenge of uncertainty also has implications for
the cost challenge. Thus, even though we portray the challenges as separate under a general theme, challenges can be intertwined among each other.
7 Discussion

The following chapter will demonstrate the theoretical contributions and practical implications of this study. Thereafter, the circumstances that limited our research will be presented along with propositions for future research.

7.1 Theoretical contributions and practical implications

Our research advances the current pool of literature on RL in the context of EVBs in Europe. Consequently, the three main contributions will be presented.

Firstly, our explorative study has investigated a highly relevant topic (Grandjean et al., 2019), in which previous research is scarce. By identifying the aforementioned challenges encountered by 3PLs and recyclers, new light has been shed on the current challenges of EVB recycling. We have explained and exemplified why collection and recycling represent a bottleneck for RL processes today (Dehghani-Sanij et al., 2019; Zeng et al., 2015) by presenting specific challenges within the RL setup. The majority of challenges were only briefly discussed in theory, hence allowing our finding to advance current literature by providing additional insights. While some challenges, such as insufficient labelling and transportation box sharing, are completely new contributions to literature. Secondly, we illustrated the complete RL chain of EVBs based on insights from 3PLs and recyclers. By doing so, we contributed to theory by expanding the standard reverse flow portrayed by Fleischmann et al. (2000), in the specific setting of spent EVBs. Finally, the overarching adaptation of institutional theory allowed us to connect the phases and processes from our framework to the concurrent challenges identified in the RL of EVBs. By applying the three isomorphic pressures introduced by DiMaggio and Powell (1983), our study deepens the understanding of where the challenges originate from while also contextualizing the drivers behind the RL setup.

Besides contributions to theory, this thesis highlights the current development of RL strategies towards EVBs. Our findings could be used as a status report for practitioners as it highlights the accumulated challenges of seven actors that are highly involved and active in the market. This thesis is especially useful for new market entrants, providing them with crucial knowledge about the complexity and the dynamic nature of the
industry. Through this understanding, new entrants would be able to determine in which areas further development and preparation is necessary. Due to the increasing environmental awareness, stakeholders of the EV market would be able to recognize the necessity of establishing proper collection and recycling structures. Which in turn, might lead to efforts to mitigate some of the presented challenges, and thus, facilitating the process.

7.2 Limitations and Future Research

As with any research paper, the content of our thesis has been affected by several limitations. The authors are aware of the shortcomings of this study; therefore, the limitations will be presented below. Further, suggestions for future research will be presented.

There are several limitations connected to the sampling of this study. Firstly, our study was limited to eight companies, including one company that did not wish to be quoted or referred to. By expanding the pool of participants, we could have been able to reach more generalized results. Secondly, there was a geographical restriction in our study since only European companies were interviewed. Gathering insights from other parts of the world could have contributed to our study as it is not uncommon that companies in the industry operate globally. Finally, the interview study was limited to 3PLs and recyclers, which means that all aspects of the complexity might not be addressed. Further, all participating recycling companies were performing collection activities, while the 3PLs did not perform recycling activities. Thus, generating a certain degree of imbalance. We also had a change of focus in our research, which shortened the already tight time frame of approximately 4 months. Originally, the focus of our research was supposed to be focused on automotive OEMs, but after several weeks without any feedback we decided for the approach presented in this study. We also have to address the limitation which is a consequence of the lack of research done regarding collection activities. A lot of our findings do not have theoretical grounding, which might cause shortcomings since many aspects are solely reliant on the experience from the interviewees.

As previously acknowledged, there is a lack of available research on the collection part of the RL process, compared to the extensively researched fields of recycling and
repurposing. Therefore, we propose more research to be made with the purpose of establishing a business model for the collection phase, as it is a prerequisite for both recycling and repurposing activities. Moreover, the framework that we have presented could assist future researchers that wish to investigate either the individual RL processes or the RL flow as a whole. The framework could also be elaborated on by researchers investigating the RL process from the perspective of another actor e.g. battery OEMs or automotive OEMs. Future scholars could use our categorization for general and new market challenges to see whether the new market challenges have been mitigated or not, and if the general challenges remain once the market has matured. Throughout the analysis, we did not give much attention to the process step of battery assessment even though it is a crucial activity. However, we deemed the gathered information to be insufficient and contradictory. Therefore, we believe that battery assessment is an activity with huge potential for improvement, which makes it important to study further. Another area of interest is the problem with expensive packaging for critical EVBs, this was brought up throughout the findings and also stated in literature. As we live in a sharing economy, with e.g. emerging car sharing technologies. Such a solution could also be investigated further in the context of special packaging for critical EVBs. Lastly, we believe that a business model for repurposing has to be developed in the future. However, as mentioned previously, the volumes of identical LIBs cannot be provided to make repurposing economically justifiable.
8  Reference list


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9 Appendices

Appendix I – Interview Guide - 3PLs

1) Could you please present yourself (your background and current position in the company)
2) What are the overall goals of the company in regard to reverse logistics of EVBs (Electric Vehicle Batteries)?
3) Could you give us an overview of your reverse logistics process of EVBs?
4) What makes [Company name] unique in EVBs/LIBs reverse logistics (compared to competitors)?
5) What are the main drivers of effectively managing the reverse flow of EVBs?
6) What starts the reverse logistics process of EVBs?
7) Does [Company name] need to repackage the EVBs/LIBs in order to transport them to the warehouse or is the OEM/Dealership doing that?
8) What are potential risks in transporting used EVBs/LIBs?
9) What are the challenges of storing used EVBs/LIBs?
10) Some researches state that a unified design for EVBs would be favorable in EOL activities (retraction, transportation, reuse, recycling etc.).
    a) Are you working with different Battery Manufacturers?
    b) Have you noticed problems with the handling of EVBs from different manufacturers because the design is different? Do you have to adjust the process depending on the manufacturer?
11) How do you transport EVBs? Are there any time limits that you are constrained to, in regard to collecting them once they have been retracted? How alert do you have to be?
    a) Do you have to act instantly? Or do you have scheduled pick-up dates/times?
    b) How are you collaborating/communicating with service stations?
12) How is the (decision) process on where the EVBs/LIBs are going after the transport to the warehouse?
13) Are you involved in the decision making process on what to do with EVBs/LIBs?
    a) Are you using second-life EVBs yourself?
    b) Do you (as a company) have your own programs (or such) for recycling and repurposing of EVBs?
14) Does your RL network/process have the capacity to handle the rising number of used EVBs/LIBs or does it need to be adjusted?
15) What is, in your opinion, the most promising areas of recycling/repurposing for EVBs?
16) Is there anything that you would like to further elaborate? Or something that was not brought up in this interview that you would like to discuss?
Appendix II – Interview guide - Recyclers

1) Could you please present yourself (your background and current position in the company)?

2) What are the different aspects/phases/stages of recycling Lithium-Ion Batteries (LIBs)?
   a) Could you give us an overview of your recycling process of LIBs from electric vehicles?
   b) What happens with the recycled material?

3) What are the overall goals of the company in regard to recycling LIBs from electric vehicles?

4) How much are you able to recycle from a lithium-ion battery?
   a) Are you able to recover the entire 1.5% of lithium that a LIB from an electric vehicle consists of?
   b) What are the main challenges when recycling LIBs?

5) How is [Company name] affected by reverse logistic processes?
   a) What does your [Company name] do in regard to reverse logistics of used LIBs?
   b) Are you able to talk about the different steps between disassembly to recycling?
   c) What are the main drivers of effectively managing the flow of used LIBs?
   d) Are you collaborating with battery manufacturers, logistic providers, or automotive manufacturers in order to find a closed loop solution?

6) Do you store LIBs from electric vehicles yourself?
   a) If no, how do you coordinate the flow of LIBs with the logistics providers?
   b) How do you manage the inflow/outflow of used LIBs?

7) What are the main challenges of managing LIBs from electric vehicles?
   a) Coordinating with battery manufacturers/logistics providers/automotive manufacturers?
   b) The hazardous nature of LIBs?

8) Since LIBs have approximately 80% of their capacity left when they are disassembled from the vehicle, there are opportunities to reuse/repurpose LIBs from electric vehicles.
   a) Are [Company name] involved in anything related to reuse/repurposing?
   b) Do you have some insights about reuse/repurposing of LIBs?

9) What are, in your opinion, the most promising areas of repurposing for EVBs?
10) Do you think that [Company name] (or the industry in general) will be able to cope with the increasing volumes of used LIBs?
    a) What do you think has to be done in order to make sure that there is enough capacity?

11) Some researches state that a unified design for EVBs would be favorable in End-of-Life activities (retraction, transportation, reuse, recycling etc.).
    a) Are you working with different Battery Manufacturers?
    b) Have you noticed problems with the handling of EVBs from different manufacturers because the design is different? Do you have to adjust the process depending on the manufacturer?

12) What makes [Company name] unique when it comes to handling (recycling + potentially reverse logistics) LIBs (compared to competitors)?

13) Is there anything you would like to further elaborate? Or something that was not brought up in this interview that you would like to discuss?