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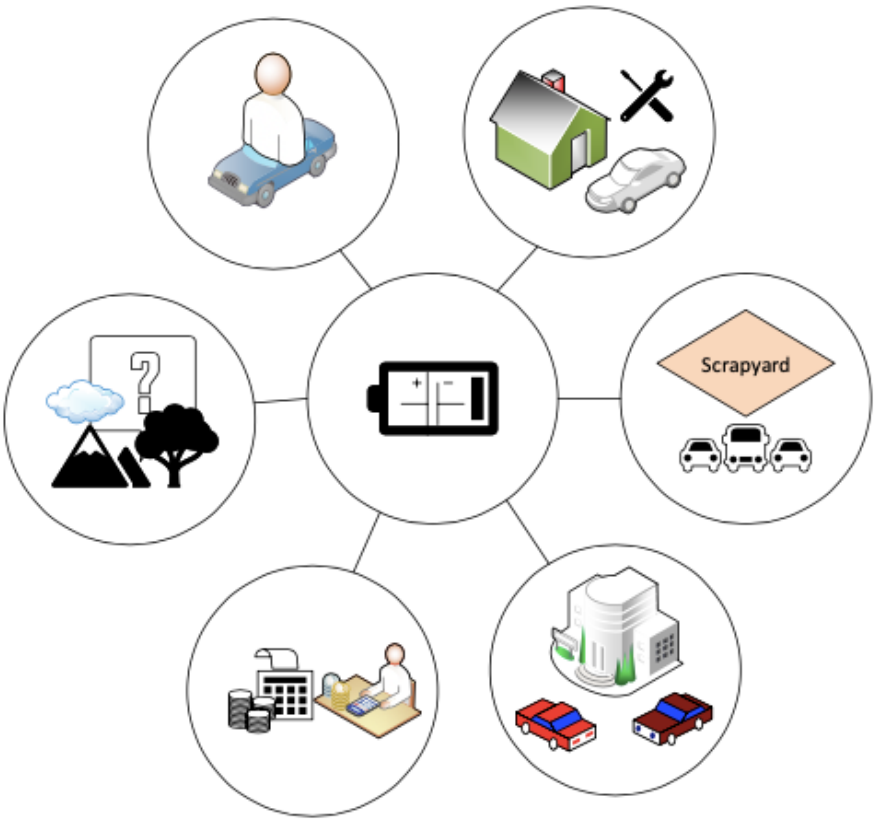

Business model for Take-back

The case of High Voltage Lithium-ion batteries in the European market

Master's thesis in Industrial Ecology

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Cover: A picture showing the six different potential outcomes that were investigated in this report, in regards to where the battery could end up. These potential outcomes are: the car owner, the unauthorized car dismantler, the scrapyard, the dealer, the insurance company and the random place.

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Abstract

The electric vehicle market is expected to continue to grow in the near future, hence the demand for High Voltage Lithium-ion batteries will follow in a similar pattern. The increase in demand for the batteries will not only affect the raw material extraction, but it will also concern the aspect of how to secure the batteries coming back, as the car manufacturers have the producer responsibility over them. In addition, these batteries are considered to be of an environmental hazard regards to their chemistries and needs to be handled with expertise. This thesis aims to explore what incentives and market-based mechanisms are necessary to secure a safe battery take-back in six potential outcomes that the battery might end up at. These potential outcomes are: the car owner, the unauthorized car dismantler, the scrapyard, the dealer, the insurance company and the random place. The main task was to create a conceptual business model for take-back, which would encourage every actor in the possession of a battery to return it.

The research methodology consisted of a documentary research to further see what take-back mechanisms are currently existing, as well as semi-structured interviews were conducted. A Delphi study that involved 19 participants were made in two rounds, to get further thoughts and opinions about battery take-back in the six potential outcomes. The results shows that as of now monetary compensation will have an important role in the various outcomes, but that there are also systems such as an exchange system that could also possibly be of interest. Furthermore, stricter rules, fines and changes in legislation could further support and make it easier to manage the volume of batteries that will arrive. Findings indicates that to be able to secure a safe battery return process a combination of economic compensation programs, exchange systems programs, regulations, rules, fine systems and setting standards in how it should be handled are necessary and recommended.

Keywords: conceptual business model, take-back system, electric vehicles, lithium-ion batteries, circular economy, extended producer responsibility, Delphi study.

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Last but not least, I want to thank my family for their never-ending support and high spirits, cheering me on and letting me talk about batteries all day long.

Elma Alcevska, Gothenburg, June 2020

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List of Abbreviations

ICE - Internal Combustion Engine

EV - Electrical Vehicle

BEV - Battery Electrical Vehicle

PHEV - Plug-In Hybrid Vehicle

HV Li-ion - High Voltage Lithium-ion

EMEA - The geographical area containing Europe, the Middle East and Africa

EoL - End-of-Life

ELV - End-of-Life Vehicle

WEEE - Waste Electrical and Electronic Equipment

EPR - Extended Producer Responsibility

NMC - Lithium Nickel Manganese Cobalt Oxide Batteries

NiHM - Nickel Metal Hydride Battery

SOH - State of Health

MAAS - Mobility-as-a-Service

CE - Circular economy

Pb - Lead

OEM - Original Equipment Manufacturer

1
Introduction

This chapter is an introduction to the thesis. A background of the current situation and the trends in the automotive industry will be described, as well as the aim and deliverables of the thesis will be introduced. Furthermore, the delimitations of the study are explained. Lastly, the chapter will be concluded with an overview of the overall report disposition.

1.1 Background

In a world with constant change, it is nothing new for mankind the many challenging obstacles that lies ahead, but also the ambitions to overcome them. As the new decade has only begun, it cannot have gone by anyone unnoticed that some issues are yet to be left behind, most specifically: *climate change*. The serious and worrying issue of climate change is still very much a reality the world have to face. In the latest years the world have witnessed never-ending, record-breaking warm weather, as well experienced severe droughts and forest fires. The Intergovernmental Panel on Climate Change (IPCC) described in a report from 2018, how the global warming is closely connected to the greenhouse gas emissions. Through human activities the primary greenhouse gas is carbon dioxide, which is closely connected to the transport sector [7].

Reportedly, only in the EU the transport stands for a quarter of the greenhouse gas emissions. This indicates how the transport sector is a large contributor to global warming. The public concern is that carbon dioxide emissions will only speed up the process, which is why urgent action is needed to save the planet. The carbon dioxide emissions caused by humans needs to decrease to limit the global warming and the ambition is to reach net zero greenhouse gas emissions around year 2050 for the EU [7].

Tony Seba, the entrepreneur and author of *Clean Disruption of Energy and Transportation* projects that there will be a fast ramp up of electric vehicles. He goes a bit further and also states that by the end of the 2020s, Internal Combustion Engine (ICE) cars will more or less be gone [8]. Even though these are only future projections, the trends are pointing to that might be the case. In Europe different countries are planning on phasing out gas- and petrol cars, which means to ban sales of gas- and petrol cars. Countries such as Norway, Ireland, the UK, France and Sweden have plans to ban gas- and petrol cars between the years 2025-2040 [9].

The automotive industry, being well aware of the need for change for the sake of the environment have started to invest more into the electrification area. Importantly, beginning to explore themselves more towards the low emission vehicle: *electrical vehicles*. For the very first time, in 2017, it was reported that sales of electric vehicles (EVs) passed over one million cars per year worldwide [10]. By 2040, Bloomberg New Energy Finance predicts that around 57 % of all sales will be electric for passenger vehicles [11]. It is clear to see that the automotive industry will change quite radically because of the electric vehicle revolution that is coming along. An electric vehicle produces in its lifetime half the amount of greenhouse gas emissions compared to an European car powered by gas [12]. Thus, electrical vehicles could be a golden opportunity to be able to minimize millions of tonnes of greenhouse gas emissions every year [13].

Volvo Cars has the ambition to become a leading player within electrification and stated how their goal is by year 2025 to generate 50% of global sales from electric cars. In 2019 Volvo Cars unveiled their first electric vehicle, Volvo XC40 Recharge, which started going for sale in 2020. Volvo Cars expressed how they aim to sell 350 000 electric vehicles or more in 2025 [14]. Only in 2019, Volvo Cars sold around 46 000 plug-in hybrid models, this being an increase of around 23% compared to 2018 [15]. It was reported that only in the month of January this year in Sweden both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) increased in a total market share of 30,2% [16]. Moreover, according to Bil Sweden, both electric cars and hybrid cars doubled in new registrations from the previous year. In April 2019 it was around 10,1 % and this year it was 22,6 % [17]. Thus, showing the continued demand for electrified cars.

The critical component in an electric vehicle is the battery and there are various versions and chemistries of the battery in different electric vehicles. However, the most common battery is one form or another of it being an High Voltage lithium-ion battery (HV Li-ion). The battery constitutes approximately half of the BEVs production value and trends are showing that HV Li-ion batteries will most likely dominate the electric vehicle battery market for years ahead. As there is projections of more electric vehicles on the roads in the upcoming years, consequently it will increase the demand and growth for batteries in the near future. In spite of the fact, that HV Li-ion batteries have a somewhat limited lifetime in vehicles, that could be around 10-15 years, their use is far from over when it has left the vehicle. In fact, it could still possess both functional and financial value, hence being used for other applications [18].

Volvo Cars has marketed themselves for a very long time to be the safest car in the world, but now they seek to be the safest car for the planet. There is no doubt that there are many benefits and opportunities that could come with the electrification mobility, yet it will create several challenges. To name a few examples: mining, waste-management and the possible leakage points of the hazardous batteries [10]. The lack of knowledge in this area is something that is useful to spend time on now,

to be able to understand how to deal with the problems and obstacles that comes with a new technology. One thing seems to be for sure. The electrification journey will not only impact the world as for now, but will have a long-lasting effect on that high value component in the car: *the battery*.

1.2 Thesis aim

The purpose of this thesis is to develop a conceptual business model, answering the research question:

- How to secure a safe battery take-back process for already used HV Li-ion batteries in the European market?

The aim is to gain a deeper knowledge about how to motivate and encourage each and every actor in the possession of an HV Li-ion battery. As well as figuring out what different kinds of incentives and market-based mechanisms are necessary to get the battery returned.

As a prerequisite, a problem definition was developed together with the stakeholders at Volvo Cars to further explore and elaborate the potential outcomes where the battery could end-up, hence being a part of the research question. Take-back means in this thesis how the car OEM is in control over the batteries coming back from the potential outcomes.

When a car is sold and is under warranty, getting the battery back is usually hassle-free as the car manufacturer both has it under control and knows it will safely be returned back. However, this significantly changes, when the car no longer is within warranty. The need for a safe battery take-back process is the largest outside warranty, because here the battery could take unknown paths and end up in different locations. In this report, six potential outcomes have been identified, which could also be seen in Figure 1.1.

- Car owner
- The unauthorized car dismantler
- Scrapyard
- Dealer
- Insurance company
- A random place

Here follows a short description of each potential outcome a bit further and to why they are part of the chain.

The first potential outcome is the car owner, who is the typical customer owning their car. As the car owner owns the car, the car owner alone can decide whatever they would like to do with it. The customer could either sell it forward a couple of

years later to another private person or perhaps will own the car for a very long time, e.g. having it unused, which makes the battery degrade. Car owners are important stakeholders in that aspect that they decide, for example: which insurance companies to choose, but also what sort of workshops and car dismantlers they would leave their cars to [**?**].

In the second potential outcome, one finds the car dismantlers, which are the ones dismantling EVs. Typically, the different parts are both removed and could be sold from the car as spare parts. In addition, they also prepare vehicles for recycling. Most car dismantlers are certified, meaning they are both trained and knows how to deal with car components, e.g. how to dismantle an EV battery [4]. However, in this potential outcome the car dismantler is unauthorized and perhaps do not have this training. But also, it is very hard to track for what they will do with the battery and if it would be sold in e.g. a black battery market. Within the report it will be differentiated when writing about an unauthorized car dismantlers and car dismantlers.

The third potential outcome is the one with the scrapyard and is where cars are getting scrapped. What happens with the battery could be unclear and therefore the scrapyard is included.

The fourth potential outcome is if the vehicle with the battery would end up at a dealer. A car dealer, sells both new and used cars. It is therefore important to understand what could happen to the battery as it is included in the car.

The fifth potential outcome, where the battery could end-up is at the insurance company. This would occur after the car has been in a crash or in an accident. Suddenly, the insurance company owns the battery and is therefore also included in the potential outcomes.

The last potential outcome, is if a private person would find the battery at a random place, e.g. in the forest or in the desert, where the battery has been dumped. Overall, all these potential outcomes have some sort of main activity and could have a high influence on the batteries path.

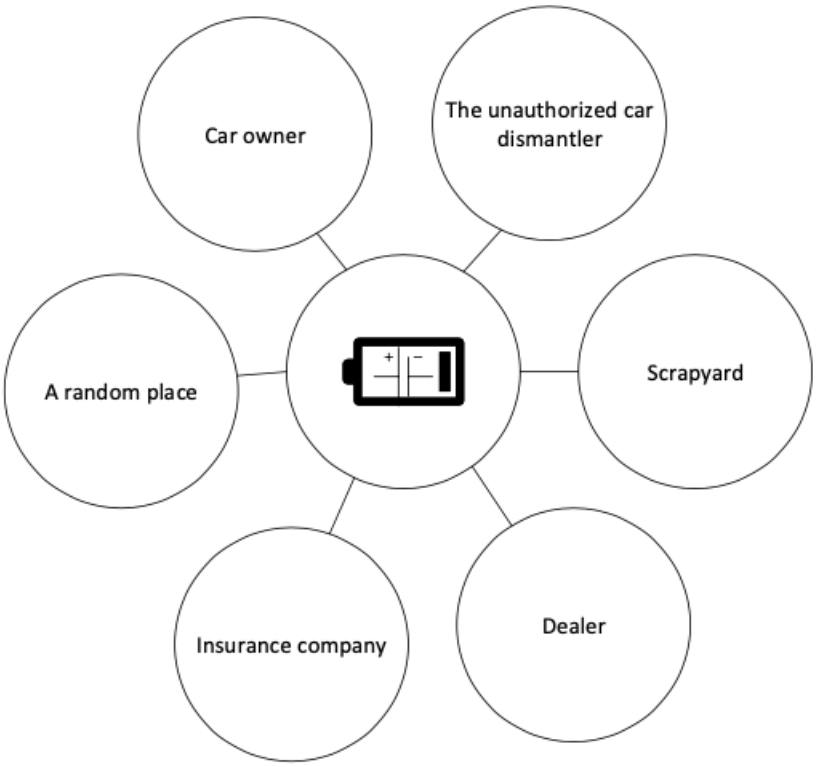

Figure 1.1: An overview over the potential outcomes the batteries could end-up at.

1.3 Delimitations

This thesis will focus on the geographical area that is the European market, including (EMEA). Due to the time constraint it will be more of a holistic view and not being specified for each country, as they all have different regulations. The thesis will be focused on the HV Li-ion batteries that comes from post first life and not second life.

1.4 Thesis outline

The thesis starts out with an introduction chapter, which is supposed to give the background to the subject of matter. This is followed by the aim, deliverables and delimitations. In chapter 2 the theoretical framework is presented. This includes a review of frameworks and literature that is related to the key topic, which will provide a good comprehension of the specific area. Furthermore, in chapter 3 the method and research process will be introduced. Following this, the findings and results from the research process will be presented in chapter 4. In chapter 5 analysis and discussion will be carried out, that is based on both the theory and the findings. Lastly chapter 6 will provide with a summary of the most important findings, concluding remarks and recommendations.

2
Theoretical framework

In this chapter, literature will be presented to gain a better understanding of the topic. The chapter will include the basics of what a business model is, as well as present the concepts of two-sided markets and circular economy. Furthermore, the actors, lithium-ion batteries, take-back systems, extended producer responsibility and benchmarking of other car manufacturers will be described.

2.1 The business model canvas

Over the years, there have been numerous definitions of what a business model is. One definition that is very well-known comes from the book *Business model generation: a handbook for visionaries, game changers, and challengers* and it states the following: "A business model describes the rationale of how an organization creates, delivers, and captures value" [1]. This definition comes from author and entrepreneur Alexander Osterwalder. According to Osterwalder, a business model can be described with nine basic building blocks and the business model canvas is a tool that can be used when one wants to build a business model. The building blocks cover the four main areas that are included in a business: the offer, the customers, the infrastructure and the financial ability [1]. The building blocks could be seen in Figure 2.1 and each block will briefly be explained below.

1. Customer segments: corresponds to the various groups of customers that the organisation is aiming for, e.g. which people are the most important customers and for which ones is value created?

2. Value proposition: describes the services or products that creates a certain value for the customer, e.g. the speed of service, price or overall customer experience.

3. Channels: the way a firm communicates with their customers to be able to provide them with a value. The channels can be indirect, e.g. retail stores, but they could also be direct, for example a website.

4. Customer relationships: describes the type of relationship between the firm and the customer. How does one maintain the relationship and give a pleasant customer experience?

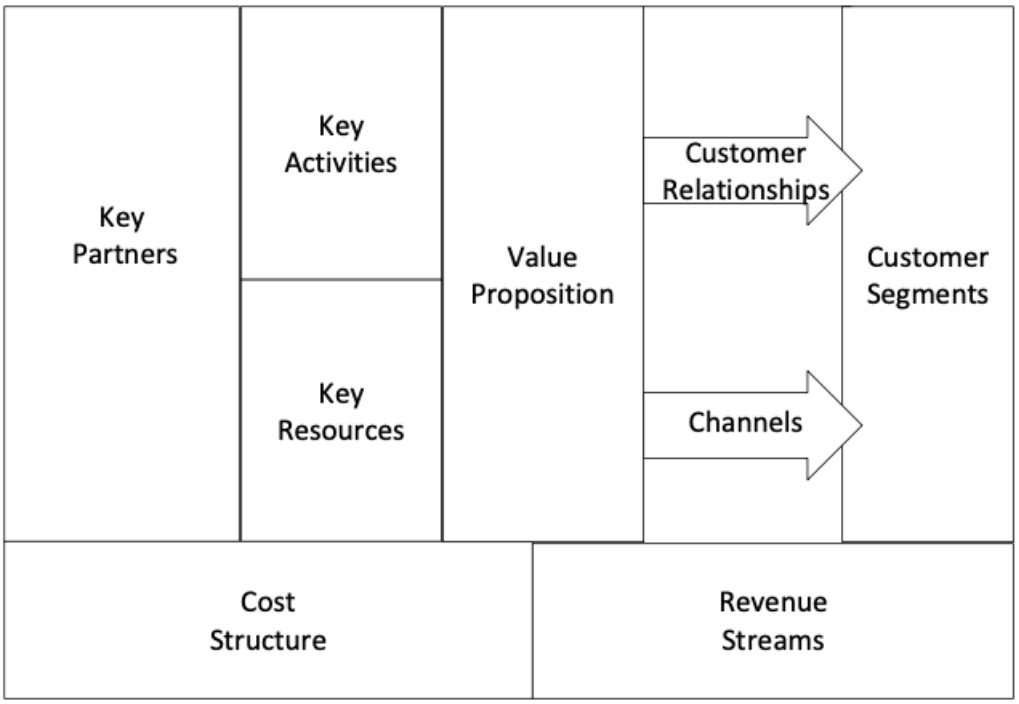

Figure 2.1: The business model canvas with the nine building blocks. The figure is based on [1].

5. Revenue streams: the amount of money a firm profits from the customer and the various ways a customer can buy for the product or service, e.g. leasing, subscription fees or buying the whole asset. What value is the customer willing to pay to get the offer?

6. Key resources: is about the important assets that are needed to make a business model function, for example something physical, e.g. buildings and manufacturing facilities. But also, intellectual resources, such as partnerships or having proprietary knowledge.

7. Key activities: the importance for the firm to do the things that enables the business model to work. This could be for example, making the production go by smoothly. Another example is solving problems for individual customer issues.

8. Key partnerships: the different key partners and key suppliers that are very much needed to make the business model function.

9. Cost structure: represents all costs that is included in the business model, e.g. what is the most important and most expensive costs in the business model?

2.2 Two-sided markets

Whilst Osterwalder shows the elements needed in a business model in a broad way, there is another theory that explores further the different relations, when bringing together different types of groups. This theory is called two-sided markets. In a two-sided market, one or several platforms enables an interaction between end-users and every group depends on the presence of the other group to be able to receive value from the network. On a regular basis, interaction with two-sided markets is taking place, for example: the credit card connects the trader with the consumer. The cable TV connects the viewer and advertiser. In two-sided markets the consumption of a product benefits another. For example, regarding externalities, the more users of a product or a service, there will be an indirect and collective surplus, which one individual cannot have control over. The reason why two-sided markets is challenging is because it needs to appeal to the different groups, while at the same time understanding their needs. The dilemma is often compared to the chicken-and-egg problem, as one side will not join without the other [19][20].

To describe it in a very simplistic way, one could picture an interaction between two end-users, seller (S) and buyer (B). A platform, generally being the marketplace, is where the seller and buyer meet. Between these two there is a potential gain in trading. If the platform could affect the volumes of transactions a market is two-sided. This specifically means that one side is more charged, while the other is less charged. One of the key points here is the importance of the price structure and balancing it right to bring both sides in. Pricing is tricky in two-sided markets, because the platform providers needs to decide which one to favour more or less. As a consequence, it is important to have an understanding of e.g. which group is more price sensitive and which group uses the most value from the platform [19][20].

The two-sided market is more of a depth economical theory and is explained here in a simple format. The reason for describing it, is because it could be later used as a support for analyzing and understanding the battery take-back with all the different actors involved. It can be utilized categorizing the different paths and the relations between them. Moreover, the opportunities one could take, placing the big actors in the value chain structure and reasoning for their respective strengths and weaknesses.

2.3 Circular economy and circular business models

For a very long time the world have had a linear economy approach. The linear economy includes the steps of extracting raw materials, manufacturing it and discarding it. In essence, it is about how everything is driven to be better, bigger and faster. In contrast, circular economy strives for keeping the materials and products in use for as long time as possible [21].

There are many definitions of circular economy, but Ellen MacArthur Foundation's definition is one that is commonly used. The definition builds on the three principles of: reduce, reuse and recycle (often referred to as the 3R's) [22]. If different materials and components follow these steps it will not only save energy, but also reduce waste as well as maximize and create value to the products life [23]. The circular economy consists of social, natural and economic capital. Together these will bring along social and environmental benefits, but also business opportunities as well [22].

Sustainable business models is getting more of a momentum and is of interest for not only companies, but also researchers. It is needed from companies to create sustainable business models to achieve both social and environmental sustainability in the long term [23]. The car industry is already entering a transition state with the ambition to be more sustainable with their products. In fact, the market is circular as the the automotive industry already have many components where they reuse and refurbish, e.g. gearboxes or engines.

It is believed that by year 2025 there will be 250 000 metric tons of HV Li-ion batteries that will have reached EoL. EoL refers to the battery no longer being useful in a car, nonetheless the capacity left could still be around 70-80% [2]. In Figure 2.2 the various steps a battery takes during its lifetime is displayed and how the extended circular battery life could look like. To be able to proceed with the 3R's and achieve circularity, one has to try to stay in control over the batteries.

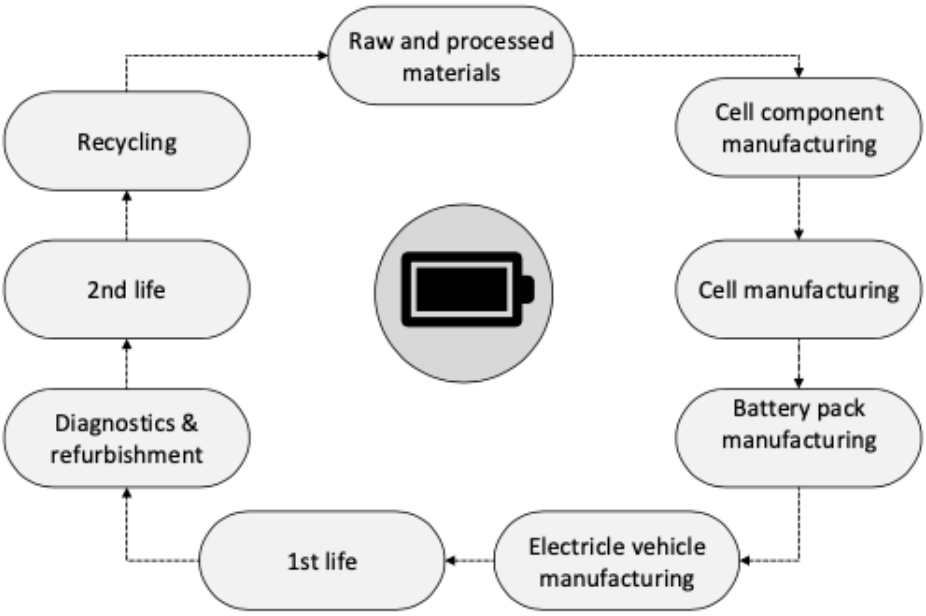

Figure 2.2: An overview over the EV battery value chain. A merge based upon the two figures from [2] and [3].

2.4 Take-back systems and mechanisms

As the world is starting to transition to becoming more environmentally friendly, many manufacturers take their action with take-back schemes. Take-back programs could either be mandated depending on where a company is situated or it could be voluntarily offered [24]. A take-back program means collecting the products from the consumers back to the manufacturer or retailer. There are many benefits to why one would like to implement a take-back system and as previously mentioned in section 2.4, it is crucial when products and materials aims to be reused and re-manufactured. This way the raw material could be secured and repurposed into the cycle, instead of using primary material. Moreover, it is also about handling the hazardous materials in a safe way, which will also mitigate the risks with it. As a result, it will help to reduce the environmental impact, as well as form a trustworthy and strong customer relationship showing responsibility over their products. In many cases, a possible problem is removed from the customer by collecting it, as the product was most likely wanted to get rid off in the first place [25].

Take-back regulations can be seen in many products that exists today. There are several market-based incentives and mechanisms to try to get something back that works quite successfully. One bright example is the deposit-refund system with PET bottles. When the consumer buys the bottle, the deposit is already in the system and upon return one would get money back. The consumer gets directly responsible here and as the bottles have a value, many people choose to return it. For instance, Sweden is one of the best countries on the deposit-refund for bottles and in 2018 the amount of returned bottles were almost 85% [26]. This shows how the incentive works well enough for the customer to return it and as a result it has also improved the collection rates, while at the same time leading to less garbage, saving energy and gaining a more sustainable society [27] [26]. This system is also applied for a gas bottle, that is needed for a gas grill. An additional deposit is on the gas bottle and when the gas bottle is empty one simply replaces it with a new one [28]. Furthermore, something very similar is a core exchange. Upon returning the original product, one could purchase a replacement for the product. This process could be seen in e.g. brake shoes, remanufacture of engines, transmission and clutches [29].

When a customer buys a product, the customer owns the product. All risks and liability is with the customer, who is the user and as a consequence the user decides what to do with the product. For example, if old tires should be recycled [22]. There was an similar dilemma, on how to get back old tires and how they would be handled properly and not go to landfill. At present time, those who sell tires on the market are responsible to get them recycled, as it has been decided by regulations and authorities. So, when the customer buys a tire, there is an environmental fee included in the price already. When the tires needs to get recycled the cost have already been paid for and everything will be taken care of [27].

Not only are those who sell tires on the market responsible for getting them recycled, but this applies to also those who are producers of electronic goods. The 'WEEE'

directive is a directive, where it is stated that the producers of the products in EU members states are responsible for the disposal. This means that the producers stands for the costs in from both the waste management, but also the transportation costs from the collection centers to recycling [30]. Consequently, this is also applied for the car manufacturers and is called the: *extended producer responsibility.*

2.4.1 Extended producer responsibility and EU legislation

Product manufacturers are held responsible for both collecting and recycling HV Li-ion batteries. This is something that is called Extended Producer Responsibility (EPR) and includes the steps from collecting, storing, treating to eventually recycling the batteries. The EU regulation, called the EoL Vehicle (ELV) directive, states how the car manufacturers have the responsibility for both the collecting and managing for the different components of scrap vehicles. This is the reason why the EPR scheme also accounts for the components such as the HV Li-ion battery. As of now, the ELV directive have had quite generic guidelines and nothing particular specific in how to handle the HV Li-ion batteries. For example, a minimum recycling efficiency of 50% regards to the weight of the battery is stated. This in turn gives the recyclers the opportunity to act very flexible at the moment and only recover the materials to what is more feasible to recover, but also what is most economically beneficial [31].

Much will be underway in the upcoming years and as of now car manufacturers operate in some sort of grey zone area, regards to how to be able to deal with the batteries. What stands clear is that the manufacturers takes the responsibility over their products, that could be both toxic and dangerous to their surroundings [24]. Currently, there are no specific directives for how to handle HV Li-ion batteries, but that subject of matter will soon change. In the nearest years, the commission will propose a new regulatory framework for batteries and this will also include legislative proposals regarding the EoL vehicles directive. At present, some glimpses of what will become more clear is already known. The commission will evaluate the battery directive and look further into how it will cohesively be applied for the HV Li-ion batteries, regards to their new chemistries and technology. Furthermore, rules will be set up of how much content that will be needed to be recycled and how to manage to improve the recovery of valuable materials e.g. cobalt, lithium and nickel only to name a few. Moreover, what measures to account for to improve the recycling rate of batteries. There will also be shared insights in how to facilitate the traceability with the batteries though the product information database. Further, a look into the raw materials and ethical sourcing, but also how big the carbon footprint will be for the production of the batteries [32].

2.5 Lithium-ion battery

To comprehend why the batteries are important to gain back, it may be beneficial to take a further look at how the battery operates and what it is made of. The lithium-ion battery was first presented in 1976 by the scientist Michael Stanley Whittingham. Since then, the design has been changed many times [33]. In the early 1990s lithium-ion batteries were commercialized and reached a high popularity among consumer electronics. It did not take long until the batteries further reached the EVs, because of the many benefits the battery managed to fulfill, e.g. the long cycle life, the long storage life, the low self-discharge efficiency and the high energy and power density [31] [34].

A lithium-ion battery is rather compact and consists of battery cells being assembled in modules, which then all assembled becomes a battery pack, surrounded with a battery management circuitry [31]. This could be seen in its simplicity in Figure 2.3.

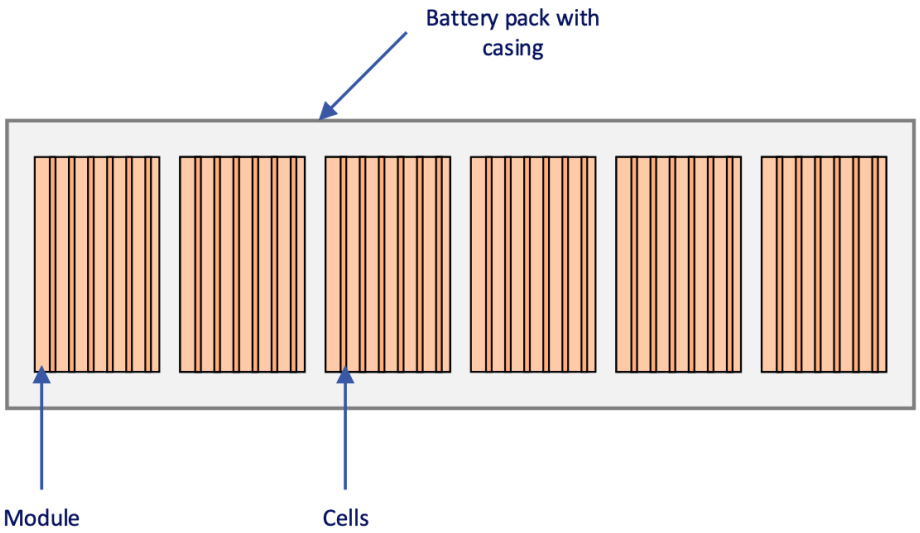

Figure 2.3: A simple overview over the battery pack, with its modules and battery cells. Figure based upon [4].

The HV Li-ion batteries that are most typically used in electric cars are in the combination of Nickel-Manganese-Cobalt (NMC). A lithium-ion battery consists of a cathode, an anode, a separator and an organic electrolyte. The cathode is usually an aluminium plate, that is covered by an active cathode material, Lithium-Nickel-Manganese-Cobalt-Oxide, $LiNiMnCoO_2$. The anode is a copper plate that is coated by a mix of graphite and the separator is made of polypropylene or polyethylene to prevent short circuiting. There is also polyvinylidene fluoride (PVDF), binder for both the cathode and anode, that acts as an electric conductor. A common solute is Lithium hexafluorophosphate $LiPF_6$, for the organic electrolyte. Electric contact is possible when the cathode, anode and separator compresses [35]. When the lithium ions travel from the cathode through the electrolyte, passing the separator to the

anode, the cell is storing energy. When the lithium ions goes back to the cathode material the cell discharges, hence producing energy [31]. See Figure 2.4. A huge advantage with a lithium-ion battery is in particular how it can be recharged at the remaining capacity. This does not affect the number of full cycles the battery does and therefore there is no need to have full discharges [33].

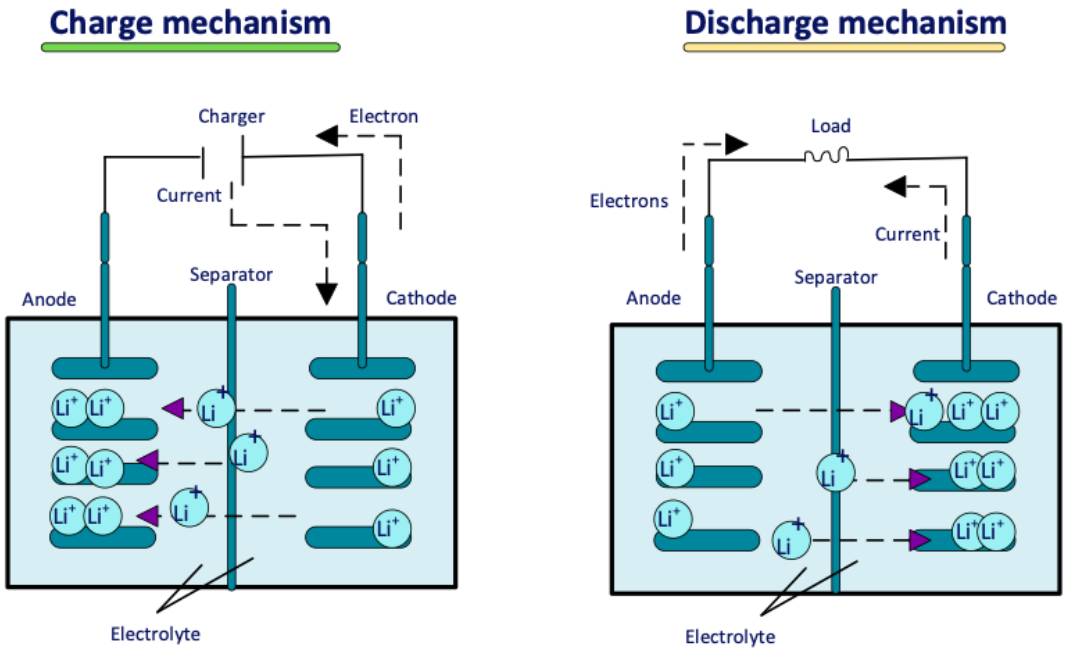

Figure 2.4: The mechanisms for charging and discharging is showed in a lithium-ion battery. Based upon the figure [5].

With an increased demand of batteries, it will highly impact the different raw materials that is needed. The raw materials that ranges from lithium, nickel, manganese and cobalt have different percentages in the battery, where for example the cobalt content could range from 10-20 % [34]. Perhaps the most widely discussed material in the battery is cobalt, where it is estimated that batteries could use up to more than 10% of the world reserves for cobalt [31]. Cobalt is almost entirely a by-product from nickel and copper production and in the Democratic Republic of Congo lies 48% of the world's cobalt reserves. It is stated that 70% of the world's cobalt is mined in the Democratic Republic of Congo. The situation have been heavily discussed as many mines are illegal, the miners living under hard working conditions and the occurence of child labour [36]. However, this raw material do not pose to be the only problematic battery material.

Lithium is believed not to be any large problem regarding shortage of the material, however it could affect the locals in a different way. For instance, lithium is usually extracted in Australia from hard rock or from Chile from the brine. When lithium is extracted from brine, large amounts of water is pumped from the ground. Some

regions in Chile are scarce on the water front, which as a result could have large affects on the farmers [36]. Recycling the materials from the batteries could help to reduce the demand of the raw materials.

The cathode materials such as cobalt and nickel are what contributes the most to the costs for the raw materials. As the HV Li-ion battery consists of valuable, heavy metals, but as well as dangerous organic materials from the separator and electrolyte the batteries are labelled as dangerous waste. For instance, if the battery would be burnt both the PVDF and $LiPF_6$ could produce gases as hydrogen fluoride, which is very harmful for the human health, animals and the environment [34] [35]. This is why it is important that the batteries do not lead ashtray, instead getting handled in a responsible manner.

2.5.1 Estimation of cost for the post first life batteries

It have been mentioned earlier that there is a value that comes with an HV Li-ion battery, however at present it is rather difficult to decipher and evaluate how much an used HV Li-ion battery could be worth. Generally speaking, it is said that its prices are valued regards to the car model, year, how many miles the car has been driven and what state-of-health the battery is in. Hence, it is very individually valued. However, there are already post first life batteries being sold at the moment. Multiple platforms such as eBay or Blocket sells cars and with that also HV Li-ion batteries. There is a possibility that when the battery no longer is in the car, the secondary market of selling batteries could become an entire industry in itself. This could be rather expensive, as it could give a hint or an indication on what the car manufacturers needs to compete with, essentially what they need to pay to get the batteries back. To get some sense of what prices the batteries are selling at the moment from different car dismantlers, an overview over some cars are seen in table 2.1. The batteries are both from EVs, as well as PHEVs. From the website Bildelsbasen a handful of HV Li-ion batteries were picked out and the price/kWh were calculated, so it could be easy comparable with how much it costs for a battery pack today to be made.

What one must account for is that these batteries have not reached EoL. In fact, the the oldest model is from 2008 while the newest is from 2019. These batteries comes most likely from cars that have been involved in an accident, but the battery is not that damaged, so it does not have to be recycled - instead it can be re-sold. Further, it needs to be pointed out that the prices that are displayed, could very well be overestimated and perhaps not the price it gets sold for. The intention is to show the different prices, showing a range of what is sold now, when the volumes still are pretty small.

Even though, it is looking like the batteries from post first life will maintain expensive, a different pattern is showed with the batteries that will be produced. The company Bloomberg New Energy Finance makes estimations and future projections

Table 2.1: In the table different car models, year, Swedish miles, battery capacity [kWh] and price/kWh are showcased. Numbers that are based from [6].

Car model	Year	Miles	Battery capacity [kWh]	Price/kWh [SEK]
Toyota Prius	2008	21	1,3	5443
Toyota Prius	2013	7,1	4,4	7102
Volvo XC60	2019	1,2	10,4	7416
Volvo V60	2017	10,6	11,2	7667
Volvo V60	2013	17,2	11,2	6696
VW Passat	2018	4,6	9,9	5971
VW Golf, e-Golf	2015	3,2	8,7	7194
VW Golf, e-Golf	2017	2,2	8,7	5603
Mercedes C-class	2017	4,3	6,2	4032
Ford Mondeo	2016	2,1	1,4	10714
Renault Zoe	2018	4,5	41	1829
Mitsubishi Outlander	2019	33	13,8	3623

annually, where they foresee that the average prices will fall for battery packs. Their battery forecast suggests that the price of an average battery pack by 2024 could be $ 94/kWh and in 2030 it could be down to $ 62/kWh [37]. As of 2019, the market average was estimated to be $ 156/kWh [38]. These predictions of course differ on region, but the highlight here is that there will be continued costs going down through the 2020s.

2.6 Benchmarking of other car manufacturers

Numerous car manufacturers are moving towards the electrification journey, hence they will be facing similar problems regards to managing the batteries. Some car companies have had longer experience and knowledge, when it comes to both EVs and PHEVs. To begin with, one could look at Toyota. They first began mass-producing their hybrid EVs since 1997. Toyota introduced a consumer incentive for the return of Toyota Prius NiHM batteries and it was the offer of $100 (Australian dollars) rebate for hybrid HV batteries. This offer is for the batteries that are no longer functional. There could also be another offer, a core exchange discount if one would purchase a replacement hybrid HV battery. This discount is $500. The $100 rebate and the $500 discount, cannot be combined in one transaction. This offer is valid for 'Toyota Motor Corporation Australia' with all its dealers in Australia, however when reading into Europe and Sweden it is not the same case [29].

On the website for the 'Toyota Europe', it is stated that they have a take-back scheme to ensure the batteries are dealt in a safe and responsible way. They retrieve 90% of their batteries in Europe, but aim for 100%. This is regards to the hybrid batteries. It is further showed that there are large second life applications with storage units [39]. However, it does not come across whether these batteries are mostly from within warranty or outside warranty cases. Moreover, there was also an unofficial price $150 cash reward floating around, that if one would give the battery

back one would get that amount of money. Interestingly enough, when contacting Toyota Sweden it was informed that there was no such system of a sum one gets if one gives back the battery, instead what they offer is to take care of the battery, standing for the recycling costs.

Toyota is the most concrete example and perhaps the nearest of what incentives are available to get the battery back, that could be found. Other car brands such as Tesla, BMW, Renault, Nissan, Mitsubishi and Daimler were also contacted to try to get some information, as it could not be found on their websites. The outcome were either that there was no response, or the response was that they could not give out that information. Renault referred to a link to their 'Circular economy of the electric vehicle battery', however it does not say anything about how the batteries are taken back, more about how they care for the batteries in second life.

Many car brands await recycling of old batteries and are also very much invested in second life strategies e.g. Nissan, Renault, BMW and Daimler. Nissan has a holistic approach to electric driving and invests in both solar panels and vehicle-to-grid technology. Renault is also very much involved in second life, with energy initiatives being very similar to the ones Nissan has [40]. This showcases, that if the different car manufacturers enables second life applications for the batteries, there is a flow of batteries coming back to them. Whether this is an already take-back scheme available or under way is something one could speculate in, but to be able to run big energy storage units, one has to have many batteries and therefore there might be some type of system most likely existing.

3
Method

This chapter explains the research design, documentary research and the overall research process. Furthermore, the Delphi method that have been used is explained.

3.1 Research design

To be able to tackle the research problem, a framework of research design is provided e.g. how to collect, measure and analyze the data. There are several research processes and in literature there are both qualitative and quantitative research processes [41]. A qualitative research process is very useful when exploring questions like: what, how and why. A qualitative research process gives an understanding of the underlying reasons and opinions regarding the problem, but also insights and ideas. In this report, data was collected in qualitative interviews and through qualitative text analysis. However, there are some quantitative measures included, which comes from the Delphi study. In Figure 3.1 an overview of the different parts that were used in the method are showcased.

For the documentary research, the sources of secondary data that were used for the report were partly articles and books from Chalmers' library and Google Scholar. Moreover, through interactions with people from different areas, more documents and reports could be found. Furthermore, there were a total of five semi-structured interviews conducted. These interviews were:

- An owner for a car dismantling company
- A project manager at a recycling company
- Three different car OEM dealers

The purpose with these interviews were to gain more insights and knowledge about the studied area. Further, the questions for the Delphi study were developed with the support from stakeholders at Volvo Cars. The six potential outcomes were central in the questions for both the interviews as well as in the Delphi study. The questions were then later revised by the supervisor at Chalmers.

Figure 3.1: An overview of the three main parts in the method.

3.2 Delphi study

The Delphi method is a type of forecasting method and is used when faced with a complex problem. A group of individuals, that are perceived as experts on the area are gathered and with the help of a Delphi study they are able to voice their opinions [42]. The outcome from a Delphi study can bring one, a step closer to how to approach and handle the specific problem. Delphi studies could differentiate based on the aim. For some, the aim is to reach some sort of consensus among the participants, but it could also be to gain a better view over the different opinions [43].

The Delphi method was chosen to be carried out, as it could reach many participants on a short time frame. Moreover, it also provided with a good fit considering the topic with the uncertainty of the batteries within the near future. The Delphi method relies very much on the experts opinions. This could be quickly considered as a disadvantage, as that easily brings along subjective ideas and thoughts to the topic, depending on how varied the participants from the expert panel are [44]. This meaning, that the point of view may be tilted more in one direction than another based on what the choice of panel ended up being. However, when there is a lack of historical data and in times of uncertainty, expert opinions could be very helpful and useful. To find the relevant stakeholders for the Delphi study the snowball technique was used. It was used in that sense of how one potential stakeholder was interviewed and through that stakeholder one could learn to find new stakeholders, hence the name of the technique, as it is growing like a snowball [45]. In this thesis an expert is considered to be one having an understanding and considerable knowledge within the studied area.

The Delphi study included two surveys that aimed to gain a deeper knowledge about how to motivate and encourage each actor in the possession of an HV Li-ion battery. The choice of expert panel were to find those with an high degree of expertise in different areas regards to the battery, that could provide with valuable insights into the report. See table 3.1.

Table 3.1: The stakeholders that participated in the Delphi study are presented.

The different areas for the panel of experts	Number of participants
OEMs	10
Research institutes	2
Recycling industries	2
Universities	3
Energy storage supplier	1
Energy company	1

A link to the questionnaire was sent out to everyone individually through email. The questionnaire was sent out to 24 participants, where 19 participants answered in the first round. The second round was sent out to the 19 participants, where 18 responded. The respondents were given two weeks to answer each questionnaire. A reminder was sent out a week after and on the very last day.

The procedure of the Delphi study was that every person in the group from the selected experts shared their opinions in the survey. When the answers for the first round were completed, all answers were summarized and then sent out to every participant. One could not see who had written what, as it was anonymous. The participants had then the opportunity to once again state their opinions or even change them when the second round of questions were sent out. To change one's opinion, it is easier when it is done anonymously, as it minimizes any impact of peer pressure in the negative kind of way. The questions in the second round focused on the questions from the first round, that differentiated the most in the answers between the participants, to see if it was possible to reach a more unanimous view over those specific questions.

Google forms was used as the questionnaire format, as it would facilitate the collection of data to simply fill it in online. Conducting a Delphi study enabled the respondents to answer when convenient. The questions were varied in the two rounds. In the first round some questions needed to be ranked in a specific order or others were more qualitative-based questions. In the second round the questions format were more of a tick-box style based on the Likert scale, which is a format that is quite often used for questionnaires [41]. The questions for the two Delphi rounds can be found in Appendix A.

3.3 Ethics of research

There are ethical principles and guidelines to be able to carry out a responsible approach, when one is doing research. One ethical principle is the risk for harm for the participants involved. This could be harm for the participants in a way that could hurt their self-esteem and therefore it is important to respect their privacy. This was why the participants in the Delphi study remained anonymous. Another ethical principle is regards to receiving informed consent. This means that the

participants got the information regards to how their contribution would be in the thesis work and understanding what the research problem was all about it [41].

4

Results

In this section the findings, the results from the Delphi study and the interviews will be presented.

4.1 Outcome from Delphi study and the interviews

The outcome from the Delphi study showcases different opinions as well as agreements in the various questions. The semi-structured interviews that were carried out were more or less based upon the same questions as the Delphi study and due to not them being able to do the Delphi study, it was chosen to do it in interviews instead.

4.1.1 The battery is in the hands of the car owner

In the first round the participants were asked to choose between four options and rank them in the specific order they would think would be the best to be able to get the battery from the car owner. The outcome could be seen in Figure 4.1. The clear majority chose economic compensation as their first choice, which was then followed by other and the exchange system. To understand the choices made by the participants summarized arguments with economic compensation, exchange system and other will be presented below.

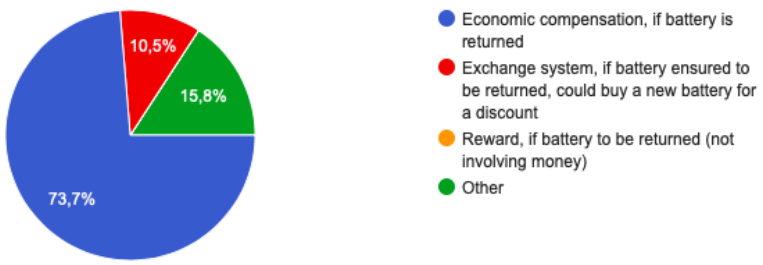

Figure 4.1: An overview of the first choice for the battery when it is in the hands of the car owner.

The arguments for Economic compensation were:

- "Easiest for the owner."
- "People like money."
- "Market competitive price for an used battery will motivate all actors globally."
- "The most effective way to get it back is to offer money for the batteries. Needs to be higher than the value of the batteries on the open market."
- "The strongest incentive for a customer to return the used battery - the customer is completely free in how to use the money."
- "To create a demand for taking care of batteries a compensation should be involved e.g. compare with lead-acid batteries where the high level of recycling/reuse creates its own business."

The possible barriers for Economic compensation were:

- "Hard to find the real market value, accruals for buy-back could be hard to estimate."
- "Transport of old batteries will always be costly and impact carbon dioxide. It can be better to recycle locally than bring back centrally."
- "Maybe resistance by producers."
- "To have a compensation built in will increase the price from the start. Who is prepared to cover that risk?"
- "The compensation for returning the battery is lower than the perceived investment, like effort and time."
- "The car has no value without an operating battery inside."
- "The price of batteries changes drastically during the first use at first consumer. That there is no established infrastructure for safe return of batteries e.g. no "dealer" in the geographic vicinity of consumer. That the pay-back is too low for consumer to justify the return."

Suggestions on how to tackle the barriers for Economic compensation were:

- "Raise the start price of the car."
- "Offer free collection of the car for removal of the battery at an official dismantling site. Include a core charge for the collection and recycling of the EoL battery."
- "It should be part of the scrap vehicle reward."
- "Evaluate each market and set up local processes with the sales company."
- "Minimize the numbers of conditions and limitations needed to put a take-back in place."
- "Go and get it. (the battery) Make it a pleasant battery owner experience."
- "Monitor the market value in order to set a valid compensation value, globally. Determine sufficient return rate v.s cost. Develop a compensation program which are simple and convenient to use."

The arguments for Exchange system were:

- "Exchange system makes sense for customers that are interested to continue to use the car with a new, or even more likely, a remanufactured battery."
- "Both the customer and the company will benefit from an exchange system."
- "From a CE perspective I favour an exchange system, because it incentivises extending the life of both batteries and the car (when the old battery is exchanged with a "new" one, the car can continue to live on)."
- "If it gets too old and therefore starts to badly perform, one could offer an exchange system (discount on new battery for handing in the old one). This system is applied in the automotive remanufacturing controlled by OEM business and works relatively successfully (especially for quantity returned, bit less for the quality that is returned - good quality used products are sold and poor ones are handed in for the discount."

The possible barriers for Exchange system were:

- "Exchange system is very dependent on second life prices for both battery modules and cars i.e. will the value of the car increase more than the price paid upgrading the battery."
- "One problem is setting a balanced demand and supply model for an exchange systems. Another challenge is to take care of the batteries that get returned. Often those batteries have remaining capacity that can be attractive for other applications (second life opportunities). However organizing a system that evaluated and accordingly distributes the batteries to relevant markets could be tricky."

A suggestion on how to tackle the barriers for Exchange system was:

- "One way is to establish a system that collects and integrates data on batteries along the value chain. Such a system can be very useful both for organizing

a distributed market that connects different ecosystems (e.g. batteries from a bus can be reused in a car, and then they can be reused in an energy storage unit) as well as for keeping track of how the battery behaves in different applications and under different circumstances. That analysis can also benefit future battery development and manufacturing to better match the demands."

The arguments for Other were:

- "Previously money has guided for example the Pb battery business. Collect and sell for Pb. In this Li-ion its a bit more complicated since the current processes are very costly. I think the producer responsibility should be taken with a more responsible approach and never let go of traceability of the batteries and be responsible for what they put on the market must come back into the eco-system of batteries. This should be done by cooperating with companies and not make it into a market commodity because then people will battle for these products and we will loose traceability. So, money should not solve this, responsibility should."
- "Prolong warranty and make it a life warranty i.e continue to use take back procedures already up and running."

Possible barriers and how to tackle them for Other were:

- Barrier: "We are a very profit seeking people, it will be hard to convince hi-level people to understand that other values have to be highlighted to ensure a sustainable product and a sustainable take-back system."
- How to tackle the barrier: "Put profit as a borderline and drop the focus on margins. Investigate other means of value, for example social and environmental impacts."

From the interviews it could further be added regards to the first potential outcome that:

- "The battery will come back with: the car + battery to a dismantler, however a used battery could take another separate flow as some would like to make business out of it."
- "All types of variations (economic compensation, exchange system etc.) will be needed to not make the batteries spread (geographically) and have more control over them."
- "Economic compensation: Positive and of importance today. Clear solution to return something. Exchange system: A well-known system. Other: Some environmental incitament, e.g. in Norway there is an ELV scrappage fee for the car with 3600 SEK when scrapping it."

In the figures 4.2, 4.3, 4.4 it could be seen how the respondents answered in the second round. It could be seen that there is a strong agreement that economic compensation is the best option for encouraging the car owner to return the battery.

There is also a large agreement towards the exchange system, however there is also a portion of disagreement as well. For the case of other, it dominates by neutrality, closely followed by a disagreement towards the option of other being the best option for encouraging the car owner to return the battery.

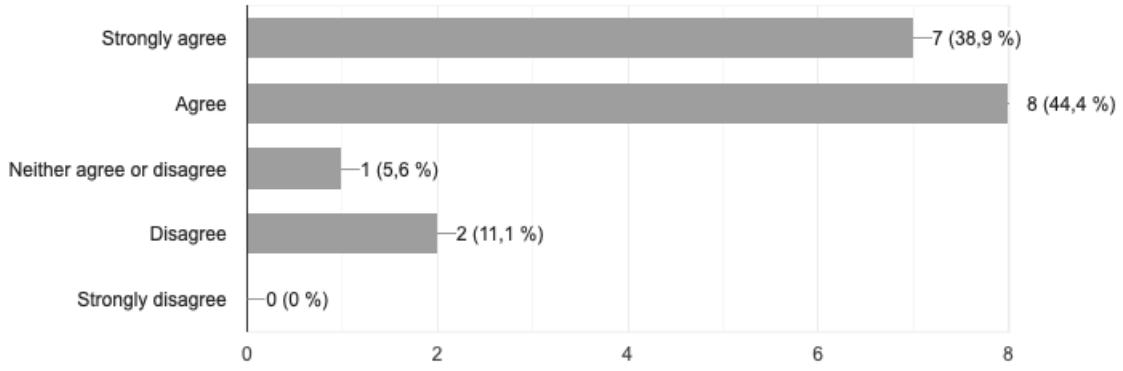

Figure 4.2: The outcome from the second round regards to the statement: 'Economic compensation is the best option for encouraging the car owner to return the battery'.

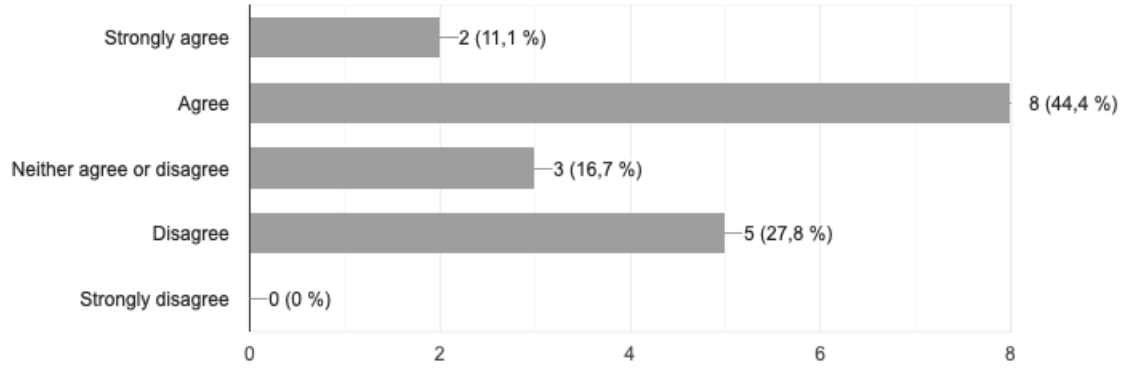

Figure 4.3: The outcome from the second round regards to the statement: 'Exchange system is the best option for encouraging the car owner to return the battery'.

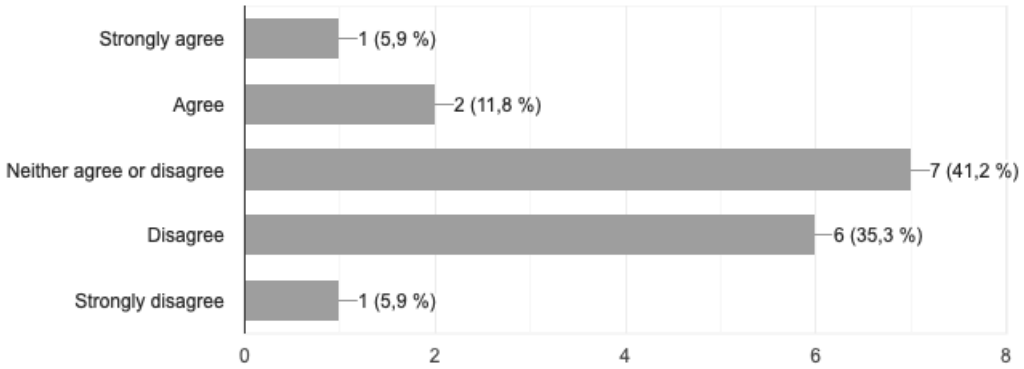

Figure 4.4: The outcome from the second round regards to the statement: 'Other' is the best option for encouraging the car owner to return the battery'.

Additional comments from the respondents mentioned in the second round were:

- "It depends very much depends on who is owning the vehicle, a company or private owner."
- "Combining the two systems of economic compensation and the exchange system could cover most scenarios."
- "Money is in the end the most important."
- "Local solutions might cause more harm than good and none will be able to find a red thread through this jungle. There must be a general / a company way of doing it and the markets might be able to adjust."
- "The framework has to be defined and tight from a corporation point of view. Combinations of the above may be more difficult to put in place and control, but flexibility may be key for this."

In figure 4.5 it could be seen what the participants thought of possibly a combination more or less for all the above mentioned. As could be seen there was a large agreement towards that statement.

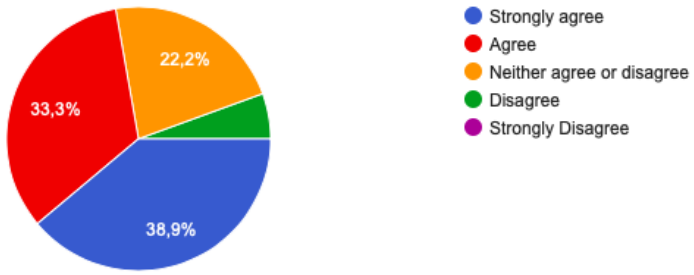

Figure 4.5: The outcome from the second round regards to the statement: 'Possibly a combination more or less for all the above mentioned depending on the different markets'.

4.1.2 The unauthorized car dismantler

The second potential outcome explored the possibility of the battery ending up at an unauthorized car dismantler. The outcome from the first round could be seen in figure 4.6. It shows the first choice of the participants ranking and what they thought to be the best choice to be able to encourage getting the battery back from the unauthorized car dismantler. To comprehend the choices made summarized arguments regards to economic compensation and other will be presented below. As there were not really any specific arguments for the exchange system that could be shared, it is not included below.

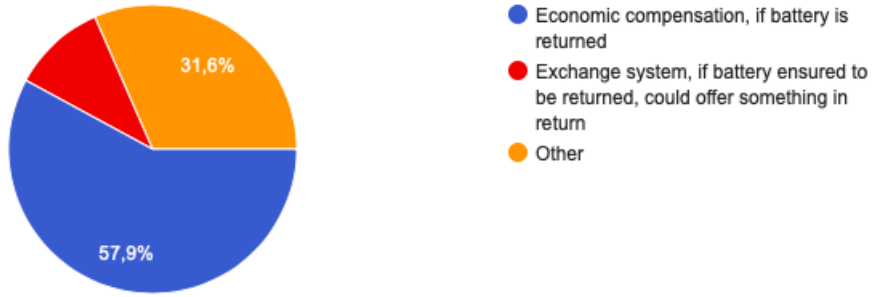

Figure 4.6: An overview for the first round of the first choice for when the battery ends up at an unauthorized dismantler.

The arguments for Economic compensation were:

- "It is all about business. The car dismantler sells the parts to the one who pays the best."
- "Economic compensation. Don´t see anything else motivating the dismantler."
- "Car dismantlers are not interested in an exchange system, the dismantler will only value the battery on the price he gets by either selling it on the open market or if the OEM buys it back."
- "Buying them back will guarantee a supply of old batteries. Another possibility is to work towards a change in legislation such that the producer responsibility can work better (somehow limit the possibility of unauthorized car dismantles to trade in those products)."
- "Dismantlers and workshops are the ones with the knowledge to test and refurbish the batteries. So they can be engaged in the ecosystem to support the process through certification processes, etc."
- "Economic compensation. Needs to be a global program."
- "Small compensation and hassle free handling together with legislation with high fees for dismantlers that are not recycling properly would be good."

Possible barriers for Economic compensation were:

- "Logistic cost to bring the battery back."
- "Hard to find the real market value, dismantlers will most likely over-state the potential prices. OEM buy back programs could also drive up prices as this is creating a larger demand and price competition."
- "Dismantlers need to get state of the art knowledge about how to work with different batteries. At the moment many of them do not have sufficient knowledge for what to do with the batteries they get and they just store them for later."
- "Borders with export of cars with different deposits in different countries... all modules ends up in the country with the best compensation model."
- "To develop an economic compensation program that works globally will have some logistics challenges".

How to tackle the barriers for Economic compensation were:

- "Use battery module ID and link that to the deposit and make it valid worldwide."
- "Acceptable price level."
- "Increase of audits of ELV actors and much much stricter certification processes."
- "More exchange of know-how and data on the batteries. Economic incentives as mentioned above."
- "Use of the battery passport which traces back the origin of the battery and the last owner of the car."
- "Secure to monitor the market value in order to set a competitive price, should be credible in order to build trust in the system long term."
- "Organized and well communicated buy-back communication with fixed prices."

Arguments for Other were:

- "For the car producer is does not make any difference if the dismantler is authorized or not. If your car is ending up at a dismantler and the battery has a market value and you want to have the battery back you have to bid higher than the market value. So a fixed compensation has no use. Exchange system neither. To be compliant you need a network of car dismantlers. maybe you can make agreements with them. But that could be just 1/10 of all dismantlers. (In Europe, negligible for the rest off the world) Note! in the moment a defect/worn out battery, cost money also for the car dismantler. He can't sell and hence must be recycled. So he will be glad to give this battery for free. So you have to distinguish between worn-out and still useful batteries if you would give a compensation. A State-of-Health (SOH) is needed than."
- "I think that incentives should be used making it impossible or difficult for unauthorized actors to be part of take-back. Avoid business model that includes unauthorised actors."

- "Another policy needs to be in place than the other two mentioned. The car dismantler would most likely try to get rid of the batteries on the black market or something similar, and this needs to be avoided."
- "Since this is more business driven this can also be handled by rules and regulations. If not returning the batteries you will be fined for example. Much better though if the business of recycling will create its own money stream."

How to tackle the barriers for Other were:

- "Very difficult as the possible compensation is directly linked to the SOH hence the market value."
- "A mix of regulations and positive actions/financial compensation."
- "Train car dismantlers on how to deal with the batteries, and based on that authorize/certify them."

From the interviews it could further be added that:

- "Opportunities of tracking to make sure it is handled in a safe and environmental-friendly way."

In the figures 4.7, 4.8, 4.9 it could be seen how the respondents answered in the second round. There is a strong agreement that economic compensation is the best option for getting the unauthorized car dismantler to return the battery. For the option of other the majority is neutral, but there is also a disagreement towards that being the best option. Further, for the option of the exchange system the majority disagrees this being the best option, even though there is also a large agreement that it could in fact be the best option.

Additional comments from the respondents mentioned in the second round were:

- "Exchange system does not solve EoL as they are assembling another battery in the vehicle. For the dismantler it is always a matter of cost and profits."
- "With my own experience I have seen even *authorized* dismantlers cut corners every day. Both management and the staff. To ensure a good system you would need a collaboration between the car importers and car recyclers with frequent auditing to ensure that the system is functioning and nobody is cutting corners.
- "A combination of economic compensation / exchange system + legislation will make it doable."

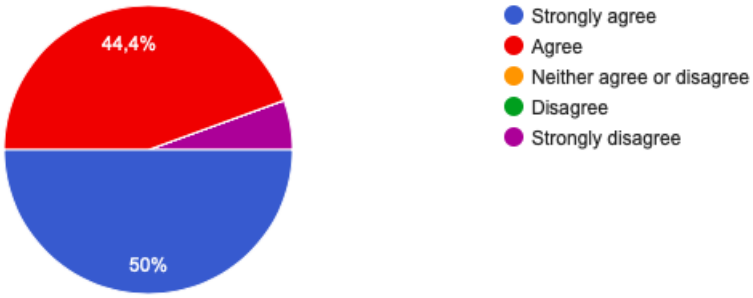

Figure 4.7: The outcome from the second round regards to the statement: 'Economic compensation is the best option for getting the unauthorized car dismantler to return the battery'.

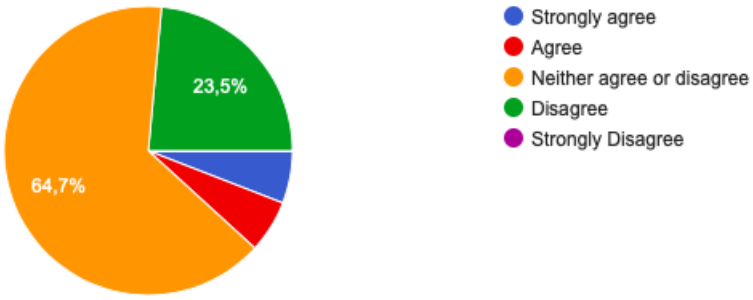

Figure 4.8: The outcome from the second round regards to the statement: 'Other is the best option for getting the unauthorized car dismantler to return the battery'.

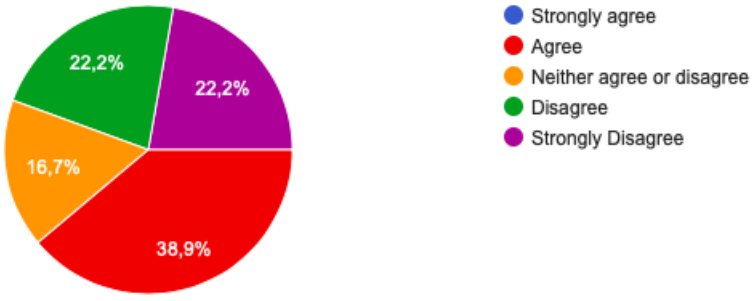

Figure 4.9: The outcome from the second round regards to the statement: 'Exchange system is the best option for getting the unauthorized car dismantler to return the battery'.

4.1.3 The battery ending up at the scrapyard

The upcoming four potential outcomes that are presented in the subsections 4.1.3, 4.1.4, 4.1.5 and 4.1.6 were only included in the first round. This is because they were already unanimous in that round and therefore were not needed to be put in the second round. The summaries of each potential outcome will be presented below.

With the potential outcome of the battery ending up at a scrapyard, there were among the respondents a broad agreement that some compensation were needed to be involved (compensation system). EV and hybrids should only go to certified scrapyards with competence due to safety. There should also be stricter permits for storing Li-ion batteries and a fine system for those who have them. Moreover, traceability, having the battery in an IT system and legislation is also a key factor here. There was also an opinion of "This would require a change in the system. At the moment it is possible for anyone to go to a scrapyard to buy components. If Volvo (or other car manufacturers) is interested in a closed-loop where they keep control over their batteries, old cars should be purchased and dismantled by them or authorized parties. This means that car manufacturers should do more (offer money/discounts) to get end-of-life cars in their system."

4.1.4 The battery ends up at a dealer

A broad agreement for some sort of compensation and exchange system. There could be a point system. Submit the old parts and then these points are worth an amount of money, which can be used to buy new parts. Moreover, having a price deduction by leaving the battery and wanting to replace it with a refurbished one. Moreover, it is about having a return order with a compensation also being imposed.

Further comments that also were made:

- "Introduce clauses in the dealer standards that no battery is to be sold to third party."
- "Authorized dealer can be encouraged to return batteries by not selling new components if they do not return old components."
- "The dealer is controlled by the importer and are under strict rules. Therefore this is no big issue."
- "It is all about business. The car dealer sells the parts to the one who pays the best."
- "Core charge compensation."

4.1.5 The battery is in hold at the insurance company

The insurance company does not have any incentives on their own in regards to what to do with the batteries. They have more agreements with dealers and dismantlers. If an accident has occurred the insurance company takes over the ownership of the entire car and this ownership is then transferred to a car dismantling company.

Therefore, it is more important to have an agreement to buy the battery back from the car dismantling company.

4.1.6 A random place

It is believed that this will be a marginal problem in the near future, however it is suggested to have an information campaign, e.g. what a person should do if one would find it and perhaps offer some type of reward for the trouble. Moreover, it is stated that it is important not to build a business model around the lost batteries. Furthermore, it is more important to fee the ones who have dumped it in nature as the batteries are an environmental hazard. It is also suggested to have an unique identifier to trace it back to the owner.

Further comments that also were made:

- "Batteries can be very dangerous and abandoned batteries can be tricky to handle by non-experts. I therefore do not recommend incentivising a "pokemon" solution where people actively look for batteries to collect and return them because they should only be transported with care and should perhaps be tested for simple faults before being transported. However, OEMs could communicate on a battery pack for instance what a person should do if they get hold of such batteries (what number to call, what information to give) and there can be reward system designed for that."
- "Since these should be handled as dangerous goods, at least according to today's regulations, I believe it should be possible to report "lost" batteries and get a refund. Important however, not to create a business out of "lost" batteries. Compare with the fundings that have been valid for old boats where instead of a high cost you can scrap your boat for free during a certain period. One idea could also be amnesty (like for weapons) where you can report your old batteries."
- "If the battery would be good it will not end up in the nature. If the battery is defect than nobody will recover that one."
- "The metals in a battery pack has a huge value, the key will be how to secure that the part has not been stolen to enable selling to a recycler."

4.1.7 The question of leasing to secure the batteries coming back

There are various ways to approach the car owner and therefore the questions of leasing as well as leaving a deposit were also included in the both rounds to further explore if these mechanisms could be an option to secure a battery take-back. In figure 4.10 the outcome from the first round is displayed, where the majority is in the field of maybe. The arguments regards to the question of leasing will be presented below.

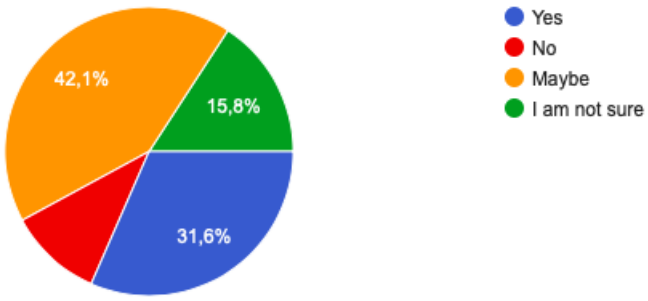

Figure 4.10: An overview of how the participants answered in the first round regards to if leasing could be the best option to secure the batteries in the near future.

The arguments for Yes as well as potential obstacles were:

- "Then the OEM owns the battery from the start."
- "I believe that leasing will grow for many reasons. There are less reasons to actually buy the car today, also since development is realising quickly. Why would you buy a technology that you are not 100% sure will last for a long time?"
- "100% will be taken back. Cons: Price of car seems high and maybe the customer chooses another brand without leasing of battery."
- "The battery is on someone's balance sheet and an OEM would not like that. However if the battery would still be omened by the manufacturer of the battery then you would get a close loop recycling. The battery should be owned by different entity than the owner, if the car is not MAAS run by an OEM."

The arguments for No as well as potential obstacles were:

- "No. When the car has a value, it becomes a problem for the insurance company and the private customer. For example: you have a leased battery, you crash and then there will be damage to it and it gets redeemed. Then you get compensation for the whole car including the leased battery from the insurance company. Then the insurance company receives compensation for the car manufacturer. If then the car will be sold and shipped to a car dismantler they will get it without a battery, then it will be low value for the dismantler and the insurance company faces a major problem. Concerns in the long run."
- "Leasing the battery will limit the sales of xEV cars in general. Its better to sell and offer an extended warranty plan."
- "Makes the car sales process complicated."

The arguments for Maybe/I am not sure as well as potential obstacles were:

- "I am not sure. Maybe my knowledge is somewhat limited here, but I do not

see many car manufacturers leasing the batteries in electric vehicles. It might be even challenging to lease a component of a product that is sold. Leasing the whole car makes things easier. Leasing is in general more expensive for companies to do than selling products, more risks are involved. Customers demand more when the lease a product than when they buy, especially when it comes to older cars. Leasing is of course a well known strategy to get products back, but it can be an expensive strategy."

- "Maybe. Maybe a good way if you want to secure that the batteries will come back, but you will still need to arrange the sending back. I do not believe in the business case of leasing only the battery. When the vehicle is getting old and start to lose value, the leasing cost for the battery will make the vehicle lose value even quicker."
- "I am not sure. In all possible scenarios the residual value off the car will be influenced. The older the car gets the more it will be traded between private customers. Here a leased battery will harm the ease and therefore the value. Special cross border (or even continent) trading that will be nearly stopped. Maybe for some selected countries it might work."
- "Maybe. When this is new it will work well with a lease system. When car is older the fixed lease cost will lower the residual value of the car."
- "Maybe. I think leasing of the battery would ensure traceability of the battery. Or it could be for example leased through an energy company instead? Why is a battery a part of the car but electricity is just a "side-product" when it is actually one of 3 vital parts for the car to accelerate forward? Maybe a bit more collaboration should be investigated."
- "Maybe. Leasing, in the way that is currently organised is often motivated by financial benefits for the OEMs and customers (sometimes even debatable if they actually have a financial benefit for the customer) and not often for circular economy reasons."

In figure 4.11 the answers in the second round are displayed. It could be seen that there still is a very neutral approach to the subject, even though there is a larger agreement than disagreement regards to leasing being the best option to secure the batteries coming back in the near future.

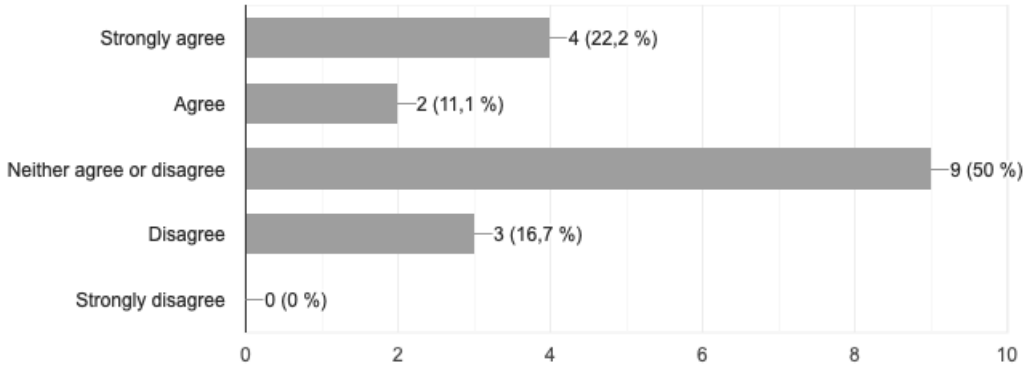

Figure 4.11: The outcome from the second round regards to the statement: 'Leasing is in the near future the best option to secure the batteries coming back'.

Additional comments from the second round regards to leasing were:

- "Dependent on situation, lease can be good for fleet but maybe not for personal owned cars."
- "If you as the car owner do not own the battery than you have to give it back. On top the owner of the battery do know where to find it and might also get health data from it. Furthermore, it makes the product more attractive due to a lower sales price for the vehicle."

4.1.8 A deposit to be able to secure the batteries coming back

The outcome in the first round regards to the question of leaving a deposit could be seen in figure 4.12. The majority responded to yes, which was closely followed by both no and maybe / I am not sure. The arguments for respective option will be presented below. If answered yes or maybe / I am not sure, it was also included to suggest an interval of the sum for the deposit.

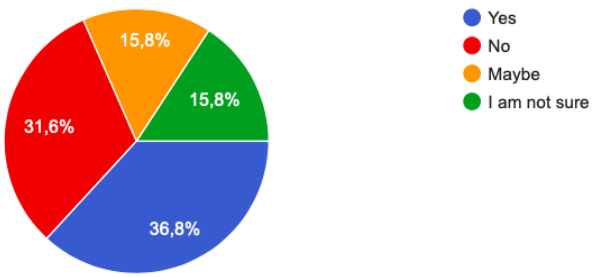

Figure 4.12: An overview from the first round regards to a 'Deposit being the best option to secure the batteries coming back'.

The arguments for Yes as well as potential obstacles were:

- "100% will be taken back. This shows that the issue is taken seriously and relies that the customer also does. Somewhere between 5000-10000 SEK."
- "Good solution if there is an infrastructure to take-back. If deposit is low and return far away, no one will use it. Somewhere between 5000-10000 SEK."
- "It is a very good system to make sure we get the battery back. This will not fly if this is not used by everyone. Less than 5000 SEK."
- "Money is key and the only thing driving all people in the same direction. Somewhere between 10000-20000 SEK."
- "This is the same as scrappage ELV fee we have today and it works perfect. It motivates people to scrap the car, including the battery. Then you have it in a controlled system. Less than 5000 SEK."

The arguments for No as well as potential obstacles were:

- "The car changes owner over the lifecycle, hard to motivate the first customer to make a deposit on the battery and at the same time the first customer understands that he will not get the funds back when the car is scrapped years later."
- "The first buyer do not probably own the vehicle when it is time for EoL."
- "Deposit is an unnecessary burden that car buyers will not like - they are looking for a discount. However, if its mandatory because of legislation. But then the buyer negotiates a discount and "does not" pay for it at the end."
- "Deposit follows the car not the customer? Today some markets add a environmental fee to the new car price in order to secure the EoL treatment is handled responsible."
- "I do not think it is a good idea to tie up the second or third owner of the car or deals they have not chosen from the beginning. It will have a negative influence of the residual value of the car."
- From an interview: “No, not as a single detail on the battery, but instead perhaps on the whole car. As a deposit or premium. There used to be a scrapping premium on the car. The car manufacturers put it on the price of that time, 1500 SEK. In 2007 it disappeared. So, the car manufacturer put it on the car and car dismantlers got it as a replacement. If reintroduced you could have it a little higher, to be able to motivate the customer, a few thousand (SEK) to take care of the battery. The customer had to leave a deposit, without a car manufacturer. An EU decision was taken, hence it was demolished. This deposit or premium was good, as it was compulsory for all cars which was put on Swedish ground and also for the used cars that were imported.”

The arguments for Maybe/I am not sure as well as potential obstacles were:

- "I am not sure. The investment and alternative risks involved are critical to this scenario. EVs can easily live for a decade and making a decision to put your money on a deposit and getting it back 10 years after can only be done

with long term calculation of interests and alternative costs."

- "I am not sure. Yes it kind of pushes the owner to be held responsible for something they know nothing about. It would still be better to keep the battery producer or retailer to take it back for free and spend more money on raising social awareness of how to properly return a battery and why."
- "I am not sure. I think that the risk today of purchasing new technology is very high. The risk needs to be limited in order to get more people to actually decide that they want to change from fossil to electricity. Paying a deposit might very well increase that risk."
- "Maybe. This strategy could work as long as the way to return the battery is very clear (as clear as it is today on how to return e.g. PET bottles), and that the amount of deposited money is worthwhile getting back. Somewhere between 10000-20000 SEK."
- "Maybe. I think it is a good idea if we could make it obligatory for all car OEMs (on a market or globally). Somewhere between 5000-10000 SEK."
- "Maybe. Choosing the right deposit price is crucial here. Pilots with other leasing programs (not batteries) have shown that products do not always come back. The price needs to be higher than what is paid for by others (i.e. if one can sell it to a higher price than what the deposit is, a fraction of the customers will go for this. Somewhere between 10000-20000 SEK)."

In figure 4.13, the answers in the second round are displayed. It could be seen that the majority disagrees with deposit being the best option to secure the batteries coming back, even though there is also a large agreement that it could be the best option.

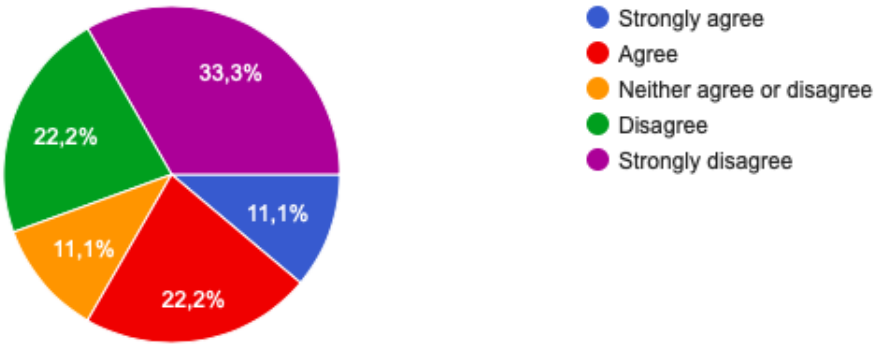

Figure 4.13: The outcome from the second round regards to the statement: 'Leaving a deposit could be the best option to secure it coming back'

Additional comments from the second round regards to a deposit were:

- "If it is regulated by law it will be a good option. Otherwise I do not think it will happen."

- "The consumer should not be held financially accountable for a product. The car industry is producing these batteries and they should calculate the whole life cycle and take responsibility that this is handled well since this is a potential hazardous waste."
- "A deposit will be a burden for the first car owner who does not have any interest of the vehicles EoL. The take back system needs to be based on the material value."

Finally, in the second round the last question was if there were any final thoughts on the survey or on the other questions. The following additional comments were made:

- "When the vehicle comes to EoL, the owner independent of if it is a company or private owner will most often sell the complete vehicle including battery to the one who pays the best. They will not sell only the battery standing alone. And the price is based on the market for recycled material and/or governmental premium."
- "It is a complex question and one solution might be to pay always above market price. Find ways to make this profitable for the entire value chain. Batteries are urban mining and thus do not harm nature since the materials have been taken out of the ground already. Make it attractive to use these recycled materials, e.g. tax cuts or burden on raw genuine materials."
- "To enforce legal solutions and demands for how these batteries will push companies to take this seriously. Turning the battery into a recyclable commodity is not yet possible since the recycling of the Li-ion battery is costly and the producers have not taken responsibility themselves of making sure that the battery is 100% recyclable. This is where we go wrong in the first place. The product is built with the focus on only one part of the batteries life cycle and not seeing the whole chain through. It is sad that we keep doing these mistakes. Bio-Plastic bags are a good comparison. Good solution but the end solution for the bag was never thought through and today we are mostly burning the majority of the bags. We see a clear future with the help of legislation trend that products will have to be designed to fulfill a full life cycle design. Unfortunately I do not see this being done with Li-ion batteries."

The other answers that reached more of a consensus and were not included in the second round of the Delphi study can be found in Appendix A.

5
Analysis and discussion

In this chapter, both the findings and the results will be discussed further with the support from the theoretical framework. A recommendation for further research will also be included.

5.1 Findings from documentary research

The findings showed that the mechanisms that are behind take-back systems, such as for PET bottles or gas bottles work in an effective way. This is understandable as there is an infrastructure behind it and in the case of the PET bottles, one does not do it primarily for the sake of the big money, rather for the environment. Therefore the deposit-refund is truly useful, when many people use it and when there is a structure behind it.

It was shown that Toyota Australia had incentives that seemingly worked for NiHM batteries. This indicates that similar trajectories are to be considered and that it could perhaps work well. This in regards to having a discount on the battery, but also the rebate for no longer functional batteries. Even though, nothing further could be found as concrete as the incentives found with Toyota Australia, there will most likely be several car brands who will have similar procedures as they will face similar obstacles.

Further, it could be understood that the changes in the battery directive from the European Commission is of high importance, as it will re-evaluate how this could be applied for HV Li-ion batteries. This is needed in order to further facilitate the process of the handling of the HV Li-ion batteries. Furthermore, the estimation of cost for the post 1st life batteries could show a clear view of how the prices of the batteries can vary and become very high. As there is no standards on how much it could come to cost, the prices could be very expensive, which in the long run could become even more expensive for the car manufacturers. The business model canvas displayed the overall building blocks and what values for a company is important. This was kept in mind when developing the conceptual business model. The two-sided markets theory made it more clear that dismantlers and the dealers could get a high value out of this. The reason for this is that the batteries will most likely end up in either one of them, where they could in many ways decide the price of the batteries, but also what to do with them.

5.2 The major findings

The research problem that has been investigated is how one should encourage each and every actor in the possession of an HV Li-ion battery to return it. Hence, how to achieve a battery take-back and from that being able to develop a conceptual business model on how to secure a safe battery take-back. The areas in focus were in six different potential outcomes, where the battery could most likely end up at outside of warranty. The method used to be able to achieve this was through two surveys in a Delphi study and several interviews as well.

The findings suggests that a monetary compensation will play a key role in the various potential outcomes such as for: the car owner, the unauthorized car dismantler and the scrapyard. There are also different systems depending on, for example, in the case of the dealer an exchange system might be a better option. However, a red thread is shown pretty clear in all the potential outcomes that much more needs to and can be done. There are many other incentives that combined could be to raise awareness for the problems with the hazard that comes with the batteries, initiating stricter rules and fines to those who do not obey by the rules. Moreover, one of the strongest initiatives could be changes in legislation, which could both facilitate and strengthen the support for a safer battery take-back.

5.3 The meaning and possible explanations of the findings

The meaning of the findings are important and essential in regards to the expected bigger volumes of HV Li-ion batteries in the near future and what the next possible steps forward are to enable securing a safe battery take-back. In order to manage and reach a circular flow it is significant to dive into the mechanisms that could lead to making it feasible for extending the batteries life as well as securing valuable metals, when it is time for them to be recycled.

5.3.1 Economic compensation preferred for car owner

The first potential outcome with the car owner is towards those having a vehicle that is long-term parked and not being used. This could lead to that the battery life will be shortened if not used regularly, hence aging faster and how should one be able to secure those batteries coming back? In figure 4.1 it could be seen from the first round that 73,7 % thought that economic compensation would be the best option for encouraging the customer to return the battery. In the second round it did perhaps not come as a surprise that economic compensation continued to dominate and this time, shown in figure 4.2, it had 83,3 % when combining both 'Agree' and 'Strongly agree'. However, it needs to be highlighted that there was in the second round one less person who answered, which could make the percentages differ a bit

in each potential outcome, but not to the extent that the results would be totally different from what it became.

The observations that could be made here was that from the first round economic compensation was in favor, which was then reinforced in the second round. Possible explanations behind these results could be that after the summary of what other persons arguments were, it was easily determined to where one would stand and therefore the majority rose in the case of economic compensation. This was in some way expected. The explanations for the arguments were very straightforwardly put and clear, with the fact it being the strongest incentive and that the customer was free to spend it how it wanted. However, many possible barriers were connected to the option. How should one set up a fair and good compensation program, not making it only a severe cost? All batteries are used differently and in that way ages differently e.g. the driving style or if the battery is situated in warmer regions or colder regions. This will have an impact on the capacity of the battery, hence it could be very individualized how much a battery could be worth, as it not only has to do with the size, the model or the miles driven. It could be difficult if the estimation of the batteries cost are set lower, than somebody is willing to pay for it, because then most likely the car owner will go to the person who will pay more for it.

The question that also arises is that if you would get money for the battery, then as a result the car would have a very low value without a functional, operating battery inside it. That could mean that the car is on its way to be scrapped and as one pointed out in the interviews, the person believed that in most cases the battery will follow the car, so then the option comes if there instead would be better to have an ELV scrappage fee on the car? In that way when it is time for EoL, the small fee that is put on the car, will be part of the scrap vehicle reward. So, in theory as long as the battery will follow the vehicle that could very well be another alternative. However, there is no wonder to why there is a high majority on the economic compensation choice. If one were to succeed in creating a universal economic compensation plan, that is fair to those involved, being easy, setting the standard and being applicable it could very well work.

Perhaps the most difficult to know at the moment is if this will financially work out. Is it enough for the car customer or can the battery find its way somewhere else? The strengths of the economic compensation is that it speaks for pretty much everyone as money is something that makes the world go round, but if there is gaps in the system and the system is not being established nor fixed enough, it could very well end up elsewhere. And the real question is how long can such a system function properly?

5.3.2 Exchange system could work for car owner

The option of exchange system as the first choice to encourage the car owner to return the battery had in the first round 10,5 %, that could be seen in figure 4.1.

In the second round seen in figure 4.3, regards to an exchange system being the best option to encourage the car owner to return the battery, there were 55 % (with 'Agree' and 'Strongly agree' put together). However, 27.8 % did not agree in this being the best option for encouraging the car owner to return the battery. The possible explanation to this could perhaps be that it was emphasized that as long as the customer will use the car, an exchange system will be of interest and in that way extending the lifetime of the car as well.

It was not unexpected that the choice of an exchange system increased from the first round to the second round, as an exchange system not only benefits the customer, but it also benefits the dealer. One possible explanation could be that if one hands in a battery, it could very well be so, that the car may not be scrapped, instead wanting to have a new, refurbished battery for a cheaper price. This could also be compared to the incentives that Toyota Australia had, with leaving a battery not being functional anymore or if one wanted to replace the battery and therefore got a discount. However, in that case these could not be combined. Moreover, further possible explanations towards the choice of the exchange system is that it supports the circular economy approach as it extends both the lifetime of the battery and car. An exchange system is also not a new system, as it has been used for a long time in different car parts in OEM business and as mentioned in the results it has proven to work relatively successfully. Although, it may be more quantity returned than quality, but as the essence is in getting the batteries back and securing that loop, it is given that the batteries will be in different states of health.

Yet, as mentioned from the results, it can be difficult to actually set up a balanced demand and supply model for exchange systems and take care of the batteries that are coming back. There could be many batteries that are not good enough to be refurbished and it also has to do with how many batteries that have been returned in the first place. The very strong point with an exchange system is how it extends the lifetime of the battery as well as the car regards to the circularity. However, the weaknesses is the difficulty in calculating and knowing where this exchange system is in demand and how it can vary in the different regions. It also has to do with other factors such as, if the car owner finds it worth upgrading the battery regards to the residual value of the car? It also depends on what the discount on the new battery would be. For the Toyota Australia case, it was regards to NiHM batteries and most likely it needs to be higher for the case of HV Li-ion batteries. Here one needs to establish an exchange system program, depending on the status of the battery and create some sort of interval with fixed prices for each category. Nevertheless, exchange systems have proven to work very well in different take-back systems before and it might work for the case of the HV Li-ion batteries as well if thoroughly viewed upon.

5.3.3 Other is not the best alternative for car owner

Lastly, for the result from the option 'Other' it could be seen as well as for the previous options, in figure 4.1. In the first round 15,8 % took 'Other' as their first choice, thus actually being higher than the exchange system. In the second round, in figure 4.4, 17,7 % agreed it being the best option, but the majority, being 41,2 % had a more neutral tone towards the choice and 41,2 % disagreed that 'Other' would be the best option to secure the batteries coming back from the car owner.

It could be seen that the option 'Other' got a bit higher in the second round than in the first, but still it dominated by neither disagreeing or agreeing to the choice, as well as being disagreed upon. The possible reason for these results were the arguments being very much based on the fact that it is more on the producer's responsibility. As stated in the results, money should not solve this, potentially leading to the batteries being looked upon as market commodities instead of environmental hazards. So, one can understand the reasoning behind the choice of 'Other' as taking responsibility is in forefront as well as investigating other types of values, such as social and environmental impacts. However, the possible explanation to why there is a big neutrality in this question is that perhaps it is difficult what this 'Other' choice can be that could motivate the car owner. As 'Other' is still unnamed and is a suggestion on being something else it could be difficult seeing exactly what that could be when there is no major legislation initiated being up and running.

Moreover, the possible explanation whereas to the disagreement regarding 'Other' could be that even though wishful thinking is that people should not be motivated by money, it is what makes the world spin. It would be good if something else, some other incentives could help push one to come to the more sustainability approach and push for it. Perhaps stricter rules and legislation needs to be set. As been mentioned before changes will occur when the EU commission will have new changes in 2021 regards to the batteries. Therefore the option of 'Other' could perhaps very much look like the ELV scrappage fee available in Norway. Because even if there is still a monetary value value as mentioned, then the value here is embedded in social and environmental responsibility, as it is an environmental fee initiative.

The strengths with 'Other' is that the alternative shows that one has done more than just thought of the easy-to-go financial compensation, but the weaknesses with 'Other' is that as nothing is established yet, there is some difficulty going forward with those steps as of now. Therefore, 'Other' could be difficult to be seen as the best alternative to encourage the car owner to return the battery, but should nevertheless be considered.

In the second round it was further asked, see figure 4.5, if a possible combination more or less for all the above mentioned options depending on the different markets would be the way to go, where it could be seen that 72,2 % agreed. Therefore, for the time being, in the case of the car owner it points to the fact that economic compensation is a clear alternative as well as an exchange system.

5.3.4 Economic compensation strongest incentive

For the second potential outcome with the case of the unauthorized car dismantler, see figure 4.6 it could be seen that in the first round 57,9 % chose economic compensation as their first choice. In the second round, see figure 4.7, it could be seen that for economic compensation 94,4 % agreed to this being the best option. Economic compensation was seen to be the strongest incentive to encourage the unauthorized dismantler with the main argument being that one could not see anything else motivating the car dismantler, who wants to receive financial compensation and is not interested in an exchange system. The possible explanation behind this result is that it is very much business oriented and the argument that either the dismantler will sell the batteries on the open market or if the OEM buys it back. This can be exploited in a way that the batteries will be seen as something of value, which could result in the price being set higher and higher, if the car dismantler knows the OEMs will most surely want to have it back either way. The car dismantler is such an important player in this ecosystem of batteries. Linking it a bit back to the two-sided markets theory, it was understandable that the car dismantler, whether it is an unauthorized or authorized is a very important actor in this system. The platform being where the potential buyer and seller meets, it is very clear that the car dismantlers are the ones that could earn and benefit more from this as the car OEMs are dependent on the batteries. Since the car dismantler is the one that removes the batteries from the vehicles, having the time and training to do so, they are very important in this process.

Moreover, it should also be noted that not all batteries have a positive value and they can in fact cost money, when it is time to be recycled. Therefore, the car dismantlers could very well be willing to give them back. However, it could also be the other way around. The batteries are in a condition that they could be sold and as previously seen in table 2.1, the costs vary and are as of now set by those who are selling them. There are no established guidelines for how the prices should be set and therefore they can very well be overestimated. Here the warning sign could be that if the car dismantlers will get the batteries sold for the prices they ask for, they can constantly increase it, if they see a demand, which in turn will bring the batteries more into being an expensive commodity. It was also suggested from the results that one could work towards it being harder for unauthorized car dismantlers to trade in these products, however another person stated that even authorized car dismantlers cut corners as well. Therefore, it was suggested setting high fees for dismantlers that would not for example, recycle it properly.

As of now the battery flows are relatively low and there are a small scale that have been trained in how to handle these specific batteries. From the results it could be seen that more resources are needed as well as state of the art knowledge to know how to handle them properly. This both takes time and training, which adds a cost. The question is therefore, could there be anything else motivating the car dismantler, e.g. paying for the training on how to handle the batteries correctly and from there making an agreement to get the batteries back? Perhaps the wishful thinking is to map out all the possible dismantlers, creating a good dialogue and agreeing

in a way that would benefit both parts as good as possible. Although, in some way it perhaps would point more to the dismantler side, as they could very much otherwise decide to sell it to someone who would offer a bit more for the batteries. So, the strengths is as mentioned before, that economic compensation is very clear way of getting something back. However, the risk is that the dismantler could very much steer the direction, deciding what to do, being well aware of the high value in this value chain. In this potential outcome it is crucial to establish something trustworthy and to try to meet ends meet. That this is more than just what the value of the batteries are, but rather the importance for the safety regards to human health and the environment.

5.3.5 Other and exchange system not of interest

To also briefly mention the two other alternatives that could be chosen for the unauthorized car dismantler, in the first round 'Other' had 31,6 % picking it as their first choice. Whilst in the second round, see figure 4.8, 64,7 % neither disagrees or agrees with this being the best option for encouraging the unauthorized car dismantler to return it. The possible explanation to this could be that it is a very tricky question, but also that there are perhaps more initiatives combined that could be of interest here, e.g. policies, rules, regulations and opportunities of tracking. Still, one does not walk away from some financial compensation being involved here as well, so therefore the outcome can be quite understandable for the option of 'Other'.

Last but least, for the option of the exchange system it could be seen that it was the least popular in the first round, however in the second round, see figure 4.9, 38,9 % agreed to it being the best option to secure the battery, but 44,4 % disagreed. This was a bit surprising to see that the exchange system was still considered, whereas a large portion did not see an exchange system being at all interesting for the car dismantler. The possible explanation for this may be that it was not realized that a car dismantler is not interested in getting one battery in exchange for another.

As it is still not technically illegal to be able to remove the battery from the car, anyone can do it. Therefore, the opportunity of tracking and auditing to ensure that the system would be functioning, could be of great support in these types of matters. Even though there are many barriers with the costs of batteries post 1st life being 'unknown' and the possibility of a higher demand in the future, that could make the prices go further up for the batteries, economic compensation is in this potential outcome needed to ensure batteries are returned. The important thing to make sure of at present is creating a good communication, making an economic compensation program as well as having agreements and communication for it to go through.

5.3.6 Incentives for the scrapyard

For the third potential outcome with the case of the battery getting into a scrapyard it was once again, the mechanisms that have been mentioned before also being applicable to this potential outcome. It is suggested that the most effective way is to be compensated economically. However, as of now it is possible for anyone to buy components in the scrapyard, which was why it was suggested that more stricter rules needs to be applied. When the battery has reached a scrapyard, it could very likely have no capacity left, but still it could be of danger and the recycling of the metals are still of value. Therefore, it is suggested that car manufacturers can do more to ensure that they are in control over their batteries, if they are interested in their closed-loop system, e.g. that old cars should be bought and dismantled through authorized parties. This can again be compared with Norway, where you have an ELV scrappage fee, just like the tires have a fee. This way securing that it is recycled in a proper manner, and many times it is believed that when the car reaches EoL, it will be included with the battery. However, this could not always be the case, if the battery still has a value and perhaps already been sold.

The interesting thing about this case was that many times many also saw that the scrapyard and dismantler were basically the same people, hence there were many times similar motivations. So, as of now for the scrapyard some sort of compensation was suggested, e.g. a proposed core cost, rewarding them with payment after check and certification of the battery. Moreover, demanding the batteries to be handled properly with the proposal of having a fine system for those who have them and do not handle them accordingly.

5.3.7 Various combinations for the dealer

The fourth potential outcome was if the battery was at the dealer. It could be seen that this question could be mistaken for if it is the dealer that would get back the battery from the customer or if it is meant to obtain the battery from the dealer. In this case it is from the dealer, but nevertheless it is in a way interconnected. From the customer to the dealer, as have been mentioned above, an exchange system with price differentiation could be a way of securing the battery. Also, the point system that is commonly used for different components from the car, hence being able to collect points, which can then be used to buy further components. The mechanisms for the dealer could be seen being alike the ones that were seen with the car dismantler, often being answered in a likewise manner. From the results it was suggested to make sure to present standards that the batteries could not be sold to third parties. It was also suggested that authorized dealers can be encouraged to return batteries by not selling new components if they do not return old components. It was also said that the dealer is controlled by the importer, hence being under strict rules and therefore it should not be a big issue. The matter seem to be business driven, that the car dealer sells the parts to the one who pays the best, which is similar to the case of the car dismantler. So, just as the car dismantler is a key player in the chain, the dealer belongs to that as well, being the intermediary between the

car owner and the car OEM. Therefore, to secure the batteries from the customer a price differentiation and a point system could be plausible offerings from the dealer. Moreover, also having dealer standards e.g. preventing them from being resold and in that way possibly manage to get control over the batteries.

5.3.8 Insurance company has no incentives

For the fifth potential outcome, with the batteries being in hold at the insurance company, it was very straight-forwardly put, that the insurance companies more or less is barely an owner of the battery within a time frame. They do not really have any intentions to do anything with the battery. As the car dismantlers have their connections with the insurance company, it will either way get repaired or recycled. From the results it could be seen that the car manufacturers can do more by setting up a system that works for everyone involved. As the insurance companies have agreements with the dealers and the car dismantlers, it is more important to approach these to be able to reach out and secure the batteries, e.g. what offer would appeal to them and why? For example, as briefly mentioned above, standing for the costs of the education on how to safely handle and remove the batteries from the cars could perhaps be something a car dismantler would be interested in. If one manages agreements, collaborations and the sense of the benefit for everyone involved, it could be possible for securing a take-back of the batteries.

5.3.9 Information and tracking for the random place

The last and final potential outcome was if the batteries would end up at a random place. It was not considered to be the most nearby problem in the future when it came to the batteries. This was understandable as many of the batteries are still within warranty and has yet to reach EoL. It is suggested that as the batteries are dangerous, it is very important to clarify and inform the public on why it is so important to retrieve it. Therefore, the communication needs to be so clear, that a person knows what it will do if they would come across a battery. The meaning here is to not initiate people to actively look for them. The tracking still stands clear as a way of handling this responsibly and to fee those who throw them in nature.

5.3.10 Overview of the conceptual business model

Below, in figure 5.1 one could see an overview of the conceptual business model for how to approach the different potential outcomes. For the car owner an economic compensation (through a compensation program) + exchange system are suggested. For the unauthorized car dismantler, economic compensation (through a compensation program) with a mix of regulations and rules are suggested. For the scrapyard, a core cost on the battery, a fine system, rules and regulations are suggested. For the dealer, clauses in dealer standards are suggested as well as a point system, having a price differentiation if the customer would like to purchase a new refurbished

battery. For the insurance company, having no further incentives, it is more important to see where the battery goes after the insurance company. The battery often goes to the car dismantlers, e.g. so how to approach these in a good way and make agreements? For example, an offer of training and education for how to handle the batteries - and in return getting the batteries back. For the last potential outcome, having an information campaign making people truly understand why the batteries are to considered an environmental hazard and in return perhaps offer a reward. This is suggested in the time of writing for all the six potential outcomes.

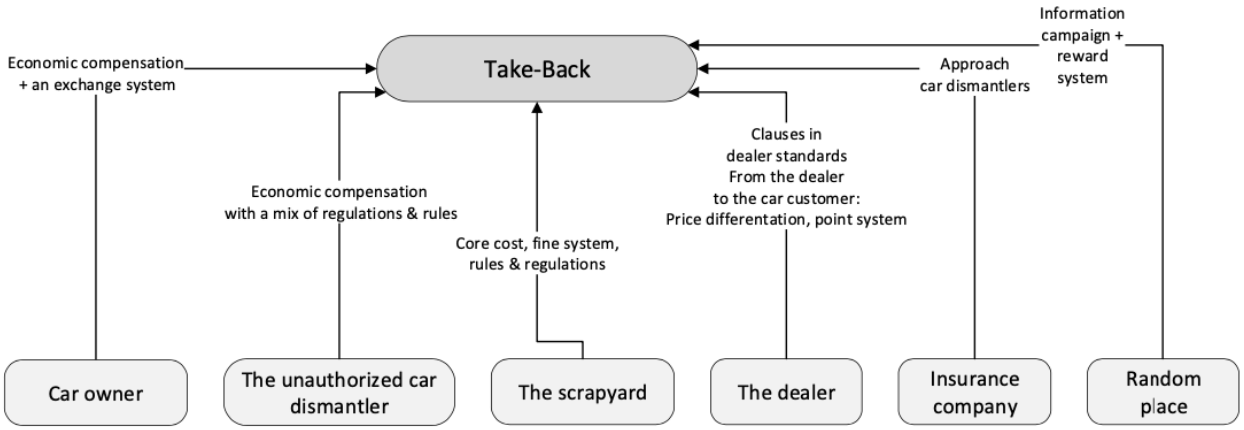

Figure 5.1: The conceptual business model over the six potential outcomes.

5.3.11 Uncertainty towards leasing

Furthermore, when coming to the cases of trying to secure the batteries in other ways, both leasing and leaving a deposit were questions asked, but were not precisely included in the potential outcomes. However they were still explored whether they could be possibilities of securing the batteries coming back and is therefore also interesting to discuss. To briefly overview what came from the results, it could be seen in figure 4.10, that after the first round leasing was dominated by 42,1 % answering 'Maybe', which was then followed by 31,6 % answering 'Yes'. In the second round, see figure 4.11, it could be seen that 50 % responded neither agreeing nor disagreeing, whilst 33,3 % were positive that leasing would secure the batteries coming back. This meant that from the first to the second round both answers of 'Maybe' and 'Yes' had gone up, which perhaps were not unexpected.

The possible explanation for the majority answering 'Maybe' could be that it is hard to know. Some of the answers mentioned, instead of only leasing the battery, that it would make more sense of leasing the whole car instead. It was more uncertain if leasing would really be helpful in securing the batteries back. Theoretically, it seems so, as the car OEM is then in control, but in cases of leasing in a longer term period is what makes more questions arise, because how would that affect the car's residual value? Is leasing more suitable in the short time instead? Or could it perhaps be

that after the short time period, the whole battery will be offered to purchase, that some car brands already have done? Also, as stated in the results, in the cases of a crash or accident, the insurance company would take over the ownership, which could perhaps make it a more complex process for the actors involved.

Still, leasing could be seen in various car brands, but is it the best mechanism to get something back? It certainly creates a sense of control over it, however does it really change the customer's attitude towards it? This to the fact if one would lease the battery in the side of ownership it would be perhaps difficult to understand and also difficult for the secondary market. Therefore, perhaps it is suggested that leasing the whole car would be preferred, than leasing only the car battery.

The definite strengths of leasing is the control one can have in the short term, but as the car and battery gets older, perhaps being traded between private owners the battery will more or less reach the first outcome of the car owner. A weakness of leasing the car would make an individual more incautious as they do not stand for the whole risk and as the batteries are set to hold for 10-15 years, this could speed up the aging process of the batteries as well. However, as stated from the results, when some people are anxious over a new technology some do not want the ownership and the full consequences of it, which also reflects in the outcome from the surveys. Therefore, leasing might very well be something that could work in the near future, but perhaps it is more important to gain even further knowledge in this.

5.3.12 Deposit could work if all used it

Lastly, the deposit, see figure 4.12, it could be seen that in the first round it was clear that both the 'Yes' and the 'No' sides were really close to each other with 'No' being 31,6 % and the 'Yes' side with 36,8 %. For the 'Maybe' and 'I am not sure' put together it was 31,6 %. In the second round, see figure 4.13, it was clear that 55,5 % disagreed with the deposit being the best option to secure the batteries coming back, where 33,3 % agreed it being the best option to secure the batteries coming back.

The question of deposit, as previously seen in theory, works well on e.g. the PET flasks or handing in a gas tank, but that is because there is an infrastructure to take it back. The possible explanations towards why so many disagree on this issue is that because at present no other car brands have this. It will not work setting a deposit on a car that the first customer presumably will not receive when it is time for EoL for the car. This could also be further linked to the 'scrapping premium fee', that was on an entire car, which disappeared in 2007. If such an incentive would be introduced for e.g. all cars in Europe, then this would work well, even though the cost might need to be higher in this scenario. This way the money is built in like a core cost with the focus being on the environment, being an environmental fee, hence going towards a more sustainable solution.

In summary, at present time the monetary compensation could be useful in the various potential outcomes, which could also seem a bit disappointing that money would be one of the strongest incentives. But, at the same time it is not something rather surprising. However, as been mentioned before if there will be further support with policies, legislation, e.g. environmental fees that would give good prerequisites for a safe take-back process.

5.4 The limitations of the thesis

As the thesis mentioned quite early on its focus would be on the European market including the EMEA in a very broad and general way. In the time frame given it was difficult to try to specifically research into different countries and see if they followed similar procedures e.g. with Norway having the scrappage ELV fee. The focus was rather to try to find a holistic view, finding incentives and value in how to succeed obtaining the batteries. This causes it to be quite difficult to set up detailed plans for how the take-back plan should be launched, however there could be a hunch for what it could possibly point towards to. Another limitation were that the results came from 19 people, who had been hand-picked, which could be discussed as the opinions are based on someone's own perceptions. Moreover, was that the sample had more OEMs compared to the other categories and that can be because it is difficult to find other participants in the other fields compared to the OEMs. It should be noted, that just because the majority had an opinion about something, that did not mean that was the best way to approach the specific outcome. Yet, the outcome gave an overall look on how the problems are addressed and thought about in the meantime. Hence, the method worked well with the time frame given. The method made it possible to collect and store answers, which gave good insights on the different potential outcomes that will very much be relevant for the future.

5.5 Suggestions for further research

Important insights have been made in this thesis, however there are still more questions that are still related to the research problem. One of them is to go into more detail with how it looks specifically in the different countries. How does the ecosystem of batteries landscape look like with the different dealers and local processes available in each country? Where will there be a higher demand and supply and where will it perhaps not be such big pressure? Even though, the countries in this report were imagined to be quite the same as they are all in Europe, there still might be some countries things can be easier done than in others. Furthermore, the compensation program needs to exist and in some way needs to be in an acceptable price range to be able to function. A suggestion might be for future directions to map out the workshops, dealers and trying to get a holistic view of how the different actors will enable the ecosystem of the batteries to work out. It could also be further suggested to explore the other possibilities of an updated plan concerning the

batteries for EVs. Which incentives and ways of getting the batteries back can be changed then? It could also be interesting to further dive into the case of leasing. Would that truly be the best option or not? Lastly, further research could be to look into the US market and if similar mechanisms, that are used in the European market are applicable there as well or if something more or different is needed.

6
Conclusion and recommendations

Volvo is on an electrification journey, with their first PHEV sold 2012 and their first BEV sold 2020, hence they are only getting started. More electric vehicles are to be expected in the near future, hence leading to a higher volume of cars reaching EoL. The take-back process is important to be able to achieve the circular economy strategy, capturing the value of the battery with reuse, remanufacturing, second life applications and recycling. There are many challenges for an OEM how to secure future business for the handling of the batteries, as they have the producer responsibility over the batteries.

The aim of this thesis was to develop a conceptual business model for a safe battery take-back in the European market, including the EMEA. Therefore, the research problem was to gain a deeper knowledge of what different kinds of incentives and market-based mechanisms were necessary in the different potential outcomes the batteries could end up at. To answer the research question: How to secure a safe battery take-back process for already used HV Li-ion batteries in the European market? It would be suggested that there needs to be a combination of economic compensation programs, exchange systems programs, regulations, rules and fine systems for the six different potential outcomes. These needs to be further communicated for how the different incentives should be implemented and work out specifically in each potential outcome.

The EoL market for HV Li-ion batteries could be easily compared to how it looked like when the batteries were first placed on the market: no specific standards, the volumes being low and with a steep learning curve. Therefore, it is important to have in mind that hopefully legislation will change, which will support further how to handle the batteries. At present time one should keep in mind on what one can do with the prerequisites currently available. The outcome here may be one way forward, which one can build on even further as it still is unknown how it will look like in the future. It is recommended to change the perspective of the HV Li-ion battery being just another car component, a possible market commodity, instead seeing it as an environmental hazard product that needs to be handled with care and knowledge. The quicker that would be realised with the actors involved in the ecosystem of batteries, maybe then one could be one step closer in achieving a safe battery take-back system.

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A
Appendix

A.1 Questionnaire from Delphi study - first round

A.1.1 Introduction

Hi,
Thank you for participating as an expert in this survey for my Master Thesis at Chalmers University of Technology in collaboration with Volvo Cars Corporation. Your answers will be anonymous in my report. However, I want you to type in your email-adress below, just so I can keep track on which ones has answered. But also, if I would not understand someone's answer, I could always ask and clarify it only with that person.

Before answering the questions, please do read the brief introduction found below.

The demand on High Voltage Lithium-ion batteries is forecasted to have an even greater demand in the future, as there will be more electric vehicles out on the roads. This increase in demand will have major effects, not only concerning the raw material aspect, but also how should one get hold of the batteries to avoid it causing severe environmental hazards, if it were to be leaked out in nature? Depending on where the battery could end up, what incentives are necessary to secure a safe battery take-back?

My Master Thesis project aims to gain a deeper knowledge about how to motivate and encourage each and every actor in the possession of an High Voltage Lithium-ion battery. The need for a safe battery take-back is the biggest outside warranty. Outside of the warranty they could end up in various locations. In this survey six different potential outcomes has been identified. For each area a couple of questions will follow.

Please answer all the questions to the best of your knowledge and do not feel limited in the style or length of your answers. Some questions will be multiple choice, where you choose one answer, but there will also be spaces for you to add comments on the underlying reasons for your response.

This survey is the first of a Delphi questionnaire. This survey has been designed to obtain your personal opinion and reflections relating to this key issue. The survey

has been sent out to 24 experts with substantial knowledge about this area. After all answers have been collected, the results will be summarised and will be sent out to all participants, together with some few additional questions to answer.

Once more, I want to thank you so much for participating!

If you would have any questions, please, do not hesitate to contact me,
Elma Alcevska: elma.alcevska@volvocars.com

A.1.2 Questions

1. One possible outcome where the battery could end up in is in the hands of a customer who has bought the car. Either the customer sells it forward a couple of years later to another private person or perhaps has their car parked nearby where they live for a long time, but rarely used. Below you find some identified methods to support take-back. Rank them based on the one you believe to be the most feasible and best option for encouraging the customer to return the battery.

- Economic compensation, if battery is returned
- Exchange system, if battery ensured to be returned, could buy a new battery for a discount
- Reward, if battery to be returned (not involving money)
- Other

1.1 Please motivate your answer with regards to what your ranking was
1.2 What do you think could be the possible barriers and hurdles with the ones you chose?
1.3 What would you suggest to be a good way to tackle those barriers and hurdles?

2. Another way to approach the issue, is if the customer wants to buy a new battery because the old battery is broken. The customer no longer has a warranty on the battery. However, if the customer would buy a new battery, there could be a standard price or a price differentiation, if they would send back the old battery. What do you think about this?

3. One way to gain the ownership of the battery and reduce risks of leakage in the nature, is if the battery would be leased. Today, many car manufacturers lease their batteries. Do you think leasing in the near future is the best option to secure it coming back?

- Yes
- No
- Maybe
- I am not sure

3.1 Please motivate, depending on what your answer was above. Possible limits or opportunities? Pros and cons?

3.2 Another proposal is, for instance, if a customer decides to buy an electric car or plug-in hybrid and if they would need to leave a deposit - meaning to pay a certain price when purchasing the car - and if the customer wants to get the money back they have to return the battery. Do you think this is a good way of ensuring that the battery is to be returned?

- Yes
- No
- Maybe
- I am not sure

3.2.1 Briefly state why you chose the option you chose

3.2.2 If answered 'Yes' or 'Maybe', what do you think would be a price to set that would correspond for the customer actually wanting their money back, but also being reasonably set, so the customer still would want to purchase the car and leave the deposit.

- Less than 5000 SEK
- Somewhere between 5000-10000 SEK
- Somewhere between 10000-20000 SEK
- More than 20000 SEK

4. Another possible outcome where the battery may end up is at an unauthorized car dismantler. Below you find some identified methods to support take-back. Rank them based on the one you believe to be the most feasible and best option for encouraging the unauthorized car dismantler to return the battery.

- Economic compensation, if battery is returned
- Exchange system, if battery ensured to be returned, could offer something in return
- Other

4.1 Please motivate your answer with regards to what your ranking was

4.2 What do you think could be the possible barriers and hurdles with the ones you chose?

4.3 What would you suggest to be a good way to tackle those barriers and hurdles?

5. Another outcome could be that the battery would end-up at a scrapyard, when the car has reached their End-of-Life. How do you think one should encourage a scrapyard to get back the battery?

6. A possible outcome where the battery could end up is at a dealer. How do you think one should encourage a dealer to get back the battery?

7. After a crash or accident the battery could end-up in the possession of the insurance company. What do you think is the best way to encourage the insurance company to return it?

8. Another outcome, which could occur is where a private person would find the battery at a random place, such as the forest or in the desert. What incentives would encourage you as a private person to return a battery? For instance, we know how 'pant' works and that if you bring it back you get money for it, (Deposit-refund system), but a three-digit kg battery, is nevertheless different. But, what would make you feel the need to return it? What offer would appeal to you and why?

9. All the above questions have been regarding the battery take-back for post 1st life, but if one would look to the 2nd life of the battery, what would the best way to handle the batteries in the 2nd life be and why?

10. What do you think would motivate someone not having anything to do with Volvo Cars, thinking that their system of taking care of their old batteries being superb?

11. The essential challenge is to get hold of an asset you do not own, in the most efficient way. As we know, there are many strategies and barriers to this. Any other reflections or personal thoughts after all the questions that haven't been directly questioned? What would you propose possible solutions for setting up a take-back system to be? Why, so?

A.2 Questionnaire from Delphi study - second round

A.2.1 Introduction

Hi again,
Thank you so much for participating as an expert in the follow-up survey for my Master Thesis at Chalmers University of Technology in collaboration with Volvo Cars Corporation.

As mentioned before, the project aims to gain a deeper knowledge about how to motivate and encourage each and every actor in the possession of an High Voltage Lithium-ion battery and what incentives are necessary to secure a safe battery take-back, depending on where the battery could end up.

The Round 2, which is the last and final round, is a questionnaire more constructed from the data gathered from the first round. Here, you will be able to read the

summaries and results from the different questions and then it will be followed with a quantitative 'tick-box' style with agreement scales. There will also be space of additional comments if there would be anything more one would want to add.
As last time, I want you to type in your email-adress below, just so I can easily keep track on which ones has answered, but also so I do not send reminders to someone who already has answered. As mentioned before, your answers will stay anonymous in my report.

Once again, a big thank you!

If you would have any questions, please, do not hesitate to contact me:
Elma Alcevska: elma.alcevska@volvocars.com

A.2.2 Questions

1. An overview of the first choice for Question 1: The outcome when the battery is in the hands of the car owner. (The figure could be seen under 'Results' in Figure 4.1).

1.1 'Economic compensation is the best option for encouraging the car owner to return the battery'

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree

1.2 'Exchange system is the best option for encouraging the car owner to return the battery'

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree

1.3 'Other' is the best option for encouraging the car owner to return the battery'

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree

1.4 Possibly a combination more or less for all the above mentioned depending on the different markets

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree

1.5 If any additional comments for Question 1:

2. An overview of the answers for 'Leasing to secure the battery' (The figure could be seen under 'Results' in Figure **??**).

2.1 'Leasing is in the near future the best option to secure it coming back'

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree

2.2 If any additional comments on Question 2

3. An overview of the answers for 'Leaving a deposit to secure the battery back' (The figure could be seen under 'Results' in Figure 4.12).

3.1 'Leaving a deposit could be the best option to secure it coming back'

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree

3.2 If any additional comments on Question 3

4. Overview of the answers from 'The outcome in which the battery ends up at an unauthorized dismantler' (The figure could be seen under 'Results' in Figure **??**).

4.1 'Economic compensation is the best option for getting the unauthorized car dismantler to return the battery'

- Strongly agree
- Agree
- Neither agree or disagree

- Disagree
- Strongly disagree

4.2 'Other' is the best option for getting the unauthorized car dismantler to return the battery'

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree

4.3 'Exchange system is the best option for getting the unauthorized car dismantler to return the battery'

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree

4.4 If any additional comments on Question 4

5. Any final thoughts on the survey or on the other questions that were summarized in the email

A.3 The other questions from the Delphi study

Here follows a short summary of the other questions that had more of a consensus and were therefore not involved in Round 2.

'The question regards in leaving a broken battery in exchange for a new refurbished battery' - a price difference if one would return the battery'

- Overall: Hugely positive and is considered as a good idea.

'The question regards to the best way to handle the batteries in 2nd life'

- Agreements to have it organized by fleet management. Leasing the batteries as energy storage is very often perfect after batteries post 1st life under controlled circumstances.

'The question on what would motivate / one would think to be a good strategy to handle the old batteries regards to not having anything to do with Volvo Cars'

- Proper advertising where social responsibility, environmental responsibilities and actions taken by Volvo cars are put forward very clear. Showing the importance of recycling and the contribution made by returning your battery. Moreover, guaranteeing the battery will be handled in the best environmental way there is (considering there is a high carbon dioxide footprint regards to the logistic burden). Make people understand that it can be used in several applications for a long time.

'Additional reflections & thoughts: What is a possible solution to set up a battery take-back system?'

- Financial reward in the whole value chain. Overall, different processes that will give the best outcome. One size will not fit all and having different solutions depending on the owner and the market. Understanding the aftermarket better is important. Learning from other car components that have a value after first life and are remanufactured already by authorized and unauthorized parties. Moreover, the legislation aspect, and exploring the opportunities to be able to track the products. Setting up a global EV car OEM battery collection and management system based on the existence of a battery passport. Then, all xEV car OEM should be able to finance a logistic service to collect from all dealers their EoL battery pack.

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