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The second life

Challenges of repurposing electric vehicle lithium-ion batteries

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Abstract

In the near future, electric vehicle battery waste will rapidly increase as a result of the growth of electrification of road transport. To address this challenge, repurposing of used EV batteries for a second-life application has gained more attention from battery-related stakeholders, such as manufacturers, recyclers, policymakers, etc. Thus, the objective of this thesis is to review current challenges the companies may face when repurposing electric vehicle batteries. Reviewing literature and interviewing key stakeholders methods are combined to gather the relevant information. Key findings of this thesis show that the most common challenges for repurposing electric vehicle batteries are technical aspects, unstable supply, transport ambiguity, profit uncertainty, and competition from other circularity strategies. A potential solution to address those challenges is the close collaboration among stakeholders in the battery value chain to alleviate the uncertainty by ensuring the availability of information as needed. Besides, this thesis also discusses the role of the New Battery Regulation Proposal on promoting repurposing electric vehicle batteries and shaping the second-life battery market.

Keywords: electric vehicle battery, lithium-ion battery, repurposing business model, the European New Battery Regulation Proposal

Executive Summary

The transport sector is transitioning from fossil-fuel combustion to electrification under the pressure of global warming. This is critical since the transport sector is the second largest contributor to the world's greenhouse gas emissions. Hence, over the last few years, the global market for electric vehicles has seen considerable growth and will continue expanding in the future. This will lead to the dramatical increase in the demand of batteries. The global market size for lithium-ion batteries, the most common battery technology for electric vehicles, is estimated to rise from EUR 15 billion in 2018 to EUR 200 billion in 2040. Eventually, the foreseen problem of battery waste will become undeniable when those electric vehicle batteries (EVB) reach their end of life. Without proper handling and treatment, battery waste will cause serious environmental pollution through the hazardous materials contained within the battery.

In response to these environmental issues, the circular economy concept has been proposed. From a management perspective, amongst the different business models put forward in the circular economy, the repurposing model for electric vehicle batteries stands out as a potential economical and environmentally favourable solution. Besides, using repurposed batteries can also create considerable financial benefits for stationary energy storage system projects, which have strongly increased due to the development of renewable energy. Hence, the approach of prolonging EVB's life by repurposing and giving give them a second life has been experimented and implemented by various companies. Even though there are promising environmental benefits and potential profitability, there are challenges that prevent companies to scale up their pilot project to commercial operations. This thesis reviews current common challenges of repurposing EVBs in Europe from a management perspective by combining methodologies of literature review with insights from interviews with practitioners. Specifically, the thesis aims to answer the following two research questions:

RQ1: What are the most common challenges when repurposing EVBs?

RQ2: What could be potential solutions for these challenges?

Findings

RQ1: What are the most common challenges when repurposing EVBs?

The most current common challenges of repurposing EVBs found are categorized into technical aspects, unstable supply, transportation of used EVBs, uncertain profitability and the competition from the recycling business model.

There are three major issues under **technical aspects**. First, without *access to the original BMS*, repurposers have to build a new BMS to overwrite the original one. This approach would limit the control of the EVBs and not allow to maximize the available capacity of EVBs. However, original equipment manufacturers (OEM) have been reluctant to permit repurposers to access the original BMS because of the risk of revealing business secret. Second, in order to be repurposed and used in another application in the second life, used EVBs need to be tested by evaluating use-phase data. However, again, EVB use-phase *data sharing* solely depends on the decision of OEMs who may lose their competitive advantages by sharing such data. Third, due to lack of standard design and differences in chemical content, it is almost impossible to *match and mix different types of battery modules*. This limits the flexibility to rebuild second-hand EVBs.

Unstable supply of second-life EVBs can be explained in three main points. Since EVB market is still a nascent market and it has grown so quickly that historical data of demand and supply is not sufficient for a precise future forecast of used EVB. In addition to *the lack of official data for*

forecasting, the business activities of trading and exporting EVs and EVBs over their lifetime also complicate the supply estimation of *when (time) and where (place)* EVBs will end its first life. Moreover, as second-life EVBs *are influenced by complement goods* (such as electric vehicle sales, automobile widget and appliance market, etc.), a single initiative or event may lead to a proportionally high impact.

The *lack of a clear definition for used/repurposed/ second-life EVBs* in the current Battery Directive 2006 leads to a grey area when **transporting repurposed EVBs**.

Uncertain profitability is one of the biggest concerns from the managerial perspective. This is because the uncertain and high *conversion cost* of repurposing used EVB to second-life EVBs and the *decrease of costs for new EVBs*

EVBs repurposing model may, or has already faced **a competition with EVBs recycling model** as it is argued that *repurposing EVBs will delay the flow of recycled materials* that go back to manufacturing in order to produce new EVB.

RQ2: What could be potential solutions for these challenges?

In the big picture, collaboration among stakeholders along the supply chain may help to address technical challenges, transportation ambiguity, supply uncertainty, through information and data sharing between stakeholders such as OEM and repurposers. Eventually, dealing with those challenges would help to solve economic challenges which prevent businesses from scaling up their repurposing business model for EVBs. Although stakeholder collaboration is not the sole answer, it is the key component in solving the problems.

Besides, instead of being a challenge, legislation could be seen as an influencing factor promoting repurposed EVBs. An example is the New Battery Regulation Proposal that includes through different provisions of redefining used EVBs, and requires (1) BMS access for third parties, (2) information sharing through an exchange platform, (3) a battery passport, and (4) QR code battery labels.

Recommendation for policymakers

The stipulations of the New Battery Regulation Proposal related to second-life EVBs, on one hand, encourage repurposing EVBs and supporting repurposers; on the other hand, raise a debate from OEMs that such provisions could damage the companies' advantages and business secrets. Hence, policymakers need to take into account the opinions of different stakeholders so that the legislation could facilitate a transition towards a circular economy without scarifying the benefit of others. There is also a need for standard testing/certificate and credit evaluation methodology for second-life batteries, as well as consistency in an information-sharing platform.

Table of Contents

List of Figures

List of Tables

Abbreviations

BMS	Battery Management System
CE	Circular economy
EMF	Ellen MacArthur Foundation
EV	Electric vehicle
EVB	Electric vehicle battery
GHG	Green House Gases

OEM	Original equipment manufacturers
RUL	Remaining Useful Life
SOC	Stage of charge
SOE	State of energy
SOH	Stage of health
SOL	State of Life
SOP	State of power
WEEE	Waste Electrical & Electronic Equipment

1 Introduction

1.1 Upcoming problem from a solution

Global warming, driven by human emissions of greenhouse gases (GHG), resulting in large-scale shifts in weather patterns, has been of great concern from both scientists and the public. Based on data provided by Our World in Data, Ritchie and Roser (n.d.) analyzed global GHG emission from 1990 to 2016. The research showed that emissions from the transport sector have almost doubled from about four billion tons in 1990 to eight billion tons in 2016. After the Electricity & Heat sector, transport is the sector with the second highest GHG emission levels, accounting for 16.2% of total global GHG emissions in 2016, with 11.9% coming from road transport and 4.3% originating from aviation, shipping, rail, and pipeline transport (Ritchie & Roser, n.d.).

Under the pressure of cutting down emissions from transportation, electric vehicle (EV) technology is seen as an auspicious solution replacing the internal combustion engine vehicle. Recently, the robust growth of battery and electric vehicle technology, the heavy investment in research and development of the automobile industry, and the stringency of public policy toward sustainability and, climate change mitigation have affected the road transport sector and especially promoted electric vehicles (EV) (International Energy Agency, 2019). Hence, over the last few years, the global market for electric vehicles has seen considerable growth. Worldwide, the average annual growth rate of passenger-car and light-duty vehicle sales in major regions, including China, the United States, Europe and others, increased by 2.5% in ten years from 2010 to 2019, and is forecasted to expand strongly and continuously in the future (Woodward, Walton, Hamilton, Alberts, Fullerton-Smith, Day, Ringrow, 2020). In one scenario, the International Energy Agency (2019) estimated that the sales of EVs could reach 43 million units in 2030. Correspondingly, the increase in EVs will affect battery demand. The World Economic Forum (2019) forecasted that from 2018 onwards, global battery demand would increase fourteen times and reach 2,623 GWh in 2030, of which, 89% would be used in the electric mobility sector. The global market size for lithium-ion batteries, the most common battery technology for EVs, is estimated to rise from EUR 15 billion in 2018 to EUR 200 billion in 2040 (European Commission, 2018).

Even though using EVs are believed to save significant amounts of GHG emissions, by replacing fossil fuels in the use phase of EVs with electricity stored in EVB – if omitting the source of electricity which may come from non-renewable energy (Ritchie & Roser, n.d.), there are unavoidable environmental issues of EVBs occurring from the extraction of virgin EVB materials, EVB production and end of life disposal stages. Different battery types contain different chemical materials. For example, the main components of lithium-ion batteries include lithium, cobalt, graphite, aluminium, manganese, nickel, copper (Albertsen, 2020). Environmental risks connected to the extraction process of these raw materials are biodiversity loss, water depletion, soil contamination, erosion etc. For example, in Chile, approximately 65% water of the Salar de Atacama region, one of the world's driest desert areas, has been used for lithium mining (United Nation, 2020). At the end-of-life stage, if the battery is not disposed of properly, such contained minerals may cause toxic pollution to the environment and humans. Moreover, from the entire life cycle perspective, the carbon footprint for EVBs was reported to range from 61kg to 200kg of CO_2-eq/kWh battery capacity (Emilsson, Dahllöf, 2019).

1.2 Problem definition

In response to these environmental issues, the circular economy (CE) concept has been proposed and is expected to provide sufficient and effective solutions from different angles such as technical perspective, management perspective, etc. Specifically, from the management perspective various business models have been suggested such as battery leasing, swapping, repurposing, recycling, or car-sharing, etc. (Hill et. al., 2019). With the quickly growing demand for energy storage which can reach 120 GWh per year by 2030, the repurposing business model for EVBs stands out as a potential economical and environmentally favorable solution (Niese, Pieper, Arora, Xie, 2020).

Repurposing EVBs for other applications can have a significant contribution to environmental impact alleviation (Reinhardt, et. al. 2019). Research showed that the environmental impact of a repurposed EVB can be less than 10% of a new EVB (Hill et. al., 2019). Therefore, the business model of repurposing helps to mitigate environmental problems occurring during the material extraction and battery manufacturing.

Using repurposed batteries also creates considerable financial benefits for energy storage operators (Hill et. al., 2019). It was estimated to save 80-90% of manufacturing cost by repurposing EVBs as energy storage (Hill et. al., 2019). One example for this is an energy storage system (ESS) from repurposed lithium-ion batteries for wind energy in the United Kingdom, which saved approximately EUR 7.8 million (Hill et. al., 2019). Moreover, there is a potential revenue stream for EVB owners from selling their degraded EVBs, which are insufficient for EVs yet qualified for other applications like stationary energy storage. According to Reinhardt, et. al. (2019), the second-life EVB market will strongly be driven by the storage solution demand. The U.S. Department of Energy (2020) has given a prediction for the global energy storage market that could grow to more than 2,500 GWh by 2020. Hence, it opens an attractive business area of using discarded EVBs to fulfil a future need for financially feasible energy storage (Reinhardt, et. al. 2019).

By 2020, major players in the automotive industry had already studied the feasibility, capabilities, and potential of the future development of second-life EVBs markets. There are various experiments, pilots, and partly publicly funded projects under joint ventures between OEMs and partners such as Daimler and GETEC, Renault and Connected Energy, Nissan and Sumitomo, as well as BMW and Vattenfall (Reinhardt, Christodoulou, Gassó-Domingo, García, 2019; Albertsen, 2020; Circular Energy Storage, 2021). However, few full-scale repurposed EVBs have found to be implemented (Hossain et al., 2019; Albertsen, 2020). Circular Energy Storage (2020) studied those certain markets are not really picking up yet despite potential opportunities for start-ups in the repurposing area. Even though the repurposing of batteries promises to be beneficial from both environmental and financial points of view, the transition from a strategy towards an innovative business model is still ambiguous (Reinhardt, et. al. 2019). Moreover, there have been so far only very few studies on second-life EVBs from a management perspective, and especially ones that focus on challenges affecting the commercialization of second-life EVBs projects from a business model viewpoint (Reinhardt, et. al. 2019). Some authors have discussed challenges of repurposing used EVBs in their papers such as: Bobba et. al. (2018) categorizes the barriers with regard to refurbishment and use of second-life EVBs into four groups: technical, environmental, economic, and social; Olsson et. al. (2018) present barriers through cognitive, organizational and technical perspectives; while Albertsen (2020) organizes them into four themes: technical, economic, internal/organizational, and regulatory. However, there has not been any systematic review of challenges from a managerial perspective that also incorporates the recent EU battery regulation proposal which has been put forward. Hence, there is a need for a good comprehensive review on challenges of repurposing EVBs and understanding how the New Battery Regulation Proposal would be able to address some of these challenges.

1.3 Research objectives and research questions

Hence, in response to this knowledge gap, this thesis aims to gain an overall understanding of repurposed EVBs by exploring the challenges which have held back the scale up of repurposing EVBs from pilot projects to commercial operations through studying following research questions:

> Research question 1 (RQ1): What are the most common challenges when repurposing EVBs?
>
> Research question 2 (RQ2): What could be potential solutions for these challenges?

1.4 Scope

The European Union (EU) was chosen to be the *geographical scope* of this thesis. As one of the three biggest EV markets, besides China and United States, the EU's EV market has grown significantly. Based on research by McKinsey & Company, from October 2019 to March 2020, nine of the top ten markets for EVs were European countries, the other one is China (Gersdorf, Hertzke, Schaufuss, Schenk, 2020). Furthermore, Regulation (EU) 2019/1242 with a clear vision towards CO2 emission reduction targets is expected to incentivize further growth in the EV market, thereby triggering demand for new EVBs that eventually will be available for reuse and repurposing.

Presently, lithium-ion batteries are the most common type of battery used for EVs (Ali, Zafar et al., 2019), and therefore this study focuses on this battery technology. Thus, in the context of this paper, electric vehicle battery technology will be limited to lithium-ion battery only, a detailed definition will be given in subchapter 3.3.2 . This is the *technical scope* of this thesis.

The whole life cycle of an EVB includes numerous stages but can be simplified as depicted in Figure 1-1, which includes raw material extraction, battery cell manufacturing, battery pack manufacturing and integration, first-life EVB used in EVs, end-of-first-life EVB collection, repurposing of spent EVBs, second-life EVB used in other application, and finally recycling. In this thesis, however, only the repurposing of spent EVB stage of the *value chain* will be studied further from *management perspectives*.

Figure 1-1. EVB's value chain stages

Source: Created by the author after Perdriaux (Personal communication, 2021).

1.5 Ethical considerations

Researcher honesty and personal integrity. This thesis research was carried out by the author individually without being funded by any external organizations. As such, the conducted analysis and presented conclusion in this thesis only followed the guidance and orientation of the thesis supervisor.

Ethical responsibilities to the subjects of research, such as consent, confidentiality and courtesy. All the interviewees participated voluntarily. At the beginning of the interview, participants were informed about the interview and study purpose, the data and information handling manner, and the consent to record the interview for the author's personal reference. All the interviewees gave the consent to disclose their name in this paper. The author of this thesis did not find any cause to believe that the participants may suffer any disadvantage or damage from their participation in the study.

The outcomes of research. Even though the names of the interviewees were not anonymized, the author found no risk that participants may face any harm or damage regarding their reputation, dignity, privacy, or relationship with other people caused by this thesis work and its results.

The manner of handling, storing, and/or making available data records. No sensitive or confidential information was included or revealed in this thesis. Interview records were saved in the author's personal devices and were not shared to third parties.

The research design has been reviewed against the criteria for research requiring an ethics board review at Lund University and has been found to not require a statement from the ethics committee.

1.6 Audience

Practitioners and researchers in the field of lithium-ion batteries are the primary audiences of this thesis. The results aim to provide an explicit view on the challenges of the repurposing business model that firms operating in this area have faced so far. By doing so, the thesis aims to contribute to the further deployment of the repurposing business model for EVBs. The findings of the thesis could be of interest for policymakers, both inside and outside the European Union, to improve policies for the EVB value chain to become more circular and environmentally friendly.

1.7 Disposition

Chapter one gives an overview of transport electrification background for the study, introduces the addressed problem, draws the scope boundaries, and introduces the targeted audience.

Chapter two reviews the literature related to the topic of repurposing EVBs including electric vehicle lithium-ion battery overview, circular economy and repurposing business model, and legislation relevant to repurposed EVBs.

Chapter three presents the research design, and methods for data collection and analysis.

Chapter 4 provides the findings in response research question 1 about the challenges of the EVB repurposing business model.

Chapter 5 discusses the possible solution for challenges found in chapter 4 in response research question 2, and outlines limitations of this study.

Chapter 6 concludes the thesis with an overall summary and recommendations for further research.

2 Literature review

2.1 Electric vehicle lithium-ion battery

After being commercialized by Sony Corporation in 1991, the lithium-ion battery (EVB) has become the most popular type of rechargeable batteries, due to its high energy and power densities in comparison with other available commercial energy-storage batteries in the market, which are lead-acid, NaS, NaNiCl, NiCd, VRFB (Hu, 2011; Ali, Zafar et al., 2019). According to the research of Drabik & Rizos (2018), an EVB may have a lifespan of eight years for its first life within a vehicle and another ten years for its second-life; so in total approximately eighteen years before fully reaching its end-of-life.

Generally, an EVB is composed of hardware (cells, modules, a pack - Figure 2-1) and software (a battery management system) (Kushnir, 2015; Ali et. al., 2019; Samsung, 2021). In an EV, one form of battery is installed: a pack, the so-called battery pack (Samsung, 2021). A battery pack is made up of a cluster of modules, and a module is formed of a cluster of cells (Samsung, 2021). The entire battery pack is controlled by a battery management system (Olsson, Fallahi, Schnurr, Diener, Loon, 2018). Within the scope of this paper, only the software part of the battery management system will be reviewed in the following subchapters.

Figure 2-1. EVB's hardware components

Source: Created by the author after Samsung (n.d.). Pictures' source: Samsung (n.d).

Battery Management system

A Battery Management System is "a system that is capable of managing a battery" (Ali et. al., p4, 2019). Through the BMS, battery or EV original equipment manufacturers (OEM) want to optimize the battery's energy flows to better power the vehicles, thereby minimizing battery damage, balancing battery cells, controlling the battery charging and discharging regime, managing the battery's temperature, and improving battery safety (Qiang, Yang, Ao, Zhong, 2006; Hu, 2011). A BMS is designed to be able to communicate and interface with the EV's motor, climate and vehicle management system as well as safety system (Hu, 2011). Hence, the BMS is one of the determinants contributing to the EV's proper operation and the length of the EVB's life (Qiang et. al., 2006; Hu, 2011; Ali et. al., 2019). With all these functions and features, the BMS, tailored to regulate the battery's specific functions and purposes, is seen as an intellectual property that differentiates OEMs (Olsson et. al., 2018).

Moreover, by collecting and sending data of usage and charging history to the vehicle management system, the BMS plays a critical role in providing information about the battery's stage of health (SOH), stage of charge (SOC), state of power (SOP), state of energy (SOE) (Hu, 2011; Ali et. al. 2019). These parameters are connected to the term of applications, driver's habits, and the use-phase environment such as temperature and humidity (Hu, 2011; Circular

Energy Storage, 2021). For example, batteries in light-duty EVs have a longer life-time than in commercial EVs, especially buses which are driven more intensively (Circular Energy Storage, 2021). Each of EVB's condition parameter (SOH, SOC, SOP, SOE) has multiple calculation methods. For example, four types of battery models and twelve estimation techniques were studied for classifying SOH (Dong, Jin, Lou, Wang, 2014). Thus, due to the scope of this paper, the following sub-chapter will briefly explain the four important parameters that characterize the quality of used EVBs: SOH, SOC, SOP and SOE.

State of Health (SOH)

SOH is defined differently by different OEMs and it has no fixed definition (Rezvanizaniani, Liu, Chen, Lee, 2014). Engineers can analyze *vehicle safety and reliability* through *battery aging and damage status* which is reflected by the SOH (Chang, Wang, Jiang, Wu, 2021). In order to estimate the SOH, one needs to study the internal mechanism of batteries (such as power, capacity, internal resistance, current, voltage, temperature, self-discharge rate) as well as other massive amounts of the batteries' signals (Rezvanizaniani et. al., 2014; Chang et. al., 2021; Ge, Liu, Jiang, Liu, 2021). It is extremely necessary to estimate the SOH to make a decision of repurposing EVBs (Chang et. al., 2021).

State of Charge (SOC)

An EVB's lifetime and performance highly depend on how the battery is charged and discharged. For example, if charging voltage exceeds the recommended limitation range, it can lead to overheating and plating condition for the EVB. Also, if the EVB is discharging for a longer recommended time, the EVB's cell voltage can drop to a much lower level of its limit, and these actions can permanently damage an EVB cell (Hu, 2011).

The SOC of an EV shows the *vehicle driving range and the remaining usage time within one discharge cycle* or in other words, *the reliability of the battery system and the remaining power of the battery* (Bai, Wang, Hu, Pecht, 2014; Ali et. al., 2019). Learning about an EVB's SOC can help to have more precise estimations of the remaining useable time of the EVB (Ungurean et. al., 2017; Ali et. al., 2019). However, due to the complexity of EVBs, it is very challenging to know the SOC without given historical charging data (Ali et. al., 2019).

State of power (SOP)

The SOP determines the *peak power available in real time* over the next time period (Lai, He et al., 2020; Chen, Xu, et al. 2021). It reflects the EVBs' maximum output or input power on the premise of ensuring *battery safety*, and has strong links with batteries' voltage, current and internal parameters (Lin, Jin, Hong, Wang, 2020; Li, Wang et al., 2021). The "SOP is necessary for regulating the propelling power and coordinating the regenerative braking and friction braking of EVs" (Zhang, Shi, Ma, p1, 2015).

State of energy (SOE)

The SOE allows a direct determination of the EVB's *remaining energy* (Li, Wei, Tseng, Soong, 2018; Zhang, Wang, Wu, Chen, 2018). In research, the SOE is often evaluated in combination with the SOC or the SOP in order to have a more precise estimation for prolonging an EVB's life, or extending an EVs driving range (Zhang, et. al., 2018).

Based on the numbers of articles and information availability, SOH and SOC seems to be more commonly investigated compared to SOP and SOE. Besides, there are many other parameters and indicators used to study an EVB's status and condition such as Remaining Useful Life (RUL), State of Life (SOL), depending on research purposes and methodologies.

2.2 Repurposing EVBs in a circular economy

2.2.1 Circular economy

Even though the notion of a circular economy (CE) was first discussed in 1990 by Pearce and Turner, the concept has become popular and been robustly promoted by researchers, governments and businesses more recently (Kirchherr, Reike & Hekkert, 2017). As time passed, CE has been developed and absorbed various schools of thought including industrial symbiosis, cradle-to-cradle, and eco-efficiency (Lewandowski, 2016; Albertsen, 2020). Nevertheless, there is no common single definition for CE, it has been interpreted differently by different people from different approaches (Kirchherr et. al., 2017). The CE definition presented by the Ellen MacArthur Foundation (EMF), "a circular economy is based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems", has been the most widely used recently (Ellen MacArthur Foundation, n.d.). Bocken et. al. (2016) also introduced three CE framework strategies which are in line with EMF's CE explanation:

- narrowing the loop, focusing on resource optimization per unit of product

- slowing the loop, focusing on product-life extension or product-utilization intensification

- closing the loop, focusing on material recycling when products reach their end-of-life.

Figure 2-2 presents an overview of a CE for EVBs starting from (1) manufacturing – including EVB innovation and design stage, to (2) the use-phase where EVBs are used in EVs, and when EVBs reaches the end of their first life. EVBs can then be processed to (3) have another second life for example as energy storage for building, or (4) be recycled so that materials will be collected and used for a new cycle. This helps to mitigate the demand for raw materials and reduce environmental pollution coming from the mining and processing of virgin materials.

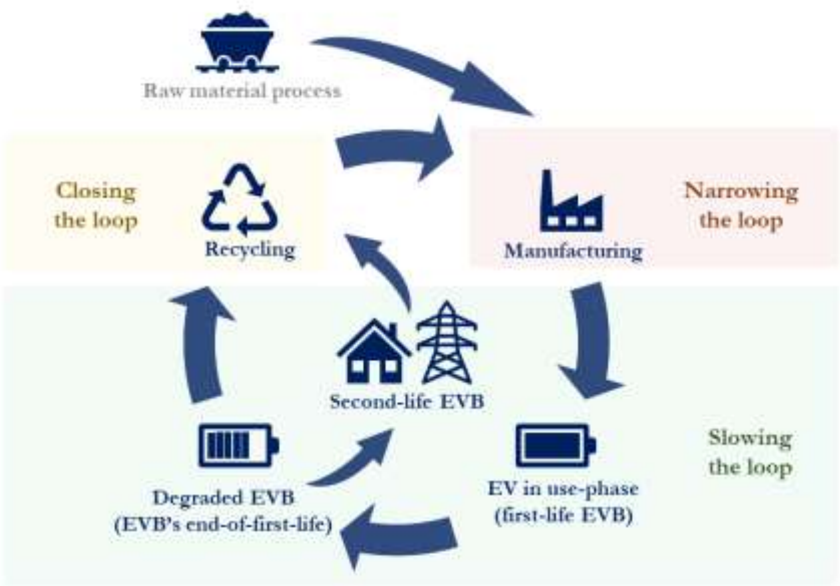

Figure 2-2. EVB's life cycle

Source: Created by the author after Ellen MacArthur Foundation (n.d.) and Bocken et. al. (2016).

2.2.2 Repurposing EVBs

A brief definition of repurposing

Even though different terminologies are used for a repurposing business model, such as product life extension (Accenture, 2014), cascading & repurposing (Lüdeke-Freund et. al. 2019), second life or second use (Albertsen, 2020), they all are used to describe the process of giving the product a second or even a third life after the product reaches its end-of-first-life. By prolonging EVBs' life, the repurposing business model helps to slow the loop of EVBs' cycles (Reinhardt, et. al. 2019).

Repurposed EVBs can be used in different applications such as stationary energy storage, compact mobile storage, or spare EVB (Niese et. al., 2020). One of the most common CE business models for EVBs is repurposing for use in energy storage systems, for the purpose of optimizing consumption, supporting power generation when having mixed power sources, controlling frequency, charging EVs, and providing emergency backup (Hill et. al., 2019; Niese et. al., 2020). End-users of stationary energy storage systems are various, ranging from private customers to business customers like EV charging operators, energy-intensive consumers, grid stabilization services, and EV companies, amongst others. Table 2-1 shows different applications for second-life EVBs.

Table 2-1. Different applications for second-life EVBs.

<table>
<tr><th>Applications</th><th>Services</th><th>Purposes</th></tr>
<tr><td>Spare EVBs</td><td colspan="2">(no further information found)</td></tr>
<tr><td>Compact mobile storage</td><td colspan="2">energy storage for other mobile applications such as forklifts, streetlamps, autonomous robots...</td></tr>
<tr><td rowspan="5">Energy Storage System</td><td>Renewable energy storage</td><td>store renewable energy such as solar, wind, hydro power etc.</td></tr>
<tr><td>Energy arbitrage</td><td>purchase electricity when it's cheap then use when it's expensive to optimize the cost</td></tr>
<tr><td>Charging station</td><td>charge EVs</td></tr>
<tr><td>Off-grid</td><td>back-up for power-cut or area with low power capacity</td></tr>
<tr><td>Grid stabilisation</td><td>balance market, regulate voltage</td></tr>
</table>

Source: Created by the author after Hill et. al., (2019); Niese et. al. (2020); Albertsen, (2020).

The repurposing process

In order to be repurposed, EVBs in different applications other than EVs, the spent EVBs need to go through a process of different stages, see Figure xx. After arriving in the repurposer's place, an EVB is tested to identify if it is sufficient for a second-life in other applications than an EV (Bobba et. al., 2018; Hossain et. al., 2019). Various parameters, such as SOH, SOC, SOP, SOE, etc. are taken into consideration. If possible, the whole battery pack that passes the test requirement is repurposed without the need for dismantling, and this is an ideal option (Bobba et. al., 2018). Otherwise, it will be sent to be recycled, reused or processed further depending on its condition (Hossain et. al., 2019). The process continues with used EVBs being disassembled into separate battery modules, which are again evaluated and sorted out (Bobba et. al., 2018; Hossain et. al., 2019). Eligible battery modules will be reassembled based on the specific needs of the new application (Bobba et. al., 2018; Hossain et. al., 2019). This is how a repurposed EVB is processed. However, Bobba et. al. (2018) raise a considerable issue that in such a normal process, the whole battery module will be discarded if it is unqualified. Hence, there is a suggestion that accessing each and every cell can be applied for big battery modules at least for the environmental aim.

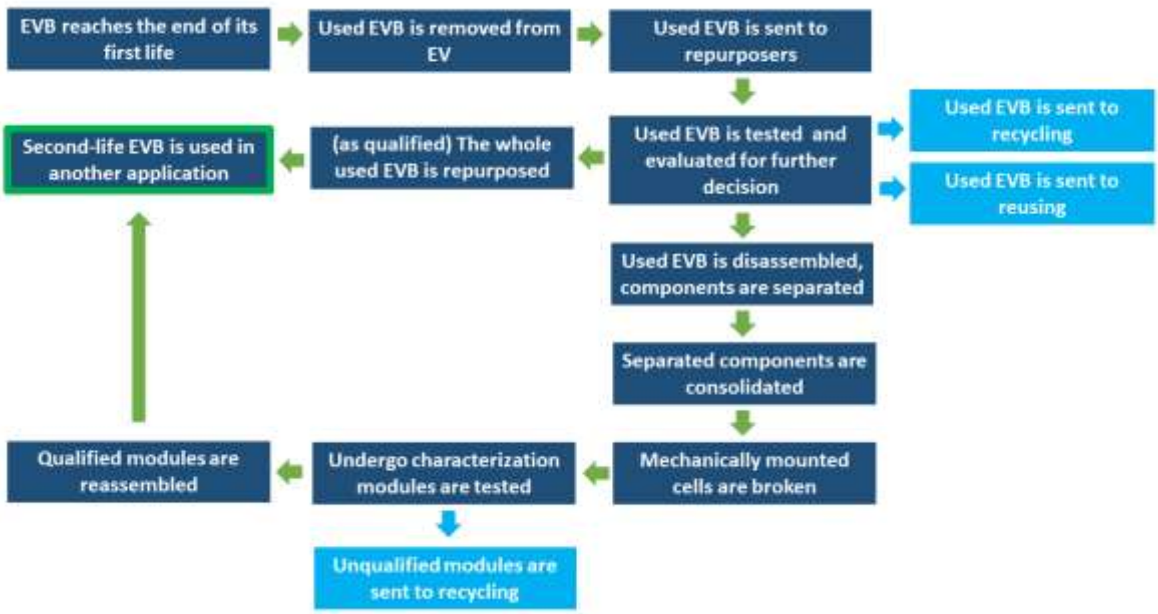

Figure 2-3. Process of repurposing EVB

Source: Created by the author after Bobba et. al. (2018); Hossain et. al. (2019).

Repurposing EVBs actors

In the current market, the flow of repurposing EVBs can be depicted in a simplified manner as shown in Figure 2-4. Repurposing EVBs involves:

- Five main actors: OEM, OEM's subsidiary, repurposer, energy storage distributor, second-life EVB customer, and
- two essential responsibilities: administration duty & implementation, ownership & Extended Producer Responsibility (EPR) (Perdriaux, 2020).

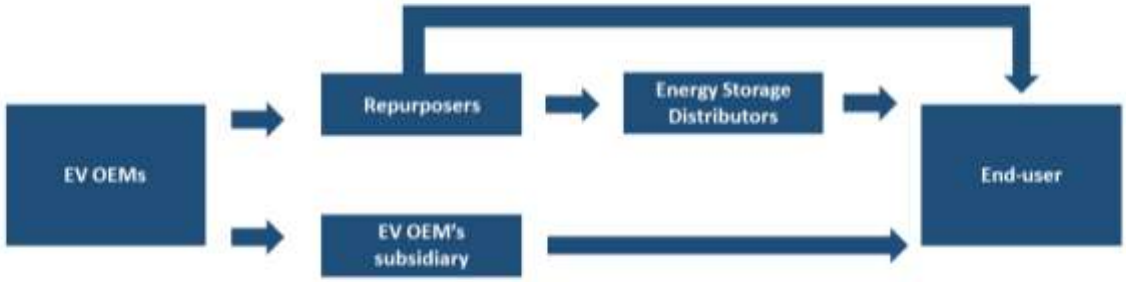

Figure 2-4. Repurposing EVB main actors

Source: Created by the author after Perdriaux (2020)

Based on ownership & EPR of EVB, the cooperation between OEMs and repurposers can be simplified into two types: (1) ownership & EPR is taken over by OEMs, or (2) ownership & EPR is transferred from OEMs to repurposers.

In the first type, the OEM also plays the role of a repurposer and keeps discarded EVBs for internal use. By doing this, the OEM can maximize the use of their EVBs and minimize the conversion cost (Respondent 2). Other examples are the ELSA experiment of Renault as well as BMW reusing batteries of their i3 model. In this case, the ownership and responsibilities are still the same and belongs to the OEM.

In the second type, OEMs work with repurposers to deal with their end-of-life EVBs. In this case, most of the administration duties, as well as the Extended Producer Responsibility (EPR) will be transferred to the repurposer along with the commercial agreement (Perdriaux, 2020).

Repurposing EVBs pilot projects and commercial operation

Table 2-2 give an overview of several pilot projects and commercial operations for second-life EVBs in Europe. The key takeaways from the table are:

- Announced second-life EVB projects in the EU are mainly ESS projects. None of the pilot projects or commercial operation for spare EVBs or compact mobile storage applications in the EU is noticed.
- In all the reviewed commercial operation cases, OEMs do not directly implement the EVB repurposing process. Instead, they collaborate and sell used EVBs to repurposers

Table 2-2. Pilot projects and commercial operations for second-life EVB in the Europe

Repurposers & OME	Collaboration	Source
Pilot projects		
Vattenfall & BMW	- 5-year project started from 2014 - Two application: EV charging station and ESS for solar power - Place: Hamburg, Germany	Vattenfall, 2021; Kane, 2018

EDF, PSA Peugeot Citroën & Mitsubishi	- Started in 2015 - Application: ESS for grid support - Capacity: (n/a) - Place: Paris, France	World Electric Vehicle Journal, 2018
Vattenfall, Bosch & BMW	- 10-year project started from 2016 - Application: ESS for grid support - Capacity: 2.8 MWh - Using 2600 battery modules from 100 EVs - Place: Hamburg, Germany	Colthorpe, 2015; Bosch, 2016; Hossain et al., 2019
(no info/ no repurposer)& BMW	- Project started from 2017 - Application: ESS for wind turbines and grid balancing - Capacity: 15 MWh - Using 700 battery packs from BMW i3 EVs - Place: Leipzig, Germany	BMW Group 2018; Colthorpe, 2017; Colthorpe, 2019
The mobility house & Daimler AG	- Project started from 2016 - Application: ESS - Capacity: 13 MWh - Using: 1,000 Smart ED2 battery packs - Place: Luenen, Germany	Mobilityhouse, n.d.
Enercity AG, ACCUMOTIVE (Daimler AG's subsidiary) & Daimler AG	- Project: Active spare parts warehouse Herrenhausen, started from end of 2016 - Application: ESS - Capacity: 15 MWh - Using: 3000 Smart ED3 replacement battery modules - Place: Herrenhausen, Germany	Daimler AG, 2017
The Mobility House, GETEC ENERGIE & Daimler AG	- Project: Active spare parts warehouse Everlingsen started from 2018 - Application: ESS - Capacity: 9.8 MWh - Using 1,920 Smart ED3 replacement battery modules - Place: Everlingsen, Germany	
Commercial operations		
Connected Energy Ltd & Renault	- Collaboration started in 2016 - Product: E-STOR, an energy storage system product of Connected Energy Ltd. - Supply of used EVBs: Renault Kangoo battery - Projects: . Grid services projects: Engie (Netherlands), Allego (Belgium, Germany), Coletta & Tyson (United Kingdom), Umicore (Belgium) . EV charging station & solar power ESS: Dundee (United Kingdom)	Connected Energy, n.d.

Connected Energy & Nissan	- Collaboration started year: (n/a) - Product: E-STOR, an energy storage system product of Connected Energy Ltd. - Supply of used EVBs: (n/a) - Projects: (n/a)	Unreasonable group, n.d.
Eaton Industries & Nissan	- Collaboration started year: 2018 - Product: xStorage home (4.2kWh- 10.08kWh), xStorage building (20kWh-10MWh) - Projects: different ESS services and purposes - Place: Norway, France, UK	Nissan, n.d.
Wärtsilä & Hyundai	- Collaboration started year: 2018 - Project: ESS projects - Place: Finland	Magnuson, 2018; Hyundai, 2018
Ibil, Repsol & Irizar	- Collaboration started year: 2019 - Product: xStorage home (4.2kWh- 10.08kWh), xStorage building (20kWh-10MWh) - Projects: ESS for energy arbitrage & EV charging - Place: Spain	Irizar, 2021
BatteryLoop & Volvo Bus	- Partnership started in 2019. - Supply of used EVBs: from Volvo Bus - Projects: . Residential energy storage for Stena Real Estate's buildings (Gothenburg, Sweden) . ESS for Port - Sea Lion Project (Gothenburg and Kiel, Sweden)	BatteryLoop, n.d. Respondent 4
Connected Energy Ltd & Renault	- Collaboration started in 2016 - Product: E-STOR, an energy storage system product of Connected Energy Ltd. - Supply of used EVBs: Renault Kangoo battery - Projects: . Grid services projects: Engie (Netherlands), Allego (Belgium, Germany), Coletta & Tyson (United Kingdom), Umicore (Belgium) . EV charging station & solar power ESS: Dundee (United Kingdom)	Connected Energy, n.d.
SNAM & Honda	- Collaboration started in 2020 - Collect Honda's EVB from 22 EU countries - The owner of the repurposed EVBs is the sister company of SNAM - Phenix Batteries who is dedicated to the second-life production and appraisal. - Projects: . Industrial-sized self-consumption: storage capacities to improve the overall efficiency of the energy management system controlling the energy	SNAM, n.d.; Respondent 7

	fluxes in an industrial application (it can also include repair/improvements on an existing energy grid in a plant, to accommodate more green energies). The goal is Europe with the commercial firsts being in France and Belgium. . Residential energy storage through an exclusivity contract with our longtime commercial partner SIREA, who integrates SNAM's repurposed batteries in their commercial solutions. This is more tailored towards the French Market. The final products are certified so that they are acceptable in all of the EU. . Collective residential energy storage, only through local authority landlord or groups, the aim is not to deal with each individual but rather an elected representative or equivalent. . Network support (frequency regulation, black start, primary reserve…): applications tailored to the characteristics of the batteries (very short response time, short-needed time, energy/power requirements…). This application is for now more developed internally, as proofs of concept and installed on our premises. . Next Generation Charging Stations, which can include energy storage, PV capacity etc. to improve both the economical equation and the environmental footprint	

Source: Created by the author

2.3 Policy related to repurposing EVBs

2.3.1 The existing regulation

The most recent legislation related to EVBs is the Directive 2006/66/EU on Batteries and Accumulators and Waste Batteries and Accumulators (the Battery Directive 2006). The Battery Directive 2006 applies to all types of batteries. It aims to increase the collection and recycling of spent batteries; improve environmental performance in the battery value chain, especially recycling and disposal; reduce hazardous substances and ban certain types of batteries (Directive 2006/66/EU; European Commission, 2020a). Since the Battery Directive 2006 came into force, several decisions and regulations have been adopted to develop or adjust some of its provisions, see Figure 2-5.

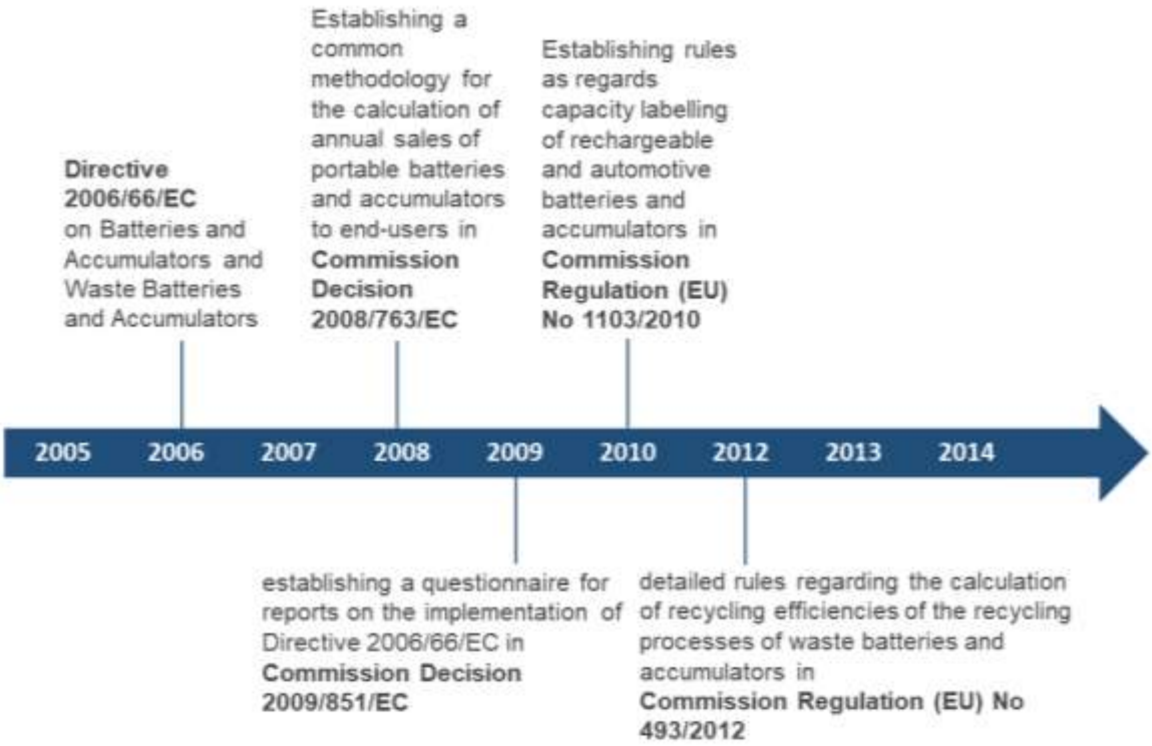

Figure 2-5. Existing regulations related to EVBs

Source: Created by the author after European Commission (n.d. a)

However, the rules and regulations for repurposing have been found to not be very clear (Albertsen, 2020). The terms "second-use", "second-life" or "repurpose" are not defined in the Battery Directive 2006 or other related regulations such as the Waste Framework Directive 2008/98/EC, the Waste Electrical & Electronic Equipment Directive 2012/19/EU (WEEE), or the End-of-Life Vehicles Directive 2000/53/EC (ELV) (Bobba, Cusenza et. al., 2018). Thus, repurposing could be seen as an absent piece in the current legislation (Bobba, Cusenza et. al., 2018).

2.3.2 The New Battery Regulation Proposal December 2020

Given new socio-economic conditions, technological innovation and developments in the battery market, the Battery Directive 2006 is considered out-of-date, and can no longer fulfil new environmental ambitions (European Commission, 2020e). Thus, a new regulation for batteries is crucially needed. Therefore, in December 2020 a *Proposal for regulation of the European Parliament and of the Council concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020* (the New Battery Regulation Proposal) was introduced. The objective of this New Battery Regulation Proposal is to set common rules to enhance the functioning of the market, alleviate social and environmental impact, and promote circular economy (European Commission, 2020h). Its main key points related to EVBs include:

Definition

- Introduce clearer and more detailed definition of EVB as "electric vehicle battery means any battery specifically designed to provide traction to hybrid and electric vehicles for road transport" (Art. 2(12) New Battery Regulation Proposal), which shows that the EU has put more attention on this strong growing EVB market which does not happen in the Battery Directive 2006.

Sustainability:

- Requirements on transparency measures, limited *carbon footprint* for evbs and industrial battery (Art. 7, New Battery Regulation Proposal)
- Requirements on minimum *recycled content* (targets for cobalt, lead, lithium and nickel) (Art. 8, New Battery Regulation Proposal)
- Requirements on EVB's *performance and durability* parameters (Art. 9, New Battery Regulation Proposal)

End-of-life management:

- Art. 7 (the New Battery Regulation Proposal) about E*xtended Producer Responsibility* regulates the responsibilities of oems as well as multiple producer responsibility organisations act on behalf of producers.
- *Collection* obligation regarding efficiency rate (45% by 31 December 2023; 65% by 31 December 2025; 70 % by 31 December 2030); battery types, and collection fee (Art. 48, New Battery Regulation Proposal). Moreover, Art. 49 of the New Battery Regulation Proposal is specifically for EVB collection which is not covered in the current Battery Directive 2006.

Data & Information:

- Requirements on *traceability of raw materials* along the value chain (Art. 39, New Battery Regulation Proposal)
- Requirements on storing data and information related to state of health and expected lifetime of batteries in the battery management system (Art. 14, New Battery Regulation Proposal)
- Requirements on oems to *grant access to the battery management systems* of batteries: evbs "shall include a battery management system containing data on the parameters for determining the state of health and expected lifetime of batteries" (Art. 39(1), New Battery Regulation Proposal) and "access to the data in the battery management system[...] Shall be provided on a non-discriminatory basis to the legal or natural person who has legally purchased the battery or any third party acting on their behalf at any time" (Art. 39(2), New Battery Regulation Proposal). This will help the information flow better for the purpose of reusing or repurposing.
- There would be an *Electronic exchange system*, which stores characteristic information and data of each EVB's type and model, "shall be sortable and searchable, respecting open standards for third party use" (Art. 64(2), New Battery Regulation Proposal)
- *Battery passport* is expected to support second-life EVB operators to have better used EVB classification decisions, and support recyclers to better plan their operations. Besides, the battery passport will be connected to the data and information stored in the Electronic exchange system (Art. 64(2), New Battery Regulation Proposal). However, it is not crystal clear which exact information is mandatory for collecting

It can be seen that the New Battery Regulation Proposal has various provisions promoting and supporting the repurposing of used EVBs. As stated in Art. 14 "for the purpose of facilitating the reuse, repurposing or remanufacturing of the battery", or in Art. 39 that OEMs are obligated to collect used EVBs "in accordance with [...] preparation for repurposing, and remanufacturing, treatment and recycling [...]". Moreover, the New Battery Regulation Proposal has Art. 59, a separate article regulating requirements related to the repurposing and remanufacturing of EVBs and industrial batteries. In general, Art. 59 repeats provisions on information as well as sharing and accessing of data as introduced above, and more detail on the rights and obligations of repurposers. An overview of the New Battery Regulation Proposal's milestone (Figure 2-6) presents the effort of enhancing second-life EVBs by improving data and information flow and availability and reducing the carbon footprint of EVBs.

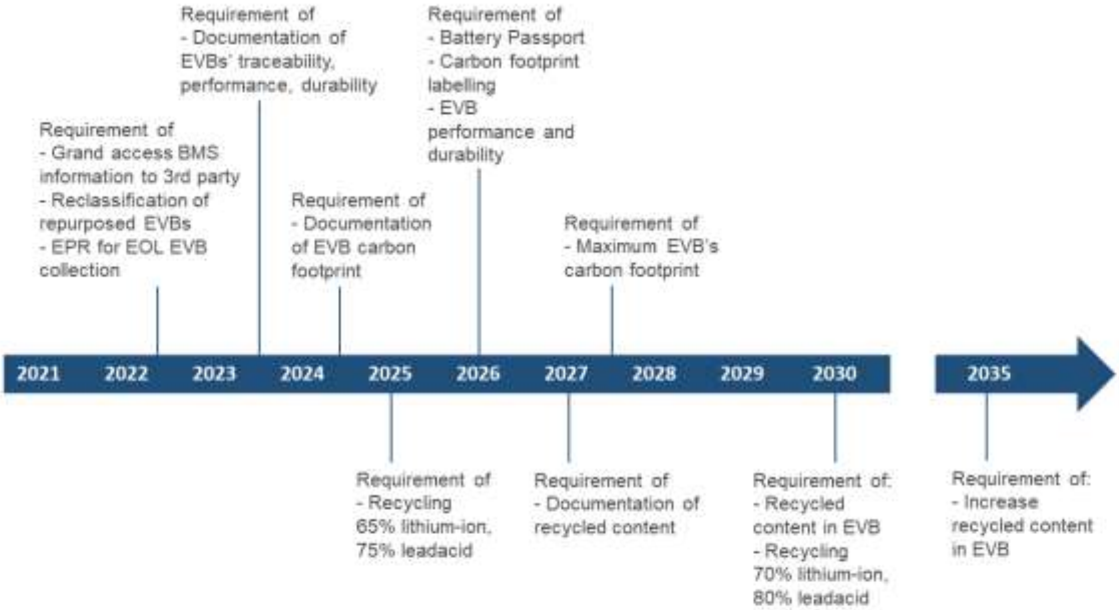

Figure 2-6. the New Battery Regulation Proposal's milestone

Source: Created by the author after the New Battery Regulation Proposal (2020)

However, some of the provisions related to information sharing for repurposing purposes may create some conflict when they are implemented. Germany's Electrical Industry (2021) points out that Art. 59(4) may crease market disruption and unfair competition between repurposed EVBs and new EVBs as repurposers are not obligated to report information on carbon footprint, recycled content, performance and durability of repurposed batteries which are placed on the market before the date the obligations become applicable. In addition, the suggestion in Art. 14(1) that the BMS "shall include a battery management system containing data on the parameters for determining the state of health and expected lifetime of batteries" and Art. 14(2) that "access to the data in the battery management system [...] shall be provided on a non-discriminatory basis to the legal or natural person [...]" raises the concern of sensitive trade secrets which leads to serious competition interference (Germany's Electrical Industry, 2021).

2.4 Knowledge gap in literature

The research on numerous pilot projects and commercial operations for second-life EVB in Europe shows that companies have been interested in the repurposing EVBs area which could be seen through the growth of commercial operations recently. Nevertheless, during the process of reviewing these pilot projects and commercial operations from grey papers and news articles, it was found that potential environmental benefits and promising financial benefits are usually mentioned, yet no challenges or obstacles that participating stakeholders, especially repurposers may face, are discussed. Barriers to the repurposing of EVBs have been introduced in different literature such as second use battery energy storage systems of Faessler (2021), circular business models for EVB of Albertsen (2020), design and analysis repurposed EVBs for ESS of Catton, Walker et al. (2019), second-life EVB assessment of Bobba et. al. (2018), etc. However, the literature reviews identified the obstacles mostly from technical or environmental perspectives, there is little focus on challenges from a management perspective. Moreover, none of the papers incorporated the New Battery Regulation Proposal published in December 2020. Thus, a comprehensive analysis of repurposing EVBs challenges under a management perspective and how it is likely to be influenced by the New Battery Regulation Proposal is needed. This is expected to provide an overview of the second-life EVBs challenges and provisions related to repurposed EVBs of the New Battery Regulation Proposal so that stakeholders, especially repurposers could gain more in-depth information for better preparation and advancement of their business.

3 Research Design, Materials, and Methods

This section outlines the methodology of how this qualitative research is conducted. It presents the reason and logic of the research design, material collection and analysis.

3.1 Research design

Based on the idea of continuous improvement and development, this thesis's research design concept is constructed. Firstly, the ontological and epistemological perception is included and plays as an overall theme for the other element of the research process. From there, research questions are formed to indicate the focused problem - "Repurposing EVBs is environmentally friendly, yet it is challenging to scale-up to commercial business models from pilot and experimental projects". Different theories, concepts and perspectives on battery, business models and legislation have been studied through academic journal papers, grey literature, news articles, government sources, and webinars to understand and build knowledge on the market background and fundamentals, sufficient enough to have a meaningful conversation with experts in the field. Then, the initial findings were formed. This first stone of the discovery brought a better adjustment of the research questions, which oriented the research to deeper analysis and exploration so that more relevant data and information can be learned. More interviews with experts were conducted so that the findings could be clarified better. The process was repeated. Eventually the research design was finalized and is visualized in Figure 3-1.

Figure 3-1. Research design

Source: Adapted from Mickwitz (2014).

3.2 Material collection & analysis

For data collection of this qualitative research, two methods, including content analysis of documents, and semi-structured interviews (Blaikie, Priest, 2019) were used in in order to ensure triangulation and alleviate potential bias that may occur during the study. Based on the material collection, the collected data and information was mostly of tertiary type and it has previously been analysed by other researchers and interviewees.

3.2.1 Literature review

The literature review is a mix of academic literature and industrial information, including academic journals, grey literature, and news articles. This approach method did not only help to know what kind of research already existed regarding the research topic of this paper but also to ensure that information discussed in this thesis is updated with the changes in this rapidly developing battery industry. Even though there is no restriction or limitation on the time range of reviewed research papers, the aim was to limit the reviewed literature to publication between 2011 and now. Moreover, as there have not been many studies in the field of repurposing business models for EVBs, and specifically for the challenging aspects, this thesis looks at all recorded and analyzed challenges reported by different information sources introduced above. The aim was to find common challenges, and then, to compare the correlation between existing researched information and practitioners' information which is discussed further in the next section. The platforms used for searching academic materials were Google Scholar, Lund University Library - Ebscohost, and ScienceDirect. Keywords used for finding literature were 'electronic vehicle battery', 'battery management system', 'state of health', 'state of charge', 'stay of power', 'state of energy', 'repurposing business model', 'second-life battery', 'circular economy', 'slow the loop', etc. Collected information was organized in a synthesis matrix as depicted in Appendix 1 to enable further analysis.

Since the geographical scope is within European countries, for information related to legislation, the thesis will only focus on EU law. Information on regulation was firstly acquired through the official summary documents published by the European Commission in order to have an overview. Then the official full-version documents were used for more detailed research by using keywords such as 'electronic vehicle battery', 'repurpose', 'second-life', 'battery management system', 'state of health', etc. In addition to the review of regulation, an analysis of documents from other organizations in the field were also used for references. The platform used for searching governmental documents is EUR-LEX.

3.2.2 Practitioner interviews

Practitioner interviews were highly important as the findings obtained from them helped to reflect how information generated in existing studies is still up-to-date and relevant to the current situation, in particular as EVs and EVBs are fast changing markets.

Selection of interviewees

The method for the selection of interviewees was purposive as it was based on the author's judgement if the background and experiences of the approached interviewees would fit the objectives of the research (Blaikie, Priest, 2019). There were four main sources used for finding potential interviewees: personal network, alumni network, professional social network and industrial conferences. Although the number of interviewees introduced by the personal network of the author, as well as through the alumni network of the university were low, the response rate was 100%. In contrast, more than twenty people had been contacted through the professional social network LinkedIn and emails, yet only two of them got back. In total, there were seven confirmed interviews: one from an EV OEM, three from repurposed EVB operators, and the other two from national research institutes. Table 3-2 depicts a list of the interviewees; more details of the interviewees and channels used for the interviews is presented in more detail in Appendix 2.

Table 3-1. The summary of interviewees' source

Stakeholder groups	Number of interviewees	Contacted through
EV OEM	1	Alumni network
Repurposed EVB operators	1 1 2	Alumni network Personal network Professional social network - LinkedIn
Research institute	1 1	Alumni network Personal network

Source: Created by the author

Conduction of the interviews

The interviews were conducted via two phone calls, four online meetings, one email exchange. No direct meetings or onsite visits were done due to the COVID19 pandemic.Online interviews were held via Zoom and Microsoft Team Meeting software based on the interviewees' references. Online interviews were recorded in mp4 format and saved in the author's personal computer while phone call interviews were recorded in mp3 format and saved in the author's personal mobile phone. Those recording files will not be shared without consulting the interviewees for permission. Furthermore, each interview was started by asking the interviewee if they wish to remain anonymous. However, all seven interviewees felt comfortable with sharing their names, position, a company name in this thesis. This information can be found in Appendix 2.

Except for the email exchange with a question list (Appendix 3), the other interviews were semi-structured and informal. In general, with this approach, interviewees can elaborate specific subjects with open-ended questions (Alsaawi, 2016) and the collected information will not be narrowed down to given interview topics and questions which may not well cover all aspects of the research questions, due to the author's limited knowledge. The interviews were organized as one-to-one interviews and no group interviews were held to allow interviewees to openly and extensively share their perceptions, feelings, attitudes, experiences and learning (Taylor, 2000; Damdinova, 2020). For all the interviews, the discussion topics were similar, yet optionally guided interview questions were tailored for each interviewee in order to gain the most information from the interviewee's knowledge and experience, since they all work in different business or academic contexts.

Analysis of the interviews

After the interviews were conducted, they were transcribed, corrected and coded. No software was needed as the interviews were not too long, around 30-60 minutes per video/call record so the job could be done by the author. Besides, manually transcribing interviews helped to capture information that may have been missed during the talks. Content analysis was used for analyzing the data and information collected to find the pattern of challenges that the interviewed company in specific and the industry in general have been facing. Then, the challenges were categorized into common themes: market, cost, BMS & data, transportation, business model competition, stakeholder collaboration, and new regulation.

4 Findings

This chapter presents the findings in response to Research question 1, the most common challenges discussed by the interviewees and as identified in the literature from a business managerial perspective. The significant challenges of repurposing EVBs includes technical aspects, unstable supply, transportation, profit uncertainty, and competition from other circularity strategies.

4.1 Technical aspects

The following subchapters will present the challenges of accessing the Battery Management System, sharing EVB's operational data, and combining different battery modules.

4.1.1 Accessing the Battery Management System

Even though the EVB's original BMS allows better control of the EVB's performance and may even provide a proper EVB's health assessment through the battery's use-phase data, OEMs have been reluctant to permit repurposers to access the original BMS. The main reason is that the BMS - the 'brain' of the battery - is seen as intellectual property which provides a competitive advantage (Niese et. al., 2020). This is strongly agreed by six out of seven interviewees who also provided additional insights. Respondent 3 commented that Asian OEMs are more willing and open to share in comparison with OEMs from the EU. Respondent 4 faced a similar situation that there is a completely different philosophy between EU OEMs and Asian OEMs when it comes to the BMS discussion. Although the company only asked for about 15 signals on the battery, not for a complete BMS, most OEMs in EU said they would not deliver the BMS, while Asian OEMs said they would deliver the BMS so that their partners could optimize the business (Respondent 4). In addition, Circular Energy Storage (2020) even raises a concern that Asian OEM players may be in a better position of meeting the new EU regulation's requirement compared to those from the EU. For example, respondent 4 commented that "the Asian OEMs have come further in their electrification strategy as they see the need for this while the EU ones still see it as a competitive edge for their own business".

Furthermore, due to the difficulty of getting access to the original BMS, repurposers have to either overwrite or build another BMS on top of the original one. However, most of the respondents concur that these two approaches are not ideal solutions to manage second-life EVBs (Respondents 2, 3, 4, 5, 6, 7). Respondent 4 said that building a completely new BMS means not being able to control all the signals from the pack, or in other words, it did not allow the EVB to perform at its highest capability, a concern that also respondents 3 and 5 affirmed.

4.1.2 Sharing data

As pointed out earlier in the literature review, different EVBs will certainly have undergone very different operational conditions during their first life (Hu, 2011; Hossain et al., 2019; Circular Energy Storage, 2021). Therefore, analyzing the status of used EVBs is a significant step in the process of repurposing EVBs. Nevertheless, the evaluation of used EVBs is highly dependent on the batteries' use-phase data and information which can only be given by the OEM (Bobba et. al., 2018; Olsson et. al., 2018; Albertsen, 2020). Thus, OEMs are considered as key players with unique power about technical information that is relevant in the activity of repurposing EVBs (Ruiz et al., 2016; Bobba et al., 2018). If SOH, SOC, SOP, SOL data, which is collected by the original BMS, is not shared, repurposers must test every single of used EVBs in order to make a precise classification decision whether to reuse, repurpose, or recycle discarded EVBs. Respondents 3, 5, and 6 have strongly confirmed this. Furthermore, despite being checked, the performance of second-life EVBs' is still uncertain and not guaranteed (Olsson et. al., 2018; Albertsen, 2020) because depending on the methodology, the test results can be different and the evaluation may not be absolutely precise (Zhang et al., 2018; Ali et. al., 2019). Moreover, respondent 3, 5, and 6 all agreed that estimating the quality, remaining use life and safety of used EVBs is not only difficult but also an enormous job for the repurposing companies. Besides, due to the lack of data and inaccurate evaluation, repurposers tend to over-design second-life EVBs, for example, using more battery modules than needed, to ensure they are sufficient for new applications (Niese et. al., 2020). This may also reduce the overall supply of second-life EVBs.

Lack of information-sharing or insufficient historical data of EVB's use phase would make the decision of repurposing used EVBs very challenging. Hence, when talking about accessing to BMS and sharing information, respondent 4 has accentuated the importance of the cooperation between OEM and repurposers that "to be successful, you need to have a good connection to the OEM". Having the same opinion, Respondent 7 also shares that his company implements full cooperation with their OEM partner concerning the second-life activities, including any data sharing, eligibility screening, second-life repurposing.

4.1.3 Battery-module combination

It is not surprising that the idea of combining different types of battery modules was not mentioned by the interviewees. An obvious reason is given by Hossain et. al. (2019), stating that due to the incompatibility between various battery module types and the lack of universal cell standards, it is almost impossible to mix and match different battery modules, not to mention the different chemistries employed. Thereby, the advantages that technical differentiation, including design, type, chemical contents, offers to OEMs in the first-life of EVBs, become an obstacle for a third party to repurpose spent EVBs. This limits the quantity and the flexibility of building second-life EVBs, and to some degree affects the market supply of EVBs that potentially can be refurbished. This aspect will be discussed in the next section in more detail.

Regarding the battery design, Bobba et al. (2018) suggest that stakeholders along the value chain should work together to design the EVBs to benefit its whole life cycle, not only its first-life in EVs but also a potential second-life and at the last recycling stage.

4.2 Unstable supply

Concerns about uncertain supply market of capturing sufficient volumes spent EVBs in order to obtain economies of scale have been shared by respondents 2 and 3. In the literature several reasons are given to explain the supply disruption and uncertainty in the second-life EVB market.

4.2.1 Official data for forecasting

There have been positive predictions for the supply of second-life EVBs based on forecasting demand of EVs in the coming years. The capacity of second-life EVBs is predicted by Drabik and Rizos (2018) to double every five years with 46,540 MWh in 2030 to 103,844 MWh in 2035, and to reach 215,200 in 2040. A report by the U.S. Department of Energy (2020) presents a higher volume of repurposed EVBs of 145 GWh in a 2030 scenario in which batteries for EVs would account for 78% of total 2.5 TWh lithium batteries. However, it can be seen that there is a big difference in the forecasted volume of second-life EVB capacity. This could be explained by the rapid development of technical innovation of EVBs as well as market growth of EVs and EVBs. In addition, the EVB market is still a nascent market which is not able to provide sufficient historical record for future supply projections. According to Circular Energy Storage (2021), there is no credible calculator modeling and/or available official data for a precise estimation of EVBs' end of first life. All forecasts of the volume of second-life EVBs are estimated based on predicted scenarios.

4.2.2 Time and place of EVBs end-of-first-life

The literature reviewed also emphasizes that new EVB models have significantly longer lifetimes, thus, the volumes that will reach the end of first life will grow slower than the volumes placed on the market. In addition, global manufacturing, the business activities of trading and exporting EVs and EVBs over their lifetime will affect the supply of second-life EVBs - when and where batteries will be available for repurposing (Circular Energy Storage, 2021). Collection and transportation of spent EVBs across countries is possible, yet the returning quantities might be considered so low that it may not make financial sense due to the lack of economies of scale as well as there are challenges in cost and regulation which will be discussed later in forthcoming sections.

4.2.3 Effects of complement goods

Since the supply forecast for second-life EVBs directly relies on how much battery capacity is placed on the market for the first-life purpose and is indirectly influenced by other complement goods such as EV sales, automobile widget and appliance market, etc., a single initiative or event may lead to a proportionally high impact. For example, a sudden increase in the adoption of electric buses in China had surprised the world when about 340 electric buses were registered every day in 2016, from almost zero in previous years, and until 2017 more than 100,000 electric buses had been recorded (Ayre, 2017; Sustainable Bus, 2019). Another example is the shortage of microchips in the experienced in 2021, forcing the automotive industry to cut production which indirectly affects the number of EVBs and EVs placed on the market (Ferris, 2021). With such surprising events, the forecasted supply of spent EVBs may be no longer be valid in the new scenario and could remain unpredictably volatile.

4.3 Transportation of used EVBs

The most common mode to transport and distribute EVBs is via road transport, which follows the European Agreement concerning the international carriage of dangerous goods by road (ADR) (UNECE, 2020; Albertsen, 2020). EVBs have to be classified as new, waste or damaged in order to have corresponding packaging and transportation methods (Albertsen, 2020). The interviews revealed different thoughts and conclusions related to the transportation of used EVBs. Transport distinctively depends on how used EVBs are categorized at the end of their first life. According to respondent 7, it is up to automotive manufacturers to determine whether their battery is considered waste or not and depending on that, they have to abide to stricter rules regarding transportation. Besides, regarding transportation fees, he also highlighted that if companies try to pass damaged batteries as products, they have to pay an incorrect-declaration extra added cost, which would be much higher than the original cost for transporting such damaged batteries. On the other hand, based on respondent 6's experience of working in different business firms, used EVBs can be disassembled and then transported under the condition of new EVBs and this should not be an obstacle. In contrast, Olsson et. al. (2018) see transport as a troublesome issue because used EVBs are considered as hazardous waste. It means that the transportation of used EVBs will be stricter and regulated under the Basel Convention; for example, air freight is not allowed, or some logistics firms will not transport used EVBs. In addition, hazardous waste will also be more costly than normal waste (Olsson et. al., 2018). Thus, respondent 7 concludes that transporting used EVBs is "still a grey area and very much varies from one manufacturer to another, which makes certification, logistics and contracting more difficult than for first-life producers".

4.4 Uncertain profitability due to conversion cost

In the context of this study, conversion cost is defined as the costs of transforming used EVBs to second-life EVBs in other applications, including building a new BMS, testing, and remanufacturing EVBs. Respondent 4 has given two simple cases for the conversion costs of repurposing EVBs.

4.4.1 Costs when no testing or major remanufacturing required

The first one is repurposing the complete battery pack. In this case, the conversion cost is very small and limited. As a repurposer, the company will take the whole battery packs, the BMS, and the cooling system from the OEM, incorporate a master BMS and then use it for stationary energy storage. Figure 4-1 shows an example of complete battery packs from Volvo Bus that were repurposed by Batteryloop. This can be seen as the most cost-effective solution for repurposing EVBs. (Respondent 4)

Figure 4-1. a BLESS – BatteryLoop Energy Storage System with repurposed battery pack and cooling system

Source: BatterLoop (n.d.)

4.4.2 Costs when full testing and rebuilding battery pack is required

The second case follows the process of collecting, dismantling, analyzing, and rebuilding. Testing used batteries and building a new BMS will result in higher prices per kWh of second-life EVBs. The cost of the testing process of used EVBs accounts for the majority of the price of a second-life EVB because it requires intensive labor and time for collecting, disassembling, grading, and reassembling EVBs (Niese et. al., 2020; Circular Energy Storage 3, 2020). In addition, research, development, implementation of a new BMS, as well as operation and maintenance requirements of repurposed EVBs also significantly contribute to higher costs (Bräuer, 2017; Olsson et. al., 2018). This is unlike to new EVBs, of which the quality of a whole batch can be graded by randomly choosing a number of EVBs within the batch to test. The results of such evaluated EVB samples are then considered to be relevant for the whole batch. For spent EVBs, same-type EVBs will result in different conditions depending on their previous application and user habits (Olsson et. al., 2018; Hossain et. al., 2019). Hence, if not fully informed by OEMs, every single EVB needs to be tested in order to know its condition and to decide how to be processed further. This significant and high cost of testing and processing spent EVBs is seen as the most significant challenge from the repurposers' business perspective.

All the respondents 2, 3, 4, 5 share the same experience as other authors have already shown earlier. In addition, respondent 4 even accentuates that this approach of repurposing EVBs would be too expensive in the EU, meaning that eventually the cost will be too high to be able to reach the needed target cost for the second-life battery. Hence, respondent 4, one more time, emphasizes the important of collaboration, he said "from the sustainability perspective, reusing and repurposing is the wining, but in order to make it cost it effective, we have to be very close to the one who building the battery". Respondent 2, 3, 5, 6, 7 share the same point of view that under the cooperation, repurposing EVBs would be more feasible as repurposers are able to access the original BMS and EVB's historical operation data. This will not only reduce cost per kWh of second-life EVBs but also optimize the use of second-life EVBs.

4.4.3 Second-life EVB cost versus new EVB cost

Even though the decline in prices of new EVBs can lead to a decrease of the second-life EVB's input price, it does not mean that the final price of second-life EVBs will drop accordingly. The cost of repurposed EVBs fluctuates in a wide range, depending on the access level to the system data and the original BMS, as well as the bidding price for used EVBs (Niese et. al., 2020). Based on recent studies, second-life EVB prices could vary from USD 18 to USD 1,183 per kWh, while new EVBs prices have dropped by 89% since 2010 to the average price of USD 137 per kWh in 2020 (Circular Energy Storage, 2020c) or are now even as low as USD 100 per kWh (Albertsen, 2020).

From the management perspective, profitability is a priority and one of the most decisive aspects influencing the feasible operation of an EVB repurposing business model. According to Niese et. al. (2020), the price for second-life EVBs should not be more than 60% of the new EVB price in order to be accepted and considered profitable. Besides, technology innovation and performance improvements have made repurposed EVBs less competitive and cost-effective compared to new ones (Bräuer et al., 2017; Martinez-Laserna et al., 2018; Yang et al., 2020). While respondents 2, 3, 4 and 5 have similar thoughts with these authors, respondent 7 raises a different opinion. He disagreed that "improvements in first life would mean that first life prices would come close to second-life prices" because their study shows that "as more and more batteries get to the end of their first-life, the economies of scale allow us to stay competitive with the first-life market". To conclude, prices and volumes are critical and inseparable elements when evaluating the cost-efficiency and competitiveness between new and second-life EVBs.

4.5 The competition from the recycling business model

Repurposing EVBs may face competition with other circularity strategies, especially recycling (Olsson et. al., 2018). There has been an ongoing discussion whether EVBs should undergo repurposing or recycling at the end of their first life. The rationale of why recycling of used EVBs would directly be better than repurposing is that the fast growth of the EV market would lead to higher demand for raw materials, particularly scarce ones like cobalt or lithium (Olsson et. al., 2018). Recycling would bring back EVB materials to be circulated and used in new EVBs, thereby supporting the material supply for OEMs (Yang et al., 2020). Extending an EVBs' life would delay this material flow (Bobba et al., 2019). Some companies, such as Tesla - one of the world's major EVB producers - and Northvolt – the biggest lithium battery producer in Sweden - would neglect the repurposing approach and choose to directly recycle their EVBs. Tesla Inc has a recycling approach with 60% of the battery pack being recycled, and only 10% being reused (Forfar, 2018). Circular Energy Storage (2021) predicted that with the current growth of EVs and stationary energy storage demand, there would be pressure on raw materials supply over the next 20 years and beyond, which forces stakeholders in the value chain to get the materials back to the value chain. Respondents 1 and 4 also comment from the perspective of EVB OEMs that some part of the society believes that repurposing will keep the material away from recycling, and that material should come back to production as quickly as possible. Respondent 2 somewhat agrees with this argument but claims that there are not enough end-of-life EVBs in the current reality. He highlighted that firms, who are now operating in the recycling business, heavily depend on financial investment because there is "not enough battery to support the business running". Respondent 5 added a contrasting point but has a similar conclusion of supporting repurposing EVB. According to him, the current recycling infrastructure has not been sufficient yet to handle the current amount of incoming discarded EVBs. And because of that, repurposing is the initial answer for used EVBs and then they can enter the recycling cycle. In the future, when the recycling system is ready and also the volume of used batteries is large enough, the repurposing and recycling models should not be in conflict but rather support and reinforce each other. To conclude, it is difficult to say which approach is better than the other, it depends on the context and the company's strategy, and no matter which one is chosen, there will always be a tradeoff.

5 Discussion

There are various challenges that companies have to face if they want to repurpose EVBs, from technical issues, uncertainties in battery supply, transportation, and financial feasibility, as well as competition from the recycling sector. However, repurposing EVBs is still an attractive business with environmental benefits and promising profitability that it may create. Suitable approaches may help to address those challenges so that companies could be able to scale-up their second-life EVB project to a business. This chapter will discuss potential solutions to address the reviewed obstacles, thereby offering a response to Research question 2 of this thesis. While collaboration along the value chain is introduced as a key solution, the new EU regulation proposal is presented as an advanced regulatory approach to not only reinforce stakeholder collaboration but also to reorient the EVB industry towards a more circular economy.

5.1 Overview of the findings

5.1.1 Collaboration along the value chain as a key approach

Even though there are challenges, it can be seen that interest in the repurposed EVB market has been growing. BatteryLoop, Connected Energy, and SNAM are notable examples of successfully scaling up repurposing second-life EVB pilot and experiment projects towards commercial businesses. It is noticeable that these companies have tight cooperation with their OEM partners: BatteryLoop with Volvo Bus, Connected Energy with Renault, and SNAM with Honda. Furthermore, collaboration among stakeholders in the value chain is also the key solution brought up several times by different interviewees. Olsson et. al. (2018) also pointed out why and how collaboration can help to deal with the challenges as discussed above. Firstly, as EVBs are naturally designed only for their first-life optimization, a collaboration between stakeholders on BMS, such as OEMs and repurposers, will make a second-life EVB conversion less costly and add more value. Secondly, information transparency will facilitate repurposers to have more precise supply forecasts of used EVBs, both in regard to the expected volumes and in terms of the chemical composition. And thirdly, uninterrupted communication will help clarifying the responsibilities of stakeholders across different stages of the EVB life cycle. This can support the circular flow of EVBs from cradle to cradle and thereby reduce the risk of prematurely discarding EVBs.

The collaboration contract will determine what and how two companies would share information and BMS control. For example, by contracting with Volvo Bus, BatteryLoop has been able to convert EVBs to stationary energy storage, both (1) with the whole battery pack and its cooling and BMS system and (2) by rebuilding it into a new stationary energy storage unit as per customers' specifications. It is a similar situation for SNAM as they contract and work in full cooperation with Honda on sharing data, as well as evaluating and repurposing EVBs. In fact, there is hidden cooperation between OEMs and repurposers, which have not been published or could not be shared at the moment due to business confidentiality. One of the interviewees also shared that no major operator in the battery value chain in the EU are outside of this business, and repurposers do not limit their collaboration to the automotive industry only.

Another idea of value chain collaboration raised by Niese et. al. (2020) is building an exchange platform where information about EVBs can be shared across the value chain. This is similar to the New Battery Regulation Proposal which will be discussed in more detail in the next section.

5.1.2 Performance uncertainty and environmental benefits of repurposed EVBs

Performance uncertainty is one of the challenges brought up in literature but not has not been discussed by interviewees. From the author's point of view, the quality uncertainty can happen for both new and spent EVBs. For example, there is a case shared by an interviewee that a considerable number of new faulty EVBs were sent to recycling by an OEM, although those batteries were still sufficient for stationary energy storage systems. However, the risk here is that if there are quality problems with new EVBs, end-users can request to change to the same EVB model with a guaranteed quality standard while on the other hand the supply of second-life EVBs is unstable as discussed previously.

Environmental issues have not been emphasized by interviewees. In literature as well as from all of the interviewees, repurposing itself is a circular economy business model without doubt of its positive environmental contribution. However, such environmental benefits created by repurposing EBV, such as carbon footprint reduction, need to be carefully calculated and evaluated for specific cases and contexts in order to conclude if repurposing EVBs would truly be more desirable than using new EVBs or applying other business models. For example, the carbon footprint added from transporting and repurposing second-life EVBs may surpass the carbon footprint cut down from production, just like financial aspects where repurposing cost could potentially be higher than the cost for new EVBs.

5.2 The role of new EU battery regulation proposal

The overview of the milestones of the new batteries regulation proposal introduced in Chapter 2 shows that the proposal is expected to initially support and encourage second-live EVBs, and especially repurposing. In a long-term perspective, it aims to boost the recycling of EVBs, and orient the EVBs industry to become circular. In the proposal, various provisions directly or indirectly seek to enable a market for second-life EVBs. These are:

- Obliging OEMs to grant access to BMS and data for the purpose of evaluating quality of used EVBs.
- Reclassifying discarded EVBs from being classified as waste towards being classified into a product category if they meet the SOH testing requirement, and are repurposed or remanufactured to be used in other applications such as stationary energy storage (European Commission, 2020d; Melin, 2020; Tedesco 2021).
- Requesting battery passports which carry reported data of the whole EVB's life. The combination of a battery passport and an exchange platform is expected to create data transparency on EVB's design, materials, carbon footprint, recyclability and performance in order to ensure information is available at the right time and place. In addition, battery passports could help to clarify producers' responsibility informing about the carbon footprint and obligate stakeholders to keep their carbon footprint under any regulated carbon footprint declaration and thresholds.

As requirements for carbon footprint become tighter, the requirements for recycled content, 65% in 2025 and 70% in 2030, comes into force later. As the requirement for information sharing takes effect, it can encourage repurposing businesses to lengthen the EVB's life in order to alleviate GHG emissions which mostly occurs in the production process (European Commission, 2020d; Melin, 2020; Tedesco 2021).

There is an optimistic attitude from interviewees towards the new battery regulation having a considerable impact on the future of second-life batteries markets. It is believed that once the new EU regulation is issued, it will have positive effects on the repurposing business and standardizing cooperation behavior. However, the requirements of Art. 59 related to the repurposing and remanufacturing of industrial batteries and electric-vehicle batteries is small compared to the stipulations on information gathering on first life battery. Besides, it is necessary to develop a general standard framework for second-life batteries regarding evaluation criteria, testing methodology, certification, quality standards, etc. Nevertheless, the standard criteria and credited testing methods need to be developed and adopted widely for better EVB judgment and evaluation.

A data pool or exchange platform seems to be an appropriate idea for sharing information. As needed information is ensured to be shared along the value chain, transaction cost, including time and effort for case-by-case negotiation related to data sharing can be reduced. Besides, it seems to level the playing field when all OEMs are compelled to share the information and data, or further, to grant BMS access for the greater purpose of transforming the battery industry towards a circular economy. However, presently this is subject to objections from OEMs as such requirements could damage the company's advantages and reveal business secrets. Hence, the question remains of how to ensure data sharing within certain security levels, in order to serve and encourage the circular economy of EVBs without disclosing confidential trade secrets. On the other hand, there are OEMs who are already ahead of the game, even before the new battery regulation is fully adopted like Volvo Bus, Renault, or Honda. It is possible that early movers will be able to gain competitive advantage from taking early steps.

Although in the long-term, all EVBs should be sent to recycling, in the short-term, the trade-off negotiation between recycling and repurposing EVBs will still continue. The New Battery Regulation Proposal’s milestone is reasonably planned by first encouraging and supporting second-life batteries to create buffer time for EVB recycling infrastructure to be ready to handle.

5.3 Methodological reflection

In this thesis, only a relatively small number of interviews could be conducted, and therefore perspectives about the challenges of repurposing EVBs from certain stakeholders of the EVB value chain are lacking. Specifically, only two interviewees are from research institutes, while four out of in total seven interviewees are from EVB repurposing businesses, and only one from an OEM. Besides, the research lacks the incorporation of viewpoints from second-life EVB end-users, policy makers, as well as electric vehicle and battery associations (e.g. EUROBAT - the Association of European Manufacturers of automotive, industrial and energy storage batteries; European Battery Alliance, etc.). Although the author contacted these stakeholders, they did not respond to enquire to participate in an interview.

In this thesis, different complementary information collection methods have been used such as literature review, and practitioner interviews on order to build more robust finding.

6 Conclusions

In the near future, electric vehicle battery waste will rapidly increase as a result of the growth of electrification of road transport. Hence, the approach prolonging EVB's life by repurposing and giving give it a second life has been experimented and implemented by various companies. Even though there are promising environmental benefits and potential probability, there are challenges that prevent companies to scale up their pilot project to commercial operations. This thesis reviewed current common challenges of repurposing EVBs in Europe from a management perspective by combining methodologies of literature review with insights from interviews with practitioners. Specifically, the thesis aims to answer the following two research questions:

RQ1: What are the most common challenges when repurposing EVBs?

Based on literature review and practitioner interviews, the findings indicate the most current common challenges of repurposing EVBs, which are categorized into technical aspects, unstable supply, transportation of used EVBs, uncertain profitability and the competition from the recycling business model.

There are three major issues under **technical aspects**. First, without *access to the original BMS*, repurposers have to build a new BMS to overwrite the original one. This approach would limit the control of the EVBs and not allow to maximize the available capacity of EVBs. However, original equipment manufacturers (OEM) have been reluctant to permit repurposers to access the original BMS because of the risk of revealing business secret. Second, in order to be repurposed and used in another application in the second life, used EVBs need to be tested by evaluating use-phase data. However, again, EVB use-phase *data sharing* solely depends on the decision of OEMs who may lose their competitive advantages by sharing such data. Third, due to lack of standard design and differences in chemical content, it is almost impossible to *match and mix different types of battery modules*. This limits the flexibility to rebuild second-hand EVBs.

Unstable supply of second-life EVBs can be explained in three main points. Since EVB market is still a nascent market and it has grown so quickly that historical data of demand and supply is not sufficient for a precise future forecast of used EVB. In addition to *the lack of official data for forecasting*, the business activities of trading and exporting EVs and EVBs over their lifetime also complicate the supply estimation of *when (time) and where (place)* EVBs will end its first life. Moreover, as second-life EVBs *are influenced by complement goods* (such as electric vehicle sales, automobile widget and appliance market, etc.), a single initiative or event may lead to a proportionally high impact.

The *lack of a clear definition for used/repurposed/ second-life EVBs* in the current Battery Directive 2006 leads to a grey area when **transporting repurposed EVBs**.

Uncertain profitability is one of the biggest concerns from the managerial perspective. This is because the uncertain and high *conversion cost* of repurposing used EVB to second-life EVBs and the *decrease of costs for new EVBs*

EVBs repurposing model may, or has already faced **a competition with EVBs recycling model** as it is argued that *repurposing EVBs will delay the flow of recycled materials* that go back to manufacturing in order to produce new EVB.

RQ2: What could be potential solutions for these challenges?

In the big picture, collaboration among stakeholders along the supply chain may help to address technical challenges, transportation ambiguity, supply uncertainty, through information and data sharing between stakeholders such as OEM and repurposers. Eventually, dealing with those challenges would help to solve economic challenges which prevent businesses from scaling up their repurposing business model for EVBs. Although stakeholder collaboration is not the sole answer, it is the key component in solving the problems.

Besides, instead of being a challenge, legislation could be seen as an influencing factor promoting repurposed EVBs. An example is the New Battery Regulation Proposal that includes through different provisions of redefining used EVBs, and requires (1) BMS access for third parties, (2) information sharing through an exchange platform, (3) a battery passport, and (4) QR code battery labels.

Recommendation for policymakers

The New Battery Regulation Proposal has important provisions to encourage the repurposing of EVBs and their use in a second-life application. The proposal redefines battery waste, requests BMS access and information sharing, and introduces a battery passport and an exchange platform. On the other hand, from the OEMs' point of view, these provisions seem to disfavor battery and EV producers. OEMs explain that there are already risks of losing a competitive advantage by sharing EVBs' SOH and even higher risks of revealing business secrets by providing access to the BMS for third parties. Hence, it is important for policymakers to take these opinions from different involved stakeholders into consideration in order to find a harmonized answer. An EVB's operational data collected by the BMS could either be stored in the BMS, or in most cases, be sent to the vehicle management system. Therefore, the OEM can also extract the EVB's operational data from the vehicle management system and share it with third parties without providing access to the BMS. Hence, the suggestion could be to keep the provision of information sharing requirement in the battery regulation, while accessing the BMS remains a private agreement between OEMs and their partners.

Besides, in the New Battery Regulation Proposal it needs to be clarified which data will be shared for evaluating EVBs' health and quality. In addition, the New Battery Regulation Proposal requests to enable information flow across different channels, including a battery passport, an exchange platform, a battery label and a QR code. This may cause bureaucracy and excessive, overlapping reporting. Hence, a one-stop information point where information is classified and controlled which information will be shared to whom for what purpose could be a less bureaucratic solution.

Suggestion for future research

The New Battery Regulation Proposal was published in December 2020 with stipulations on repurposing EVBs which have not been seen in legislations before. Therefore, not much research has been done about it yet. Thus, it could be worthwhile to investigate how the new battery regulation will impact the businesses and the behaviour of stakeholders within the EVB value chain, as well as the whole second-life EVB market in coming years. There is a good overview of different repurposing EVBs pilot projects, however, the analysis of these pilot projects is beyond the scope of this thesis. Hence, one can research these projects further and in in-depth detail.

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Appendix 1: Synthesis matrix

Topic/ Article	**Article 1**	**Article 2**	**Article 3**	**Article 4**	**Article 5, etc.**
EVB (general info)					
State of health					
State of charge					
State of power					
State of energy					
Battery Management system					
Repurposing business model					
Second-life applications					
Financial challenges					
Technical challenges					
Logistics challenges					
Operation challenges					
Other challenges					
Regulation barrier					

Appendix 2: List of interviewees

<table>
<tr><th>No.</th><th>Company</th><th>Representative</th><th>Position</th><th>Type of company</th><th>Date</th><th>Time</th><th>Mean</th></tr>
<tr><td>1</td><td>IVL Swedish Environmental Institute.
Sustainable Consumption and Resource Flows Group</td><td>Alexandra Wu</td><td>Project Manager</td><td>Research Institute</td><td>11.03</td><td>00:30</td><td>Online</td></tr>
<tr><td>2</td><td>Nobina Europe AB</td><td>Maher Kasskawo</td><td>E-mobility Specialist</td><td>EV & EVB OEM</td><td>25.03</td><td>00:45</td><td>Phone call</td></tr>
<tr><td rowspan="2">3</td><td>ReVolta</td><td rowspan="2">Aimilios Orfanos</td><td rowspan="2">Co-founder</td><td>Energy management service</td><td rowspan="2">08.04</td><td rowspan="2">01:00</td><td rowspan="2">Online</td></tr>
<tr><td>Watt 4Ever</td><td>EVB Repurposer</td></tr>
<tr><td>4</td><td>Batteryloop</td><td>Rasmus Bergström</td><td>Executive Director Product Development & CEO</td><td>EVB Repurposer</td><td>13.04</td><td>00:40</td><td>Phone call</td></tr>
<tr><td rowspan="2">5</td><td>Council on Energy, Environment and Water</td><td rowspan="2">Ashish Guhan Baskar</td><td>Technical Consultant</td><td>Government</td><td rowspan="2">27.04</td><td rowspan="2">01:10</td><td rowspan="2">Online</td></tr>
<tr><td>Second-life EVB Pilot Project</td><td>Entreprenur</td><td>EVB Repurposer</td></tr>
<tr><td>6</td><td>French Alternative Energies & Atomic Energy Commission (CEA)</td><td>Elisabeth Lemaire</td><td>(Researcher)</td><td>Research Institute</td><td>05.05</td><td>01:00</td><td>Online</td></tr>
<tr><td>7</td><td>SNAM</td><td>Nicolas Perdriaux</td><td>Projects Economic Assistant</td><td>EVB Repurposer</td><td>19.05</td><td>-</td><td>Email</td></tr>
</table>

Appendix 3: Question list for email exchange

1. How do you position SNAM in the circular battery value chain?

2. Since SNAM signed the contract with Honda as an OEM, are you able to:

- Access to the OEM's Battery Management System (in order to control BMS partly or fully)?
- Receive sufficient information of the batteries' state of health from the OEM in order to make a decision if the batteries will be sent to recycling or repurposing?
- Or do you have to do all the assessments yourself? - if so, what is the approximate cost of making this assessment/tests in % of the total cost of repurposing used batteries?
- Who is the owner of the repurposed battery? (Honda, SNAM, end-customer using repurposed EVB…)

3. Who are your battery suppliers besides Honda EU?

4. From the collaboration video (link), SNAM and Honda will collect Honda's batteries from most of the EU countries and transport them to France.

- What are the reasons why some countries are not included (for example Sweden, Finland…)?
- How are used batteries categorized for trading and transportation? (waste, materials, products…?) - Do you face any challenges in this stage?

5. Can you provide more information on the second-life battery projects? (I tried to google but so far can only find the cooperation announcement). What are the key challenges in implementing such kind of project(s)?

6. What is your view on the future development of the second-life battery market? (since the battery technology is changing so fast, bigger capacity, higher efficiency with lower cost, and also the idea of recycling instead of repurposing?

7. What is your view on the future development of the second-life battery market? (since the battery technology is changing so fast, bigger capacity, higher efficiency with lower cost, and also the idea of recycling instead of repurposing?