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Exploring Circular BESS for the Commercial and Industrial Sector

A customer-centric perspective

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Abstract

In recent years, battery energy storage systems (BESS) have gained prominence as a key technology enabling much needed electricity grid flexibility while simultaneously providing distinct value to its end-users. With the anticipated increase of residual value holding used batteries from mobility applications entering the market, more and more companies are looking to construct BESS offers around these second-life batteries in an attempt to unlock the potential of circular business offers. Aiming to add knowledge that supports the development of more circular BESS offers, this thesis takes a three-step approach exploring what constitutes a feasible circular BESS offer and how digital tools can be used to enable respective customer journeys. In an initial step, current circularity practices applied from active BESS suppliers were mapped, reviewing current BESS offers and comparing them to a circularity strategy framework. A second step comprised the mapping of customer preferences towards a hypothetical more circular BESS offer through interviews, followed by a process of mapping digital technologies that enable respective customer journeys. It was found that BESS suppliers, irrespective of their focus on circularity, provide a high degree of servitisation. Customer interviews highlighted the importance of third-party actors in delivering circular BESS offers. Companies should concentrate on offering product-centric product service systems (PSSs) as customers are largely not ready for business models altering traditional ownership structures. Moreover, governmental funding mechanisms are not adapted to support use-centric PSSs. Establishing local presence through collaborations with third party actors is expected to yield significant advantages for establishing customer relationships and interfaces to these partners along a high performing energy management system, the controlling and optimisation unit of the BESS, are essential enablers of the respective customer journeys. Given the far reaching servitisation degree of linear BESS offers, customer journeys of circular ones were found to not differentiate much from the linear ones. Practitioners should focus on using second-life batteries, providing narrowing and slowing services along clear contractual relationships that enable reverse logistics and therefore closing the resource loop in the end-of-life stage to reap the benefits of circular offers. Further research is needed to investigate hindering factors that foster scepticism towards use-centric PSSs and to develop adequate government support mechanisms to encourage such business models.

Keywords: BESS, Circular Economy, Circularity strategies, Customer journey, Digital enabler

Executive Summary

Background

Under the current paradigm of the European energy transition, the electricity grid is going through a phase of change that is aimed at increasing the share of electricity from renewable sources in the grid. To enable such a transition, increased grid flexibility is needed to cope with the intermittent nature of the renewable energy sources. Holding distinct features that enable increased flexibility, battery energy storage systems (BESS) are gaining prominence. Simultaneously, the electrification of the mobility sector is progressing and with it the expected volume of residual value holding lithium-ion (Li-ion) batteries returning to original equipment manufacturers (OEMs) of the mobility sector. These returning batteries create opportunities for the development of second-life BESS and companies are exploring opportunities to develop circular solutions to tap the potential of circular business offers. Such offers have the potential to provide value towards all three dimensions of the sustainability triple bottom line. While reuse has been explored as a recommended practice to increase the circularity of Li-ion batteries, research exploring circularity on the product level of BESS is largely missing. As such, customer perspectives and the role of digital tools beyond the technically necessary ones are lacking, hindering the development of more circular BESS solutions. This thesis focuses on the commercial and industrial (C&I) sector as a potential customer group given the anticipated importance of electrification for this group, the challenging technical and contractual requirements arising from the combination of front-of-the-meter and behind-the-meter activities typically required by C&I systems, the market potential of the customer group and the lack of knowledge about it.

Research aim and approach

This thesis aims to provide knowledge to support practitioners in their approach to develop more circular BESS solutions. To contribute to this aim, the following research questions (RQs) have been explored:

1. *What constitutes a feasible circular BESS offer to the European commercial and industrial sector?*

2. *How can digital tools be used to enable a feasible customer journey for a circular BESS offer to the commercial and industrial sector in Europe?*

To answer these research questions, three tasks have been developed. The first task is concerned with mapping circularity strategies applied by current BESS suppliers and comparing their practices with theory on circularity strategies. The second task consists of mapping the life cycle of a hypothetical circular BESS offer and takes a customer-centric approach to the development. As part of the Service Engineering Method (SEEM), the method chosen as a framework, customer personas, the respective customer journeys and a service blueprint have been developed. The third task, the mapping of digital enablers needed to facilitate the customer journey, builds directly on the second tasks and complements the methodological steps chosen to answer the research questions. While the conduct of the first task builds on the analysis of company material mainly, tasks two and three are predominantly informed by interviews with existing BESS customers, third-party experts, and existing second-life BESS suppliers.

Findings

The analysis of 25 different BESS market offers highlighted that most BESS solutions are currently offered as part of product-centric product service systems (PSS) with a high degree of service provision. In order to improve the circularity performance of an offer, it has been found feasible to combine multiple circularity-enhancing strategies. The analysis showed that the

different offers of fist-life and second-life BESS suppliers, who often promote their offers as "circular" or "sustainable", were often so similar, that they only differed in the utilisation of second-life batteries. Modularity, scalability and flexibility were the descriptors most commonly used in the offers of the different players.

Meanwhile three different customer personas for the C&I sector were mapped. The customers differentiated in their motivation to engage with BESS and therefore also the applications desired and operated. The personas differentiated with regards to electricity consumption, the importance of consumption peaks, availability of funding, their attitude towards large unproven enterprises as new market entrants and system suppliers, as well as their stated preference towards sustainability aspects of an offer. This impacted their preference towards system characteristics which can be addressed in the marketing stage, and nuances in their customer journeys calling for individualised solution planning and delivery. However, the most significant differences in their journeys occurred depending on the third-party actors involved in the value delivery. The collaboration with third-party actors has proven viable to increase credibility, gain access to customers and better perform on circularity strategies based on increased specialisation within service delivery.

The enabler mapping confirmed the preconceived relevance of digital tools for the delivery of services and therefore the enabling of the customer journey. The energy management system (EMS) proved to be of special importance due to customers' demand for real-time access to battery performance data and the need for the provision of interfaces to third-party actors. Beyond the EMS, a collection tool for customer specific data should be used to enable customisation and correct sizing of the project in the planning stages, and customised approaches towards information sharing and communication proved important to customers.

Conclusions

RQ1: What constitutes a feasible circular BESS offer to the European C&I sector?

In line with the logic of the circularity metrics used to evaluate circular products, circular BESS was defined as BESS that contributes to the principles of the circular economy. Rather than one universal solution, multiple approaches for creating such circular BESS offers have been identified. The different circularity strategies facilitating these approaches were found to be stackable, increasing the circularity of the offer and addressing new impact areas. Despite the context specific nature of circularity design, four essential constituents of circular BESS have been identified: circular sourcing of material and components, product design that follows the circularity principles and enables the services offered, a high degree of servitisation as well as the facilitation of clear contractual agreements to facilitate reverse logistics in all instances.

Reuse and repurposing strategies were identified as the most widely applied circular sourcing strategies and respective decisions should be accompanied by environmental assessments to avoid rebound effects. Given the significance of its impact against all three dimensions of the sustainability triple bottom line, a special, but not sole, focus during the selection of components should be put on the battery. Examples for reused components include the casing of the BESS, and parts of the battery management system.

Product design has the potential to impact all five impact categories, narrowing, slowing, closing, inform and regenerate and should be conducted on the product and service level simultaneously. Sufficient sizing, adaptability, modular design enabling easy disassembly and high-quality components enabling the service provision were identified as key constituents of circular BESS.

Through the provision of additional services, narrowing and slowing strategies can be facilitated. Essential services include utility maximisation through application stacking, operational optimisation towards longevity of the system as well as remote monitoring at the cell level and the facilitation of maintenance.

Lastly, the contractual facilitation of reverse logistics enabling recycling of the technical components of BESS is enabled. Use-centric product service systems have been identified as well-suited business models contributing multiple values and shift ownership structures to enable the respective end-of-life control of the BESS supplier. To confirm the feasibility of the circular strategies, preferences of customers have been analysed. While the suggested circularity strategies impacting product and services were met with acceptance by customers, who largely considered more sustainable product offers as desirable, it was especially business models with altered ownership structures that were not accepted by them. Suppliers should accordingly focus on the provision of product-centric product service systems to ensure uptake of the offers.

RQ2: How can digital tools be used to enable a feasible customer journey for a circular BESS offer to the C&I sector in Europe?

Digital tools were identified as essential components on different levels of the offer. They proved to be essential at both the product level, where they facilitate functionality and service delivery, and along the customer journey, where they enable the smooth execution of the customer journey.

On the product level, sensors monitoring battery performance on the cell level, the connected battery management system (BMS), and the EMS were identified as key enabling technologies that should be focused on to enhance the circularity performance of the BESS. On the level of the customer journey, each touchpoint was found to require distinct technical solutions, ranging from contact channels to process management tools and the aforementioned EMS, which requires specifications to meet customer expectations. To facilitate operation and integration of the BESS controller into the system of third-party experts, such as aggregators or BMS operators standardized interfaces should be implemented. Beyond that, a customer demand for customised information sharing with regards to frequency and content has been identified. Besides an EMS customer portal that delivers real time performance information of the BESS, customised performance reports are expected to be send regularly. Challenges arise from the identified lack of standardisation in BMS and EMS communication protocols which hinders system integration.

Many of the steps and tools required to realise the customer journey were found to be identical with standard sales processes and focus on internal process logistics. The tools that stand out as enablers for the customer journey of the circular BESS are the customer information sheet, the EMS, the BESS controller, the EMS customer interface, and the respective third-party interfaces.

Recommendations to BESS developers:

1. **Be ambitious with the application and stacking of circularity strategies.**

2. **Avoid use-centric business models but seek to adopt their benefits in product-centric systems.**

3. **Engage with third-party experts to improve credibility and access to customers.**

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Abbreviations

BESS: Battery Energy Storage System

BMS: Battery Management System

C&I: Commercial and Industrial

CapEx: Capital Expenditures

EOL: End-of-life

EU: European Union

EMS: Energy Management System

LCO: Lithium Cobalt

LFP: Lithium Iron Phosphate

Li-ion: Lithium-Ion

LMO: Lithium Manganese Oxide

NCA: Lithium Nickel-Cobalt-Aluminium Oxide

NMC: Lithium Nickel-Manganese-Cobalt Oxide

OEM: Original Equipment Manufacturer

OpEx: Operational Expenditures

PSS: Product-Service-System

RES: Renewable Energy Source

RQ: Research Question

SOH: State of health

1 Introduction

At COP27, in November of 2022, António Guterres stressed that "the red line we must not cross is the line that takes our planet over the 1.5-degree temperature limit" – once more highlighting the urgency of fighting climate change (United Nations, 2022). While the issue of climate change has been part of the political debate at least since the formation of the Intergovernmental Panel on Climate Change (IPCC) in 1988 (IPCC, n.d.), the urgency of the matter keeps rising as the prospects of achieving a climate resilient development are increasingly limited (Pörtner et al., 2022). In its 2022 report, the IPCC recommends investments, engagement and capacity building from all sectors to enable resilient development (Pörtner et al., 2022). Decarbonisation, as a key mitigation activity and measure to enable decarbonisation, is at the heart of the demanded actions. Rapid progress and exploration of respective initiatives is needed to stay within the described limit, highlighting the relevance of this research project.

At the level of the European Union (EU), the policy direction for future industrial development is clear as the EU stipulated the ambitious goal of a complete decarbonisation until the year 2050. This goal is at the heart of the EU Green Deal and reflects the Union's commitments to the Paris Agreement (European Commission, n.d.-a). In order to achieve this goal, electrification has been identified as "the key enabler in delivering a robust European Green Deal" (Vattel, n.d.). While electrification of processes and industries formerly powered with fossil fuels is a prerequisite for a carbon neutral future, its practical realisation comes with challenges. At least two of these challenges have major implications on the preconditions for Battery Energy Storage Systems (BESS), the main subject of this thesis.

First, with electrification being advanced in all industrial sectors, the EU's demand for electricity is projected to increase by up to 50% by the year 2050 (Goldman Sachs, n.d.). The EU intends to meet this demand by significantly increasing the electricity production from renewable energy sources (European Council, 2022b). These renewable energy sources – like wind, sunlight, or waves - are intermittent energy sources, meaning that they are not constantly available with predictable intensity as their availability is impacted by natural forces. This intermittent nature creates temporary fluctuations in supply. Enabling the uptake of renewable energy sources, the electricity gird must therefore be somewhat flexible in order to compensate for these fluctuations (Brouwer et al., 2014). Energy storage plays a key role in the electricity grid of the future, providing the needed flexibility (Mohler & Sowder, 2017). With their rapid response times and their stackable capacity, batteries possess unique features that play an important role in compensating electricity fluctuations of the grid.

Second, among the sectors electrifying is the transport sector. With 27% of all emissions generated within the EU in 2017 stemming from this sector, its impact on the Union's carbon footprint is significant (EEA, n.d.). The sector is under pressure as the "Fit for 55" road map, developed to guide the sectoral emission reduction activities in line with the European Climate Law, stipulate a 90% emission reduction from the transportation sector by 2050 (EEA, 2022). First policy instruments are currently being installed to regulate the manufacturers' activities and align them with the imposed goal. One example for this is the provisional agreement that has been reached on the EU level to reduce the average emission level for newly sold cars in the EU by 55% compared to the average emission level between July 2019 and June 2020 in the EU by the year 2030 and to ban the sale of new combustion engine cars from 2035 on (European Council, 2022a). Similarly, from 2025 on, manufacturers will have to reduce their fleetwide CO2 emissions on newly registered lorries by 15% compared to the EU wide average between July 2019 and June 2020 with minimum requirements doubling in 2030 (European Commission, 2019). Electrification of their fleets in all sectors, passenger transportation but also goods transportation and vehicles for the construction industry, is the key path manufacturers are taking to respond to these policies (Mercedes-Benz Group, n.d.; Toyota Europe, n.d.; Volkswagen, 2021; Volvo Group, 2022).

Research confirms that the electrification journey manufacturers are pursuing is capable of reducing the greenhouse gas emissions of the transportation sector - and that not just of the end-of-pipe emissions, which the EU focusses on with its policies, but that of life cycle emissions (Booto et al., 2021; Yang et al., 2018) depending on the respective electricity mix of the region. Beyond the potential GHG savings, literature also shows that electrification of the transportation sector minimises the pollution of vehicles beyond greenhouse gas emissions. As combustion engines contribute greatly to the release of particulate matter and other air pollutants such as nitrogen oxides, the electrification of the transport sector is not solely a matter of climate change mitigation, but one that also aids the mitigation of health risks (Brunekreef et al., 1997; Ramirez-Ibarra & Saphores, 2023). This reduction of health risks has been on the agenda of the EU for a long time and the dual impact reduction delivered through electrification can therefore be considered as a great success and a positive development.

Projections made by the International Energy Agency (2022) estimate that the global sales of electric vehicles (EVs) will reach between 30 and 65 million per year by the year 2030, depending on the respective policy developments. With a yearly sales volume of 6.6 million EVs in 2021 (International Energy Agency, 2022), that increase is predicted to be significant. As each EV depends on a battery pack for energy storage and powering of the vehicle, that number also indicates that the demand for batteries will continue to increase exponentially. While the global demand for lithium-ion batteries, the most common battery type used in EVs to date (Fortune Business Insights, 2023), amounted around 275 GWh in 2020, it is projected to increase to around 4500 GWh in 2030 with 90% of this demand expected to come from mobility applications (McKinsey, 2022). As the operational environment and the use patterns in these mobility applications are challenging for lithium-ion batteries due to the sheer amount of incomplete charging cycles, the temperature fluctuations and the high-power charging rate, the performance of the batteries inevitably decreases over time (Zhu et al., 2021). Once the reduction in performance capacity reaches a point at which the battery is unable to satisfy the use standards of the transportation application, the battery will be exchanged.

After being replaced from their first-life EV application, batteries still hold a significant residual value that comes from the material value of the raw materials built into the batteries and their remaining performance capacity that typically lies around 80% of the original capacity (Williams & Lipman, 2011; Haram et al., 2021; Zhu et al., 2021). This form of residual value opens possibilities of additional value capture for those actors controlling the batteries at the end of their first-life application inside an EV. Given the increased demand for EVs mentioned above, the number of such batteries that have reached the end of their first-life application but still hold significant residual value will increase equally.

Repurposing is seen as an attractive strategy for dealing with these valuable batteries as it simultaneously addresses the two challenges outlined above: it opens possibilities to address the need for more flexibility in the electricity grid and maximises the value capture on the batteries before they are ultimately recycled. The most widely discussed application for such repurposing activities is stationary storage in the form of a battery energy storage system (BESS). A BESS is a large-scale battery consisting of multiple smaller battery packs that possesses the same functions as small-scale batteries, namely charging, storing, and discharging of electricity. These features allow for utilization of such systems to overcome challenges that the electricity grid and its providers face today and at the same time provide economic and resilience value to its end-users. Potential end-users in this case could range from private owners integrating such systems to their PV installations to maximise the self-consumption of their produced electricity, to commercial and industrial (C&I)

players who can implement BESS into their energy management systems to cut costs and increase their electricity resilience, to large scale investors operating the systems to provide and earn money on the provision of grid stability. C&I actors are of particular interest as the typical size of C&I systems and their location behind the electricity meter allows for applications of behind the meter optimisation and services offered to the grid simultaneously. This dual functionality raises the complexity but also the attractiveness of such offers and forces suppliers to investigate enablers for the full range of possible BESS applications. Given the expected market potential of the segment (Colthorpe, 2023; Walton, 2016; Wilson, 2018), coupled with the lack of knowledge about it, further exploration of this attractive area seems relevant.

Given the stationary nature as well as the less demanding operational environment and applications of stationary storage systems compared to mobility applications, second-life batteries can feasibly be utilized in these systems allowing for the repurposing of used batteries. Using the second-life batteries in such a system meanwhile holds multiple benefits. While the main benefits for end-users lie in lower costs and a reduced carbon intensity of the system, it is also the owners of the batteries, typically original equipment manufacturers (OEMs) of the transportation sector, who benefit from extending their batteries' life through repurposing. Reputational gains are expected to come from the company's engagement with sustainable and responsible handling of batteries and the exploration of novel business models through which the OEMs can deepen their relationships with existing customers and expand their traditional customer base. On top of that, repurposing has positive effects on the accounted carbon intensity of the batteries in their first-life phase. Furthermore, economic benefits can be achieved as the lifetime extension defers the OEMs' obligations for responsible afterlife treatment in the form of recycling, which is costly today, but expected to become profitable through a process of technological and procedural maturity as well as increased demand (Ali et al., 2021). Beyond that, the extension enables additional value capture from the already owned batteries and OEMs may even be able to leverage a competitive advantage in developing second-life BESS as they are in possession of valuable data on the batteries, potentially enabling the creation of more efficient technical solutions. Besides the previously described opportunities for the stakeholders involved, there also lies environmental value in the usage of repurposed batteries for BESS, as it decreases the demand for additional virgin batteries, that are extremely resource intensive in the production phase, to achieve the desired grid flexibility (Ahmadi et al., 2017; Hua et al., 2021).

Adopting second-life batteries as the central electricity storage medium in BESS is a practice that aligns with the principles of the Circular Economy (CE), an economic development that has been strongly demanded and pushed by academia (Hartley et al., 2020; Kobza & Schuster, 2016) and the EU through the installation of the circular economy action plan (European Commission, 2020). The concept of circularity focusses on raw material streams and aims to decouple economic growth from the extraction of raw materials. It therefore follows three main principles, namely the elimination of waste and pollution, the circulation of resources at the highest value possible and the regeneration of natural resources (Ellen MacArthur Foundation, n.d.-b). While having multiple benefits, circular practices among other things hold the potential of significantly increasing both the environmental as well as the economic performance of a product and are therefore considered as one possible strategy to increase the competitiveness of companies and their offerings. Strategies are used to operationalise the principles of the CE and can be operationalised by practitioners, referring to someone involved in a skilled job or activity (Cambridge Dictionary, 2023) on different levels to improve their company's circularity performance and unlock the potentials of the circular economy.

1.1 Problem definition

In the light of these arguments, the development of circular BESS offers is desired by the key actors of transportation OEMs, legislators and a customer group that is sensitive to price and sustainability performance. Despite the many opportunities and the expressed interest of transportation OEMs to enter the market with their own BESS offers (Volvo Energy, n.d.), the development of circular offers is progressing slowly as it faces obstacles in the form of uncertainties that are caused by knowledge gaps.

In academic literature concerned with BESS, two major research streams can currently be observed. The first research stream focusses on the optimisation of BESS aspects at a very detailed level and predominantly with a technical focus. Examples of these optimization suggestions include proposals to optimize the usage of BESS in certain applications, like peak shaving (Reihani et al., 2016), the battery lifetime (Apribowo et al., 2022; Maly & Kwan, 1995; Wu et al., 2022), choosing the right market and application for a BESS to operate in at the right time (Li et al., 2020; Maly & Kwan, 1995; Y. Zhang et al., 2019), the optimal sizing of the BESS (Bagheri-Sanjareh et al., 2020; Kerdphol et al., 2016; Mulleriyawage & Shen, 2020; Shin & Hur, 2020; Teleke et al., 2009; Wu et al., 2022) and combinations of these features. The detailed level and technical nature of these improvements, often in the form of software and optimisation logic (Amani et al., 2023; Azahra et al., 2020; Li et al., 2020; Teleke et al., 2010), has the potential to incrementally improve a BESS solution. The predominantly practical and applied nature of these proposed improvements allows practitioners to draw inspiration from these publications that can help overcome practical optimisation problems. Through these optimisation processes, the publications therefore have the potential to improve the product characteristics, which has the chance to increase the attractiveness of the offer and positively impact the marketability of the offers.

The second research stream takes a macro perspective on BESS and is concerned with the technology's impacts in real-world scenarios. Publications classified under this stream of research are primarily looking at the system's applications, impacts from BESS on the electricity grid, and the feasibility of such installations. Common for this research stream are case studies looking at impacts on renewable energy generation sites in specific geographic locations (Bastos & Trevizan, 2023; Dratsas et al., 2022; Nikolakakis et al., 2023; Pontes et al., 2023; Wongdet et al., 2023) or on other dimensions such as grid stability (Amani et al., 2023) or EV charging solutions (Filho et al., 2023). This stream of research primarily seeks to guide decision making processes of end-users and legislators and is concerned with questions of feasibility. Given the relative novelty of the technology, impact assessments and feasibility concerns have been of high interest but other aspects beyond the technical functioning and its impacts are still largely undiscovered.

The first major knowledge gap identified for this work is related to an apparent lack of focus on the sustainability dimension of BESS. Evidence of this was supported by an initial Scopus search that highlighted that only 187 articles out of all 5,427 articles concerned with BESS mention sustainability[1]. The existing literature on sustainability can also largely be grouped within the two major research flows, with some exceptions. It includes articles proposing technical improvements, such as battery lifetime extension discussed from a circularity perspective (Xie et al., 2022), it analyses the correct sizing of the system from a sustainability perspective (Prakash et al., 2022), discusses the importance of social concerns to enable stable supply chains (Koese et al., 2023), analyses the technology's impact on the sustainable development goals (Hannan, Al-Shetwi, et al., 2021) and even discusses the impact of second-life battery usage with regards to sustainability and circularity (Silvestri et al., 2022). What is perceived as both important and missing however is a cohesive understanding over what circularity means in the context of BESS. Neither a definition nor a strategic approach towards understanding what or how circularity strategies are or can be

[1] The search for all BESS articles used the following search terms: BESS AND battery. The search for sustainability related articles on BESS used the following search terms: BESS AND batter* AND sustainab*. Both searches were conducted on the 11th of April 2023.

applied to BESS was found. The knowledge on essential practices and potentials for circular development of such systems is missing.

The second research gap is concerned with customers of potential circular BESS offers. While technical aspects of BESS are extensively discussed, knowledge on the end-users of such systems, especially C&I actors, is largely missing. Industry reports section the market into different end-user profiles and while the segmentation of the market is useful, knowledge of end-users, their infrastructure and their preferences remains scarce. The lack of an end-user focus in the literature complicates the decision making process, especially for decisions on a potential business model – which would logically be formulated by an actor wishing to enter the industry. For this work, mobility OEMs will be the focus, given their important role as responsible parties and holders of batteries and their respective end-of-life treatment. Beyond that, an integration of end-user perspectives is essential for a potential product and service offer, as a disregard of future customers incorporates the risk of designing and planning a business model that does not create value or is unattractive for customers. Missing market demand would not only sabotage the implementation of a functioning business model, it would also mean that the solutions to sustainability challenges described in the introduction section would be lost, and potentially increase customers' scepticism towards BESS or circular technology offers overarchingly. This is a valid threat as for example Singhal et al. (2019) show that remanufactured technology products carry an increased performance risk, impacting the overarchingly perceived risk which in turn is negatively correlated with the purchase intention.

Literature suggests multiple approaches that are suited to overcome the increase in perceived risk. One of them is the building trust, which can be achieved by involving clients in the planning and design process and has been described as a mitigating factors in overcoming perceived risk (Mitchell, 1999). Another factor that could impact the purchase intention and outweigh the effects of the perceived increased risk is the receival of a risk premium. Risk premiums are a common phenomenon in asset pricing, especially on the stock market but the concept has also been applied to areas such as product prices in global trade (Barrot et al., 2019) or electricity prices (Viehmann, 2011). The concept builds on the assumption that investments with increased risk are less attractive than those with low risk. An additional payment, however, can increase the attractiveness of risky investments. A risk premium is therefore a payment that makes the investor indifferent between a high-risk or a risk-free investment (Duarte & Rosa, 2015). Risk premiums may therefore be suited to overcome the perceived risk among customers. Overarchingly, several authors argue that only specific customer groups would consider engaging with remanufactured products in the first place (Pearce, 2009 as cited in Linder & Williander, 2017; Mugge et al., 2017). Among those that would consider remanufactured products without prior experience with the product, Pearce (2009) mentions customers that are environmentally conscious, and price sensitive. Finding out if those customers exist for BESS and what preferences they have towards product and service delivery could benefit practitioners in their business model development efforts as well as confirming the academic theories and serve as a foundation for additional research on the topic of BESS.

A third constraint and knowledge gap in the context of circular BESS development is that the aforementioned focus on the technical aspects of a BESS offering is rather narrow, focusing mainly on the technically necessary elements of a BESS only (Chatrung, 2019; Shi et al., 2010). While important for product design, this focus neglects important aspects of the product life cycle by disregarding aspects of the sales and operational phases. While the focus on technical aspects through a digital lens is appreciated and essential to the functioning of Product Service Systems (PSSs), the narrow focus limits the applicability and draws an incomplete picture of the life cycle of BESS PSSs. Digital enablers are of high relevance for PSSs as servitisation, and digitisation are considered to be developments that go hand in hand and foster each other. Digital tools collect and analyse product and use data to improve transparency and performance of the offer

(Antikainen et al., 2018). Practically, digital tools are used to monitor and track products, to provide technical support, facilitate maintenance at the right time, optimize the product usage, upgrade the product, or manage suitable end-of-life activities correctly (Bressanelli et al., 2018a). Expanding the existing view and incorporating customer needs and infrastructure as well as organisational aspects that exceed the functional necessities into the mapping of digital tools for circular BESS holds the potential to drawing a more holistic picture of the BESS life cycle. Customer journeys hold the potential to facilitate such a holistic perspective as they map all interactions between the customer with its supplier throughout the entire life cycle of the product. In combination with customer personas, which are fictional representation of groups of people with similar needs and motivations (Fergnani, 2019), this process can be conducted for different end-user groups, considering specific demands and infrastructures, and can provide a basis for the identified lack of enabler identification beyond the technically necessary ones. Customer personas are meanwhile necessary to consider in order to avoid overgeneralisation when creating the respective customer journeys. The interplay of customer personas and journeys is proven and has been suggested for several methodologies and use cases.

Overarchingly, there is uncertainty about the character and potentials of circular BESS solutions as the sustainability dimension of the emerging technology is largely still developing. A focus can currently be observed with regards to technical improvements of BESS components, planning and operationalising as well as impact assessments and feasibility studies for different contexts. The focus of the literature is rather narrow and product-centric with perspectives on end-users and the digital infrastructure needed for the commercial offering of a BESS beyond the technical details missing. This is seen as problematic as important aspects of the systems life cycle are neglected and knowledge gaps slow down the development of the desired circular offers.

1.2 Aim and research questions

The overarching *purpose* for the conduct of this research is to contribute to the ongoing development of more circular BESS solutions for the C&I sector and enable the benefits they yield.

The problem definition provided above highlights that knowledge to support the development of new, more circular BESS solutions is lacking. Building on the identified research problem, it is therefore the *aim* of this thesis project to add knowledge on how circularity strategies are currently applied, what end-user preferences towards such circular offers are and how the usage of digital tools can enable a circular customer journey. Covering a wide range of topics, this knowledge is envisioned to create an overview over the life cycle of circular BESS offers and support practitioners in their approach to construct circular and marketable BESS solutions that directly contribute towards the emerging challenge of untapped residual value of the growing stream of batteries returning from their first-life application and the sustainability challenges connected to the development of a sustainable electricity grid.

Two research questions have been formulated to guide the research process:

RQ1: What constitutes a feasible circular BESS offer to the European C&I sector?

RQ2: How can digital tools be used to enable a feasible customer journey for a circular BESS offer to the C&I sector in Europe?

In order to address these research questions adequately, three key tasks have been defined. Each task can also be understood as a distinct research objective for the work with the tasks being linked sequentially. Therefore, the preceding task respectively provides essential insights for conducting the next.

The *first task* is concerned with mapping circularity strategies applied by current BESS suppliers and comparing their practices with theory on circularity strategies.

This task combines the theoretical knowledge on circularity and resource efficiency theories with practices from existing BESS projects in an attempt to map feasible practices that make for a more circular BESS offer. Such a map, combining practical and theoretical elements, could guide practitioners in their design process of new BESS solutions and highlight potentials for improvement towards the sustainability dimension of such solutions. On top of that, it creates an understanding of the feasibility of theoretical concepts and is the foundation for informing RQ1.

The *second task* consists of mapping the life cycle of a hypothetical circular BESS offer.

By mapping such a hypothetical offer, the knowledge gained through the completion of task one is applied and put into context. To feasibly create a hypothetical offer, additional knowledge is needed with a special focus on BESS end-users and customers. The customer focus is motivated by the lack of knowledge on BESS customers in the existing literature and necessary to ensure marketability of the hypothetical offer. Task two complements the findings generated through task one and contributes to the answering of RQ1. Simultaneously, the mapping of a hypothetical circular BESS offer enables the process of mapping digital technologies in an applied and informed manner, serving as the foundation for the completion of task three.

The *third task* is to map digital enablers needed to facilitate the customer journey of the hypothetical circular BESS offer.

Given that digital enablers are the backbone of a well-functioning BESS solution and are believed to be the decisive factor in creating a future competitive advantage as the product component of the PSS is commoditising (representative of Volvo Energy, personal communication, 07 December 2022), the third task was developed as the key informant of RQ2. The knowledge created will deliver value to the aforementioned practitioners and together with the findings of tasks one and two create a foundational framework that can serve as a starting point for the systematic academic coverage of circularity and sustainability aspects of BESS offers.

1.3 Scope and delimitations

The overall scope of this project is limited by three elements, the product group under investigation, the end-user segment, and the geographic scope.

The thesis project is concerned with the product group of BESS and its accompanying or supporting elements. More specifically, this work is investigating solid state BESS that is utilizing lithium-ion (Li-ion) batteries as a storage component. The Li-ion battery specification on BESS has been chosen as in 2021, Li-ion BESS had a global market share of 98%, making it by far the dominant technology in the field (Fortune Business Insights, 2022). On top of that, Li-ion batteries are the dominant battery type used in EV construction to date (Fortune Business Insights, 2023) and can therefore be expected to be the most widely available second-life battery type for utilisation in BESS in the coming years. Accompanying and supporting elements meanwhile refer to elements that are needed to facilitate or enable Li-ion BESS. Those elements will be considered with no further specificity or scoping due to the exploratory nature of the project.

As customers of BESS are the prime study objects of the project, it is essential that they are more clearly defined. In the following, customers will therefore be referred to as parties that enter a contractual relationship with the BESS supplier. This includes service as well as linear sales contracts. In many cases, customers are also the end-users of BESS, which are understood as the party on whose property the BESS is placed and behind whose electricity meter the system operates. However, there are cases in which the end-user for example tasks a third party with the development of a holistic energy system. In such cases, it is oftentimes not the end-user, but the third-party solution developer who enters into a contractual situation with the BESS supplier. Given this differentiation, this project is concerned with behind the meter BESS installations that are placed with end-users from the C&I sector.

The term C&I is frequently used in the BESS literature but nonetheless hardly ever defined. As the BESS market is mostly segmented into utility, C&I and residential customers, C&I end-users will be understood as end-users operating BESS behind the meter for non-residential purposes. This includes businesses, industries, institutions and public organizations which tend to be large to medium electricity consumers, which typically make up the largest electricity consuming group (ACCC, 2018). This work focusses on such customers involved in behind the meter BESS projects for C&I end-users. The focus on the C&I sector is based on the fact that this market segment is projected to have steady growth potential and increasing demand (Fortune Business Insights, 2022), as the proven cost saving potentials, the importance of energy costs to the sector and the possibility for essentially all companies of this sector to engage with such solutions, depending on the regional grid context, drive the attractiveness of these solutions (Wrålsen & Faessler, 2022).

In a last step, the geographical scope is defined. In order to do justice to the complexity of the topic, an additional distinction has been made between PSS related, technical aspects and customer related aspects. While a product's characteristics, business decisions and technical components can serve as an inspiration regardless of its geographical origin, customer preferences and perceptions are much more contextual and subjective. Given this difference in transferability for these two groups, two different geographical scopes were chosen. Therefore, all technical and business aspects, in particular those of existing offers, relevant to informing task 1, were analysed on a global scale. Customer perceptions and experience driven analysis were conducted within the scope of the EU, Norway, and the UK. For simplicity, the RQs both use the term "Europe" but also refer to the geographical scope of the EU, Norway, and the UK. In addition to the context specificity of customer perceptions mentioned above, the decision for a narrower scope is also based on the higher cultural familiarity of the researcher with the defined geographical scope which might therefore help to avoid misinterpretation errors. The significant increases in energy prices in response to the war in Ukraine (Ari et al., 2022), together with the stated aim of increasing investments into renewable energy sources (European Council, 2022b), increase the relevance of the chosen scope. A lot of development and demand for grid flexibility can therefore be expected in this market, making an adequate understanding of the customers' perspectives all the more important and the scope of the EU, Norway and UK a relevant one for the development of circular BESS solutions.

It is meanwhile recognised, that the research questions and the delineated tasks cover a wide range of topics. This choice was deliberate, given the focus of the current literature on detailed aspects of BESS and the lack of overarching frameworks to tie the research strings together. As the literature on both, sustainability aspects as well as end-user and customer perspectives is still largely in the developing stages, a broad approach can be of value in creating an overview and highlighting additional research needs. Beyond that, the tasks chosen to inform the research questions follow a logical flow that allows for a holistic picture of the customer-centric perspective on circular BESS and maximises the practical value by deriving actionable advice and overviews to practitioners. This applied and practical nature of the project is in line with the intrinsic motivation of the researcher as well as the standard and goal of the IIIEE, justifying a focus on breadth over depth.

1.4 Ethical considerations

The research project was conducted in collaboration with Volvo Energy who financially supported and hosted the researcher while conducting the research project from Göteborg, Sweden.

Thematically the research originates from a joint development process between the two parties which defined both, the topic and the focus of the project. Throughout the research process Volvo Energy assisted the researcher by providing insights into the company and its current work wherever relevant and appropriate. In addition, interviews with experts from the Volvo Group were facilitated. The thesis work was conducted under a non-disclosure agreement between the researcher and Volvo Energy, which permitted the publication of the final version of the thesis.

As the project is exploratory in nature, potential biases would limit the transferability of the results into practice and therefore the value of the work to the company. A neutral, realistic and unbiased assessment of the topic is therefore desired by both parties, Volvo Energy and the researcher, who maintained academic integrity by adhering to academic standards throughout the research process. To guide the research process and further ensure independence and integrity throughout the research process, regular consultations with academic staff from Lund University were conducted. These involved regular meetings between the academic supervisor and the researcher as well as four joint meetings between the academic supervisor, the supervisor at Volvo Energy and the researcher.

Interviews with external stakeholders and experts were the main method of primary data collection for the research project. To ensure that interviewees could make an informed decision about participating in the requested interviews, all interview partners received written information about the topic and the purpose of the interviews as part of the outreach email. That initial email furthermore contained information on the researcher's collaboration with the industrial partner Volvo Energy and were reminded that the participation is voluntary. When reaching out to BESS customers and end-users to hear about their experiences with BESS, no existing business connections between the interviewees and Volvo Energy existed and no other conflicts of interest were known to the researcher.

As part of the research process, also a number of second-life BESS suppliers with operational businesses were contacted and asked for an interview to clarify their approach towards circularity as well as to confirm and discuss preliminary findings of the research project. It is recognized that Volvo Energy might compete with these companies in the future. To protect the existing BESS suppliers, additional emphasis was put on highlighting the collaboration between the researcher and Volvo Energy in the outreach email. The collaboration was mentioned again throughout the interviews where potential conflicts of interests and risks were touched on as well. Both parties were therefore aware of the situation and made sure that no sensitive information from either side was shared over the course of the interviews. Given the deliberate sharing of information by all interview partners and the character of the of contents discussed, the results of the study are unlikely to harm any participant's reputation. Furthermore, all interviewees were granted anonymity in the publication of the thesis.

The design of the research 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.

1.5 Audience

The primary audience for this thesis is practitioners that are exploring options to develop or improve second-life BESS PSSs. This directly reflects in the research aim which is intended to be met through the provision of knowledge on potential circularity improvements, end-user profiles, outlining the life cycle of an idealised BESS PSS through the eyes of a customer, and lastly by providing a framework for the designing of digital tools needed to facilitate a potential customer journey. These outcomes directly answer to the research questions, contribute to the goal of the study and directly address the identified research problem. While not all outcomes may benefit different suppliers of BESS equally, it is expected that at least elements of the thesis can help practitioners to reflect on own practices or give inspiration or guidelines for the development processes. Especially the combined focus on circularity strategies which are assessed through a customer-centric perspective on the level of the product life cycle and digital enablers is novel to the knowledge of the researcher.

One direct beneficiary of this thesis is Volvo Energy as the project's topic and focus have been developed in close collaboration. As other companies are on similar trajectory, realising the potential of repurposing their end-of-life batteries and developing own circularity motivated BESS solutions, it is assumed that knowledge, that is of interest to Volvo Energy may also be of interest and potentially beneficial to additional market actors.

Beyond the group of practitioners, the findings of this thesis advance the academic debate by providing first frameworks on circular BESS that address the issue of circularity on the level of BESS technology and not the basis of the battery alone. By applying existing theories on resource efficiency, circularity, business model innovation and marketing to the context of BESS, it is expected that knowledge is gained for all the respective research fields. On top of that, existing research needs mentioned in the problem definition will be addressed and discussed, driving the academic knowledge especially on the development of circular business models and customer-centric PSS design. Overarchingly, the acceptance and conceptualisation of PSS will be tested and new knowledge on the combination of customer journey and digital enabler mapping created. Furthermore, the creation of a foundational framework on circular BESS can serve as a starting point for highlighting the need for additional research.

1.6 Disposition

The first chapter of this thesis derives the relevance of the research project, highlights key knowledge gaps, defines the aim and research questions of the project and addresses its scope, the author's ethical considerations as well as the projects audience.

Chapter 2 gives an overview over the current literature on the topic, builds foundational knowledge on the technology and key concepts relevant to answering the research questions. Beyond that, underlying theoretical concepts are addressed, and the choice of methods chosen to address the aim of the research are theoretically backed and justified.

Chapter 3 presents the research design of this thesis and introduces the approach and methods chosen to investigate the research questions. Beyond that, the chapter gives an outlook on the data collected and explains how the data has been analysed.

Chapter 4 presents the project's findings along the analysis of the findings in an intertwined manner. The chapter is structured along and will answer to the research questions of the thesis.

In chapter 5, the findings will be discussed and analysed in the light of existing literature. New contributions will be highlighted, and the research process reflected.

Chapter 6 concludes the thesis by summarising the findings and highlighting future research implications along recommendations for practitioners.

2 Literature Review

In the following sections, the literature review provides an overview over the current knowledge on BESS and the concept of circularity. Starting with the introduction of energy storage, the technical dimension of BESS, its value creation potential and market trends, the thesis lays a foundation needed to position the research in the market and establish a joint understanding on the technical context. The review then continues by introducing the concept of circularity and the circular economy, before bringing the topics together and analysing what circularity means for the concept of BESS. By introducing theories and concepts of relevance to the topic, the chapter concludes by explaining the rationale for the research and justifying the focus of the work. The introduction of theories and concepts bridges the literature review section with the following methods section and serves as an introduction.

2.1 Energy Storage

The importance of energy to our societies cannot be underestimated. To date, energy is considered to be the most important consumer good on earth and essential for the development of our planet (Aneke & Wang, 2016). Energy storage itself meanwhile is not a novel concept. Whether it is storing firewood for the winter or filling a domestic oil tank for heating, energy storage is a common practice to overcome the mismatch of energy supply and demand. In our modern societies energy storage delivers services ranging from large scale energy backups in the form of hydro energy storages, to the powering of portable electronic devices that use single battery cells (Whittingham, 2012).

With an increasing share of our grid electricity coming from renewable energy sources, the concept of energy storage has gained in prominence as the intermittent and unpredictable nature of the renewable energy sources can be effectively mitigated by storing energy in times of regional surplus generation and releasing these stored assets in times of shortage (Suberu et al., 2014). Installing an adequate capacity of storage systems, with their positive effect of providing the respective flexibility and stability is therefore inevitable for the transition towards a more sustainable, independent, and non-polluting energy system (Gallo et al., 2016).

Within the category of energy storage, different types of storage systems are available, each with its unique features and contributions to the grid. A relevant differentiation between the systems can be conducted along the system's storage capacity and discharge time (Moore & Shabani, 2016). As a stable electricity system needs both, quick responses to frequency fluctuations as well as long lasting supply for the bridging of regional supply shortages, the right mix and distribution of different storage systems is needed (IEA, 2022). Figure 2-1 shows the features of different energy storage systems in the aforementioned categories. Their features along these categories then indicate their potential usefulness in fulfilling grid support applications. Applications with rapid response times are useful for balancing fluctuations, while those with large storage capacity are suited for time shifting which can be utilised in different ways to overcome regional and timely shortcomings and bottlenecks.

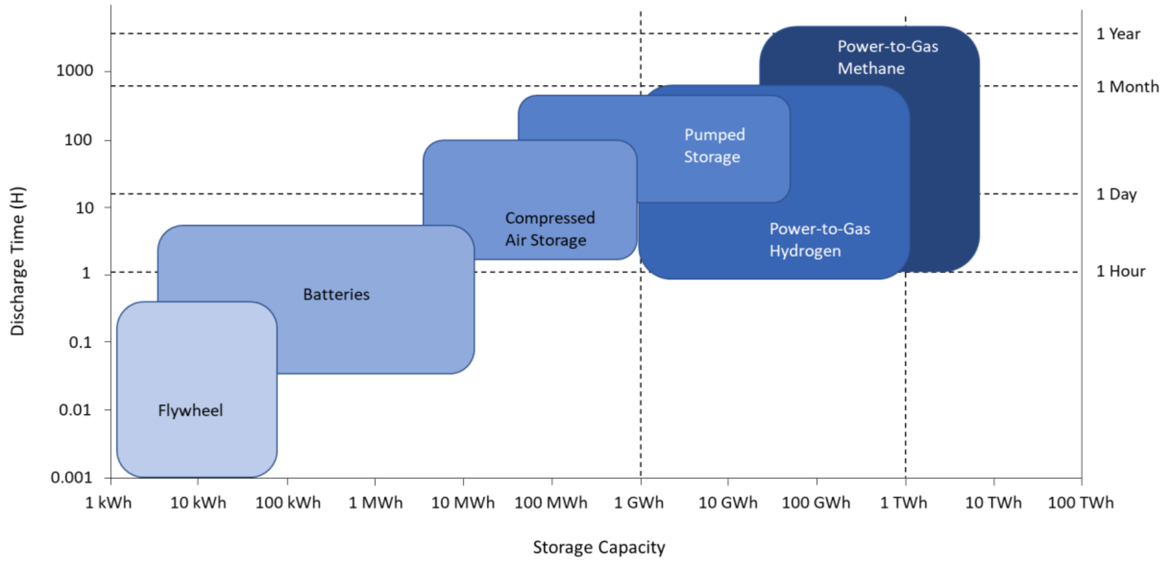

Figure 2-1. Energy storage technologies

Source: adapted from Moore and Shabani, 2016

The European Association for Storage of Energy formulates five main categories of energy storage applications: Generation Support Services and Bulk storage Services[2], Services to Support Transmission Infrastructure[3], Services to Support Distribution Infrastructure[4], Ancillary Services[5] and Services to Support Behind the Meter Customer Energy Management[6] (EASE, n.d.-a). While battery storage is unable to provide grid support for long-term, high-power demand such as bulk power management for example for seasonal arbitrage, its unique features with rapid response times and simultaneous relatively large storage volumes, this technology can offer solutions towards the remaining four application areas (Services to Support Transmission Infrastructure, Services to Support Distribution Infrastructure, Ancillary Services and Services to Support Behind the Meter Customer Energy Management)(EASE, n.d.-b) providing value for the grid.

2.2 BESS

Before looking at the applications and benefits delivered through BESS, it is important to understand the product.

[2] Generation Support Services and Bulk storage Services refers to services provided by energy storage that can ensure the provision of big amounts of clean energy. Focus lies on the volume of energy provided (EASE, 2021d).

[3] Services to Support Transmission Infrastructure are services offered by energy storage that provide alternatives or can complement traditional transmission infrastructure (EASE, 2021e). Examples are storage units that can store and release energy locally to meet an increased energy demand without having to upgrade the transmission grid.

[4] Services to Support Distribution Infrastructure refers to the same as Services to Support Transmission Infrastructure, but only on the distribution grid level. More applications are possible as other services such as intentional islanding are not possible and desired on the transmission level (EASE, 2021c).

[5] Ancillary Services are services provided by energy storage that support the efficient operation of the grid and include services such as frequency control or black start services (EASE, 2021a).

[6] Services to Support Behind the Meter Customer Energy Management are services provided by energy storage installed behind-the-meter to support end-users to manage their energy supply and/or costs (EASE, 2021b).

2.2.1 BESS technology

A BESS is a large-scale battery consisting of multiple smaller battery modules that are fitted within a joint frame and are oftentimes containerised to enable smooth transportation and easy placement.

Chatrung (2019), Jose et al. (2021), Shi et al. (2010) and Thien et al. (2015) all mention 4 main components that are needed for a BESS to function: the battery, an inverter system, a battery management system (BMS) and an energy management system (EMS).

The battery is the main electricity storage component of the BESS and multiple kinds of batteries are feasible to be used in stationary storage systems (Hannan, Wali, et al., 2021). The batteries used in such systems differ in terms of battery type (Farias & Canha, 2018), chemistry (Stan et al., 2014), power (MW) and capacity (MWh) (Choi et al., 2021), all of which have to be fitted to match the specific needs of the desired applications. Beyond that, also charging/discharging rates, efficiency and life cycles differ between different systems and ultimately are among the factors influencing a battery's price (Hannan, Wali, et al., 2021). Among the different battery types used in BESS are flow batteries, lead acid batteries and Li-ion batteries (Hannan, Wali, et al., 2021). Li-ion batteries are by far the most widely used battery type in BESS, making for a global BESS market share of 98% by capacity in 2021 (Fortune Business Insights, 2022). It is the combination of excellent energy density, power density, round trip efficiency, response time and low self-discharge rate that makes them so attractive for a large variety of power applications, including BESS (Arangarajan et al., 2014). Beyond that, Li-ion batteries are scalable and can be introduced to practically all voltage, power and energy requirements and require low maintenance (Eurobat, 2016; Gandhok & Manthri, 2022b). The high uptake of Li-ion batteries in BESS is furthermore aided by the high investment and research activity into the technology along a dramatic drop in price for Li-ion batteries and Li-ion BESS overarchingly (Gandhok & Manthri, 2022a), which is not at last correlated to the high demand for Li-ion batteries in the automotive industry.

While the characteristics of different Li-ion batteries are largely the same, some differences can be observed based on the different battery chemistries available within the group of Li-ion batteries. All Li-ion batteries follow the same engineering logic and have the same technical structure. They consist of an anode, a cathode and an electrolyte, separating the two. While the anode is typically made from graphite, the materials of the cathode vary and determine the detailed characteristics and the name of the battery chemistry (Stan et al., 2014). Categories between which differences can be detected are safety[7], specific energy[8], specific power[9], performance[10], lifetime[11] and cost (Dinger et al., 2010). Trade-offs between the different features have to be made when deciding for a battery chemistry. Kwak et al. (2018) claim that NCA and NMC are the best performing battery chemistries available for EV installations today, while LCO, LMO and LFP are currently the most widely used batteries in EV applications (Houache et al., 2022). These battery chemistries can therefore be expected as the major second-life battery streams available in the future. NMC meanwhile seems to be the dominant chemistry moving forward and is recommended as a focal technology for future

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[7] Considered as the most important criterion for EV batteries as public trust is essential. Thermal runway is the biggest safety concern which is triggered by overcharging, overtemperature and mechanical abuse. Design for safety and strict monitoring mitigate the safety concerns while some battery chemicals remain more prone to thermal runway, as for example NMC and LMO, compared to others (Dinger et al., 2010, Thien et al., 2015).

[8] The battery's capacity of storing energy per kilogram of weight. Typically measured in Wh/kg (Dinger et al., 2010).

[9] The amount of power batteries can deliver per kilogram of weight (Dinger et al., 2010).

[10] The ability to function in a wide range of temperature environments without showing performance degradation (Dinger et al., 2010).

[11] Either expressed in cycle stability (numbers of full charges and discharges before degrading to 80% of the original capacity) or overall years a battery is expected to remain useful (specific to the individual case)(Dinger et al., 2010).

mobility solution development (Houache et al., 2022). As mentioned in the introduction, it is technically possible and proven that second-life batteries from the transportation sector can be introduced to stationary BESS applications (Ahmadi et al., 2014, 2017; Chai et al., 2021). Literature highlights that energy and power output, along energy density and cell-to-cell heterogeneity are categories in which second-life batteries are expected to differentiate from first-life batteries, but it is recognised that monitoring and management systems can be used to overcome these potential challenges (Martinez-Laserna et al., 2018). Battery safety and lifetime remain areas in which increased uncertainty prevails (Martinez-Laserna et al., 2018) and both factors should be accounted for in business model design and practical implementation of second-life BESS into a given technical context.

As batteries store electricity in the form of direct current (DC) while our global electricity grids and the majority of all household and industrial applications uses alternating current (AC), there is a need for the second essential component of a BESS, namely an inverter (Thien et al., 2015). The inverter transforms the AC coming from the electricity grid into DC to enable the charging of the battery. In the process of battery discharging, the inverter than transfers the DC back into AC to make it usable for household and industrial applications as well as compatible for feeding it back into the electricity grid. Today's inverters are therefore largely bidirectional and able to support both the charging and discharging with the same device (Hannan, Wali, et al., 2021). In order to fit inverters into a BESS, they must be sized according to the respective requirements they face, especially with regard to the power requirements of the system. Correct sizing is needed to access the full capacity of the BESS (Hannan, Wali, et al., 2021). Inverters can meanwhile be placed in a central location or paired per battery pack (Thien et al., 2015).

The third component essential to the functioning of a BESS is the battery management system (BMS). A BMS is responsible for monitoring key parameters of battery cells and communicate them to other systems via interfaces. BMSs therefore enable information collection on the health and security of the battery and therefore play a key role in enabling safe and long operation of battery containing technologies. The key parameters collected and monitored by BMSs typically include the battery cell's voltage, current and temperature, that help estimate the respective state of charge[12] and state of health[13] (SOH). Meanwhile, the BMS also receives data from the energy management system and the controller that communicate instructions such as power requirements and therefore control the charging and discharging of the battery (Chatrung, 2019; Hannan, Wali, et al., 2021; Jose et al., 2021).

An energy management system (EMS) is the fourth component essential for the functioning of a BESS. It is the single tool that collects all battery performance data and controls the charge and discharge of the battery. All battery specific information that is collected by the BMS is transmitted to the EMS where it is then analysed and prepared for visualisation, reporting and decision making. Different levels of complexity exist for different EMSs as different BESS applications require different operation of the BESS. While BESS for self-consumption optimisation of renewable energy is rather simple, only considering behind the meter information, applications combining behind and front of the meter information require more complex optimisation algorithms. As all operational activities of BESS are however data-driven, the EMS is essential for the controlling and value creation with the BESS. The EMS can meanwhile also be extended with different interfaces to serve additional purposes. As such, the EMS can provide access to real time monitoring, to perform additional optimisation services to consider degradation and as a reporting tool to send out performance information reports to the end-user. The essential function as a controlling unit

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[12] information on the current amount of energy stored in the battery (Noura et al., 2020)

[13] figure indicating the battery level of degradation (Noura et al., 2020)

makes the EMS a central part the system. In order to send and receive information, modern BESS need to be equipped with internet connection that allows for data and command exchange. Jointly, these components enable the operationalisation of the three main functions of the battery, charge, storage and discharge in a value creating way.

Beyond these four essential components there are additional components regularly found in commercial BESS systems and discussed in literature on BESS that are considered non-essential by some authors (Chatrung, 2019; Jose et al., 2021) but mentioned by others as components that contribute positively to the safety and operation efficiency of the system. Examples of such elements are a system for heating, cooling and air conditioning (HVAC) that maintains the optimal environment for a BESS to avoid degradation and reduces risks of malfunction or fire (Thien et al., 2015), transformers capable of increasing the BESS's voltage to match the grid voltage (Hannan, Wali, et al., 2021), hardware capable to connect the BESS to the internet and SCADA communication systems to coordinate external commands between the BMS and the inverter system (Thien et al., 2015).

BESS components, particularly batteries, are expensive products. In combination with the current high demand for BESS, the product is expensive as in 2020 the average price for BESS was 345 USD per kWh of storage capacity (Cole et al., 2021). Beyond that BESS systems are heavy and bring a certain level of risk as thermal runoffs can lead to fire and explosions which are difficult to extinguish and can be caused by either physical damage or overvoltage (AIG, n.d.). Furthermore, certain battery components like the electrolyte are considered as hazardous (Winslow et al., 2018). As customer acceptance is critical to market adoption of BESS, operational risks and their mitigation are of the highest importance to the system suppliers which leads to a strong emphasis system security. Especially digital tools contribute to the safe operation of BESS as they enable remote monitoring which allows for precautionary actions to prevent malfunctions and dangers (Thien et al., 2015).

2.2.2 BESS Applications

As previously discussed, batteries hold unique features that translate to their application within a BESS. Their unique features of high energy density, efficiency, rapid response time and capacity make it extremely versatile in its applications and siting (Lawder et al., 2014). The placing of BESS in multiple positions on and off the grid can meanwhile deliver significant value to the grid, its operators as well as BESS end-users which will be highlighted in the following sections.

Utility scale BESS

One way in which BESS projects are carried out is in the nature of large, utility sized storage systems. Therefore, the scalability of li-ion batteries is utilised as multiple BESS containers are stacked and connected to operate as one unit. The storage capacity of such units can be enormous with the biggest BESS utility project to date having a storage capacity of 1,600 MWh (C. Murray, 2022c). As the price of BESS is significant, these large-scale projects are typically funded by grid operators, energy suppliers, investment funds or banks. The projects are strategically placed to provide value to the grid which can either be monetised or defers costs that would have otherwise occurred (Akhil et al., 2013). Monetisation of BESS services happens either through electricity arbitrage, the charging of the at times of low electricity prices and the discharge when prices are high, or through the monetisation of load shifting and capacity provision on respective ancillary and capacity adequacy markets (TerraStor, n.d.). Beyond that, costs can be avoided when the existing electricity transmission or distribution lines are not sufficient to transport the demanded amount of electricity. In such cases, BESS can be placed behind bottlenecks of the grid and in times of peak demand discharge electricity to add capacity to the areas behind the bottleneck. This practice can be used to defer costly grid upgrades. As a third front of the meter BESS installation, the system can be paired with renewable energy sources (RES) production sites to control when the generated electricity is provided to the market. This allows for protection against curtailment caused by grid overvoltage and the overall smoothing of the energy output generated by RES (Liao et al., 2018; Wei et al., 2014).

Given their large capacities, these systems have big impacts on the flexibility of the grid and are welcomed by investors for their revenue generation opportunities, grid operators for the provision of flexibility and politics as the flexibility enables increased uptake of renewable energy sources. Despite the utility scale projects making for the largest capacity of BESS currently installed, they are not the focus of this study.

Off-grid BESS

Similar to the way we use energy storage in portable devices, BESS can also be used without a grid connection. In the so called off-grid applications, BESS is used for its storage capacity, charged when connected to the grid and delivering electricity to places where the grid is not available. Construction sites with lacking grid connection are a typical example of a scenario in which off-grid BESS would be needed. Off grid BESS can also be used to support the stability of micro grids which are grid constructs that can work connected to the main grid as well as fully decoupled from it. Micro grids cover a limited proximity and contain own energy generation and consumption technologies (NREL, n.d.). BESS can then be used to overcome temporary electricity deficits, shift loads temporarily, balance the frequency of the microgrid or manage the power control (Nguyen et al., 2015). Same as utility scale projects, neither off-grid applications nor micro-grid BESS is part of this projects scope but quickly mentioned to create a holistic overview over the BESS landscape.

Behind the meter BESS

Besides their applications in utility sized applications, off-grid and micro grid systems, battery storage can also deliver value to behind-the-meter (BTM) end-users. In contrast to front-of-the-meter systems, BTM systems are placed on the end-user side of the utility's service meter, close to the electricity consuming tools or applications. While the BESS technology with its components remains largely the same compared to front-of-the-meter BESS, the systems differ in their ownership structure, the number of installations and the size of the systems. Typically, BTM BESS are much smaller due to the limited availability of funding, the clearly defined purpose, often directly related to the end-user's electricity consumption, and the grid connection being a limiting factor. BTM BESS installations typically range between a few kWh to a maximum of 40MWh capacity (IRENA, 2019; C. Murray, 2022a), with most systems well below 10 MWh (IRENA, 2019). The BTM BESS segment is further divided into residential and C&I end-users (Fortune Business Insights, 2022; Transparency Market Research, n.d.). While the ownership form and utilisation of the system makes for the formal differentiation criteria between the two groups, the size of the installations varies as well. Residential installations are typically sized around 15 kWh and do not exceed the capacity of 100 kWh (IRENA, 2019), while C&I systems are typically sized between 100 kWh and 5 MWh (IRENA, 2019).

For residential customers, the literature highlights resilience services along with the integration of BESS with RES generating systems, predominantly PV, in order to optimise self-use and reduce the electricity bills as the main drivers for BESS investments (Barchi et al., 2019; ETCC, 2020; IRENA, 2019). In 2019, 40% of all German rooftop PV installations were equipped with residential BESS systems, highlighting the influence of BESS on renewable energy uptake (IRENA, 2019; Transparency Market Research, n.d.) and its rising importance and popularity for residential BTM applications. Despite the projected increase in uptake of residential BTM BESS, the residential sector is not in focus for this project either.

Instead, the project focusses on BTM C&I BESS. This decision was made due to the sector's anticipated steady growth, driven by the increased need for energy resilience (Fortune Business

Insights, 2022), combined with the fact that C&I BESS is unique in providing services directly to both the BTM end-user and the grid.

Research shows that the different application possibilities of C&I BESS can largely be grouped into two dimensions, defined by the end-user's motivation to engage with the system. The dimensions are either the end-user's desire to improve the economic performance of its operation or increase the resilience of the electricity infrastructure (Redmond et al., 2022). The two motivations are to be understood as a continuum with some applications being clearly motivated by one of the two values and other applications showing features of both. Figure 2-2 visualises this continuum and places the different applications of BTM C&I BESS systems, adapted from the European Association for the Storage of Energy, on the continuum. Services that can rather be seen as economically motivated are the offering of capacity to the markets for Ancillary Services, Energy Arbitrage, Peak Shaving[14], and compensation of reactive power.[15] Resilience motivated activities include the insurance for continuity of electricity supply, limitation of upstream disturbances, requirements towards power quality, and maximising self-production and consumption of electricity (EASE, 2020; Svenska Kraftnät, 2023a).

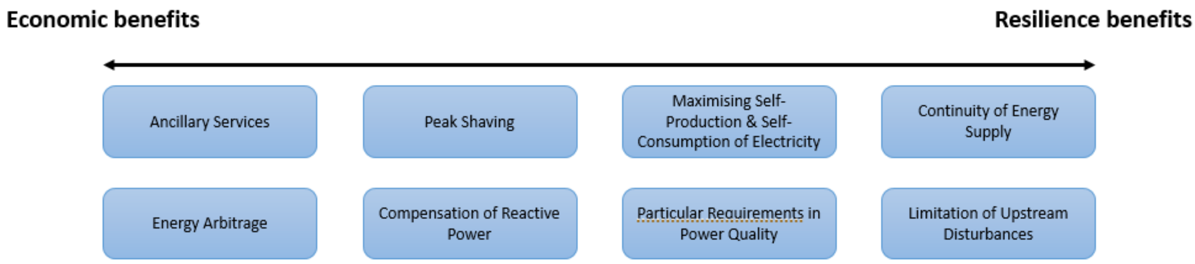

Figure 2-2. C&I BESS applications

Source: adapted from (EASE, 2020; Redmond et al., 2022)

Ancillary services and Energy arbitrage derive direct value in the form of cost cutting and revenue generation (Mustafa et al., 2021), while peak shaving and the compensation of reactive power reduce the charges for electricity (Beach, 2019; Mexis & Todeschini, 2020). The impact of resilience creating applications can be felt more indirectly. As such, continuity of energy supply and limitation of upstream disturbances enable the continuous operation during periods of grid failure and ensure a predictable and uniform supply with electricity. While the monetary value of this service may depend on the operation that it complements, predictability is important to the majority of organisations. Overarchingly, it is recognised that resilience is difficult to value and is therefore often undervalued (Simpkins et al., 2016). However, the demand for resilience services furthermore depends on the grid context and the likelihood and frequency of disturbances experienced in the absence of a BESS which determines the opportunity costs. Optimising self-consumption of renewable energy generation meanwhile contributes to cost cutting while also enabling an increased level of self-sufficiency along carbon emission reductions caused by the increase of green electricity consumption replacing grid electricity (Ahmadiahangar et al., 2022). The application of BESS to ensure sufficient power quality provides value towards both goals as it is an enabler for operations with specific power requirements, such as EV rapid chargers that cannot be installed in specific cases due to limited grid connection and at the same time it defers alternative costs for a potential

[14] The reduction of the load peaks drawn from the electricity grid with the purpose of lowering the electricity bill, as the peak demand determines a large fraction of the electricity bill (Boyouk et al., 2018)

[15] use of energy storage to compensate locally the reactive power. As reactive power is charged in some instances, its compensation can contribute to cost-saving (EASE, 2021f)

infrastructural retrofit beyond the BESS. In addition to that, literature highlights potential carbon accounting benefits as BESS is capable to replace diesel generators for back-up power and has the potential for increasing the uptake of self-produced renewable electricity (Mustafa et al., 2021; Nair & Garimella, 2010). This might be of interest to companies that have committed to carbon reduction goals.

Interestingly, the grid connected C&I systems do not solely benefit their respective end-users but also the grid and its operators. As the market mechanisms reflect the supply and demand of electricity on the grid, as well as the need for additional services to ensure sufficient flexibility in the respective markets, the market mechanisms create a situation in which BESS end-users, acting in their individual self-interest, support the grid (Mexis & Todeschini, 2020; Svenska Kraftnät, 2023b). Even beyond the ancillary markets, reflecting Adam Smith's principle of the invisible hand, use cases show that especially in the context of networks with high levels of RES integration, the installation of small and medium sized BESS has had a positive impact on self-sufficiency and self-consumption levels, reducing the pressure on the grid, leading to lower grid losses and mitigating the overall impact of RES on the grid (Ramos et al., 2021).

BESS profitability

While there is widespread agreement on the potential benefits that can be achieved by BTM C&I BESS installations on both the organisational and the grid level (Hannan et al., 2021; Ramos et al., 2021; Schulz-Mönninghoff & Evans, 2023; Jose et al., 2021; Englberger et al., 2020; Hu et al., 2022), it is the practical profitability that is questioned and identified as a potential barrier to wide market uptake (Englberger et al., 2020; Faessler, 2021; Hu et al., 2022; Lombardi & Schwabe, 2017). With the revenue streams and BESS applications along with their monetarisation options being well defined, studies on use cases and theoretical calculations do not lead to clear conclusions on the profitability of BESS. Some authors highlight contexts in which BESS can be operated profitably (Mohamed et al., 2021; Mustafa et al., 2021; Pusceddu et al., 2021; Sun et al., 2020), while others claim the opposite, pointing at case studies and scenarios where BESS operation has not been profitable (Hu et al., 2022; Silvestri et al., 2022). Costs of the system, the applications chosen for the system and the context of the operation have been identified as key factors influencing the profitability of the system (Mohamed et al., 2021).

The cost of BESS systems can be impacted by numerous factors, including raw material prices, the lifetime of a system, the production location, the technology used, component sourcing volumes from the BESS producers, the scale of the project, or the overall pricing strategy of the supplier (BloombergNEF, 2022a). Beyond that, circularity aspects such as the reuse of product components and the application of circular design principles influence the costs of a system. The refurbishment process of batteries, as a central circularity strategy in the context of BESS, is a work intensive process that includes a certain level of disassembly, physical inspection, testing of power and capacity as well as sorting, repackaging and adding of new equipment such as control and monitoring equipment along a new and suitable BMS (Ahmadi et al., 2014; Sanghai et al., 2019). Despite the increased cost for labour and materials throughout the refurbishing process, the reuse of Li-ion batteries in BESS is expected to result in price savings of between 11% and 70% due to the elimination of the need for new batteries and the distribution of the added costs over the different use cycles (Ahmadi et al., 2014; Engel et al., n.d.).

As a second factor, the operation of the system also has an impact on the profitability of BESS, as the use of different revenue streams results in different earnings and cost savings created. Extensive coverage on optimising the energy management system exists, highlighting different software solutions for revenue maximisation and concluding that revenue stacking, the usage of the BESS for different applications and participating in different markets, maximises the value generation significantly (Englberger et al., 2020). Besides the stacking as a response to competing needs and revenue opportunities, synergetic effects between different services have been identified. This way, energy arbitrage and fast frequency response have been found to enhance the revenue generation of each other (Pusceddu et al., 2021).

Lastly, context plays a major role in the profitability dimensions of BESS as the prices offered for different services as well as opportunity costs and the level of price fluctuations vary depending on regional differences. The factors electricity price, electricity price volatility and the renumeration on the ancillary markets are highlighted as context specific influencing factors on system profitability (Hu et al., 2022; Sun et al., 2020). Political forces such as taxation, regulation or potential subsidies also influence the profitability of BESS installations. Pre-existing infrastructure has a major impact on these factors (Hu et al., 2022), as the existence of flexibility mechanisms balances the market and accordingly decreases the demand for additional flexibility, with negative effects on arbitrage and ancillary service revenue potentials. The existence of alternative energy storage such as pumped hydropower or advanced uptake of BESS can facilitate such development. This line of logic highlights that the revenue potentials for BESS through arbitrage and ancillary services is expected to decrease over time. In addition, trends such as the anticipated further price decline of virgin Li-ion batteries could support the uptake of first-life BESS while simultaneously reducing the attractiveness of second-life systems (Engel et al., n.d.). Adding an additional layer of complexity, Hameed et al. (2021) point out that even within a specific context, different levels of profitability can be achieved based on different positioning within the grid. This shows the importance of individual judgement, flexible solution development and flexibility on the level of service provision. This poses challenges of optimal value delivery to BESS suppliers and poses hindering factors to the standardisation of solutions. Active engagement with customers and awareness of the different influences is required. Customers with less knowledge on the topic of energy management, on the other hand, must make a decision and understand how the quality of an offer compares in the market. Research highlights that in such situations, where customer preferences are ill-defined due to a lack of expert knowledge, it is not just the fit with preferences that determines their decision on a business offer but also other factors such as the customer's receptiveness to a certain offer or the perception of the relationship (Simonson, 2005).

2.2.3 BESS Trends

Prominent energy storage news outlets like energy-storage.news (Colthorpe, 2023), report on the approval of large-scale BESS projects on a weekly basis. And while this indicator of rapid market development may be anecdotal and subjective, industry reports confirm the notion of a rapidly growing market by reporting increasing annual capacity installation numbers each year. Through the year 2030, a 21% compound annual growth rate is expected with global capacity installations anticipated to reach 1,194 GWh in the year 2030. This translates to 15 times increase compared to the 56 GWh of storage capacity that was installed in 2021 which confirms the market development of recent years and clearly highlights the potential of the growing BESS market overall (BloombergNEF, 2022b).

At the moment, there are multiple factors influencing the development of the market which do not all work in favour of the market participants. The influencing factors can be grouped into three categories along the developments that caused them. Those developments are the aftermaths of the Covid 19 pandemic, recent geopolitical conflicts, predominantly the Russian invasion of Ukraine and subsequent political responses, as well as market developments (BloombergNEF, 2022b).

Expectations of recent years projected the prices of BESS to continuously drop with increased maturity of the product, developing economies of scale, established supply chains and increasing competition (BloombergNEF, 2022b; Fleer et al., 2016). In reality, however, the opposite has happened, with the price of a turnkey BESS increasing by around 25% between the year 2021 and

2022. As the main reason for that, increased raw material and component prices have been identified which are impacted by lasting disturbances in the global supply chains (Murray, 2022b). As a result, especially the utility scale project development has slowed down due to the longer lead times and in anticipation of price drops. Also the recent increases in global interest rates will likely impact the development of large scale BESS projects as under the classical purchase business models, these systems require a high investment. Eyraud et al. (2013) show that Green Investments are particularly sensitive to interest rate movement, especially given projects of high capital intensity and upfront costs.

While these developments negatively impact the development of utility scale projects, the recent geopolitical conflicts, political reactions, and respective market responses are expected to impact the development of behind-the-meter, C&I as well as residential projects positively. This is due to the fact that increased energy prices make renewable energy production in the form of PV roof installations more and more desirable. As BESS improves the self-consumption of such installations, growing interest is expected in this market. Beyond that, the EU has increased its already ambitious renewable energy production goals under the Fit for 55 plan again as part of the REPowerEU plan which translates to an increased need for energy storage (BloombergNEF, 2022b). Supporting this development, incentive programmes have been introduced in Europe, the Middle East and Africa to encourage the deployment of residential BESS (BloombergNEF, 2023).

Long term, market developments are expected to drive the positive market development described above with improved knowledge on system design and integration, economies of scale and dropping component prices. Falling prices can then be expected to favour the uptake of both utility scale and BTM systems once these effects materialise (Cole et al., 2021).

With stationary battery storage systems continuing to prove that there is a business case for end-users that increases the attractiveness of the systems and creates a growing demand for the solutions, more and more players are looking into the development of the systems. The market development highlights that the availability of key components and related thereto their price are key determinants of market success (NRECA, 2020). Repurposing previously used batteries from mobility applications offers the opportunity to potentially mitigate these problems.

2.3 Circularity

We are currently living in a world that is largely still ruled by the economic paradigms of the take-make-dispose logic of the linear economy (Ellen MacArthur Foundation, 2013). With resource extraction, production and consumption becoming more and more separated, for a long-time people failed to see the effects of their extensive consumption habits on the earth's ecosystems and the actors along the supply chain. While raw materials have historically been dramatically cheaper than human labour, companies have been able to gain a competitive advantage, by substituting human labour with the extensive use of raw materials. The regulatory environment allowed for these wasteful practices, as externalities were not required to be priced into the products' prices. (Sariatli, 2017). Meanwhile, the continued exploitation of the earth's raw materials is leading to a scenario in which new resources are becoming increasingly difficult to obtain, putting pressure on profits through rising raw material prices and pushing actors to expand the destruction of ecosystems (Sariatli, 2017). At the same time, the open-ended nature of the current economic practices allows valuable resources to go to waste, leading to extreme littering of the planet (Su et al., 2013). With a growing population and a respective growing demand for consumption, the world won't be able to meet the current ad future needs of its population in the same way if humanity does not change its economic practices, especially with regard to a more efficient use of natural resources (Angioletti et al., 2017).

On top of that, economic and political arguments support the call for a change in economic practices as the linear economy holds significant shortcomings. As such, the system tolerates and fosters the existence of structural waste, which inevitably leads to economic losses as materials in which a lot of energy and resources have been invested into as part of the creation process, are not fully utilised. Beyond that, the dependence on raw material imports holds political and supply chain risks, while price risks arise from raw material price volatility and global responses to regional shocks (Ellen MacArthur Foundation, 2013, 2015). Together with the demographic developments, infrastructural demands and increased awareness, these shortcomings all point to the limits of our current linear system (Ellen MacArthur Foundation, 2013).

The Circular Economy is an alternative economic system that directly focusses on overcoming the shortcomings of the linear economy (Ellen MacArthur Foundation, 2015). It developed from a multitude of different conceptual frameworks and theories, such as the limits of growth, cradle to cradle, industrial ecology, biomimicry, the blue economy and many more (Geissdoerfer et al., 2017), and aims to create a regenerative economy by decoupling, economic growth from the consumption of finite resources (Ellen MacArthur Foundation, 2015).

Due to the multitude of theoretical influences and backgrounds that contributed to the formulation of the CE concept, multiple interpretations and definitions of the concept exist. The underlying idea however, is the circulation of products and materials as part of a closed loop system (Geng & Doberstein, 2008). As closing the loop alone neglects the potential for increasing resource efficiency, other authors define CE differently and refer to it as one that is "restorative by design and keeps products, components and materials at their highest utility and value, at all times" (Webster, 2015). Webster's (2015) definition adds two additional dimensions to the concept by referring to the cycling of products, components and materials at their highest utility and by focussing on the regenerative nature of the CE concept. All three dimensions are picked up by the Ellen MacArthur foundation in its attempt to establish foundational principles of the CE. The principles defined are: 1. The elimination of waste and pollution, 2. The circulation of products and materials at their highest value and 3. The regeneration of nature (Ellen MacArthur Foundation, n.d.-b). The definitions show that raw material streams are at the centre of the CE theory, which is what the principles build on and elaborate. Among raw material flows, the CE differentiates between biological and technical cycles due to their different physical properties. While the cascaded use, the maximum value containment through extended lifetime and circling at the highest value is desired for both cycles, biological materials are safe to return to the natural world as they degrade over time and re-enter the natural nutrient flow to start a new cycle (N. M. Bocken et al., 2016). Technical components however must be captured at the end of their extended lifetime and recycled without a downgrade of their properties in order to fulfil the principles of the circular economy (Bocken et al., 2016). A slowing of the resource extraction loop is therefore considered as a preferred option that contributes to the efficiency of a system before also technical components are ultimately recycled and the cycle is closed.

The CE principle elimination of waste and pollution refers to the effectiveness of the system, which is achieved by uncovering and designing out of material leakages and negative externalities (Ellen MacArthur Foundation, 2015).

The circulation of products at the highest level refers to the practice of viewing recycling as a last potential step of material treatment, which should always be preceded by practices that maximise usage and preserve the internal energy and labour of a product at its highest level (Geissdoerfer et al., 2017). By preferring practices of the "Inner Circle", like repair, reuse or repurpose, the embedded costs of material, labour and energy are kept small (Ellen MacArthur Foundation, 2013) and the net value created can be increased through extended utilization (Linder & Williander, 2017). The logic of maximum energy and utility containment can also be found in other frameworks that propose a hierarchy of practices to facilitate the efficient handling of products and resources. Examples for such frameworks are the 3R (Ghisellini et al., 2016; King et al., 2006) and 4R waste hierarchy strategies that are used as the foundational concepts for the Circular Economy Promotion Law of the People's Republic of China and the EU's Waste Framework Directive respectively (Kirchherr et al., 2017).

Lastly, the regeneration of nature refers to the preservation and enhancement of natural capital. This can be achieved through the dematerialisation of utility and the wise selection of materials and resources in product design. Renewable resources should always be preferred, and nutrient flows should be enabled.

Although CE is not sustainable by definition, its successful implementation contributes positively to all three dimensions of sustainability: economic, environmental and social (Korhonen et al., 2018). Korhonen et al. (2018) describe several benefits achieved through the circular economy that are summarized in table 2-1.

Table 2-1. Potential benefits of the CE

Environmental benefits	Economic benefits	Social benefits
Reduced demand for virgin materials and energy input	Reduced costs for raw materials, energy, emission control and waste management	New employment opportunities from new use of value in resources
Increased share of renewable material input	Reduced costs from environmental legislation, taxes and insurance	Increased sense of community through the transition prom consuming to sharing economy
Reduced waste and emission output	Benefits for the image and new green and responsible market opportunities	

Source: adapted from Korhonen et al. (2018)

However, the positive effects achieved by the concept are not guaranteed. In fact, literature highlights instances in which the implementation of circularity strategies may contribute positively to one circularity principle, but hurt another, if improvements are planned without the necessary holistic perspective. Extending the life of inefficient and polluting products, or the extensive use of raw materials in the repair stages of products that lead to minimal environmental benefits are examples for that (Bocken et al., 2016). In a similar fashion, Allwood (2014) argues that implementation of circularity strategies, such as repurposing, may generate more negative externalities than acquisition of new raw materials and Andersen (2007) notes that economic value may be lost if those strategies are more costly than new production. Also economic scenarios in which circular products, instead of taking market share from first-life products, may increase the overall size of the market leading to additional environmental impacts and instead of reducing environmental impacts through successful competition with linear products, rebound effects may occur that increase the overall environmental impact of a product offering (Lüdeke-Freund, 2010; Zink & Geyer, 2017). Harris et al. (2021) warn to not push circularity just for the sake of circularity if it does not lead to any measurable environmental improvements. Saade et al. (2022) support this idea and suggest that circularity concepts should be used together with environmental assessment tools to ensure the environmental relevance of circular practices. Corona et al. (2019) suggest to categorically charge higher prices for circular products to avoid rebound effects and to utilize indicators considering both, environmental as well as economic indicators to estimate and prevent effects of potential rebound effects. Lastly, also the complete neglect of the social dimension as part of the CE debate is highlighted and criticised by scholars (Murray et al., 2017).

The wide range of criticisms of the concept of CE highlights that the danger of careless implementation of CE measures has the potential to backfire on all three fronts of the triple bottom line. Nonetheless, table 2-1 highlights the potential gains that can be achieved. While the implementation of CE principles does not automatically contribute to sustainability, it is undoubtedly a potential pathway to greater sustainability (Weissbrod & Bocken, 2017) and is even considered to be a necessary condition for achieving a sustainable future by some (Bakker et al., 2014 as cited in Geissdoerfer et al., 2017). However, the examples and recommendations show that careful planning and the recognition of overarching environmental assessments into the planning process of a circular strategy are needed to facilitate real environmental benefits.

2.3.1 Circularity strategies

In order to practically work with the concepts and principles of circularity, strategies are formulated to operationalize the theoretical contents, make them applicable to use cases and guide decision making. Mintzberg defines strategy as "a plan [that entails] some sort of consciously intended course of action, [...] to deal with a situation" (1987). Following this logic, circularity strategies can be understood as action plans aimed at overcoming the linear economic system of the present by consciously implementing the principles of the circular economy. These plans can meanwhile be implemented on different levels of the economic system with scholars arguing that a simultaneous implementation from the top (top down approach), including legislative changes and economic initiatives (Govindan & Hasanagic, 2018; Lieder & Rashid, 2016) and the bottom (bottom up approach), with efforts from private companies, is needed to implement the CE successfully (Lieder & Rashid, 2016).

As established by the definitions of circularity, the circularity strategies focus on resource streams. The framework developed by Bocken et al. (2016) defines three key strategies that facilitate circularity, namely, narrowing, slowing, and closing of the resource extraction loops. As a first strategy, narrowing describes the attempt to minimise the amount of resources used per product and manufacturing process. Slowing on the other hand describes prolonging the life of a product, while closing refers to the reuse of materials through recycling (N. M. Bocken et al., 2016). Examples of such strategies include the elimination of production waste (narrow), design for ease of maintenance or repair (slow), or design components, where appropriate, with one material to facilitate recycling efficiency (close) (Konietzko et al., 2020). Beyond this framework different approaches to strategies can also be found. In order to incorporate the role of material specificities and technological development, Konietzko et al. (2020) added the dimensions of regenerate and inform to the framework. Regenerate refers to the usage of renewable, and non-toxic materials and the usage of renewable energy, while inform refers to the usage of information technology to support circular development (Konietzko et al., 2020).

2.3.2 Circular business models

And while strategies make circularity actionable and are an important tool to guide businesses in their approach to become more circular, Hall & Wagner (2012) point out that in order to fully reap the benefits of your circular practices, business model innovation is necessary. Business models in themselves describe "the rationale of how an organisation creates, delivers, and captures value" (Osterwalder & Pigneur, 2010). They simplify the complex practices of a company's economic activities and break it down into the most fundamental elements. Osterwalder & Pigneur (2010) defined nine elements that outline key action fields that describe the underlying logic of how a business operates. The categories are value proposition, customer segments, customer relationships, key resources, key activities, key partners, channels, cost structure, and revenue streams. These elements are grouped into three overarching categories of value proposition, delivery and capture that jointly form a business model.

The changes that have to be made at the product level to align products with the CE principles inevitably impact how businesses create value (Brennan et al., 2015) and therefore influence the building blocks of the business model. By enabling a product to have a longer lifetime, a replacement for the product will be needed much later impacting the revenue streams of the business. While this may impact the traditional business model negatively, an innovative approach towards business model design holds the potential to open new revenue streams (Brennan et al., 2015). Instead of sticking to the traditional business model and selling circular products through a linear business model, the literature suggests adapting the business model in order to take advantage of the changed product characteristics. The change of one or more of the building blocks suggested by Osterwalder and Pigneur in an attempt to find novel ways of creating delivering and capturing value is known as business model innovation (Osterwalder & Pigneur, 2010). It is important to highlight, however, that the definitions of circular business models are not always clear cut. As such, Bocken et al. (2016) argue that while narrowing strategies have a positive impact on the circularity principles, they are also commonly applied in linear business models in an attempt to cut business expenses, without questioning the nature of the resource flows. Their true value as circular business model practice is therefore questionable. Multiple frameworks exist that attempt to guide the innovation process and focus on combining circularity strategies with business model archetypes to create circular business model archetypes (Bocken & Ritala, 2021) or to alter existing business model design tools (Lewandowski, 2016). While attributes and features like reverse logistics and increased collaborations are rightfully often mentioned in the context of circular business models, the ultimate decisive factor that makes a business model circular is the inclusion of a circular strategy in the offer, that is directed at altering material flows (Nußholz, 2017).

2.3.3 PSS and Servitisation

Out of all circular business model applications, Product-Service-Systems (PSS) are among those receiving most recognition by academia (Kühl et al., 2018; Stål & Corvellec, 2018). They are of significant relevance to BESS due to its product-centric nature and the proven nature of the concept which in itself can take many different forms. PSS is seen as either a subdomain (Kühl et al., 2018), or a comparable concept (Baines et al., 2007) to the concept of servitisation that evolves around the idea of integrating services to the traditional offerings of products (Oliva & Kallenberg, 2003). Responding to the changing needs among customers, and a progressing commoditisation of products (Kühl et al., 2018), the uptake of servitisation measures is predominantly seen as motivated by economic considerations. Meanwhile, the act of introducing services to the traditional product offer is considered to create a competitive advantage as services open the possibilities of additional stable revenue streams that accompany a product and can spread out over its entire lifetime. They furthermore have higher margins than products, are demanded by customers who ideally want to focus on core activities and are more difficult to imitate given their intangible and competence dependent nature (Oliva & Kallenberg, 2003).

PSS follow the same logic and describe the businesses moving from a product-centric business model to a service-centric customer interaction (Kowalkowski et al., 2015). In practical terms, the shift from a product to a service-focused business model means that instead of offering linear sales of a product, the PSS focusses on selling "integrated bundles" of goods and services (Vandermerwe & Rada, n.d.). Instead of relying on the utility provided through the product and its specifications, like in traditional product-centric business models, a PSS aims to address the needs of the customer through a strategically designed system of products, services, supporting networks and infrastructure (Mont, 2002). Differentiating the two concepts is the focus and motivation of the surrounding debate. Where servitisation is predominantly discussed in the light of economic improvement potentials, the debate on PSS has a strong focus on potential environmental benefits achieved through the shift to PSS offerings (Kühl et al., 2018). The key arguments for this are the increased resource efficiency of the respective offers through the business model's contribution to increased efficiency and the dematerialisation of value creation (Mont, 2002).

The nature of these product service bundles can meanwhile vary in the extent to which they rely on the sale of products or services respectively. Tukker, (2004) formalized this notion by identifying three categories of PSS, which all hold different characteristics and positions on the product-service continuum, defining the degree of either product or service focus of the offer. Product-oriented PSSs are mainly concerned with the sales of products, but the product offer is still accompanied or bundled with related service offers effecting its productivity or lifetime. Use-oriented PSS are also product focused as the availability of the product is at the core of their offer. At the same time the product ownership remains with the seller and the customer simply acquires the right to use the product. With result-oriented PSS on the other hand, the supplier and customer agree on a predetermined result with no product being part of the offer specifically.

These three archetypical business models have the potential to enable and support the circularity of an offer by creating room for the integration of circularity strategies. In product-oriented PSS offers, slowing strategies can be implemented in the form of supporting services that extend the product's life or maximize its utility. Meanwhile, use-oriented PSS offers contain ownership structures that allow for afterlife control over the product and its integrated components and raw materials by the supplier, simplifying reverse logistics and creating an interest in the owner to build, operate and maintain the product in a long-lasting way. The responsibility over the afterlife phase furthermore creates and interest of the owner to adapt design practices in a circular manner to facilitate unproblematic after-life handling. Lastly with result-oriented PSS offers there is no need for new product creation or definitions of their usage at all, as long as the desired outcome is achieved by the supplier. This model also ensures a maximum degree of professionalism in the use phase, allowing for maximum utility and longevity of the used products.

In line with the servitisation debate, the main benefit of a PSS for the supplier comes from its economic implications. Besides the aforementioned diversification of income flows, the new stable nature of income flows, the higher margins, the customer demand and the difficulty to imitate these new offers (Oliva & Kallenberg, 2003), PSS literature also highlights the collaborative nature in value creation with PSS that comes with the long-term relationships formed over the value delivery of a PSS (Linder & Williander, 2017). These relationships form naturally due to the shift from a transactional to a relational interaction between stakeholders, the lock in effects created by the service nature, and because frequent change is costly in multiple dimensions. This new and unique way of collaborating builds trust and fosters creative problem solving and innovation – not only in collaboration with customers but also third-party actors involved in the value creation process (Graça, 2021). It also leads to an improved and more in depth understanding of the customers' needs which can lead to better offers and is proven to increase customer satisfaction and therefore loyalty (Ardolino et al., 2016; Linder & Williander, 2017; W. Zhang & Banerji, 2017). Besides that, the end-of life control that is enabled through some PSS potentially allows for new revenue streams, especially with regards to a CE environment.

Environmental aspects are mainly discussed through the elimination of materials leading to less raw material extraction, improved material efficiency through professional operation and customised solutions, and the enabling of end-of-life control. The diverse nature of different PSS offers however shows that the degree of environmental benefits achieved largely depends on the individual case. In line with this, scholars in turn also warn that PSS in itself is no circular business model and that the degree to which this is true strongly depends on the integration of the circularity principles into the offers. Barquet et al. (2016) even warn that PSS can also have reverse effects on the environment if for example end-users are tempted to use products with less care as they do not hold ownership.

Social benefits are largely created through the altered relationship between the different stakeholders of a business interaction. The transition from a transactional business model to a relational one facilitates the formation of trust and a positive attitude between the players which is considered as an intrinsic social benefit (Rapaccini & Adrodegari, 2022) as well as an essential contributor to superior value creation (Graça, 2021). The close collaboration can furthermore contribute to joint learning and facilitate behavioural change with regards to the understanding of consumption overarchingly (Barquet et al., 2016). On top of that the aspects of local service delivery and the change in value capture add social benefits. As enhanced local service delivery becomes inevitable, the need for local personnel has the potential to create jobs locally compared to scenarios where the interaction does not exceed the delivery of a product. On top of that, the as-a-service nature, especially of use oriented PSSs, enables increased product availability under which a product can be made easier accessible for actors who cannot afford to purchase a product but can pay for the service (Barquet et al., 2016).

Despite the mentioning of benefits towards all three dimensions of the sustainability triple bottom line, servitisation and PSS, like circular business models, are not considered as sustainable business models in themselves. This is due to the aforementioned lack of necessary value provision to all three aspects of the triple bottom line of the concept itself. While both circular business models and PSS hold the potential to serve as a foundation of a sustainable business, their consideration as such depends on the final implementation and is not inherent in the concept itself (Barquet et al., 2016).

Sustainable business models are meanwhile understood as "an approach to creating […] business cases for sustainability" (Lüdeke-Freund, 2010). This refers to the process of integrating societal and environmental matters into the core business of the company (Schaltegger & Wagner, 2006), while the activities must exceed the regulatory minimum and be voluntary additions to the business model (Schaltegger & Müller, 2008). Sustainable business models therefore aim to reduce the negative impacts of the business operations on the environment and society, while simultaneously meeting the economic and sustainability goals of the company (Nosratabadi et al., 2019). Accordingly, this concept exceeds the ambitions of circular business models as they focus specifically on resource streams.

The potential of circular business models to contribute to all dimensions of the triple bottom line through the look at resource streams is highly interesting. Despite the absence of potentially hard to achieve requirements for the social aspect of the triple bottom line, engagement with circular business models is not necessarily easy, as it requires a complete rethinking of how to conduct business. At the heart of this is an adjustment in the logics of how value is created and the shifting of responsibilities. As a result of that, challenges occur that provide difficulties to the development of a CE. The challenges occur at three different levels: the supplier level, the product level and the customer level. Overarchingly the interactions between all three levels changes significantly with the introduction of circular business models (Antikainen & Valkokari, 2016).

For suppliers, the logic by which they provide value is changing, potentially challenging old habits of determining success. As such, it can be expected that the offering of PSS will cannibalise the traditional product offers as the switch from product sales toward service sales progresses (Beuren et al., 2013; Linder & Williander, 2017; Michaud & Llerena, 2011). On top of that, the distribution of risk can be expected to change. While economic risk in linear offers occurred up until the point of sales, the need and uncertainty of the value capture on the offer is now stretched over a prolonged time if the ownership strategy is altered. On top of that, this change in strategy would mean that the operational risk and liability arising from the product would now predominantly lie on the supplier (Beuren et al., 2013; Linder & Williander, 2017). Furthermore, new expertise would need to be developed to match the change in product characteristics, value proposition and risk distribution (Linder & Williander, 2017).

At the product level, supply chains would be the main component that changes. While linear offers only require one forward supply chain, circular offers also require reverse logistics (Antikainen & Valkokari, 2016). This highlights the need to alter the relationships and previously existing networks of the supplier companies (Antikainen & Valkokari, 2016). On top of that, challenges arise as not all products are suited to specific circular strategies (Linder & Williander, 2017). As the production in a CE largely relies on returned or recycled materials, it is challenging that the return flows are more difficult to predict in a circular system (Östlin et al., 2009). Given the design for longevity and changed interaction with products, companies are furthermore unable to adapt their products in line with demand changes and trends (Mont et al., 2006).

However, the challenges do not end with the suppliers, but also include and originate from the customers. To enable a CE, customers must overcome their resistance to change, as well as habits and practices that are learned over a long period of time. As such, they have to overcome the traditional tendency to own and engage more actively in service relationships (Beuren et al., 2013). While more intense engagement might be a downside of the CE economy from a customer's perspective, they benefit from the shifted responsibilities and risk and get access to tailored solutions.

To realise such circular PSSs, enablers are needed. Ambatha (2008 as cited in Bhattacharya et al., 2020) defines enablers as inputs and processes that facilitate a desired performance or result. While enablers can be found at different levels, it is the combination of multiple enablers that facilitates success (Bhattacharya et al., 2020). Operational and process excellence, unique products and services, entering of new market segments, value innovation, as well as capability and resources creation are all examples of enablers of lasting success in business (Bhattacharya et al., 2020). Meanwhile, one commonality that these factors have is a connection to or the fact that they can directly be influenced through the adoption of digital enablers. Key terms used to describe their role and purpose in that process are connectivity (Murugaiyan & Ramasamy, 2021) and transparency (Antikainen et al., 2018).

At the level of a PSS, several authors describe the adoption of digital enablers as follows: The usage of the internet of things helps to generate large amounts of data, also called Big Data, which can then be analysed with the purpose of making predictions and improve decision-making (Antikainen et al., 2018; Bressanelli et al., 2018b; Kagermann, 2014).

The data is therefore generated through the strategic deployment of sensors in and on the product from where the data is collected. Through the integration of microcomputers, which are connected to the internet (Kagermann, 2014), the data is then sent out for analysis. The data retrieved is typically information on the product's status, position, and usage (Antikainen et al., 2018; Bressanelli et al., 2018b). Due to the sheer volume of data, specific analytics and data mining programmes must be used for the analysis process, depending on the use case (Bressanelli et al., 2018b). The analysed data can then be used to inform different processes, such as performance monitoring (Antikainen et al., 2018), remote controlling, analysing the data to make predictions with regard to predictive maintenance, optimising the operation of the products, and the quality and time at which the products reach their end-of-life to facilitate return logistics (Pagoropoulos et al., 2017). Data can also be stored and used at a later time to inform remanufacturing (Antikainen et al., 2018), or it can be sold directly, opening up new market potential (Ardolino et al., 2016).

To summarise the product level applications, it can be said that digital enablers facilitate the collection, monitoring, controlling, analysis and optimisation of data (Antikainen et al., 2018; Murugaiyan & Ramasamy, 2021). This facilitates increased efficiency of the PSS delivery and an increase in the value of the respective offering (Ardolino et al., 2016). Furthermore, these applications can mitigate the challenges linked to the business model of the PSS, like operational risks, loss of ownership, willingness to pay, technology improvement and return flow uncertainties (Bressanelli et al., 2018b). On top of that, the utilisation of technological tools within a product enables the simple process of updating the product's software, which is oftentimes enough to prevent obsolescence of the product (Bressanelli et al., 2018b).

But also beyond the product level, the use of digital enablers has the potential to benefit the perceived performance of the PSS. As such, digital enablers can improve the satisfaction and therefore the expected durability of customer relationships by connecting suppliers and customers more efficiently. While these potentials undoubtably exist, it should be noted that they do not automatically materialise and lead to competitive advantages, as digital interactions between suppliers and customers are largely taken for granted (Cenfetelli, 2004). However, entire distribution channels can be virtualised with the help of digital technology and value can be delivered in new, virtual ways, with implications for the circularity motivated dematerialisation efforts and performance improvements (Antikainen et al., 2018). Rather than being a voluntary perk, digital enablers should therefore inevitably be utilised to achieve environmental and customer performance improvements, not only at the product level, but also to facilitate the customer journey.

2.3.4 Circular BESS

After reviewing the potentials and challenges of a transition to a more circular business conduct, this section explores what such a transition means in the context of BESS.

What circular BESS can imply

The previous review on circularity highlighted the potential, especially environmental and economic, that can be achieved through the strategic implementation of circularity strategies. Both of these areas are of significant relevance to the technology of BESS, given its high price, which is based on expensive components and input materials, and its environmental impacts, mainly from the battery. But what exactly circular BESS means remains unclear as no mainstream definition was found during the conduct of this project. Defining circular products overarchingly contains challenges as circularity is not an inherent attribute that a product either has or does not have. It is much rather understood as a guiding principle or a measure that determines the impact of a product or service on the circular economy (Corona et al., 2019). Measuring this impact is of relevance as it enables managerial and regulatory decision-making. Circularity metrices have been developed for that purpose as they attempt to quantify the theoretical concept of circularity (Corona et al., 2019).

Such metrics can generally be applied at different levels. At the micro level, the level of products, companies or single consumers, the meso level, the level of industrial parks, or the macro level, the level of cities, provinces or regions (Geng & Doberstein, 2008). At the product level, which is the most relevant level for this thesis, matrices and indicators look at material flows and supplement measures to arrive at one or multiple numbers or levels that assess the company's progress in developing a product that is in line with the principles of the CE (Ellen MacArthur Foundation, n.d.-a). Considering the existence of assessment tools that measure circularity performance on a product level, the definition of circular BESS should be consistent with the interpretation of the results of the tools. Going forward, circular BESS will therefore be understood as a BESS that contributes to the goals of the CE through the alignment of product characteristics with the CE principles as outlined on page 22. In line with the product level assessment, the attribute "circular" should hereby not be interpreted as something that is either given or not given, but rather as a level at which it contributes to the principles of the CE.

What exactly that means for BESS and how a circular or more circular BESS looks like has equally not yet been established. The last chapters highlighted that in order to design a circular offer, circularity strategies should be applied and incorporated alongside a suitable business model

(Kirchherr et al., 2017). Different models and frameworks are available to support the design process at both, the product and the business model level. The frameworks are directed at practitioners and suggest that design workshops and joint brainstorming sessions are a suitable setting to define potentials for circularity improvements and make design decisions on the product as well as the business model (Konietzko et al., 2020; Shahbazi et al., 2020). This highlights the practical and applied nature of the processes and shows the individual nature of the circular business and product design processes, which depend on the individual understanding of circularity and existing organisational resources and capabilities (Amit & Zott, 2010).

The circular design frameworks contain selections of circularity strategies that are suggested to guide the development process of the respective product and business model. Practitioners are targeted and asked to make an educated judgement on potentials to improve their products and business models based on the strategies suggested (Shahbazi et al., 2020). The different strategies are meanwhile grouped into impact categories that can be prioritised according to two suggested indicators (Bovea & Pérez-Belis, 2018). The margin of improvement, as well as the relevance of the improvement, were deemed relevant to serve as such prioritisation indicators, highlighting the most relevant fields of action for which improvements can be expected to lead to meaningful improvements in circularity and resource efficiency. The suggested prioritisation is in line with the aforementioned need to evaluate the environmental impact of a measure when implementing strategies or action steps towards circularity. Meanwhile, different authors suggest different categories of relevance. Bovea and Pérez-Belis highlight the areas extending life span, disassembly, product reuse, components reuse and material recycling and accompany the different indicators with questions that guide the evaluation process. Van den Berg & Bakker (2015) suggest future proofness, ease of disassembly, ease of maintenance, reproducibility of parts and recyclability as indicators. All these strategies are very specific and can be used to guide the development of individual offers.

Product level sustainability of BESS

The academic coverage on sustainability features of BESS as a product or PSS is still in the developing stages. Out of 5,427 articles on Scopus that contain the search terms BESS and battery, 187 are concerned with sustainability of the system[16] and 9 articles contain the search terms BESS, battery and circular[17], but are rather locating it as a circular measure for the handling of Li-ion batteries as opposed to analysing the circularity performance of the product BESS itself. Despite the lack of literature on product level circularity assessments of BESS, the literature looking at BESS as a potential technology for the reuse of Li-ion batteries from EVs is extensive.

In order to foster sustainable development of electrified mobility, a sustainable handling of their batteries needs to be established. Several authors discuss the optimal handling of EV batteries from a circularity perspective (Albertsen et al., 2021; Sheth et al., 2023). Many authors put forward the notion that in order to enable circular treatment of Li-ion batteries, recycling is the inevitable treatment for the EOL phase, but state that prior reuse decreases the environmental impact of the product significantly and should be pursued as a first treatment option before closing the resource extraction loop (Ahmadi et al., 2017; Ali et al., 2021; Curtis et al., 2021; Hua et al., 2021; Melin, 2019). This practice is in line with the hierarchy suggested as part of the technical cycle proposed by the Ellen MacArthur Foundation and reflects the CE principle of cycling materials at the highest value possible. The arguments for such a hierarchy of practices are not just backed by theory but follow the practically proven arguments in favour of the CE as an approach for generating environmental and economic benefits (Hua et al., 2021; Melin, 2019). A report published by a

[16] Search terms: "BESS AND battery AND sustainab*". The search was conducted on the 11th of April 2023.

[17] Search terms: "BESS AND battery AND circular". The search was conducted on the 11th of April 2023.

government affiliated organisation (the national laboratory of the U.S. Department of Energy Office of Energy Efficiency & Renewable Energy), describes extensive reuse of EV batteries is described as a desirable practice as it is anticipated to strengthen domestic businesses and create local jobs, reduce the dependence on raw material imports, reduce the disposal of reusable products, reduce environmental impacts, lead to cost savings, increased profits, enhanced competitiveness and increased trust in secondary market products (Curtis et al., 2021).

It is furthermore recognised that the continued usage of their batteries holds potential benefits to the owners of first-life batteries. The benefits for them are summarised in table 2-2.

Table 2-2. Potential benefits for battery owners from engaging with second-life BESS

Arguments for battery owners to engage with second-life BESS		Source
Residual value	Additional income can be generated through the sale of the batteries or the development and sale of second-life BESS.	Mustafa et al. (2021)
Legal requirement	The batteries directive 2006/66/EC: The responsibility for after life treatment (recycling and disposal) of batteries (lithium-ion batteries) is on the party introducing the battery to the market. An update of the EU's batteries directive (battery regulation) is currently under development. This will likely consider BESS and accept repurposing as a form of EOL treatment.	Directive 2006/66/EC Prop. 2019/1020
Reputation (risk avoidance)	Batteries are considered as hazardous waste. Mishandling can cause environmental and health damages (Zhu et al., 2021). Reputational losses due to waste disposal risks can be mitigated through responsible end-of-life treatment.	Ahmadi et al. (2017)
Reputation (gains through innovation)	Engagement with innovative end-of-life solutions may positively impact the OEMs reputation.	Huang & Li (2017)
Recycling delay	Second-life applications delay the EOL treatment giving recycling technologies time to mature. Potentially positive impact on economic and environmental performance of recycling tech with the potential to making recycling profitable.	Ali et al. (2021)
Lower prices for first-life applications	There is potential to increase the competitiveness of the first-life battery application through price reductions enabled through the added revenue streams in its second life.	Martinez-Laserna et al. (2018)

Source: see table

LCAs on Li-ion batteries and BESS confirm and emphasise the focus on the battery, as the battery is by far the BESS component with the highest level of global warming potential (Ahmadi et al., 2017; Gutsch & Leker, 2022; Sadhukhan & Christensen, 2021). The studies are unanimous in their result that the battery is where the environmental hotspot of the BESS lies. Beyond the classical LCAs, Koese et al. (2023) highlight that battery manufacturing is also associated with intense negative social impacts that are largely related to the raw material extraction and working in close contact with chemicals. Martinez-Laserna et al. (2018) furthermore show that the costs connected to the battery are also the main cost contributors to BESS overarchingly. Besides having the largest environmental impact, batteries therefore show to have the largest social and economic implications as well. Accordingly, the desired circularity improvements should focus on this component of the BESS predominantly.

The previously mentioned reports on the positive contribution of the re-use of used batteries from mobility applications offer a solution with proven environmental improvements. By utilising refurbished batteries, the need for additional raw material extraction is limited to the maximum which is fully in line with the circularity strategy of narrowing the resource extraction loop for the

BESS. Simultaneously, by offering a second-life application for the batteries, the reuse process slows the resource extraction loop for the implemented Li-ion battery. This practice of value maximisation therefore contributes to the second principle of the CE (circling materials at the highest value) and is an important strategy for creating a more circular BESS by focussing on its most impactful component.

While the use of second-life batteries has a positive impact on key impact categories, particularly those related to the extraction of raw materials and the manufacturing phase, it is important to note that the refurbishment of the battery poses certain challenges. Risks arise during the process itself, which consists of the identification and collection of used EV batteries from their owners, the transport to central depots, sorting, disassembly, testing of the modules or cells, reassembly and packaging (Ahmadi et al., 2017; Hua et al., 2021; Koese et al., 2023). These risks take the form of regulatory, safety and profitability risks, but can also extend to social risk. All risks have to be carefully considered when implementing the suggested second-life solutions. Furthermore, the environmental dimension is not unanimously positively impacted, as the benefits described from the usage of second-life batteries come at the cost of potential negative impacts on "metal depletion" (Ahmadi et al., 2017). As the practice of prolonging the life of the batteries prevents them from immediate recycling, less recycled material is available for the production of new or replacement batteries for EVs. The closing of the raw material extraction loop is therefore slowed through the practice of reuse. For the product of BESS, using second-life batteries aligns with the first and second principle of BESS as it avoids the creation of additional waste by eliminating the need for additional raw materials for the battery and furthermore presenting opportunities for the cycling of previously used batteries at their highest value. Reuse therefore seems to present a more circular option to the usage of virgin batteries.

Beyond the usage of second-life batteries for BESS, literature highlights additional best practices for the design of more circular BESS offers. Xie et al. (2022) highlight that professional operation impacts the lifetime of the BESS. Prakash et al. (2022) highlight the importance of correctly sizing the BESS infrastructure as oversizing and overvoltage can cause inefficiencies by requiring too many raw materials. On top of that, Silvestri et al. (2022), recommend the coupling of BESS with renewable energy production sites as the integration of the systems leads to the biggest emission savings. Finally, specific product level recommendations are given by Sadhukhan & Christensen (2021) based on their LCA findings. They support the theoretical claims made by the circularity strategies and call for extended life of the batteries through careful and professional operation and point towards the significant positive impacts of recycling, especially for the cathode materials of the BESS batteries. Beyond that they recommend that also non-battery components should be sourced from second-life sources, and that application stacking for increased utility achievements.

These findings show that while reuse is relevant for all components of BESS, a clear focus should be put on the batteries of the system. The usage of second-life batteries prevails as the most impactful and relevant component of BESS for the application of circularity strategies. In addition, the literature review shows that professional operation, together with the provision of reverse logistics in the end-of-life phase, is a significant factor in reducing environmental impact (Kühl et al., 2018). Given the need for a fitting circular business model to support and leverage the value delivery created by the circular product, a high level of servitisation along reverse logistics is highlighted. Given the aforementioned benefits of PSS, literature points towards second-life BESS that should be offered as part of a use-centric PSS, as this facilitates reverse logistics and enables professional operation of the system. The notion that customers perceive higher risk and therefore show lower acceptance for remanufactured products has shown to be mitigated by the transfer of ownership (Roy et al., 2009) and the convenience of non-ownership (Akbar and Hoffmann, 2018), supporting the call for PSS as a desired ownership model.

2.3.5 Theories and Concepts

The literature review highlighted that BESS holds features capable of positively contributing to solving the electricity grid's flexibility issues created through large scale electrification and the simultaneous increase in reliance on renewable electricity production. But as BESS production comes with own sustainability challenges, the successful adaptation of a circular BESS offer seems desirable to meet the demand for BESS while mitigating its impact. While the details on what makes an adaptation successful in this context are debatable, customer acceptance and competitiveness are thought to be important factors for sufficient adaptation of a given circular BESS offer (Casadesus & Ricart, 2011). As this thesis aims to inform practitioners and enable the successful creation of circular business offers, it is of interest to investigate academic approaches towards circular business model design especially focussing on the two factors mentioned above.

Business models are designed around the logic of creating, capturing and delivering value (Osterwalder & Pigneur, 2010). Value, in this case, is understood as both, the solution to a customer's problem (Hsieh et al., 2007) and the price paid by the customer for the solution to the problem (Linder & Williander, 2017). A business interaction therefore creates value for both parties involved, the solution to a problem on the side of the customer and monetary value for the supplier. What this logic shows is that the customer is the central stakeholder in conducting business and the central figure in all business models. Given the power of the customer in this construct, literature describes a growing influence of the customer-centric philosophy in marketing (Tueanrat et al., 2021) and a need for successful companies to develop a customer-centric business culture (Brady & Cronin Jr, 2001). The customer-centricity is therefore described to aid the business model development in two phases: the design and the improvement phase. In the design stage, focussing on customer perceptions primarily facilitates understanding of expectations and needs from customers (Tueanrat et al., 2021). Given the goal of businesses to deliver value by addressing needs of customers, understanding their perception is essential. This can be particularly important in service and product-service relationships with a desire to build long lasting relationships that go beyond onetime purchase of a product. The question is how this longevity in customer relationships can be assured. One key component for continuous engagement with a supplier is the indicator customer satisfaction. Satisfaction overarchingly is a measure that reflects the perceived performance of the supplier by the customer (Tseng, Qinhai, & su, 1999). It is created when the value delivered aligns with the customer's expectation (Tueanrat et al., 2021). Especially the term “perceived” or perception in general, shows that the experience of the customer is extremely important in the achievement of satisfaction and therefore long-lasting relationships (Koetz, 2019; Marino & Presti, 2018). The importance of customer experience is reflected in a large body of research concerned with the topic of customer experience.

This line of argumentation highlights the relevance of the customer-centric perspective for business model development (Karimi & Walter, 2016) and its relevance for this project. This justifies the customer-centricity of the research questions defined and therefore the focus of the qualitative analyses.

While the importance of customer experience has been highlighted, it is furthermore relevant to explore how it can effectively be managed. Literature tells us that the perception of a company is continuously adjusted at every touchpoint between the company and its respective customer (Meyer & Schwager, 2007). Touchpoints can be understood as individual interactions between the customer and parts of the company or its offerings (Maechler et al., 2016). These can occur either directly with representatives of the company or indirectly, for example through advertisement (Meyer & Schwager, 2007). These touchpoints are the main components of customer journeys, a method that visually illustrates the relationship between the customer and the company through a depiction of all encounters between the two parties. A customer journey is defined as the “process or sequence that a customer goes through to access or use an offering of a company” (Følstad &

Kvale, 2018). The concept of the customer journey is powerful because, rather than managing the customer experience at the level of an individual touchpoint, it recognises the holistic nature of the customer's interactions with a company and approaches the customer experience from a holistic, end-to-end perspective that allows for real understanding of the customers experience (Maechler et al., 2016). Customer journeys are established through the gathering of internal insights on these interactions which are then coupled with customer perspectives, which together inform the creation of the visual representation of the journey (Temkin, 2010). The strength of the journey lies in its tangible nature which allows the company to view the holistic journey and by including customer perspectives, allow to take an outsider's perspective and identify potential improvements through the eyes of the customers. By telling an engaging story that represents the customer experience, a switch of perspective is enabled, and valuable insights can be gained (Stickdorn and Schneider, 2010). Today, wide uptake of the concept in the non-academic world can be observed hinting towards implementation of the recommended customer-centricity in business practice. Personal communication (Customer Experience Manager at Volvo Group, March 07, 2023) revealed that entire teams are devoted to understanding, capturing and integrating customer perspectives into business practices. There are also numerous offerings of customer journey mapping tools and guides can be found on the internet, including integrations with common working tools such as Miro or SurveyMonkey (miro, n.d.; SurveyMonkey, n.d.).

Despite the strengths, customer journeys also hold a risk of oversimplification, as the responses collected from customers can be complex and potentially different from one respondent to another, also depending on the context (Tueanrat et al., 2021). Hence, oversimplification of the journey is a risk that limits the practical usefulness of the tool. Beyond that, Temkin (2010) warns that the employees of companies creating the customer journeys tend to project themselves with their skillsets and perceptions into the touchpoints of the customer journey. This holds the risk of creating wrong impressions, leading to overwhelming service design. Another customer-centric tool, customer personas, could potentially help overcome these risks (Temkin, 2010).

While a customer journey can guide the development and improvement process of an offer with the goal of creating a satisfying customer experience, in order to develop a customer journey, one has to know who to target (Halvorsrud et al., 2016). Knowing who to target is important considering the complexity of customers' experiences and responses, and the fact that there is no ultimate service design that fits all customers and contexts (Stein & Ramaseshan, 2019). As such, the same touchpoint can impose different effects on different individuals, and it is therefore of relevance to understand and capture the context and motivation of different customer groups to engage. Maintaining and institutionalising this focus is important as it appears to conflict with the traditional process of engineering, which is described as developing the product before developing the supporting services in an intuitive process (Cavalieri & Pezzotta, 2012). This way the full potential of value creation is never reached as customer and user perceptions are neglected (Cavalieri & Pezzotta, 2012) leading to unfulfilled expectation and therefore a compromised experience.

Customer personas are archetypes of user groups that synthesise their goals and behavioural patterns (De Marsico & Levialdi, 2004). The fictional representations of these different users or customers represent typical behaviour (Fergnani, 2019) and can provide value to all stakeholders involved (Temkin, 2010). Typical applications of the concept are either in the marketing domain (Micheaux & Bosio, 2019) or in user-centric design (Fergnani, 2019). Literature highlights the benefits of customer personas in creating a foundational and a common understanding of different customers across the organisation. Meanwhile, they are considered superior to archetypes as they are based on research and less static (Micheaux & Bosio, 2019). Personas are commonly mentioned in customer journey literature as they allow for a stronger customisation of the journey creation process (Märtin et al., n.d.). In order to inform the findings in the most precise way, personas must contain the key motivations and needs of a customer to inform the journey creation and inform decision making (Modha, 2023).

The creation of the persona can meanwhile be based on observations and interviews (Temkin, 2010), as well as existing material and internally known features of personas and customers (Carleton et al., 2013; Pruitt & Grudin, 2003). Fergnani (2019) introduces the concept of future personas, which are depicted as scenario-specific personas that in this form do not yet exist and are shaped by the circumstances and external factors around them, making for a specific scenario. In the case of BESS, however, the customers are future customers in the sense that they have not yet made a purchasing decision. Nonetheless, the customers and potential customers with their preferences and perceptions do already exist. It is therefore much rather the scenario and the business case that is yet to be shaped.

2.3.6 Summary

The literature review has shown that the technology of BESS holds features that are unique among established energy storage technologies and can generate significant benefits to the grid as well as to its end-users. One way to improve the environmental performance of the technology is to implement circularity principles, facilitated through the implementation of circularity strategies and supported by the deployment of circular business models. For BESS it has been shown that the environmental hotspot is at the battery. While literature suggests that decisions on the adoption of circularity practices should be made specific to the respective context, multiple aspects were identified as foundational for a circular BESS offers. Given that the environmental hotspot of the system lies in the battery, multiple sources point to the use of second-life batteries, and therefore to a slowing strategy aiming to slow the extraction of raw materials by reusing batteries as an essential way to increase the products circularity. Beyond the reuse of li-ion batteries, use-centric PSS business models emerged as a supposed best practice enabling optimal circularity through the facilitation of clear ownership structures in the EOL phase. Additional findings point to the availability of service options that are capable of slowing the product degradation and enable superior economic performance. The feasibility of these practices remains questionable. Gathering data and facilitating optimisation processes along the value chain for front-of-the-meter applications, the role of digital enablers was found to be crucial in enabling respective circular offers and facilitating remote services. And while the existing research highlighted BESS as a viable application for second-life batteries, the circularity perspective on BESS as an independent product, not as an extended part of the battery lifecycle which neglects components beyond the battery, was found to be less developed. The research questions

RQ1: What constitutes a feasible circular BESS offer to the European C&I sector?

RQ2: How can digital tools be used to enable a feasible customer journey for a circular BESS offer to the C&I sector in Europe?

are therefore considered as relevant in contributing to the goal of the thesis, which is to add knowledge to enable the construction of more circular BESS offerings.

Meanwhile, customer-centric approaches to circular BESS analysis were identified as essential, given the central role of customers in all business interactions. Perceived value adds must be recognised as such by the customers in order to facilitate market uptake. Customer journeys emerged as a powerful tool to plan and map the interactions between the supplier and the customer in a holistic way, specifically focussing on to customer's perspective. To address to the complex and highly individual perspectives of market participants, customer personas have furthermore been identified as value adding.

3 Research Design, Methods and Materials

This chapter outlines and presents the approach and methods chosen to answer the previously defined research questions. It introduces the research design before presenting the methods used for data collection and analysis.

3.1 Research Design

Aiming to uncover knowledge that helps improve the development of more circular BESS solutions, this thesis follows the logic of inductive knowledge creation. The research puts practitioners at the centre and uses them as the main source for primary data generation. Qualitative research was conducted in an approach to understand practitioners' problems and perspectives (Creswell & Creswell, 2018) and to derive generalisable findings.

Furthermore, a transdisciplinary approach was chosen, as transdisciplinary research has been highlighted as particularly powerful in addressing real life problems. This is described to be achieved by eliminating knowledge gaps through the involvement of different disciplines (Aboelela et al., 2007; Wickson et al., 2006), and applies to problems that are both societal and concurrently scientific (Lang et al., 2012). This thesis therefore utilises concepts, theories and frameworks from the fields of business, sustainability science, and information technology in an attempt to generate solution-oriented and transferable knowledge with high legitimacy (Lang et al., 2012).

Given the problem-centric research approach, this thesis follows the pragmatic worldview that focusses on actions and consequences and considers "what works" as truth (Creswell & Creswell, 2018). To solve the problem defined in Chapter 1.1 those methods that "best meet [the researcher's] needs and purposes" (Creswell & Creswell, 2018) were chosen, along with pluralistic approaches to tackle the issue at hand in the most adequate way possible. That is of particular relevance for this thesis as it combines social scientific research with a high degree of technical elements.

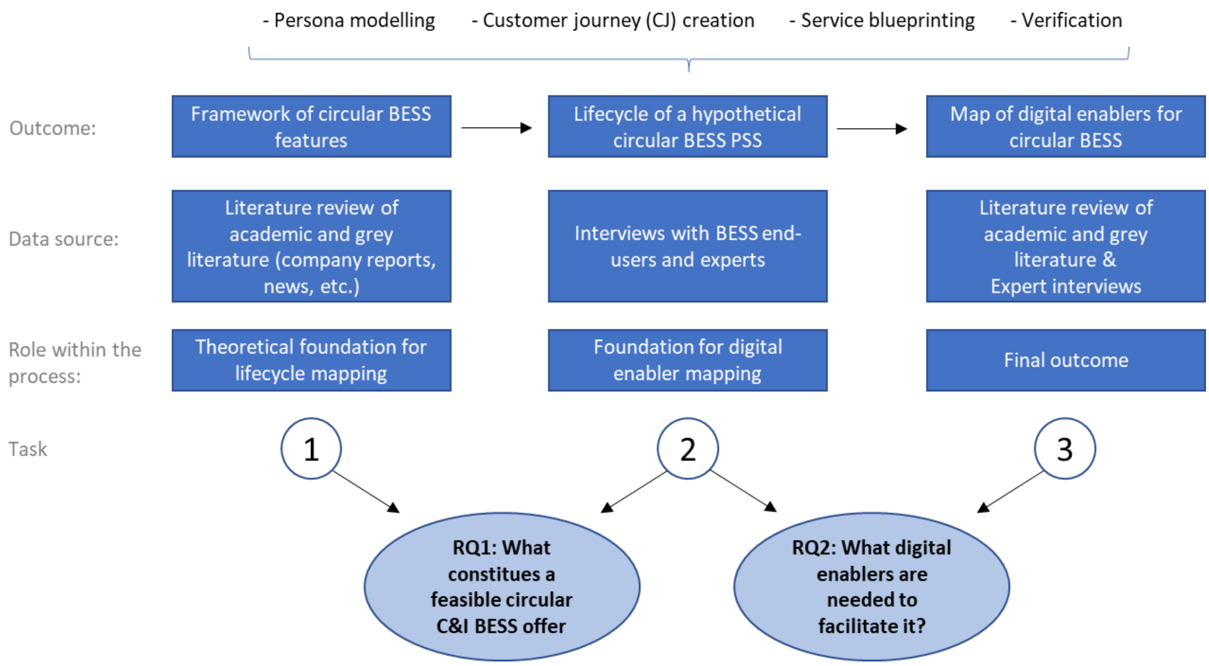

Figure 3-1. Research design

In order to adequately address the constituents of a circular BESS offer in a holistic manner, it was considered important to understand the complete life cycle of a BESS with its technical elements, information streams and stakeholder interactions. Therefore, a three-step approach has been developed, with each step creating one or more outcomes that contribute to the understanding of the life cycle. The individual steps prepare and jointly contribute to the life cycle and enabler map of a circular BESS offer in Appendix 8.

The first step of the research process consists of a literature review conducted to define features of circular BESS offers. As it was observed that there is little evaluation of circularity aspects of BESS on the level of the individual offer, a comparative overview over the differences of theoretical and practical implementation of circularity strategies was created. For that, the literature on circularity and resource efficiency strategies was scanned and mapped in a table where theoretical circularity strategies were sorted along the lifecycle stages as defined by the ISO standard 14001 (ISO, 2016). After that, real life practices of existing BESS offers were analysed and sorted in the same way. These frameworks (Appendix 1 and 2) provide value in a three-folded manner. Firstly, the analysis shows what is circularity improving strategies are theoretically possible; secondly, they map the status quo by indicating which circularity practices are considered practically feasible; and thirdly, by mapping the current practices against the theoretical knowledge of circularity theories, improvement potentials are highlighted and a foundational understanding of what is currently possible is created as a baseline for the following steps of the research design.

The second step consists of the application of an adjusted version of the Service Engineering Methodology (SEEM; Pirola et al., 2022). The SEEM was developed as a collection of tools to map and develop PSSs in a customer-centric manner, among others combining the aforementioned concepts of customer journeys and customer personas. It traditionally consists of a customer need analysis phase, a solution definition phase, a process design phase, a validation phase and the implementation and monitoring of the offer. The adjustment lies in two changes. First, the proposed "Product Service Concept Tree" method, which makes up the solution definition phase, is replaced as the solutions that the hypothetical PSS is centred around are defined by the findings of the first step of the proposed research design. The second adjustment lies in the abandoning of the offer implementation step, given the theoretical nature of this work. The SEEM was developed in close collaboration with practitioners and has been chosen as the methodological foundation for step two because it considers the potential impact of different customer personas and utilises service blueprinting for the creation of PSS frameworks. Service blueprinting is practically oriented as it builds on the established customer journeys and maps a company's internal processes needed to enable the desired customer journey (Bitner et al., 2008). Its detailed nature of the analysis of practices is well suited to map digital enablers.

Given the previously established essential nature of digital enablers to the delivery and optimisation of PSSs and the technology of BESS, these digital enablers are mapped in a third step. Talks with practitioners (representatives of Volvo Energy, personal communication, March 14 and 16, 2023) further defined the need for such knowledge and highlighted the important indicators of data needs, data owner and digital tools as important factors for the PSS development. These categories integrate seamlessly with the service blueprinting process and the SEEM methodology was extended accordingly. While the research design presents the PSS creation (step two) and the digital enabler mapping process (step 3) as two distinct action steps, both the service blueprinting and the digital enabler mapping will be presented jointly in the findings (Section 4.2) as the digital enabler mapping builds directly on the service blueprint.

To inform these different steps, a qualitative and exploratory multiple case study approach was chosen. Given their relevance for understanding contemporary phenomena in their applied contexts, case studies emerged as the method of choice. Multiple case studies were selected to triangulate the findings and generalise theoretical constructs and findings (Eriksson & Kovalainen, 2015).

3.2 Data collection

Two different data sources and methodological tools have been utilised to collect the data for the four different tasks. A review of literature was conducted to inform tasks one, two and three, while in addition to that interviews have been conducted to inform tasks two, three and four. Driving forces for the utilisation of multiple sources were the increase of the internal validity through data triangulation and the possibility to derive complementary information.

3.2.1 Literature

The literature review used two types of literature. Academic literature, predominantly used to complement and verify the findings compiled from task four and RQ2 respectively, and company websites and materials used to inform task one and RQ1.

The academic papers reviewed for task four were selected in a targeted manner to map digital enablers for specific practical processes. The literature has been retrieved from Google Scholar and the Scopus data base.

For the review of company information on BESS offers, as a means to conduct task one, offers of 28 different companies were analysed. In an initial step, a list of 15 second-life BESS companies operating in Europe was received from Volvo Energy and the offers of all companies analysed. The analysis focussed on official company websites as well as product offer sheets and additional freely available information material, like presentation slides. Assuming that not only second-life BESS suppliers apply circularity strategies, 12 additional first-life BESS companies and one battery manufacturer were added to the scope. The companies were selected based on judgement sampling (Marshall, 1996) following a search for BESS suppliers using Chat GPT.

3.2.2 Interviews

Interviews were selected as the second method for data generation in this thesis as they are considered to be one of the most essential sources of evidence for case studies (Yin, 2014). Interviews with individual representatives of end-user and customer companies have been conducted to inform the tasks two and three. They were chosen as a suitable method for data generation as, especially in the form of semi-structured interviews, they allow for understanding and capturing of the interviewees' perceptions of the world and the circumstances studied (Qu & Dumay, 2011). Furthermore, the semi-structured approach provides guidance while also allowing for flexibility and capturing hidden behaviours and attitudes through selective deviation from the interview guide (Qu & Dumay, 2011). The sampling method for the interviews was purposeful, selecting participants who were considered to be best suited to inform the research questions (Creswell & Creswell, 2018) and criteria-based. It was decided that existing second-life BESS end-users would be best suited as interviewees to this project, as they represent a group that has chosen a greener BESS system and experienced second-life BESS customer journeys. The information obtained from this group is therefore grounded in practical experience and perceived as highly relevant to the project.

In order to contact these actors, the websites of all known European second-life BESS providers have been searched and all reference cases contacted. In total, a purposeful sample of 63 companies was identified, from which 56 companies were contacted. No contact information could be found for the remaining 7 companies, which led to their exclusion from the sample. To increase the likelihood of a positive response, individual leads within the company were identified and invited to participate in the research project. In cases where no individual leads were found, the company was contacted through their official communication channels directly. In total, two rounds of outreach were conducted. One for the initial invitation and one to remind those who have not yet responded. This way, twelve interviews with representatives of BESS end-user companies from five different countries, Norway, Sweden, Germany, the Netherlands and England were conducted in English (seven) and German (five). The full list of interviewees can be found in Appendix 3. Three exceptions apply among the twelve interviewees. Over the course of the interview, it turned out that one customer (I3) had not yet installed its BESS at the time of the interview. As the interviewee experienced the decision-making process and was in contact with suppliers, the data generated was still considered relevant and valid and therefore included. A second end-user forwarded the interview request to its BESS operator and claimed that the operator will speak for the end-user in this matter (I10). A third interview was significantly shorter than the others due to limited availability of the interviewee (I12). This led to the situation that not all topics of the interview guide were covered. All three interviews were still included in the analysis.

While it was initially planned to record all interviews given the interviewees consent, it was quickly noticed that the recording had an inhibitory effect on the willingness of interviewees to share information. It was therefore decided to not record every interview and switch to a method of writing interview scripts immediately after the interviews. While most authors suggest recording the interviews to prevent systematic biases (Nordstrom, 2015; Tuckett, 2005), it is acknowledged that not recording can be the better option under specific circumstances, provided there is a valid justification (Rutakumwa et al., 2020).

Over the course of the interviews, it became apparent that besides the end-users, also external planning offices for holistic energy solutions played a major role in the BESS customer journey. It was therefore decided to also conduct interviews with representatives from this stakeholder group. Due to time constraints, it was decided to contact the partners of the initial interviewees for this cause, which led to an interview with one planning office (I14). On top of that, a semi structured interview on the same topic was conducted with an external energy solutions consultant (I13). For both additional interviewee groups, the interview guide was slightly adjusted.

For conducting task four, all known existing second-life BESS suppliers from Europe were contacted and invited for an interview. In total, 15 companies were contacted and one interview with an existing second-life BESS supplier (I15) conducted. The interview was conducted online in a semi-structured manner and not recorded. Due to the limited number of participants from the second-life BESS suppliers, a second semi-structured interview with the planning office (I14) and one unstructured interview with an internal expert from the Volvo Group (I19) were conducted. The interview with the planning office was conducted remotely and not recorded, whereas the expert interview with the participant from the Volvo Group was carried out in person.

Besides these interviews, four additional interviews with Volvo Group internal experts were conducted to prepare for the interviews with end-users and enable the persona and customer journey mapping process. These interviewees were purposefully sampled with the interviews being conducted in a semi-structured fashion. One of these interviews were held in person, four were conducted remotely and none of these interviews were recorded.

This results in a total of 20 interviews with the experts described, conducted over the course of the project.

3.2.3 Previously generated primary data

A third form of data used to inform the findings is primary interview material that has been collected as part of a pre-study (Redmond et al., 2022, pp. 72-83) that was conducted as part of a 'graduate study-program consultancy project' conducted with the IIIEE MSc program, which was carried out in collaboration with Volvo Energy prior to the thesis project. The primary material consists of transcripts and recordings of interviews conducted with potential BESS end-users in Sweden in October 2022. The author was part of this research project (which involved a team of three graduate-students, and a IIIEE supervisor) and conducted several of these interviews himself. The consultancy project was conducted in a collaborative fashion with Volvo Energy, but at distance, and not under the terms of an NDA. The primary material was accessed to identify relevant key customer segments and draft personas based on the available data. Relevant dimensions and themes for the development of the interview guides were identified to inform the creation process of the interview guide for the end-user interviews. This step was recommended by a customer experience expert of the Volvo Group (I20) and considered important due to the limited time available to conduct each end-user interview and the wide range of topics covered. High quality interview guides and a maximum level of preparation were therefore recommended.

3.3 Data analysis

Different methods of data analysis were applied depending on the nature of the material and the desired outcome.

After reviewing different frameworks of circularity strategies, the framework by Konietzko et al. (2020) was chosen as a foundational framework informing about the academic status quo. It stood out because of its tangible, applicable nature and great level of detail matched the descriptions of the company offers well. The individual strategies were organised along the life cycle stages of ISO 14001 (ISO, 2016) and used as a reference for the applied practices.

The data on these practices, retrieved from the individual offers of second-life BESS providers, was initially collected and organised in a synthesis matrix. Again, the ISO 14001 life cycle stages were used as themes to organise the data (ISO, 2016). After collecting and organising the data accordingly, the identified strategies and practices were analysed against the strategies proposed by Konietzko et al. (2020). Although being designed as a tool for brainstorming sessions in an organisational context to support the development of circular business models, the applicability of the strategies to the context of BESS was largely given.

The primary data retrieved through the pre-study was also analysed with the help of a synthesis matrix. Here the themes were derived inductively through the identification of relevant and reoccurring topics. These themes or relevant dimensions were then used as a foundation for the creation of the customer persona section of the interview guide and served as a foundation for persona creation overarchingly.

The interviews were analysed using qualitative content analysis (Mayring, 2004). The coding schemes were deductively created and following the predetermined dimensions of relevance for task two, the life cycle steps for task three and the predefined supporting services for task four. The process behind the analysis of data retrieved for the answering of each of these questions was identical for all cases. After each interview, the interview was transcribed with the help of notes and recordings. After all interviews were conducted, the transcripts were holistically reviewed to create an overview, before being analysed and coded (Creswell & Creswell, 2018).

The results of the targeted literature review, applied for answering RQ2, were systematically collected and organised in a synthesis matrix along the predetermined supporting services identified as part of the preceding service blueprinting. The structure was deductively applied and not changed over the course of the review.

4 Findings and Analysis

In the following chapter the results of the established tasks will be presented and analysed in an intertwined manner. Section 4.1 covers the findings of task one, the circularity strategy mapping, section 4.2 is concerned with the customer personas, section 4.3 covers the customer journey while section 4.4 presents the service blueprinting and the mapping of the digital enablers in an intertwined manner, given the close thematic and methodological fit between the two concepts and the derived findings.

4.1 BESS providers' approach towards circularity

On the theoretical level, the operationalisation of the CE principles is achieved through the combination of circular business models, determining a company's approach towards value creation, delivery and capture and the product level implementation of circularity strategies. After reviewing the academic status quo on circular BESS as part of the last section, practical approaches towards circularity will be delineated and compared with theoretical frameworks, highlighting areas of practical focus and theoretical gaps in the industry's approach.

4.1.1 Business model

The analysis of 25 different BESS offers showed that most BESS suppliers follow a product-centric approach in their offers. In fact, all 25 companies analysed sold their products as part of a one-time, linear transaction. It stood out that most companies offered several BESS products, which differed mainly in capacity and casing (e.g. Eco-Stor, BeePlanet factory, Lithion Battery) and were marketed to target different end-user segments. Out of all offers analysed, only the company Connected Energy visibly offered the possibility to acquire their C&I BESS in the form of an as-a-service model - an alternative to the linear sales model that was also offered by the company. In both, the linear and the as-a-service offer, the products offered were identical. Connected Energy clearly positioned their as-a-service model as an alternative financial model that alters the financial structure of the transaction from one in which the capital expenditures (CapEx) dominate to one that increases the operational expenditures (OpEx) of the customer but limits the customers CapEx. While mentioning benefits such as flexibility, the holistic nature of the services offered and the performance guarantee that comes with the use-centric PSS and overlap with the benefits defined in literature, such as reduced risk and shifting responsibilities to the supplier (Baines et al., 2007; Mont, 2002), especially implications on the ownership situation with its effects on the responsibilities for reverse logistics in the EOL phase are not mentioned. While companies offer warranties on their products sold in a linear fashion, ownership considerations over batteries in their EOL phase were not mentioned by any supplier. That notion was also confirmed through the interviews in which all end-users except one (I9) stated that the topic of EOL treatment was not discussed with their BESS supplier. I9 stated that the EOL phase was discussed between the two parties, but no contractual agreement was ultimately reached. I9 added that uncertainties over future cost developments prevented an agreement on EOL ownership and both parties agreed to postpone this discussion. While no explicit agreements were reached between suppliers and any of the customers interviewed, all customers stated that they expect the battery packs to be recycled after their utilisation in the BESS and that they furthermore expect the supplier to take care of the logistics and facilitate EOL treatment. However, it should be considered that a battery within a BESS can reach its end of life for a specific customer in different ways. One constellation would be that the cell or module is replaced due to a loss of capacity. A second possible scenario is that the end-user decides to stop operating the BESS. As the replacement and continued operation is expected to be the main case, it seems logical and unproblematic for the BESS supplier to take care of the old battery when replacing the new one according to the customers interviewed (I7, I4). However, even in cases where the whole system is to be decommissioned, the supplier would be the first point of contact for the end-user and would be expected to offer take-back with subsequent recycling (I4, I6, I7, I11). One of the two BESS suppliers contacted stated that no considerations of afterlife treatment for batteries from BESS have yet been made as the company is relatively new to the market and expects the systems to function without the need of replacement for the next years (I5). The second provider emphasised the importance of circularity to their business and highlighted existing contractual relationships with recyclers. They currently take back all batteries from their installations with no additional cash flow in any direction and state that recycling is still costly at present (I15). Reports and literature on the topic of recycling costs are mixed, with multiple authors confirming the unprofitable nature of current recycling practices for Li-ion batteries due to a lack of standardisation, difficult disassembly processes and logistical reasons (Gaines, 2019; Lander et al., 2021; McKinsey, 2023; Spector, 2022), while others claim that the high prices paid for the recycled materials of Li-ion batteries, such as the black mass, a mixture of different metals retrieved from the batteries, make the operation already profitable to date (Curran, 2021; Loveday, 2022).

Meanwhile, a high degree of servitisation was observed among the group of BESS providers. All 25 suppliers offered some degree of service to complement their product, with the provision of a customer portal to monitor of the system's operation being observed as an optional minimum level of service provision (Voltfang). The companies Saft and Fluence offered staggered service packages at different prices. While the staggered prices can be seen as a positive measure that increases the attractiveness of the BESS solutions through service and pricing strategies that align with the customers demands and capabilities, the framework of Konietzko et al. (2020) highlights long warranties and enabling repairs as a matter of prolonging the system's life and slowing the resource extraction loop as ways to increase the circularity of a system. Compromising these dimensions by excluding maintenance through the supplier or shortening the warranties in favour of lower prices and potentially higher uptake of the solution is therefore not in line with the framework on circularity strategies and could lead to faster degradation of the system, ultimately leading to a premature need for components and raw materials. While the lowering of circularity impact by reducing the service offer may be mitigated by extraordinary individual capabilities of the customer, reducing the warranty and maintenance offer is not suggested.

Additional services that are offered by the different BESS suppliers include the following: educating customers (e.g. Fluence), providing regular performance reports (e.g. Fluence), providing access to the 24/7 help desk that facilitates problem solving (e.g. Fluence), software upgrades (e.g. Fluence), reactive maintenance (e.g. Fluence), performance guarantees (e.g. Fluence), complete asset management, including monitoring (e.g. Fluence), proactive or preventative maintenance (e.g. Saft), routine inspections (e.g. Saft), equipment cleaning (Saft), access to a live web portal (e.g. Tesvolt), and optimising capacity utilisation (e.g. Connected Energy). A holistic overview over the different services and circularity strategies applied by current BESS suppliers can be found in Appendix 2.

Additional differences in the business model adaptations of current BESS suppliers can be seen in the value delivery, especially with regards to the installation stage of the BESS. This stage differs between the different actors, as some companies deliver and install the product themselves, while others collaborate with local electrician companies and experts to deliver the value in a joint process (e.g. Tesvolt). The local collaboration is a practice of organising the steps of installation and maintenance in a local context. Fostering local skills and capabilities rather than centralising it is an important issue in the sustainability debate and part of the discourse on circularity (European Committee of the Regions, 2020). By involving local actors in the implementation of the CE, knowledge on the CE and its practices is disseminated and the creation of jobs resulting from it promotes the resilience of the society (European Committee of the Regions, 2020). The interviewees indicated that the integration of local experts in the value creation and delivery process is largely perceived as positive. They described a practice as part of which the pre-existing relationships between the customer and local electrician companies were respected, with the BESS provider integrating the local electrician company into the partner network (I7, I8). Overarchingly, the close collaboration with local experts, and in particular the described practice of respecting existing relationships, led to a mitigation of perceived risk through the knowledge that support is always available locally (I1, I7, I9). In addition, familiarity with the local context, similar attitudes and values, and a special relationship between the installer and the end user were perceived as positive (I7). However, I6 also mentioned that the involvement of too many different actors could create confusion and complicate the project unnecessarily. A focus on clear communication and responsibilities is therefore important to consider for the suppliers.

4.1.2 Circularity strategies

In the following section, the circularity strategies applied by active BESS suppliers will be highlighted in order to map the status quo of the industry. The mapping of current practices can serve as an inspiration for practitioners and inform what circularity practices can be considered realistic in the context of BESS in the current state. Mapping these practices and analysing them against the theory then defines the type of PSS for which the customer journeys will be created as part of the coming tasks.

Acquisition of raw materials

Raw material acquisition is the initial step in a product's life cycle as defined by the ISO standard 14001 (ISO, 2016). This is a crucial stage for the sustainability impact of the BESS as LCAs show that the raw material extraction phase along the manufacturing of the different components is the product's life cycle stage with the biggest environmental impact (Ahmadi et al., 2014; Gutsch & Leker, 2022). Accordingly, all companies address the battery they use in their offers. While first-life BESS suppliers do not specifically mention acquisition details, second-life BESS suppliers do address the sourcing of their batteries. All second-life batteries of the analysed offers are acquired from the transportation sector. The repurposing of the battery is presented as a major competitive advantage due to increased economic efficiency or environmental benefits like emission reduction improvements (e.g. Voltfang). The companies Octave, Connected Energy, Watt4Ever and ADS-TEC specifically highlight the carbon emission reductions that are achieved by using second-life batteries for their BESS as compared to virgin batteries. Meanwhile, Watt4ever extends the communication on environmental benefits and communicates other areas where the use of second-life batteries can minimise negative impacts, namely reducing hazardous waste, negative impacts on water and the need for new cobalt and lithium. These companies are therefore acting in line with the theoretical expectations towards circular BESS providers, by implementing actions to reduce the environmental impact of the battery, thus demonstrating that repurposing is feasible.

Beyond that, it was found that even within the sourcing of second-life batteries, major differences occur. While some companies speak of using repurposed EV batteries (e.g. Voltfang), others mention that they acquire unused batteries from mobility OEMs that are not used in EVs due to the OEM switching to different battery technologies, products from different battery manufacturer or minor external damage to the battery (I15). Another way of sourcing is the mass acquisition of all second-life batteries of a certain type and condition. By having lower standards and requiring less data and transparency on the SOH of the batteries from the seller, the second-life BESS producers can significantly lower the purchase price of the battery modules (I15). In these cases, despite the lower price, the sale of the batteries is described as valuable to the original owners of the batteries, as the sale avoids the cost of recycling (I15) (see discourse on profitability of recycling on page 42). After the sale, the different battery cells can then be analysed, classified and repacked into a new module by the BESS suppliers (I15) or randomly assembled, as in the case of Relyion, who developed a technical solution that allows them to operate their batteries independently of the "worst performer" battery module (Relyion, n.d.), which usually determines the capacity and therefore the performance of the entire battery module or pack. By overcoming this limitation, costs are saved during the acquisition, as well as for the analysis and diagnostics prior to installation.

It also enables the repurposing of batteries with lower remaining capacity that would be rejected by other providers, giving these otherwise neglected batteries an additional purpose.

Examples seen in the industry show that while the repurposing of the batteries is key to enable maximum circularity of BESS offers, companies are also considering the recyclability of the batteries they are repurposing. The Canadian Renewable Energy Association (CanREA, n.d.) communicates that Li-ion batteries are 95% recyclable. Meanwhile, Relyion mentions a recycling rate of up to 99% for its battery, and Enermore is focusing on a completely different type of battery, lead-acid, to achieve recycling rates close to 100%. Both examples show that next to performance and safety concerns, the recyclability of the batteries is also considered during acquisition. The different recyclability numbers highlight that there are differences in the recyclability of different battery types and chemicals that can be considered at the acquisition phase. The CE core principles highlight the importance of materials being circled at the highest value possible. Circling is only possible if the materials are recyclable. As material reuse narrows the resource extraction loop, it can be considered a circularity practice at the level of the component being reused, regardless of its recyclability. However, reusing non-recyclable products neglects one of the main principles of the CE – elimination of waste. While reuse certainly helps to reduce the need for raw materials, the combination of narrowing and closing strategies should ideally be combined. While reuse reduces the environmental impact of a product, suppliers should not be satisfied with reusing batteries, but should simultaneously push for a combined approach of reusing recyclable components.

Meanwhile, the company Octave shows that sourcing considerations and optimisations are currently taking place beyond the battery component. Octave states that, in addition to the battery, they are also reusing parts of the BMS from EVs and incorporating them into their BESS. Another company that is reusing existing products as components of its BESS is I5, which is using previously used shipping containers of sufficient quality to house its BESS.

Fluence also states on its website that it has a code of conduct in place to enforce high standards on its suppliers. As the code of conduct was not published at the time the research was conducted, the extend of circularity impact or practices enforced on their suppliers remains unknown. However, the practice shows that this tool is actively applied to realise increased standards.

Raw material acquisition improvement potentials

The chosen framework by Konietzko et al. (2020) mentions four strategies that can be located within the raw material acquisition stage, and the examples stated above show that three of the four have been at least partially adopted by practitioner to date. The examples show that remanufacturing, and repurposing of existing products and components, as well as the establishment of local waste to product loops are at least partially realised by the industry today. Significant potential for improvement can be found in the remanufacturing of components beyond the battery, and in a greater focus on local sourcing. Localisation seems appropriate, particularly given the difficulty of transporting heavy batteries, but the limited availability of second-life batteries, which is expected to increase in the future, is currently a constraint (I15). This hampers activities towards this fourth strategy of localising supply but should be focussed on in the future.

Design

The design stage is widely considered to be the key stage in determining the circularity performance of a product. It determines all the key characteristics of a product and it is estimated that 80% of a product's environmental impacts are already determined in the design stage (Ellen MacArthur Foundation, 2022; European Commission, n.d.-b). Accordingly, the most diverse set of measures of applied and theoretical circularity strategies was identified for the design stage. Consensus was found around the three key attributes "modular, scalable and durable", which appeared in the description of all BESS offers, regardless of first or second life. These three attributes are in line with the circularity principles, as modularity allows for ease of repair and disassembly (slowing and closing), and scalability allows for flexible planning procedures and adaptability a to changing contexts, avoiding system redundancies (slowing). The two strategies therefore contribute to the prevention of obsolescence, allowing for long value creation. The modularity is also reflected in the high degree of standardisation in the components and systems offered (e.g. Octave), which allows for intersystem integrations and facilitates ease of maintenance. The third key characteristic, durable design, contributes directly to circularity as it reflects the concept of slowing the resource extraction loops by enabling a longer life and is achieved at the design level by facilitating high quality components. While there are cases where the durability of a product hurts its environmental impact, for example in cases where the use phase is highly polluting, this practice is fully in line with the circularity principles as there are no use-phase emissions for BESS. The equivalent of such would be an increase in the self-discharge rate as a process of battery degradation. Early retirement and replacement of the battery cells should be considered when the self-discharge rate exceeds an unacceptable and overly wasteful level. Therefore, when considering a design for durability, a focus on modularity and design for an ease of repair should therefore be considered so that the polluting or wasteful elements can be easily replaced. Evyon and Red Earth Energy explicitly mention their focus on high quality and durable design, whereas other companies implicitly express this through the provision of long product warranties.

Additional physical design considerations mentioned on the companies' websites include design for transport flexibility (Connected Energy and Fluence), design to protect the BESS, for example by raising it off the ground or tilting the roof (ADS-TEC), reducing the need for additional equipment through plug and play systems (e.g. Tricera), HVAC systems to enable optimal conditions, ease of disassembly to enable replacement of degraded components and reinforced insulation of the casing as well as all connections to avoid degradation and enable maximum performance (Volvo Penta, BeePlanet factory).

Beyond the physical design considerations of the BESS suppliers, software considerations contributing to increased circularity were mentioned on the BESS suppliers' websites. A noteworthy practice is the implementation of charge and discharge limits aiming to reduce the degradation of the system. Premature degradation, referring to suboptimal degradation, is an important cost factor to the owner of the system and can be avoided by implementing degradation into the optimisation software of the BESS. The practice has been mentioned theoretically, for example, by Sufyan et al. (2019) and is practically applied by the companies NorthStar or Octave, among others. This software adjustment has the potential to additionally contributing to the slowing of the resource loop and is backed by a clear cost saving factor that delivers direct value to the owner, which would be the customer in cases of linear sales offers. In addition to degradation optimisation, cell-level monitoring is practised by several practitioners (Octave, Relyion). Monitoring the battery performance data at the level of the individual cell enables targeted replacement that slows the loop through avoiding the replacement of cells that still hold significant residual value while enabling exchange of individual cells to avoid voltage imbalance and low efficiency among cells (Pragallapati et al., 2018). Correct sizing with a focus on compactness (e.g. BatteryLoop) and the regular provision of safety updates (Evyon) were mentioned as additional software enabled design strategies with impacts towards the circularity performance of the BESS. A holistic overview of all strategies applied can be found in Appendix 2.

Design improvement potentials

One aspect that is mentioned in the framework of Konietzko et al. (2020) but not by current BESS suppliers, is the focus on the usage of specific materials. The circularity strategies suggest a strong focus on monomateriality and the use of renewable and non-toxic materials. There is a dilemma here, as current li-ion batteries are not fully recyclable. A dilemma between the performance and circularity aspects therefore exists. While the innovation and adaption pressure lies on the battery manufacturers, BESS suppliers should be aware that true circularity that eliminates pollution and waste streams cannot be achieved with li-ion batteries under the current regime and recycling technologies (Mossali et al., 2020). At the same time, the literature on circular design also suggests that there is a need to focus on a particular set of circularity goals and design strategies, as it is simply impossible to follow all strategies (Shahbazi et al., 2020). The contribution of second-life BESS in extending the useful life of the existing batteries and creating grid flexibility is a valid cause. However, the suggested strategy of the framework highlights the potential for improvement that should be taken seriously, especially for first-life BESS in order to minimise waste and pollution in the EOL phase, and to emphasise the need for battery manufacturers to innovate. A last strategy highlighted by Konietzko et al. (2020) for the design phase and relevant to second-life BESS is the construction of material database ecosystems. This feature is currently being widely discussed in the form of a battery passport, the adoption of which is not mentioned by BESS developers, but has the potential to facilitate circularity practices by providing essential data on product characteristics that enable adequate handling in all life phases (Walden et al., 2021).

Production

The life cycle step of production has received little attention in the description of BESS offers and their impact on sustainability and circularity. Production in the context of second life BESS essentially refers to the aforementioned steps of disassembly, physical inspection, testing, as well as sorting, repackaging and adding of new components (see page 19). The only published information linked to the production of second-life BESS was shared by Watt4Ever, claiming that their BESS is produced and sold locally.

Production improvement potentials

For the production stage, the framework points towards the elimination of production waste along the usage of renewable energy for the production processes. While no information on this was found published by BESS suppliers, battery manufacturers appear to be focussing on this, with battery manufacturer Nilar highlights the automated nature and usage of renewable electricity for their practices.

Transportation

Similar to the production process, transport is rarely mentioned by BESS suppliers. Again, working with local experts is worth mentioning, as it not only spreads knowledge of circularity principles and creates local skills, but also reduces the distances travelled to deliver value. On top of that, the company BeePlanet Factory is investigating the minimisation of packaging materials for BESS and its components. On a similar note, Connected Energy published information on its reuse practices of transport boxes for battery modules.

Transportation improvement potentials

Theory furthermore emphasizes that light-weight transportation should be aimed for along with powering of the transport vehicles with renewable energy sources. Given the safety risks associated with the transport of li-ion batteries, which are classified as dangerous goods by the UN (EPTA, n.d.), safety considerations are of utmost importance to the BESS suppliers, also given the high impact of safety on customer acceptance. Transport considerations, while valid, are therefore likely to be of limited applicability to BESS.

Use

Considering that the use phase of a BESS does not itself generate emissions or waste products, the focus is on processes and services that impact the product in ways that prolong its life and maximise its usefulness, mainly. These practices cover slowing and narrowing practices.

In order to prolong the life of the system, it is the remote monitoring in particular that enables preventative actions, contributing to the system's longevity and operation under optimal conditions. Despite being conducted in the use phase, the physical infrastructure and features enabling such practices have to be implemented in the design phase. They include the planning and installation of cell level sensors, a capable BMS and an internet connection to transfer the information collected. While those activities are performed by all analysed BESS suppliers to some degree, there are some practices that stand out. One of these practices is the so-called harmonised performance mentioned by Relyion, which focuses on operating battery cells at different intensity. Relyion claims that based on their level of degradation, battery cells with a higher SOH will be used more than cells with less SOH which over time leads to the harmonisation of all cell's SOH, providing longer lifetimes of the overall system. Another practice aiding the longevity of the systems is the aforementioned limitation of the charge and discharge level applied by NorthStar or Voltfang.

The maximisation of utility is also mentioned by all BESS providers and can be considered as the main reason for engaging with BESS. While also fostered through product characteristics and infrastructural influences, this is predominantly ensured through professional service delivery and operation. For BESS operating solely behind-the-meter this lies in optimised charging from the grid or renewable sources respectively to allow optimal scheduling of peak shaving without compromising other desired features. For BESS also operating front-of-the meter with applications such as arbitrage and ancillary service provision, that contains optimisation of application picking. In both cases, the EMS is responsible for the optimisation, which can be supported through automated processes (Fluence). Professional operation of the EMS has the potential to maximise the utility provided by BESS and is offered by several BESS suppliers, including Fluence and Saft. Beyond that, the ability to participate in multiple markets is also seen as a maximising factor that is actively pursued. Some suppliers (e.g. RedEarth Energy Storage) are working with third party experts that specialise on specific aspects of the use phase, facilitating the maximisation of utility provided and therefore narrowing practices.

In addition to these rather common practices, suppliers are also applying more unique features such as educating the customer on the functioning of the system (Fluence) or adding additional services, such as implementing a crypto miner powered by the BESS in times where no other application is prioritised (RedEarth Energy Storage).

End-of-life treatment

The key activity pursued by BESS suppliers as part of the EOL stage is the recycling of the battery and additional components of the system (Watt4Ever, Voltfang, Northvolt, Ferroamp). Recycling is seen as a key technology for closing the loop, one of the core principles of the CE. As 100% recycling is not possible for some battery types, NorthStar furthermore points out that the residues from the recycling processes are recovered and sent to the metal industry to be used.

End-of-life treatment improvement potentials

Besides confirming the relevance of proper recycling of products in adequate facilities, the circularity strategy framework furthermore mentions the possibility to reuse and sell components and materials from discarded products. As batteries are generally assumed to degrade before other components, scenarios in which customer decide to return the BESS before the degradation of all components seem feasible. The reuse of components or the entire product should then always be preferred to immediate recycling, adhering to the principles of the CE. The aforementioned modularity in BESS design supports this strategy as it enables easy replacement of individual parts. Reverse logistics, enabling the return of the system shall therefore always be installed. Localisation of waste to product loops as well as the engagement with industrial symbiosis are furthermore suggested and should be considered during the development of BESS solutions.

The chapter highlighted a variety of circularity practices applied by current BESS suppliers. All lifecycle stages have been shown to hold significant potential to improve the circularity performance of a PSS offer. It was also found that many different strategies were and can be feasibly followed simultaneously and that there were no major differences between the PSS offers between first-life and second-life BESS suppliers – with the obvious exception of the origin of the battery. Least activities were noted for the production and transport phase making them prone for future improvements and under the stated restrictions.

4.2 Customer Personas

This section presents the different customer personas that were identified as part of the process conducting task two. After reviewing the primary material collected as part of the pre-study (Redmond et al., 2022), four different customer personas were identified as preliminary customer personas to inform and guide the development of the final personas. Conducting the interviews with existing and experienced BESS users, as opposed to hypothetical users as part of the pre-study, only three of the personas were confirmed. After giving an overview over the personas identified (a comparative overview of the three final customer personas can be found in Appendix 5), a detailed description of the findings follows, organised along the three personas.

Overview over the identified customer personas

Throughout the interview process, three distinct group of end users were identified. The groups differed mainly in their motivation to engage with BESS, which was reflected in the different applications they used in operating the BESS. The 4 case studies informing Customer Persona 1, Jörgen, were found to be rather large corporations with easy access to money and a tendency to engage with BESS for additional revenue generation. The applications sought by these end-users were therefore more focused on front-of-the-meter activities such as arbitrage and the provision of ancillary services. Their electricity consumption was overall perceived to be high, with rather stable consumption patterns and a low impact of peak consumption on the overall electricity costs. Sustainability aspects were seen as largely not important for the investment decision on BESS. Large companies from other industries or product lines entering the BESS realm from other industries were trusted overall, but the lack of a track record was seen as an additional risk factor.

Customer Persona 2, Christopher, was informed by 6 case studies, all public sector actors with a high reliance on electricity in their operations and a low impact from electricity peaks. Their motivation to engage with BESS stems from resiliency concerns and political requirements to decarbonise overarchingly. They have shown an interest in professionalising their energy management and building for the future. The organisations showed a strong interest in bringing in external expertise for consulting and tendered their solutions with a strong focus on the sustainability aspects of the offer. While costs were a consideration in the tenders, funding was generally sufficiently available for these essential infrastructural upgrades. Large suppliers were seen as reliable partners due to their financial stability compared to start-ups and were therefore considered as preferred suppliers, even in the absence of a track record in the BESS industry.

Customer Persona 3, Eva, was informed by 7 different case studies that comprised smaller organisations, primarily driven by their desire to reduce the rising electricity costs and create their own on-site electricity generation. Their electricity demand was described as lower compared to the organisations of the previous personas, with peak demand having a bigger influence on the electricity costs. Funding options for these organisations were limited and the desire to engage with sustainable product offers described as high and intrinsically motivated. However, cost remained the key factor in their choice of solution. Big, unproven suppliers were not necessarily seen as attractive given their stated desire to support local businesses and the preference for local support options. Concerns were stated that, as smaller customers, they would not be of highest importance to big supplying organisations.

In the following the personas will be presented in detail. In line with the literature and methodology on customer personas, the personas are described in a rather unscientific manner. The story-telling and detailed way of describing customer personas is seen as a strength, fostering the identification of solution developers and professionals in the supplying companies with the respective persona.

Customer Persona 1: Jörgen. CEO from the Mining/Quarrying Sector

Jörgen is the first customer persona defined. He is the CEO of a medium-sized mining company with over 200 employees. An active enquiry from a BESS supplier introduced him to the technology, and while BESS can provide multiple functions that benefit his business, it is the revenue generation potential that ultimately convinced him as the decision maker for major investments. Jörgen operates highly rational and knows the limits of his and his company's expertise. It is of high importance to him that the technology that is not essential to his business is operated at the highest capacity and given the shortcomings of the company's own expertise, is monitored and operated by professionals. Jörgen believes that “outsourcing” (PM1) maximises the value generated and additionally minimises the need for own time commitment. While Jörgen is very involved and knowledgeable about the business details of the deal, he is not very involved in the operational details. As the business is not dependent on the system's operation, high uptime is seen as important for its money-making potential and the opportunity costs associated with downtimes, but not essential to the business. Contractual security regarding uptime and lifetime of the system is extremely important to Jörgen and he knows exactly what his rights and obligations are under the service agreement. As-a-service offers have not been of interest to Jörgen so far, as offering the system as-a-service means that it is lucrative renting it out. As the company is large, has large revenue streams and is able to obtain attractive loans, buying the system is not a problem to Jörgen's company. While he is not completely opposed to the idea, it is the business case and the hard facts presented that ultimately matter to him. Stakeholder opinions are really important to Jörgen and both the revenue generation as well as the involvement with green and innovative technologies are perceived as positive by the public. Therefore, the installation of the system is treated as a marketing event and prominently covered by the media. Jörgen identifies himself strongly with “his” company and tends to be risk averse. He sees working with large companies as an additional security factor, as he believes that these companies have a similar attitude to risk and reputation as he does. Because he believes that his company is capable to adapt, he projects the same ability onto other larger companies, which is why a missing track record of an established manufacturing company switching industries and presenting unproven products is not seen as a dealbreaker to him. To avoid risk, Jörgen is also sceptical about repurposed technical systems. However, financial considerations could change his mind.

Additional details on the case studies informing persona 1, Jörgen

The first customer persona combines and synthesises the views and characteristics of 4 different companies, two of which were interviewed as part of this thesis work (I1, I10) and two for which primary data was available, collected as part of the pre-study (PM1, PM2). All four are medium to large sized organisations with the key factor in their grouping being that that their BESS is or is intended to generate profits for them – three (I2, PM1, PM2) through the combination of participation in ancillary markets and through arbitrage, and one (I1) by packaging the system with other energy products and renting them out as a combined unit. The operation of all four organisations was meanwhile described as rather energy intensive, with electricity peaks not mentioned as a significant factor for their energy charges. The representatives of all four companies stated good access to capital either due to internal access to money or because of access to money from banks under favourable conditions. CAPEX investments were therefore not perceived as a hindering factor. All four of the interviewees meanwhile stated that the companies would be interested in a service situation in which operation of the BESS is conducted by an external provider as energy management is not part of their expertise. For the delivery of the PSS, three companies stated high trust in established corporations of other industries that are new to the market of BESS, while one interviewee stated no preference between established companies and start-ups (I1). At the same time all actors highlighted their preference towards reduction of risks and a certain track record and experience in the field as a clear bonus when choosing suppliers. At the same time, strong guarantees were expected and seen as major mitigation factors for that risk.

One major influencing factor in the decision for a BESS that was brought up from interview partners from all industries and different personas was the availability of funds. Governmental funds are available in multiple countries and were brought up by several actors as a factor that influenced their decision making and made them invest in BESS. These funds are usually given out at different administrational levels, from the national level to the regional level and at different financial support volumes and were found to promote green investments. In the context of these funds, many interview partners stated that sustainability aspects of the respective project are of importance to them. Interestingly, many of the fund issuing institutions considered BESS as a green infrastructure component with no further requirements on the details of the product or the offer. This manifested the mindset of persona A organisations, who perceived and marketed their BESS investment as a green investment, with no additional interest in the sustainability aspects of the respective offer. In contrast to the other personas, no persona A interviewee considered additional sustainability aspect as relevant for their decision making. With regard to funding, persona A interviewees pointed out that funding is only available for linear purchase contracts and that, for example, use oriented PSSs are not supported and covered by public funding mechanisms (I7).

Customer Persona 2: Christopher. Head of Estate in the Human Health and Social Work Sector.

The second customer persona is named Christopher. Christopher is male and between the ages of 55 and 60. He works as the Head of Estate at a public hospital with over 200 employees. Christopher is well aware that energy and electricity are of the highest importance to the functioning of the hospital. The importance of the electricity availability is driving the interest in engaging with BESS. The technology was introduced to him by external experts he consulted as part of a regular meeting preceding the renewal of the hospital's energy contracts. Christopher is knowledgeable on the topic of electricity but since BESS is a new technology he prefers to rely on experts for the operation of the BESS. In the light of recent increases in electricity prices and ambitious political targets for reducing emissions, the hospital decided to restructure its internal energy supply and security infrastructure. Christopher sees the changing energy infrastructure as a risk, while his excitement about the new developments dominates. Overall, he recognises that the politically decided dimension of carbon reduction is now at the heart of all decisions made for the hospital. For transparency reasons and coupled with the receival of funding, the new solutions have to be put out to tender, and Christopher and his team decided that emission savings, circularity and service availability should be the three main categories of criteria to complement the category of the price. Christopher collaborates with external partners to create the tender document. He is also responsible for selecting the best offer and seeks input from external consultants to ensure transparency in decision-making. Christopher aims to set up to system for the long-term and in a sustainable way. He is therefore seeking partner companies that are stable and interested in long-lasting relationships to ensure the security of the system. Larger corporations are preferred over start-ups as "nobody knows how long start-ups exist" (I3). Transparency is of high importance to Christoph and detailed information on the functioning and conditions of the system are therefore of high importance to him. Security remains the highest priority and as such a BESS is not the only back-up solution the hospital is working with. Generators are present as well and are perceived as the most proven and more reliable technology. Nonetheless, if BESS proves to mitigate all major risks and proves capable of meeting the back-up requirements, moving away from the generators is conceivable to Christopher. Meanwhile, engaging with BESS applications beyond back-up power is possible and interesting to Christopher. In making such decisions, Christoph listens to and trusts the advice of external experts. Given the increasing importance and impact of energy on the functioning of the hospital, it is considered that a new full-time position of Energy Manager will be created, responsible for the operation and monitoring of the BESS and for the internalisation and professionalisation of the control of the hospital's energy infrastructure.

Additional details on the case studies informing persona 2, Christopher

The customer persona Christopher represents five public actors whose motivations were primarily driven by the need to create a resilient and future proof infrastructure, in line with current knowledge and influenced by the public agenda, especially regarding sustainability. The actors represented are three actors interviewed directly for the thesis project and three actors for whom primary data was available (PM3, PM4). For these organisations it was found that decision making over the investments and project details were delegated by the heads of the organisations to project leaders or officials in the respective departments. The tendering process was mandatory for all actors with the ultimate decision on the product itself being made by the functional departments. The interview partners stated their obligation to maximise the utility of all investments, and while security and reliability were the dominant criteria for selecting the BESS providers, choosing a partner capable of combining these requirements with an attractive business case, for example enabled through cost cutting measures and, where possible, revenue generation and application stacking, was seen as beneficial. Established companies, regardless of their track record with BESS, were overarchingly perceived as superior in terms of reliability (I3). Track records were not seen as important in this regard, but rather the ability to be transparent and to provide a well-rounded offer that takes into account all the different aspects. Transparency, data availability and holistic plans for all eventualities and aspects of the offer were important (I6). The organisations perceived the role of electricity to their operation and their electricity demand as high and the demand as rather stable. Funding was not perceived as a problem as all interview partners highlighted the availability of money for necessary updates of critical infrastructure. While prices of the investments were considered, price was not the main determining factor in decision making. The sustainability dimension along reliability and reputation of the partner was considered as more important and was preferred in the tendering process. Circularity was specifically mentioned by I6 and deployed as a graded impact category in the projects tender. Given the availability of money, and the importance of energy infrastructure along with the familiarity in the tendering process, investing in infrastructure is seen as a preferred method compared to as a service offers. It was furthermore found that the help of external experts such as academic partners, engineering offices and technical experts was looked for in many cases (I3, I6, I11). While some actors want to have a reliable partner that manages and optimises the operation (I3, I11), I6 mentioned that they are looking to internalise the task and created a new position for energy management given the importance of the task.

Customer persona 3: Eva. CEO of a midsized organisation in the Accommodation and Food sector.

Customer persona 3 is Eva, a woman between the age of 35 and 45. Eva is the CEO at her company, a hotel with 40 employees. She wants to deliver a great all-round experience, where activities for the whole family are at the centre. Furthermore, she wants to be in direct contact with her guests and personal connections and relationships are important to her. With regards to electricity, the rising costs along the fear the grid connection becoming insufficient to provide the required power quality to the hotel worry her the most. Eva is well connected within the town and beyond its borders through her extensive network of guests. As the hotel grows and the interior is frequently upgraded, electricity demand and costs have increased significantly. She initially decided to start her own solar production on the roof and had great success with it, bringing down the electricity bill. After noticing that electricity peaks make up big parts of her electricity bill, she contacted a professional planning office that designed the plan for upgrading the solar capacity and installing a BESS to maximise self-consumption of the self-produced electricity and simultaneously shave the electricity peaks. Eva says that the increased sustainability that comes with engaging second-life batteries. At the same time costs were a big factor and it was only possible to realise the project due to governmental funding. Economic considerations dominate but the sustainability aspect of the second-life offer is also perceived as a nice plus.

Additional details on the case studies informing persona 3, Eva

Persona 3, Eva, represents the biggest group of companies interviewed as part of this project, consisting of 5 companies (I1, I4, I7, I8, I9) and one company from the pre-study (PM7). They noticed that there is a need or potential to improve their energy management and decided to install solar panels and accompany this with a BESS to increase self-consumption. The motivation of all these companies lies in the cutting of energy costs, and peak shaving was introduced by all companies interviewed, in addition to RES self-consumption optimisation. The applications therefore all lay behind the electricity meter. Arbitrage was not conducted by any of these companies; however, one company mentioned the possibility of exploring it in the future (I9). Overall, all of these companies were mainly financially motivated, mentioning that there was a business case to be made for installing BESS. This is reflected in their overall rather low availability of own funds and their stated reliance on public funding. The funding schemes again supported green infrastructure and were mainly targeted at PV installations. In combination with these PV systems, BESS was often eligible and supported. While sustainability was often brought up in that context, with the exception of one company, the biogas producer (I8) for whom CO2 accounting was very important financially, the companies did not describe any further details why sustainability was important to them or what exactly they were trying to do in the sustainability realm. Two interview partners (I7, I8) expressed a strong interest in sourcing the BESS as locally as possible and were satisfied with the involvement of local electrician companies into the installation and maintenance process of their BESS. As reasons for that, supporting the local economy, quick availability, standing relationships with these partners and stronger trust. Beyond the local electrician companies, it was mentioned that other local experts, such as the fire department were oftentimes involved in the planning stage to deliver a safe solution and ensure a smooth approval process (I4, I6, I7, I8, I9, I10, I11, I12). Also, local engineering and planning offices were often contacted to plan and help facilitate the project. The planning offices were described as unbiased experts who would ensure a quality installation of a suitable solution with up-to-date equipment. In several cases, the planning offices were the ones bringing the attention to BESS as end-users were only aware of PV. The exact engagement with the planning offices meanwhile varied from case to case. While in some cases, the planning offices performed the planning and calculated the demand to support the BESS installations solely and left it to the end-user to contact and realise the BESS in collaboration with the supplier, in other cases, the offices developed holistic solutions and became active as customers themselves, performing the planning, closing contracts with BESS suppliers, facilitate the installation and monitor the BESS. Initially, all companies limited the applications of their BESS to the two described above, but the companies showed interest in potentially installing EV rapid chargers in the future and noted the value that BESS could provide for that (I7, I8, I9). RES self-consumption optimisation and cost cutting through peak shaving really is the dominating motivation for companies represented by persona Eva. Although electricity consumption was generally lower than for the larger organisations of the other customer personas, it was still described as essential to business operations and electricity peaks were seen as more significant (I4, I7, I9). The companies were usually smaller with no company having more than 100 employees and the access to capital was rather difficult and therefore weaker. The companies furthermore stated their perceived importance of personal interaction and quick availability which they feared would be compromised when engaging with bigger suppliers. Despite highlighting the sustainability dimension of second-life BESS, the economic argument was described as the dominant indicator in decision making of these actors.

4.3 Customer Journeys

In this section the findings on the customer journey creation will be presented. The journeys were developed following semi-structured interviews with current BESS end-users, representatives of planning offices, and energy management companies. The interviewees were walked through the different stages of a hypothetical BESS journey in an attempt to understand their preferences for an ideal journey, influenced by, but certainly not limited to, their personal experiences and preferences. It was attempted to understand pain points and improvement potentials to inform the future development of customer journeys for more circular offers.

The interviews presented differences from one end-user to the next as well as between the different system providers that the end-users engaged with. The major differentiating factor impacting the course of the customer journeys, however, was found to be the kind and number of external stakeholders brought into the planning and operating stage of the BESS. Overarchingly, five different stakeholder groups were identified and are therefore represented in the customer journeys of the interviewed companies. At the same time, no journey showed more than three different groups involved in the same project. The different stakeholder groups were the end-user and its employees, external engineering or planning offices, professional energy or EMS management companies, local electrician companies and the respective BESS supplier. While the role of the end-user is clear, the role of the additional stakeholders will be defined more closely in the following.

BESS suppliers

BESS suppliers are the companies offering BESS and their related services to the market. They differentiate in experience, size, vertical integration of value creation and by the product and customer segments they cater.

The different services offered by suppliers can meanwhile include but are not limited to BESS planning, provision of the product, certification, installation, monitoring, maintenance, reporting and decommissioning.

The engineering office

The engineering offices proved to be influential players in BESS customer journeys as they frequently were the first point of contact for the customer in cases where neither the customer contacted the BESS supplier directly, nor tenders for projects were created. I7, I8, I9 and I11 and all described a similar process they went through. The initial motivation to reach out to the engineering office stemmed from the realisation that their current energy management is suboptimal combined with the assumption, that room for improvement exists. The problems in this case were either risen costs of electricity, which triggered the idea for own renewable electricity production to achieve an increased level of self-sufficiency or the large impact of peak charges on their overall electricity costs. Following the realisation, they decided to turn to professional planning offices to explore holistic solutions which in all cases included renewable energy production in the form of PV along energy storage. The offices were chosen based on prior collaborations and familiarity (I8, I9), because of local availability (I7), or in the case of I11, the public hospital, a standard procedure as the planning office was responsible for all public energy infrastructure projects. After conducting the planning for the holistic energy solution, the role of the planning offices was found to take one of two routes. The office either gets the end-user involved with a BESS supplier, facilitates an alignment of plans, charges the end-user for the services, who then carries out the project in collaboration with the respective technology suppliers

(I7, I8, I11). Or the planning office takes control of the purchasing processes and stays involved in the project as a project manager. In this instance, the planning office becomes the customer of the BESS suppliers as it buys the BESS from the supplier, facilitates its installation and, through a shared interface with the EMS, controls the operation of the system. In case the operation productivity drops to an insufficient level, the project manager would then contact the BESS supplier who determines the technical need for maintenance. The BESS technology was new to all interviewees who stated that they would not have contacted BESS suppliers without the input of the planning office (I7, I8, I9, I11). In addition to that, the involvement of the planning office gave them a feeling of security as they were seen as an independent and unbiased expert (I7). For the case of the planning office taking the role as the project manager, the customer experienced the single point of contact through the project manager as extremely comfortable and desirable (I9).

The different services offered by suppliers can meanwhile include but are not limited to BESS planning, potentially purchasing, licensing, monitoring, reporting and managing the project along the communication with the BESS supplier.

Energy management companies/Aggregators

An energy management company can enter the customer journey at different points, depending on the specific case, and can also be involved in the project from the beginning, similar to the planning office (I10). The main expertise of energy management companies is typically software solutions, and their main purpose in the BESS customer journey is the optimal management of the EMS and therefore the optimisation of service delivery. They integrate the BESS EMS with their own management systems via an interface and maximise revenue generation and cost cutting in accordance with the needs of their customers. Given their size and reputation, the energy management companies, in the case of I10 the subsidiary of an energy supplier, are contacted by end-users interested in setting up a BESS and help to facilitate contact with a BESS supplier and to finance the investment. The energy management companies typically work together with different BESS suppliers and are open to collaborate with different systems. Alternative payment structures are theoretically possible, but the details of the PSS have to be jointly developed as the energy management companies take over the operation and optimisation of the BESS with their systems, limiting the services provided by the PSS supplier. In general, depending on the capabilities of the BESS supplier, it could be conceivable for the companies to work closely together and offer a joint as a service offering combining the expertise of both companies (I10). However, I10 stated that the energy management company is generally sceptical towards working with second-life BESS as the price differences are not believed to be relevant enough to attract enough additional customers, but the risk is perceived as a lot higher, anticipating significantly more off time due to replacement and maintenance work. In line with this, current experience also shows that the warranties offered by second-life BESS suppliers are shorter compared to first life offers. Knowing and respecting that performance guarantees are a pain point for energy management points, collaboration is conceivable, despite the lack of experience with jointly developed PSSs. Such collaborations would likely have the energy management companies take care of everything software related, while BESS suppliers focus on hardware provision and maintenance. The advantage of energy management companies is that they are typically already registered as grid balancing parties and therefore hold the licenses to offer capacity to the electricity markets. However, collaborations are only attractive to energy management companies in projects with BESS systems of at least 500 kWh capacity and where BESS is available for money generation for an extended period of time (I10, I11).

The services offered by energy management companies can meanwhile include but are not limited to EMS operation and optimisation, market access, reporting and potentially financing.

Local electrical installation company

One stakeholder that BESS suppliers frequently engage in the value delivery process are local electricians. The interviews showed that the practical aspects of installation and the conduct of maintenance work are often outsourced to local electricians who are in close proximity to the end users' facilities. By involving local players, the BESS suppliers enable quicker response times to emergencies, avoid potentially long distances travelled to arrive at their customers, and simultaneously cater to the liking of the end-users, who in the interviews expressed great satisfaction with working with local electricians (I4, I7, I8).

The services offered by local electrical installation companies can meanwhile include but are not limited to the installation and maintenance of the BESS hardware.

The different partners identified hold different core competencies and are involved in different parts of the customer journey. The involvement these additional partners is either facilitated by the BESS suppliers themselves, or because they were the initial point of contact for the end-user. Where this was facilitated by the BESS supplier, it was for practical reasons such as facilitating closer availability for end-user enquiries, maintenance requirements, and the level of competence or lack thereof. Indirectly, it is also influenced by the characteristics of the project and the desired service delivery. The interviews showed that many projects, especially those conducted with the customer persona Eva, did not consider engaging with grid services, an application that requires special skills and licences. The need for external partners in the absence of own licenses was therefore significantly lower. If the optimisation plans were to include such services without the respective skills and licences at hand, the involvement of additional actors would be inevitable.

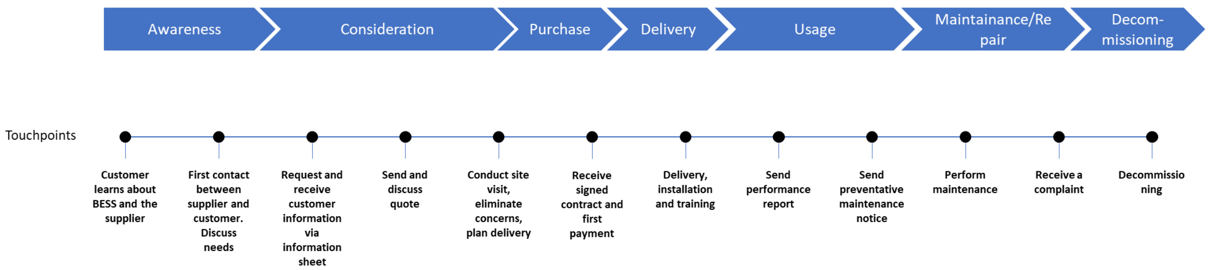

Figure 4-1. Customer journey with all touchpoints performed by focal company.

Figure 4-1 shows a customer journey between a customer and a BESS supplier with all services delivered by the BESS supplier. Such a customer journey was found with interviewee I1, I2, I4 and I5. This customer journey is contrasted with the one in figure 4-2, where all possible elements and services are outsourced. The different stages are discussed below, highlighting the findings of the interviews and the preferences of the interviewees.

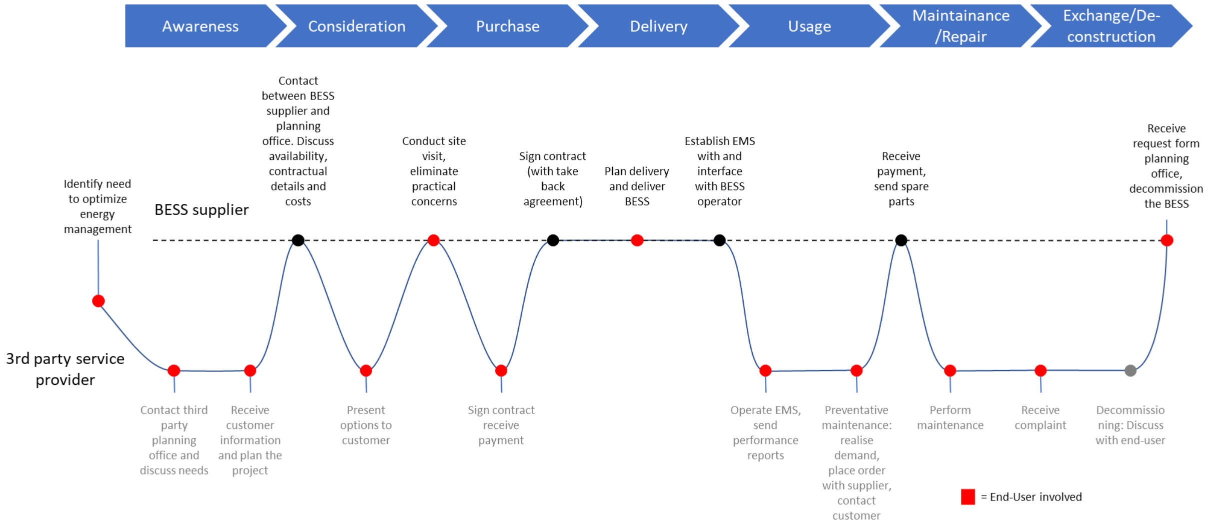

Figure 4-2. BESS customer journey with a maximum degree of outsourcing.

In the awareness stage, two different processes were identified. Either the end-user learned about the technology on their own (I1, I2, I3, I4, I10), searched for companies and contacted the BESS supplier with the intention to install a BESS (I1, I2, I4, I10) or the end-user identified a need to optimise their energy management and contacted a planning office (I6, I7, I8, I9, I11, I12). An additional practice outlined by I5 was that in the case of the construction company, the BESS provider proactively contacted them. For this practice, the BESS supplier identified two specific industries where they believed they could provide exceptional value and where they had existing reference projects and contacted companies in these sectors. Other large enterprises (I3) reported that such proactive outreach by service suppliers happens to them regularly for different products and services.

Customers stated that in initial talks the overall needs are discussed and contact information exchanged. To advance the planning, it is common practice that both, BESS suppliers and planning offices, send end-users a data request sheet (details discussed on page 62). Based on this data, the BESS supplier or the planning office begins to develop initial plans. End-users emphasised that among these planning results, the importance of economic modelling is of high significance in their decision-making process. The service providers furthermore factor in technical feasibility, weigh it against the economic prospects and decide on potential contractual engagement (I14). The characteristics of the grid connection available, for example, was a key factor in determining possible applications and costs connected to the execution of specific BESS applications (I14). Different applications are feasible depending on the need to upgrade the connecting infrastructure. Meanwhile, investments to overcome connection limitations can deliver great economic value by deferring grid upgrades (I9, I14). This is particularly relevant for EV fast chargers, where BESS can help overcome insufficient connection infrastructure and avoid costly upgrades (I9).

While the BESS supplier can present its plan directly to the customer, planning offices can either do the same (I7) or reach out to potential BESS suppliers first, discussing availability and costs for the systems they designed before informing end-users about their plans more specifically. Customers overarchingly stated that cost security is an important factor so the early contact between solution planner and BESS supplier is appreciated. One additional step that was sometimes seen at this stage was the creation of a tender. The tender was seen to be designed by either the solution planner (I11, I6, I8) or by the end-user themselves (I7). As part of the presentation of the quote or the initial plans, all relevant internal stakeholders are involved and as many questions as possible are resolved. Similar talks happen after deciding for a certain tender offer. Following the presentation of the offer and the agreement for an offer, a site visit is planned. Site visits were described to be of high importance to all sides. As such, BESS suppliers, energy management experts and customers addressed the importance of good communication and a relationship of trust, especially for large investment projects such as BESS (I1, I4, I5, I6, I7, I10). On top of that, practical aspects such as the correct placement of the BESS are of importance to ensure safety, maximise the use of existing space and infrastructure, and jointly select a location for the BESS that provides good working conditions that are supported by both insurance, fire safety experts and the BESS suppliers to ensure that warranties are eligible. Interviewees highlighted that oftentimes the promised guarantees are coupled to specific environmental conditions which are sometimes monitored by specific equipment installed with the BESS. A good environment also reduces the need for high levels of ventilation or heating. In cases where planning offices are involved, usually all three parties, the BESS supplier, planning office and the end-users are present for these site visits. They offer additional opportunities to discuss practicalities, eliminate concerns and plan the next steps. I17 and I18 emphasised that data security and the cross-checking of BESS suppliers' plans by an external expert are also very important in the American market. Site visits would furthermore be accompanied by facility managers and other customer internal stakeholders. While the interviews with BESS stakeholders in Europe confirmed the involvement of different departments in the BESS installation and the internal talks as relevant, data security was not mentioned as factor of concerns.

Overall, it was described that the touchpoints and negotiations between the supplier, the planning office and the client were not experienced as long or negative. On the contrary, the interviews indicated that the main difficulties arose in negotiations with energy and grid suppliers. Here, the main problem was not the lack of legislation or regulation, but rather the lack of experience with BESS on the part of the various partners, especially at the customer service level. One example given was the metering of BESS. Here there was confusion over the definition of BESS as consumers or producers of electricity and the respective metering practices (I14). The processing of building and grid connection registrations, fire safety certification and commissioning of BESS were also reported to be time consuming and a major challenge. With the exception of I11, all interviewees described their interactions with planning offices and BESS suppliers as largely positive and smooth, as they were mainly concerned with practical aspects of the installation such as siting, safety and ventilation, and delays did not arise from this side. However, this is the stage that is expected to take the longest and have the most variation and potential for additional touchpoints between the actors, depending on the concerns of the partners involved.

Once all concerns have been addressed and practical and financial issues have been resolved, the contracts can be signed and the first payment installation made. Depending on the ownership and project structures between the planning office and the customer, the contracts are either closed between the end-user and the supplier, as in the most cases, or between the planning office and the supplier. The payment structure also varies greatly from case to case. While some BESS suppliers require advance payment and receipt of money prior to the installation, others require the receipt of money after installation (I15). After the contract is signed and the payment received, the next touchpoint is the planning and the delivery of the BESS. Here, oftentimes local installers were found to be brought in. The advantages of those stakeholders have been discussed above, and the installation of the BESS is usually followed up by a commissioning by the BESS supplier before official commissioning by an official, state-approved actor. Along with the installation, end-users are often trained on the features and core performance indicators of the BESS along with the usage and interpretation of the customer portal for real life data on the BESS. While not being necessarily and regularly used by all customers, the live monitoring for customers has become an unofficial standard and is expected and perceived as useful by some actors (I4, I6, I7, I8, I9). If the EMS is operated and monitored by the energy management company or the planning office, now an interface between the actors needs to be established. I10 mentioned that a mapping procedure is needed for that to align the BMS and EMS controls of the battery with the ones of the operator, so that the BESS can be implemented into the operator's optimisation and control infrastructure.

With the operation phase starting, the next touchpoint between the service provider and the customer is the sending of performance reports. While most end-users are predominantly interested in the economic KPIs (I1, I3, I4, I5, I6, I7, I8, I9, I10, I11), other key figures are perceived as interesting as well (I4, I5, I6, I7, I8, I9, I10, I11). However, due to diverse needs, it can be assumed that the customisation of such reports mentioned by I15 is also relevant for other actors. In addition, customers unanimously said that if changes to the settings of the EMS are necessary to improve performance in any way, adjustments are not only accepted but expected to be made by the controlling party without prior consent needed. In fact, the interviewees stated that they don't want to be informed about standard changes in the monthly reports either as a trusting relationship is important to them (I1, I3). End users have made it very clear that they expect a high level of service, as they don't want to be disrupted in their day-to-day business and often don't have the knowledge to operate and assess the situation themselves. Only I6 wished for their BESS to be fully integrated into their own management system and stated that they created a position for energy related activities to professionalise and optimise their energy management. Besides that, all end-users expected operation through either the BESS suppliers or the energy management company.

Meanwhile, the use phase was the same for all the different applications of BESS, whether it was for self-consumption improvements or grid services. Apart from performance reports, the frequency of which is also expected to be customised, as some end-users expect daily reports (I11) while others expect half-yearly reports (I1), interaction between customer and supplier is expected to take place when preventive maintenance or complaints occur. For preventative maintenance, prior notice is necessarily expected as practical concerns regarding access to the properties need to be solved. The maintenance is either carried out by the supplier directly or by a local electrical installation company. In both cases, timely communication is necessary. For cases in which complaints occur, quick replies are expected. The complaints can either be left with the project manager of the planning company who then contacts the BESS suppliers or with the BESS suppliers directly. Again, prior to the actual access to the property, customers wish to be contacted and kept up to date. Given the importance of communication in the collaboration mentioned above, some suppliers conduct regular in-person check-ins in the form of site visits to physically inspect the BESS (I10, Saft). In fact, some online material suggests that cleaning the BESS is offered in these cases to ensure long life and don't burden the end user with handling and close contact with electrical equipment (Saft). If the customer is satisfied with the service delivered and the benefits received from BESS, the process of usage and monitoring, reporting and maintenance continues. If the customer decides to cancel the service or does not want to operate the BESS any longer, the customer expects the BESS supplier to take care of the decommissioning and the initiation of EOL treatment. It has shown that a responsible treatment, with reuse of components and recycling, is important to end-users.

Summary and learnings:

Several learnings emerged from the interviews. Learnings with implications for the design of improved customer journeys for circular offers.

The first learning is that only few end-users are aware of the technology BESS. The interviews showed that at least half of the customers who ended up being direct or indirect customers learned about BESS through independent planning offices. If it wasn't for them, the end-users would not have become BESS customers. As similar knowledge gaps can be expected for other end-users as well, the importance of planning offices that are contacted as independent experts becomes clear.

The second learning is that the investment into their energy infrastructure is perceived as a long-term alteration of their energy management. As its reliability is critical to end-users, customers desire stable relationships with low risk and high guarantees.

Third, large end-user organisations view start-ups as risky partners for deals surrounding critical infrastructure. Smaller end-user organisations prefer local solutions. Involving local electrical installation companies in the customer journey was perceived as positive and was identified as a potential factor bridging the scepticism of smaller end-users towards large and distant OEMs.

Fourth, customers are aware of the importance of their energy infrastructure and their own limited expertise. Therefore, customers expect a high degree of expertise and servitisation with as little involvement from their side as possible.

Fifth, with increasing specialisation, including in other areas of management, end-users appreciate having as few contacts as possible to resolve issues around a topic. Reducing the number of contacts and contact people with the customer is therefore appreciated for its increased clarity.

Sixth, as energy management is a core activity for very few customers, condensed summaries of system performance are desired. Given the diversity of customer needs and levels of expertise, a high degree of customisation among frequency and KPIs displayed on the performance reports sent is desired.

Seventh, none of the interviewees had arrangements for end-of-life treatment of their BESS. As one of the key enabler for circularity, such arrangements should be installed from the beginning. As most interviewees stated that environmental concerns were of importance to them, it should be possible to find solutions. Given that recycling currently costs money but is expected to become profitable, it might be economically advantageous for suppliers to enter into agreements now.

Eighth, the current public funding mechanisms are not compatible with use-centric business models. No example of BESS systems offered as-a-service supported by government subsidies was found.

4.4 Digital enablers

This section presents the results of the service blueprinting and the digital enabler mapping in an intertwined manner. A graphical depiction can be found in Appendix 8.

Confirming the findings of the customer journey mapping stage, I19 stated that in most cases, BESS will be integrated into a more holistic energy solution often including a form of RES. This statement is in line with academic recommendation of maximising value through value stacking (Englberger et al., 2020) and was seen among multiple interview partners (I1, I2, I4, I6, I7, I8, I9). It furthermore infers that instead of reaching out to the BESS supplier directly, end-users are often not aware of the technology or are aware but are not interested in the sole value provided through a standalone BESS. Instead I19 assumed that end-users would much rather know of their energy related problems or identified optimisation potentials that they attempt to solve or realise through the engagement third party actors. A planning or engineering office would be an example of such a third-party entity and the interviews conducted highlight and support this notion. 6 out of the 11 end-users interviewed (I5, I6, I7, I9, I10, I11) reached out to planning offices because of either a limited grid availability (I5, I10), because of cost considerations (I7, I9, I11) or in the attempts to build a state-of-the-art energy infrastructure (I6). Reaching out to a planning office is convenient as end-users typically like to focus on their core activities and are unaware of technological developments in areas beyond that. Instead, the customers turn to experts as they trust them and expect them to know and evaluate the matter better than they can themselves (I10). It was found that often, the planning offices are picked on a basis of either long relationships and previous collaboration (I9) or regional familiarity, convenience and a notion to support local businesses (I2, I7). The latter was especially seen with smaller scale installations.

In contrast to the assumptions by I19, the interviews also showed that three commercial actors (I1, I4 and I8) proactively reached out to BESS suppliers in order to jointly plan a solution and start the collaboration. In these three cases, awareness of the topic was raised through, discussions with business partners (I1) that highlighted improvement potentials, in internet forums (I4) and through internet news outlets (I8). Overarchingly, the main way in which end-users became aware of BESS was by contacting third party experts, such as planning or engineering offices specialising in holistic energy solutions (I5, I6, I7, I9, I10, I11), followed by internet research, either targeted or random, in the form of news articles, podcasts or social media. The Internet was also the channel through which most C&I end-users reported keeping up to date with technological developments in general (I2, I3, I4, I7, I8), together with word of mouth through discussions with partners and existing customers (I1, I5, I6, I9, I10, I11), involvement in industry networks (I2, I6), articles (I3, I8) and conferences (I3). Besides gaining a relevant market position and generating awareness through word of mouth, all four remaining channels can be influenced either through a strong web presence, the collaboration with academia and journalists, or by organising and attending conferences. In order to activate these channels, data and knowledge on the own business case and technical details of the offer have to be given. As this knowledge is held internally by the BESS supplier, this information can be transported directly through the channels to increase customer awareness. The digital enablers for this are a company website and social media presence, as well as an events calendar that highlights popular events where attendance can be beneficial.

As BESS matures, becomes more widely distributed and proves its business case, chances are that BESS storage becomes more sought after by end-users. The direct contact to suppliers could increase. Given the high relevance and tangible, easy to understand benefits of BESS towards RES self-consumption improvements, it seems inevitable that holistic energy solution providers or planning offices will remain important customers or actors in facilitating BESS installation. Integrating the planning of holistic solutions into the own service portfolio would facilitate additional vertical integration, service offering to the PSS, and might be financially beneficial moving forward given that these are the actors companies typically turn to for their energy transformation needs. If transportation OEMs manage to enter the second-life BESS market, they have proven that they are capable of developing and reconfiguring capabilities in the light of changing demand and environments. This is in line with the concept of dynamic capabilities, which asserts that these firms are adaptive and capable of maintaining competitive advantage (Teece et al., 1997). Given these capabilities, a further expansion into this field seems possible. An alternative would be to actively target the existing planning offices that already have a reputation and client base in the market. Here, the notion of I19 might be helpful to create awareness among these planning offices. Given the anticipated significant risk aversion of clients and the high importance of safety in the context of batteries, the reputation of the transportation manufacturers might positively affect the reputation of a BESS produced by the same or a subsidiary. Interviews showed that the strong name of an established company diversifying their portfolio and entering a new segment can have effects in both directions. While trust was generally perceived as higher, it was found that especially smaller companies were afraid of not being adequately prioritised by big OEMs, that have a variety of customers of bigger sizes and allegedly bigger impact. On the other side, I3 stated that start-ups are not considered as reliable partners as it is unclear if and for how long they will be in the market.

Ultimately, the digital solutions mentioned above - a corporate website, social media presence and event calendars to facilitate attendance at conferences - are a result of the interview findings and are believed to enable increased awareness among customers.

In the consideration stage, customers are aware of the company, have decided to contact the company and are ready to consider the company's offers.

The interviews showed that despite the identified potential of proactively reaching out to third party planning offices, it is the customers, either end-users or the planning offices, that contact the BESS suppliers after identifying demand. BESS suppliers then respond and identify the respective demand. In order to enable that step, contact channels have to be established and administered. Especially phone calls have been mentioned as a best practice to enable quick information exchange and for establishing a relationship (I1, I2, I4, I7). Besides the traditional way of contacting, tenders have been encountered as a tool to establish initial contact. Tenders have been used in public procurement processes and when governmental funding was involved. In the case of an invitation to tender, the dynamics of the consideration phase change, as the supplier now has to actively apply and submit a bid (3, 6, 7, 11). Several interviewees mentioned that public funding had a major influence on their decision to install a BESS, also in combination with PV, as it had a major impact on the profitability of the project (I1) or made the project possible (I7). The interviews made clear that while funding works well for purchases, it is not available for as-a-service contracts.

After the initial contact between supplier and customer is established, the supplier should register the customer with its specific demands and specific information so that the sales process can be forwarded internally. Customer relationship management (CRM) systems are recommended as tools that enable the managing the relationships and interactions with customers (Greenberg, 2010). As lead time is an important KPI for the interviewees (I2, I5, I9 and I11) quick collection of that information is recommended. Existing BESS companies use questionnaires to collect this initial data which seams suitable for the collection of data for the development of an initial quote. The sharing of the data was meanwhile not seen as sensitive by the interviewees. Despite I15 stating that information on the grid connection, requirements and prices of insurance companies are usually only requested after signing the contract between customer and BESS supplier, the interviewees unanimously agreed that as much cost transparency provided from an early stage, the better. Therefore, two important potential additional price points, the increased insurance costs and the adaptation of the grid connection, should be requested at an early stage. This is particularly important as respondents indicated that communication with grid operators and electricity suppliers was a common reason for delays in BESS projects (I14). The interviewee claimed that it was not the lack of rules or regulations that was the problem, but the institutional lack of experience with behind-the-meter BESS installations. Early involvement of these parties was therefore recommended by I14 with no additional digital tools identified to standardise this process.

Once the customer information sheet is filled in, the supplier knows that the customer is committed to exploring the opportunities of BESS. Upon transmission of the information sheet, customers expect confirmation that the information has been received by the supplier. Beyond that, a timeline for the next steps should be established. While the specific information needs to be processed and entered into the CRM tool, I15 recommends that credit checks are carried out on customers to ensure that they are able to meet the terms of a potential contract.

The next customer activity includes receiving the initial quotation, discussing its details and, if they agree to proceed with the plan presented and scheduling a site visit. To perform these steps, the supplier must create, send and inform about the drafted offer. This is facilitated through the performance of a technical and financial feasibility study as well as an internal profitability analysis. Ramos et al. (2021) highlight the need for the performance of both, as each situation and installation is unique. The information required to perform this analysis is the data collected from the customer information sheet, as well as contact with the DSO and the insurance company. While customers generally prefer short lead times and a minimum number of contact points, additional phone calls and emails are seen as appropriate to resolve ambiguities. Digital tools needed to perform these tasks are a project planning tool and a business case simulator. In order to carry out the internal profitability analysis, these steps must be followed up by the profitability analysis.

To do this, component prices and availability must be checked. Therefore, a stock and procurement tool is required. After these three calculations are performed, a drafted offer can be created using a service contract tool. After sending the offer to the customer, discussing the possibilities as well as the business case, clarity upon the service model, payment terms and timeline have to be created.

From a circularity perspective, it is desirable that a complete service package is agreed upon that includes monitoring, maintaining, reporting and replacing until a continuation of the service is no longer desired. Practical examples of current BESS offerings (Fluence) show that differentiated service models are being offered. The end-user interviews showed that in most cases full coverage of all services is desired (I1, I3, I7, I9, I10, I11). The interviewees want to maximise the systems utility while simultaneously focussing on core competencies. It is furthermore widely recognised that professional monitoring is in the interest of all parties.

The interviews showed that larger client organisations tended to have more specialist staff qualified to operate BESS (I6). They are more willing to hand over control. I10, I14, I17 and I18 confirmed this tendency. However, with increased specialisation, more people tend to be involved in the discussions around the offering, and the security requirements are often higher. I17 and I18 reported on digital security and the approval of the BESS supplier's design by third party engineers to minimise risk. In particular, risk concerns are justified by the tendency for larger C&I players to also have higher electricity consumption and available funds to invest in larger, more expensive systems. The nature of as-a-service offers may remove some of the factors associated with financial risks perceived by the end user, but security concerns remain. Depending on the level of involvement and cross checking, this step may take longer for these actors. In addition to these tendencies of large actors, I4, the operator of a small BESS, stated that there was no preventive maintenance contract. While this may be an exception, there is a tendency for smaller players without access to large amounts of cash to save on the services requested more than larger players. An as-a-service model could help overcome this tendency, given the lower upfront costs and increased contractual flexibility.

In addition to the level of service, payment terms need to be negotiated. Several models are conceivable. While all end-users interviewed are currently part of a product-based PSS, I15 reported offering different payment models for as-a-service options. The most common option for this provider is to charge a monthly fee but also require an upfront payment. This deal shifts the price load of classical product-oriented PSS by reducing the upfront cost but increase the running costs. Combinations are conceivable in which the monthly fees can later be converted into a down payment, so that ownership of the systems changes after a certain period of use. Despite desired by customers, changes of ownership are not desirable under the CE paradigm, as they impede reverse logistical flows.

The timeline is another point of discussion. While the concrete delivery date cannot be determined at this point, a timeline should be established to create a sense of urgency and establish a joint roadmap. Factors hindering the determination of a fixed delivery data are uncertainties associated with the construction permit, grid permit, potential safety and fire protection approvals as well as the finalisation of the product construction.

Depending on the business model design, after these discussions and reaching an agreement on the project and its characteristics, the procurement process can be initiated. Considering that cost is the dominant determinant of the commitment to a BESS and its respective PSS (I1, I8, I10), it can be assumed that the early involvement of all relevant cost-inducing stakeholders in the project through the business case simulation will significantly contribute to the validity of the offer and reduce the risk of cost jumps that may cause the customer to change its mind.. Upfront transparency is overarchingly desired as transparency has a mitigating effect on perceived risk (Paluch & Wünderlich, 2016), a factor that continuously comes up on the theoretical level (see problem definition and decisions for the customer-centric approach of this project) and the practical level, mentioned by I2, I4, I10 as a factor influencing their decision.

Given the financial security and the importance of short lead times, starting the procurement process early is recommended and in line with customers preferences. It is noted however, that the procurement cycle might also not be as flexible for second-life products as it might be for first-life products (I19) as the procurement for components, especially batteries require the availability on the market for exhausted first-life batteries.

After the offer has been discussed and the general plan has been agreed upon, site visits were mentioned as an essential component of the consideration and project planning phase. During the site visit it is necessary to respond to the customer's internal stakeholders, answering their questions and addressing their concerns, as well as ensuring the practical feasibility of the project, deciding on a suitable site for the installation of the BESS, determining the need for additional materials and components based on the placement, and discussing practical aspects of the delivery process. In order to have a feasible site visit it is therefore required to have the technical details considering size and capacity of the needed solution as well as connectivity requirements mapped out and planned. Furthermore, it is of high relevance having reached out to the local authorities that are in charge of ultimately issuing a construction permit and as well as to the local fire department to ensure that the necessary fire protection standards are understood and kept (I14). As the regulations for the installation of BESS are largely fragmented and in some parts missing (RI.SE, 2022), it is suggested to keep track of the different requirements. While the process of attaining the information cannot be standardised and is expected to require individual outreach to the local authorities. However, a requirements database might help keeping an overview, create internal processes and speed processes in cases installations occur in similar regions. Areal plans and information on the availability of space is needed to decide on the final placing of the BESS and are to be extracted during the site visit. Final hardware demands that were discovered throughout the visit should be added to the bill of materials and procured. The newly found information should then be added to the project planning tool.

After settling concerns and finalising the planning, the service contract can be set up and signed. In line with the service contract, the payment terms should be obliged, and the first payment installation made. This requires a customer invoicing system with the customer's contact and bank details. The invoice has to be created and send. Depending on the business model the timing of the initial payment can vary and the point directly after signing the contract is the earliest possibility. Other timeslots for that would for example be after the installation of the physical BESS. While circularity literature does not touch on the specifics of that, the initial payload should not be too high to enable wide uptake of the solution. The avoidance of high initial payments, although sometimes necessary for the supplier to be able to provide its services (I15), leads to increased accessibility and the inclusion of more businesses in the range of potential customers. While that might be in the interest of the supplying company, it is also in line with the debate on social equity, one of the key factors for social sustainability (Dempsey et al., 2011; Pastor, 2007). Also depending on the business model, is the start of the production of the physical BESS.

While the production start can very well happen before the signing of the contract, this would be a typical time for it to mitigate supplier risk at the cost of increased lead time. An order and production order tool would be digital enablers for this process. This would also be the time when the first requested order date is set and the timeline for the delivery can be adjusted. The delivery process should now also be coordinated internally and, if the installation is to be carried out in conjunction with a local electrician, details of cost and availability should be discussed. This is also the time when the construction permission and the grid registration and permission should be initiated. Both of these processes vary depending on the local authority and the grid provider.

The next step in the customer journey is the delivery stage where the customer receives the physical BESS, the system is installed, and training is conducted. It is important to point out that after the BESS is delivered and installed, it is time to receive commissioning from the local authority on the building permission and the fire protection regulation with both processes being certified. While regional regulations differ, these two requirements have been named from most interviewees as key steps in the installation process that were particularly time consuming. Early registration is therefore required. On top of that, the software can now be adjusted in line with the end-users needs. The programming of the EMS has to happen in close collaboration with the customer as individual requirements are oftentimes present. Many economic possibilities meanwhile lay in the participation in different markets and while the EMS as a digital enabler is capable of coordinating and facilitating the participation on different markets it is important to note that registration and the permission, also called license depending on the market and reginal context is needed to participate (I15, Svenska Kraftnät, 2023). While the license can be obtained, it is also possible to cooperate with balancing responsible parties or other licensed parties, depending on the market. In order to participate in arbitrage, a feed-in contract is needed that can be closed with an energy supplier.

In order for the EMS to obtain information on the electricity markets and to monitor it, the EMS has to be connected to the internet. While a physical connecting device is needed, a cloud solution or VPN can be used as a digital enabler to facilitate the monitoring (I14, I15). The supplier, responsible for managing and maintaining the BESS as part of the service contract remains in control of the master controller that can overrule and control the EMS, while the customer receives access to a customer portal that is capable of obtaining real life information on the condition and activity of the BESS. While not all customers necessarily need real time access, the analysis of existing BESS offers showed that basically all offers deliver such solutions, making it the unofficial standard.

The degree to which customers want to be informed about BESS activity and status varies from customer to customer. Some customers stated that real-time information was not needed and that half-yearly updates on the financial performance of the BESS were sufficient (I1), others stated that either daily updates, if not real time data, were strongly desired along with a depth of information (4,7,9,11). As none of these partners have engaged with as a service offers for BESS before and due to their ownership of the system might have the stronger need to control the operation, the degree to which as-a-service customers that do not own the system have the same demand for information is unclear. While it can be expected that less frequent reporting on key KPI would be sufficient in such cases, the diverse responses of the interviewees as part of this study shows how different the preferences can be. Customizing the customer portal to the needs of the customer is recommended, especially as some interviewees felt overwhelmed by the data presented to them and were unable to interpret it fully (I11).

This leads directly to the next step in the customer journey, the performance reports. The reports were widely expected and seen as value adding and relevant. The importance of the report is perceived very differently with no correlation between end-user profile and importance of the report apparent. However, the economic dimension of the report can be seen as most relevant to the actors (I1, I3, I5, I7, I9, I10). As suggested for the real time data, customisation of the reported KPIs is also suggested for the regular reports. Same is true for the frequency of the report. For some interviewees, who were mainly interested in the technical performance data of the BESS, the real time information was perceived as sufficient and, coupled with a history whose timespan could be adjusted by the end-user, seen as superior compared to reports (I4). Others were interested in reports with their preferences ranging from daily (I11), over monthly (I5 and I6) to half yearly frequencies. In order to facilitate the reports, different approaches were seen as admirable. While most interviewees preferred email communication throughout the entire life cycle of the BESSs operation, one interviewee said that a one stop place for all interaction with the supplier would be nice. The example given was Tesla, where all controls, payment and service requests can be facilitated through a smartphone app (I2; Tesla, n.d.). While most customers still largely prefer email as a way of communicating, the integration of other features into the digital enabler of the customer portal for real time access, such as availability of performance reports or the integration of contact channels to the BESS supplier should be considered as something potentially positively influencing the customer experience.

One benefit of the as a service model, beyond the change in payment structure, is the remote monitoring that is coupled with preventative maintenance. The ability of the BMS to monitor the health of the system with monitors enables predictive and preventative action to be taken. The monitoring can go all the way to the cell level of the battery and detect developments that are out of the norm. When such developments are detected, alerts can be installed that can then be reviewed by a controlling team of experts. The digital enabler necessary for the remote monitoring is the BMS in combination of the cloud-based data connection and the master controller interface of the EMS. Once the maintenance requirement has been identified and further defined, depending on the problem, spare parts may need to be collected or ordered, requiring the stock and procurement tool, the end user contacted to arrange an appointment and an internal or external technician booked to carry out the maintenance. There was a strong desire in the interviews for the end user to be alerted and for the visit to be scheduled. The reasons for this were mainly practical, as access to buildings often requires a permit or authorisation (I3, I6, I7, I8, I9, I10, I11). Registration is particularly important for critical infrastructure, such as the hospital (I11), and it was noted that proof of competence is also required before access is granted. The additional components needed for the maintenance also have to be processed and accounted for internally. The digital tool behind this depends on the infrastructure and processes of the company and can be added to the projects bill of materials, a database or directly to the accounting.

The reparation itself is then carried out in agreement with the end-user and does not require any more digital enablers other than the ones needed for the physical exchange process of the components which depends on a case-to-case basis.

Besides the preventative maintenance cases of unplanned errors may occur. When these are first noted by the supplier, the processes of preventative maintenance apply. In cases where the customer is the first to recognise the need for maintenance, communication channels need to be in place to allow a rapid and professional response. Interviewees claimed that they are capable of differentiating between urgent and non-urgent emergencies and stated that either a phone call or an email would be the preferred ways of communication in such instances (I6, I7, I9, I10, I11). Determining whether an incident is urgent or not could meanwhile be included into the initial training in which end-users are informed about the functioning and interpreting off BESS and its data. Depending on the decision on the level of additional functionality to be integrated into the customer portal, channels could also be implemented there as part of a chat function (I2). One interviewee also stated that the channel does not really matter and that customers would use any channel they are told and that the important factor really is quick availability (I3). On receipt of the call, the problem should be checked and further details obtained from the supplier's main controller. After receiving the information, the stock and procuring tool should be accessed to attain the needed materials. Again, the material need should be registered for internal purposes. At this stage a technician should be send out to perform the maintenance. Depending on the case, it could also be conceivable to send the technician out first to collect information from the field.

Once the system is installed, the regular use phase continues with the operation and possible adjustment of the EMS settings to improve the service according to the needs of the end user, the sending of regular reports and the monitoring of the system as well as the performance of maintenance. It was observed from other offers that during the lasting relationship between end-user and supplier, regular physical meetings between representatives of the company and the end-user are carried out. The purpose of these meetings are described as regular check-ins with the technology, but more can be assumed behind that. These visits also show the suppliers involvement in the collaboration and highlight that the service relationship is important to the supplier. The check-ins highlight the collaborative nature of the relationship and the core principle and thought behind the use-oriented PSS. Handing over the operation to external service providers in a PSS is a unique relationship as the supplier carries the risk of the operation. Both parties are interested in maximizing performance while jointly enabling a circular business model. With regard to potential adjustments of the EMS in the background it is important to highlight that all relevant interviewees that related to the need of updating the EMS and being flexible with the settings expected the supplier to do so in the background and not inform them about it before. Part of their pursuit of the as-a-service model would be the character that everything is taken care of without you having to worry about it. I1, I2, I3, I5, I7, I8, I9, I10 and I11 solely expected reports about the performance in hindsight and more than once such a hypothetical scenario was compared to the one of outsourcing where external service providers are paid to perform a certain service. The interviewed end-user want to improve their energy performance without really having to worry about any aspects of it, knowing that it is taken care of by experts.

As a final step, there may be the need to decommission the system due to a cancelation of the project. As the current systems are all rather new, a big lack of knowledge was encountered interviewing practitioners on the EOL of BESS systems. While BESS in itself is a solution to the EOL problems transportation OEMs experience with batteries, the EOL phase of this solution is largely uncovered. The following step is therefore largely hypothetical and not based on interview findings anymore.

If the contract is terminated by the end-user while the BESS and its components are still in good condition, it could make sense that parts are reused again. Given the nature of the BESS as a service offering, where the end user cannot expect to receive a new BESS with new components, as long as the customer receives a functioning and performing BESS, the customer is satisfied. An initial step therefore is an analysis of the BESS components. Whilst the battery capacity is easy to determine as it is connected to the BMS, this part should be routine. Other parts such as inverters etc. may be more difficult to assess. Once the remaining power has been determined, it should be possible to assess the suitability of the reuse options. An internal business case tool could be developed to facilitate this.

5 Discussion

Reflecting on Findings

The thesis aimed to support practitioners in their approach to develop feasible and more circular BESS offers. In this pursuit, an overview of the current application of circularity strategies implemented by BESS suppliers, the mapping of three identified customer personas, two customer journeys, portraying different levels of outsourcing, a service blueprint and building on this, a mapping of digital enablers were conducted and presented. In the following subsections, a selection of key findings are discussed in the light of existing research.

Attitude towards circular products and circular BESS

The initial screening of companies that informed the mapping of circularity strategies applied by BESS suppliers showed that the majority of second-life BESS suppliers presented their products as environmentally advantageous compared to first-life offers. Companies marketed their BESS products as "sustainable" (e.g. Octave, Tricera, Voltfang), "circular" (e.g. BatteryLoop), "climate-neutral" (Fenecon (commercial)) or "planet-friendly" (Evyon), making the environmental performance a central part of the product pitch and the marketing construct. In the context of the pre-study (Redmond et al., 2022), which showed that environmental aspects were of little relevance to potential BESS customers, this focus on the green aspects was surprising. The existing research on purchasing behaviour in the context of green products portraits diverging notions. While customers largely perceive refurbished products as being of lower quality and associated with an increased risk (Singhal et al., 2019), studies show that green products trigger an increased willingness to pay (Duan & Aloysius, 2019). Signalling theory claims that an increased willingness-to-pay can predominantly be observed with products that are highly public (Berger, 2019). Unless being proactively showcased, BESS is not a public good given its role as a part of the energy infrastructure of a company. Instead of increased prices, as suggested by some authors (Berger, 2019; Duan & Aloysius, 2019; Harms & Linton, 2016), second-life BESS currently has lower asking prices compared to first life offers (Marthaler et al., 2022). Differentiation is therefore assumed to be the main purpose of the green marketing focus. The interviews showed that in contrast to the findings of the pre-study, the end-users stated to care about the sustainability aspect of the offer, naming it as the most important factor in their decision making, along the price. This finding confirms the findings of Pearce (2009) who highlighted environmentally conscious, and price sensitive customers as two main customer groups interested in remanufactured products. Besides the more direct cost benefit that might attract customers towards the investment perceived as more risky, the companies differentiate their offers in the environmental dimension, aligning their stories with the beliefs of their customers, increasing their effectiveness of their communication efforts (Duan & Aloysius, 2019). As such, alignment requires an understanding of the customer's perspective, which gives added relevance to the customer-centric approach of this work. The thesis shows that there is a customer base that is concerned about the environment and highlights various nuances, particularly through the use of task 2 and as part of the persona mapping. One thing that stands out is that despite the claims for sustainable and circular offers, no interviewee could confirm the existence of considerations and contractual arrangements for reverse logistics. This creates a mismatch between the own portrayal and actions, as the enabling of reverse logistics is one of the fundamental practices for enabling circularity.

Interestingly, the literature review highlighted the need for circular business models to maximise the impact of circularity concerns and endeavours. Use-centric PSS seemed to be a logical fit for BESS given their properties of ensuring professional operation, maintenance, clear EOL arrangements, lasting relationships and performance guarantees. While these values also align with the discovered preferences of customers, customers largely expressed a preference for linear sales business models. This is surprising given the overlap with their overall preferences. Scepticism was voiced with regards to economic considerations. This answers to the uncertainties voiced by Mont (2002) over 20 years ago, asking if customers are ready for the adoption of PSS. While for BESS, product-centric PSS are not just accepted, but also requested by customers, the experienced scepticism towards use-centric PSS confirm the assumption. Profitability was stated as a concern holding people from entering such agreements but largely also a lack of knowledge. Throughout the interviews, the concepts of as-a-service and leasing were used interchangeably in several instances, indicating a lack of awareness of the benefits and how the concept works.

Perspectives on the operation

For the operational stage of BESS, it was found that a multitude of services have been offered and advertised by BESS suppliers irrespective of their usage of second- or first-life-batteries. This reflects the observed end-user preference for servitisation, as they indicated that they wanted energy management to be taken care of and did not want to be actively involved in the process. This confirms the findings of Dachs et al. (2014), which indicate a positive correlation between product complexity and the desire for servitisation, and assume that a servitisation strategy may yield the best results for complex, highly customised products. While the product BESS is not overly complex, its set-up, programming and maximising its utility is highly specialised and customised. The study highlighted that energy management is a field in which the respective customers did not possess pre-existing expertise and that customers wished not having to worry about. The desire for a high degree of servitisation of BESS operation was found not to be motivated by circularity consideration but from the desire to delegate responsibility of over a new action field to a trusted partner. Long term relationships and stability were therefore mentioned as important factors in supplier selection. While literature describes long and lasting relationships as a product of engagement with circular business models (Rapaccini & Adrodegari, 2022), this study found that stable partnerships and lasting relationships were actively sought after by customers and a condition for the operation as opposed to a result of it. Handing over the function of energy management to a third party can meanwhile be understood as a degree of outsourcing. Many of the features highlighted as benefits in the literature on outsourcing were perceived as beneficial to BESS customers as well, for example the enabling of value that could not have been achieved by internalising the function. Also, the possibility to stay up to date by engaging with experts was perceived as a benefit. At the same time, literature points out flexibility as a key argument in favour of outsourcing (Quinn, 1999). The previously stated points argue against an interest in high flexibility that is also reflected in the stated preference of interviewees to engage in linear transaction with the BESS supplier, preferring purchasing agreements.

The addition of a BESS and the professionalisation of the energy management overarchingly was perceived as a factor adding complexity to the operations of the interviewees. While the servitisation was seen as one way to mitigate the complexity, flexibility in channels and contact points was desired to further decrease the complexity. Contact points refer to the point of contact and the channel through which customers can address their needs, and the overarching wish of all customers was to reduce as far as possible the number of different contact points responsible for different activities. Preferred points of contact varied however due to the nature of different partners involved in the interaction. Planning offices were often seen as a preferred point of contact, while others preferred direct contact to BESS suppliers. Reducing the number of necessary contacts for the end-user requires excellent coordination internally and a good vertical integration of tasks. Decreased complexity of channels was meanwhile understood differently among the players calling for individualised approaches.

Reflections on the methodology

The thesis was designed in a customer-centric manner to advance the knowledge in this direction and enrich the debate on sustainable and circular BESS on the feasibility dimension. This customer-centric approach has proven valuable as it contributed to the challenging of pre-existing notions, for example formed through the pre-study. The selection of interview partners is meanwhile recognised as a key factor on influencing the results. The interview partners willing to participate were found to operate BESS with smaller capacity mainly, which might have effects on the customer personas and the customer journeys identified. On top of that, the interview was designed to incorporate an ideation process that is based on the experiences of the interviewees but intended to elevate and create a hypothetical scenario off of the knowledge base of the interviewees. It is recognized that the preexisting knowledge could lead to biases as interviewees have been through a customer journey already, with the risk of interpreting their own experiences into the ideation process. Potential customers could have been chosen as interview partners instead and while that might have had a positive influence on the ideation process, given the unbiased position of the interviewees, the complexity of the product and the services connected to it led to the decision to choose existing end-users.

The customer-centric approach furthermore had implications on the mapping of the digital enablers. The methods chosen were well aligned with the customer persona and journey mapping process, but also significantly limited the view of digital enablers due to the strong focus on the customer journey. Product level enablers were only partially mapped through the execution of task 1, but in an unstructured and incomplete manner. A respective change of the mapping approach would have been possible and equally valid but would have resulted in very different results. Similarly, the ideation process of mapping a hypothetical PSS in an attempt to create an overview of the holistic life cycle of a circular BESS offer could have been guided by a different methodology and framework. Authors suggest a combination of a view model and adapted versions of service blueprinting to create an overview over a PSS (Shimomura et al., 2009). This approach would have created an offer based on the detailed look at one specific company. The rationale for deciding for the SEEM method (Pirola et al., 2022) was the consideration of multiple potential customer companies that enabled an overview over the customer landscape. Given the lack of information on second-life BESS customers overarchingly, and the call for greater customer integration into the design process of circular business models (Schulz-Mönninghoff & Evans, 2023), this method seemed most adequate to generate knowledge in a meaningful way and was ultimately selected.

It is furthermore recognised that the broad approach was challenging to realise for practical reasons. As interviews served as the major source of information, and the interviews with the customers informed three different methodological steps, the time granted for each interview by the customers had to be used carefully. Despite a great deal of effort in the planning stage of the interviews, the limited time available during the interviews led to some shortcomings in the depth of information generated on each of the individual methodological steps.

Task one was primarily based on literature and publicly available documents provided by the respective companies. As a result, the information provided on their circularity strategies may not have been complete and targeted to their stakeholders. Potential biases were therefore considered in the analysis stage. Beyond that, triangulation was attempted through the conduct of interviews with only one interview ultimately conducted due to unavailability from the contacted interview partners. A closer collaboration with active BESS suppliers would have supported task one and enabled a more complete picture but was not followed given the scope of aim of the thesis.

Task two was mainly influenced by the context specific of the interviews. While resiliency considerations were extensively discussed and highly valued as a driving factor for BESS adoption in literature (IRENA, 2019), back-up power was only scarcely mentioned by the interview partners. The interview partners that participated in the project were operating rather small BESS which might have impacted the outcomes of this project. The geographical and the grid context can be assumed as a key reason for that while certainly also the temporal context is significant.

6 Conclusion

Circular BESS solutions are envisioned to overcome the challenges of lacking utilisation of the residual value of the growing stream of Li-ion batteries returning from their first life application and the simultaneous need for flexibility in the electricity grids to balance the intermittency of renewable energy sources. The thesis aimed to generate knowledge needed by practitioners to enable and guide the development of more circular BESS solutions. Two research questions have been developed to facilitate the conduct of the project which were answered as follows:

RQ1: What constitutes a feasible circular BESS offer to the European C&I sector?

In line with the logic of the circularity metrics used to evaluate circular products, circular BESS was defined as BESS that contributes to the principles of the CE. Instead of one solution for creating a circular BESS offer, multiple approaches have been identified. The different circularity strategies facilitating these approaches were found to be stackable, increasing the circularity of the offer and addressing new areas of impact. Despite the context specific nature of circularity design, four essential constituents of circular BESS have been identified: circular sourcing of materials and components, product design that follows the circularity principles and enables the services offered, a high degree of servitisation as well as the facilitation of clear contractual agreements to facilitate reverse logistics in all instances.

Reuse and repurposing strategies have been identified as most widely applied sourcing strategies for components and materials. A special focus has been put on the battery as the BESS component with the biggest impact against all three dimensions of sustainability. While the debate around BESS has largely focused on BESS as a second-life option for Li-ion batteries, individual companies are using other batteries, such as lead-acid batteries, which have superior recyclability. As the return flows are only slowly developing, instead of creating BESS with virgin Li-ion batteries that are simply not fully recyclable to date, choosing alternative battery components should be considered. Environmental assessments should guide such decision-making processes. Beyond the battery also other components can and should be sourced from previously used materials ideally created through local waste-to-product cycles.

Meanwhile, product design has the potential to impact all five impact categories, narrowing, slowing, closing, inform and regenerate and should be conducted simultaneously on the product and service level. The development of strategies across the five dimensions can be pursued simultaneously. Sufficient sizing, adaptability, modular design enabling easy disassembly and high-quality components are core strategies that were frequently mentioned complemented by practical protection strategies, insulation, the usage of temperature control mechanisms and standardization of components. Hardware installations that enable service delivery, such as cell-level sensors, should also be pursued. Through the provision of additional services, narrowing and slowing strategies can be facilitated. The essential services identified for the use-phase evolve around the aspects of monitoring, maximizing utility through operation management and maintenance. Maximisation for all these practices should meanwhile not be put on utility maximization solely but incorporate lifetime maximizing and therefore slowing practices.

Lastly, the contractual facilitation of reverse logistics enabling recycling of the technical components of BESS should be enabled. Use-centric product service systems have been identified as well-suited business models contributing multiple values and shift ownership structures to enable the respective end-of-life control of the BESS supplier.

To confirm and ensure feasibility of the circularity strategies, preferences of customers have been analysed. Costs and sustainability aspects of the respective offer have indeed identified as key decision-making parameters facilitating uptake. Beyond that, local involvement and partnerships have been identified as important to end users and therefore BESS suppliers. Especially engineering and planning offices have been identified as key partners to facilitate trust and access to customers. Beyond that, it was found that use-centric PSSs are not desired by end-users. While many of its features are desired, scepticism towards the economic efficiency prevail. End-users should look to transport the desired values of shifted responsibility, maximum utility creation through professional operation and performance guarantees to product-centric PSS that proved to be easier accepted – not at last due to existing funding mechanisms that support sales models.

RQ2: *How can digital tools be used to enable a feasible customer journey for a circular BESS offer to the C&I sector in Europe?*

Digital tools were identified as essential components at different levels of the offer. They proved to be essential on both at the product level, facilitating functioning and service delivery, and along the customer journey, where they enabled smooth customer journey performance.

At the product level, sensors monitoring battery performance on the cell level, the connected BMS, and the EMS were identified as key enabling technologies that should be focused on to enhance the circularity performance of the BESS. At the customer journey level, each touchpoint required distinct technical solutions, ranging from contact channels, to process management tools and the aforementioned EMS, which required specifications to meet customer expectations. To facilitate operation and integration of the BESS controller into the system of third-party experts, such as aggregators or BMS operators standardized interfaces should be implemented. Beyond that, a customised customer demand for information with regards to frequency and content has been identified. Besides an EMS customer portal that delivers real time performance information of the BESS, customised performance reports are expected to be send regularly. Challenges were identified from a lack of standardisation in communication protocols of the BMS and EMS that hindered system integration.

Many of the steps and tools required were found to be identical with standard sales processes and focus on internal process logistics. The tools that stand out as enablers for the customer journey of the circular BESS are the customer information sheet, the EMS, the BESS controller, the EMS customer interface, and respective third-party interfaces.

Recommendations for practitioners

As the case study highlighted the feasibility of circularity strategy stacking, practitioners should not limit their approaches to a single item or strategy, but should approach the circular design process holistically, seeking to create an outstanding impact that can then be marketed given the existing market base of sustainability interested actors. Beyond that, collaborations with local service providers should be pursued to increase credibility and access to customers. Lastly, while holding significant features for value delivery, the nonacceptance of as-a-service models should be recognized. Close engagement with customer to increase understanding or a transfer of the desired features to product centric PSS should be pursued.

Recommendations to academia

After creating an overview on product level circularity strategies applied in the context of BESS, environmental impact assessments should be developed to guide the decision-making process of academia further. Beyond that, overcoming scepticism towards use centric PSS. Furthermore, analysing the mechanisms creating reluctance towards use-centric PSS would be interesting. Beyond that, given the shortcoming of Li-ion batteries in recyclability overarchingly, alternative battery types should be investigated, better suited for recycling. While lots of pressure is hitting the recyclers, additional opportunities for high performing battery alternatives would be desired and should be investigated.

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Appendix

Appendix 1. Overview over application status of circularity strategies for BESS

Life-Cycle Stages							
Acquisition of raw materials		**Design**				**Production**	
Circularity Strategy	Category	Circularity Strategy	Category	Circularity Strategy	Category	Circularity Strategy	Category
Repurpose existing products and components	Slow	Design for multiple functions	Narrow	Track the resource intensity of the product-in-use	Inform	Eliminate production waste	Narrow
Remanufacture existing products and components	Slow	Design for physical durability	Slow	Design with low-impact inputs	Narrow	Produce and process with renewable energy	Regenerative
Build (local) waste-to-product loops	Close	Design for ease of maintenance and repair	Slow	Design light-weight products	Narrow		
Localize supply where appropriate	Narrow	Design for easy dis- and reassembly	Slow	Provide an unconditional lifetime warranty	Slow		
Power transportation with renewable energy	Regenerate	Design for upgradability	Slow	Design for emotional durability	Slow		
		Design for standardization and compatibility	Slow	Turn disposables into a reusable service	Slow		
		Upgrade and adapt existing products	Slow	Design with recycled inputs	Close		
		Encourage sufficiency	Slow	Design components, where appropriate, with one material	Close		
		Design for easy disassembly at the end of the product life	Close	Design with renewable materials	Regenerate		
		Design with materials suitable for primary recycling	Close	Design self-charging products	Regenerate		
		Embed renewable energy production in the existing infrastructure	Regenerate	Design with living materials	Regenerate		
		Virtualize	Inform	Design with non-toxic materials	Regenerate		
		Design connected products	Inform	Regenerate polluted ecosystems	Regenerate		
		Use product-in-use data for circular design	Inform	Manage and sustain critical ecosystem services	Regenerate		
		Track the condition, location, and/or availability of the product	Inform	Use artificial intelligence to develop new materials with circular properties	Inform		
		Market circular products, components and materials through online platforms	Inform	Build material database ecosystems	Inform		
		Use artificial intelligence to optimize circular infrastructure	Inform	Co-create products, components, materials and information via online platforms	Inform		
		Operate service ecosystems via online platforms	Inform				

Green:	Application mentioned by practitioners
While:	No information available/found

Life-Cycle Stages						Beyond traditional lifecycle	
Transportation		**Use**		**End-of-life treatment**		**Additional measures**	
Circularity Strategy	Category	Circularity Strategy	Category	Circularity Strategy	Category	Circularity Strategy	Category
Organize light-weight urban transport	Narrow	Maximize capacity use of products	Narrow	Enable and incentivize product returns	Close	Recover nutrients from urban areas	Regenerate
Power transportation with renewable energy	Regenerative	Organize maintenance and repair services	Slow	Recycle products in proper facilities	Close		
		Power the use of the product with renewable energy	Regenerate	Reuse and sell components and materials from discarded products	Close		
		Enable and incentivize users to consume less	Narrow	Build (local) waste-to-product loops	Close		
				Engage in industrial symbiosis	Close		

Green:	Application mentioned by practitioners
While:	No information available/found

Appendix 2. Circularity practices mapped from practitioners

Life-Cycle Stages									
Acquisition of raw materials		**Design**				**Production**		**Transportation**	
Circularity Strategy	Applied by	Circularity Strategy	Applied by	Circularity Strategy	Applied by	Circularity Strategy	Applied by	Circularity Strategy	Applied by
Utilisation of second life battery	E.g. Tricera	Scalable (upgradeability)	E.g. ECO STOR	Ventilation system (optimal condition for increased safety and min. degradation)	e.g. Octave	Production process powered by renewable energies	Nilar (Battery producer)	Research into minimum waste packaging and biodegradable packaging	BeePlanet factory
Code of Conduct for battery/raw material providers	Fluence	Modular (easy repair)	E.g. Evyon	High degree of standardisation. E.g. Modbus (easy integration)	e.g. Octave	Automated and highly efficient processes (reduce production waste)	Nilar (Battery producer)	Reuse of battery module transport boxes	Connected Energy
Use of second-life parts beyond battery. E.g. BMS, one way shipping container	E.g. Octave	Flexible (adapt to changing power requirements)	E.g. Connected Energy	BMS monitoring on cell level (voltage and temp. Enables targeted maintenance)	e.g. Octave	Local production (sales)	Watt4Ever		
		Compact (efficient spacial use)	BatteryLoop	Extensive testing prior to installation (avoids disturbances during installation and waste of resources)	Relyon				
		Durable design (high quality components, reflected in long guarantees)	RedEarth Energy	Individual demand planning with consideration of future needs (sizing. avoid inefficiencies and overconsumption)	BatteryLoop				
		Grid connection is fitted to grid context. No additional transformer needed	Tricera	Reinforced insulation on all connections	BeePlanet factory				
		Smart design with sufficient protection from the elements (raised base for standing water protection, pitched roof, sufficient enclosure)	E.g. ADS-TEC	Insulation of the housing	Volvo Penta				
		Batteries 100% recyclable (claim)	Enermore	Web interface for monitoring. Digitalised and dematerialised	Watt4Ever				

Life-Cycle Stages						Beyond traditional lifecycle	
Use				End-of-life treatment		Additional measures	
Circularity Strategy	Applied by	Circularity Strategy	Applied by	Circularity Strategy	Applied by	Circularity Strategy	Applied by
Remote monitoring	e.g. Octave	Charge and discharge limit control (full charge and discharge disabled to slow degradation). 100% available for backup	e.g. BeePlanet factory	Recycling of battery	E.g. Northvolt, Voltfang, Watt4Ever	Consideration of sustainability aspects beyond the product itself. (support of cycling to the office, etc.)	BeePlanet factory
Cell level monitoring	e.g. ADS-TEC	Routine inspections (prolonged life, slowed resource extraction loop)	Saft	Residues of recycling process sent to metal industry for reuse	NorthStar	Open EMS software provided. Remove barriers for market uptake.	Fenecon (commercial)
Proactive maintainance	e.g. Saft	Local installers	Voltfang, Tesvolt	Recycling of "other materials wherever possible"	Ferroamp	Webinars for customers? Educating on best practices?	Fenecon rental, Fluence
Individual component replacement	Saft	Web based support portal	E.g. Saft			LCA on second life BESS (science driven approach)	BeePlanet factory
State of health monitoring (increased predictability and maintenance efficiency)	e.g. Octave	Regular software updates (maximum performance)	Evyon				
Professional EMS operation. (Predicts future markets. Maximum utility)	Fluence	Harmonised performance of batteries (those more degrated are used less)	Relyon				
Multiple applications	MerusPower	For inactive times: crypto miner installed	Red Earth energy				
Cooperation with 3rd party expert to implement strengths of different actors.	Red Earth energy	Insurance management system. Integrated additional function to make further applications redundant.	Connected Energy				

Appendix 3. Interview partners

Abbreviation	Industry/Function	Role	Customer Persona Group	Language	Country	Date
Potential Customers. Interviewed as part of a Pre-study						
PM1	Mining	Potential Customer	1	English	Sweden	17.10.2022
PM2	Pulp and paper	Potential Customer	1	English	Sweden	14.10.2022
PM3	Municipality	Potential Customer	2	English	Sweden	20.10.2022
PM4	Port	Potential Customer	2	English	Sweden	17.10.2022
PM5	Dairy	Potential Customer	not confirmed	English	Sweden	20.10.2022
PM6	Hotel	Potential Customer	3	English	Sweden	24.10.2022
PM7	Logistics	Potential Customer	3	English	Sweden	14.10.2022
Existing BESS Customers. Interviewees						
I1	Real Estate	Existing BESS Customer	1	English	Norway	17.03.2023
I2	Offgrid Construction	Existing BESS Customer	out of the scope	English	Norway	17.03.2023
I3	Port	Potential Customer	2	English	Sweden	20.03.2023
I4	Hotel	Existing BESS Customer	3	German	Germany	21.03.2023
I5	Solution Planner, BESS supplier	Customer Spokesperson for Construction Company	3	English	Norway	22.03.2023
I6	Municipality	Waiting for Installation	2	English	Sweden	22.03.2023
I7	Bus	Existing BESS Customer	3	German	Germany	23.03.2023
I8	Energy producer	Existing BESS Customer	3	German	Germany	24.03.2023
I9	Hotel	Existing BESS Customer	3	German	Germany	24.03.2023
I10	EMS operator	Customer Spokesperson for Entertainment Company	1	English	Netherlan	24.03.2023
I11	Hospital	Existing BESS Customer	2	English	England	29.03.2023
I12	Municipality	Waiting for Installation	2	German	Germany	23.03.2023
External Experts. Interviewees						
I13	Energy solutions consultant			German	Germany	27.03.2023
I14	Energy solutions planning office			German	Germany	04.04.2023
I15	Second-life BESS provider			German	Germany	13.04.2023
Internal Experts. Interviewees						
I16	Sales Expert. Volvo Energy			English	Sweden	multiple
I17	Product Expert. Volvo Energy			English	USA	02.03.2023
I18	Sales Expert. Volvo Energy			English	USA	02.03.2023
I19	Digital Product Expert. Volvo Energy			English	Sweden	multiple
I20	Customer Experience Manager. Volvo Group			English	Sweden	07.03.2023

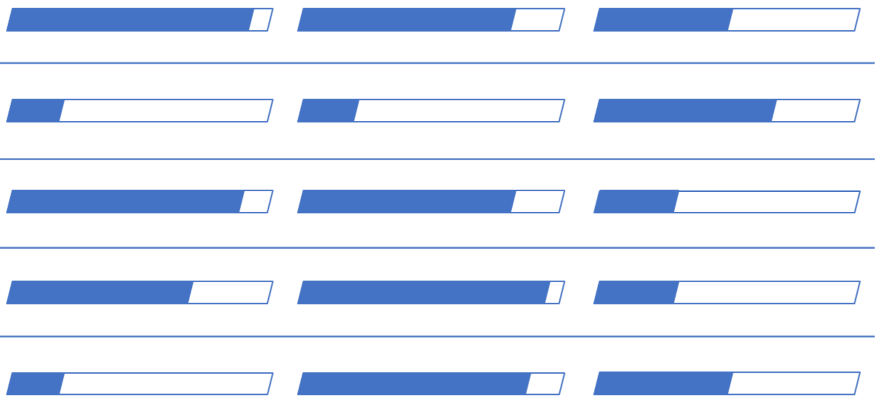
Appendix 4. Interview guide

Topic	Qs for BESS users.	Probes
Energy profile	What **role does electricity** play for your organisation? What are your main **challenges** when it comes to electricity management?	Do you have a high electricity consumption that impacts your economic performance in a relevant way? Do you experience significant electricity peeks?
Familiarity with BESS	**How long** has your BESS been running for and what is your overal **verdict** on the project/investment so far? How does the **service agreement** look like? Does the provider take care of the operation (especially the EMS settings)	
Needs from BESS	What was the **key motivator** for you to engage with BESS? What did you hope to gain from it?	
What is important to you?	What is **important to you when engaging with external service providers**? What is important to you when making investment decisions?	
Key aspects of consideration	What made you choose **your BESS supplier**? Is there something specific you would **look out for** in hindsight?	
Main challenges with an as a service BESS offer	What were the **main challenges** or special needs for you **starting the project** (performance, own involvement, finances) Think about **subscribing to a BESS** (as a service). Would that be a viable option and would there be any other **challenges** that come with such a busniess model?	
Walk through the customer journey.	I would like to understand how an optimal journey for a circular BESS would look like for you. I drafted a hypothetical journey and would like to get your input on how you view the individual steps would like to engage with your solution provider.	
Initial introduction to BESS	-How do you **stay updated** on technology topics? - Do you follow any specific mediums? - Do you want to be contacted about tech updates/offers by a supplier? OR Realize yourself and then approach someone proactively.	
Contact with supplier/dealer. Discussion on needs and opportunities	IF **yourself**: whom would you naturally turn to? In what way? - What are critical points/information that you would like to have clarification on by the technology provider before talking about an actual contract? (you need cost estimations, right? Guarantees? ROI? Alternative scenarios? Did you (have to) reach out to any other partners/players to confirm the suppliers statements?) - Which partners would you like to have involved in these negotiations? - Is the availability of space a concern? - I heard that the contract negotiation period takes a long time. many meetings are often required. True for you? Why is that? Is the sharing of electricity data a problem?	If contacted by **supplier**: how? Through which medium? Is the sharing of electricity data a problem?

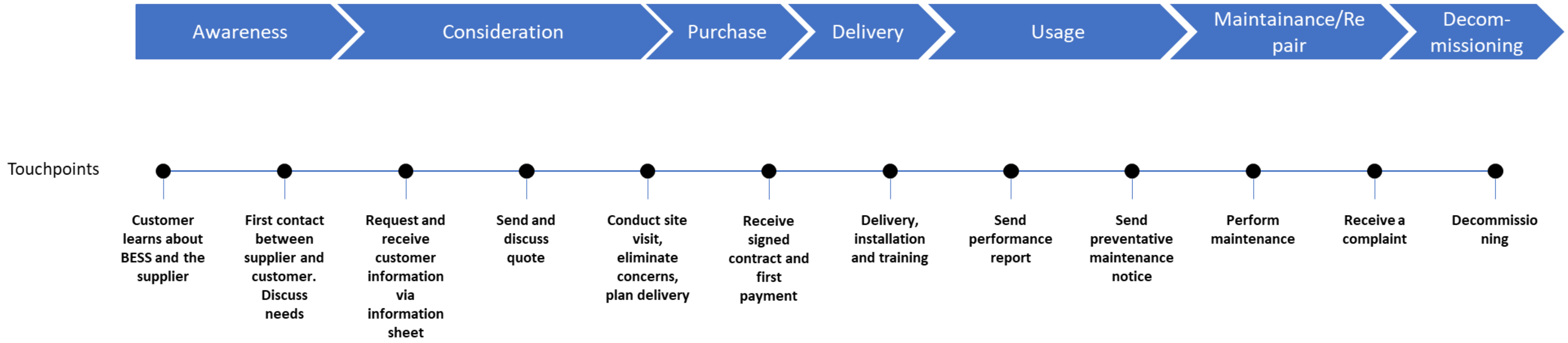
First offer. Sitting down and discussing the offer.	- How would you want to communicate with the supplier? Initial contact, negotiations, site visits, regular check ins? making complaints? - Which **partners** would you like to have **involved in these negotiations**? - Is the availability of space a concern?	For current BESS users: has the **engagement with BESS led to other electricity related infrastructural changes** at your company? Did you upgrade the own electricity production?
Receiving the finalized offer	In what form/through which medium would you like to receive it?	
Last minute changes and signature	Do you expect an openness towards renegotiations? IF YES: What reasons for such renegotiations do you foresee?	
Delivery, installation and training.	- Any preferences towards the delivery process itself? - What **level of service would you like**? Do you expect different options at different price points? Which option sounds most attractive to you? Range: High degree of self management at small price to everything taken care of by the supplier at higher charge? - Is there an **interest in being trained**? How to interpret the different performance metricsl, gaining in depth knowledge of the different markets the BESS operates in to make money? etc. (or is it enough to know that professionals are maximizing utility and get economic performance reports?)	
Follow-up call: Check-in	Is a check in after the installation appreciated? Would you like to receive an initial analysis with it?	
(in the background) Adjust settings	- Do you want your **service partner to be able to make changes to the software** to optimise the revenue generation? - Do you want to be informed about changes made to the software settings (prior to them being performed)? *Alternative: regular performance reports coupled with options for future settings optimisation?*	
Preventative maintainance. Inform and schedule appointment	- How long of a notice before maintainance workers arrive? - Does it make a **difference who does the maintainance work**? The supplier´s staff or trained local workers?	
Perform the maintainance work.	Any additional preferences/experiences?	
Complaint/Follow-up call	How would you like to **contact the supplier in case of a complaint**? - Acceptable response time?	
Regular performance and achievement report	How often would you like to get **updates on the performance**? Daily? Monthly? - Written form? Via an App at all times? With consultation? - **what type of information would you like to receive through these reports**? - are sustainability performance indicators of interest e.g. for reporting?	
Decommissioning/replacement (after life treatment)	If the batteries were to be exchanged, what information would you like to receive on that?	

Appendix 5. Customer personas

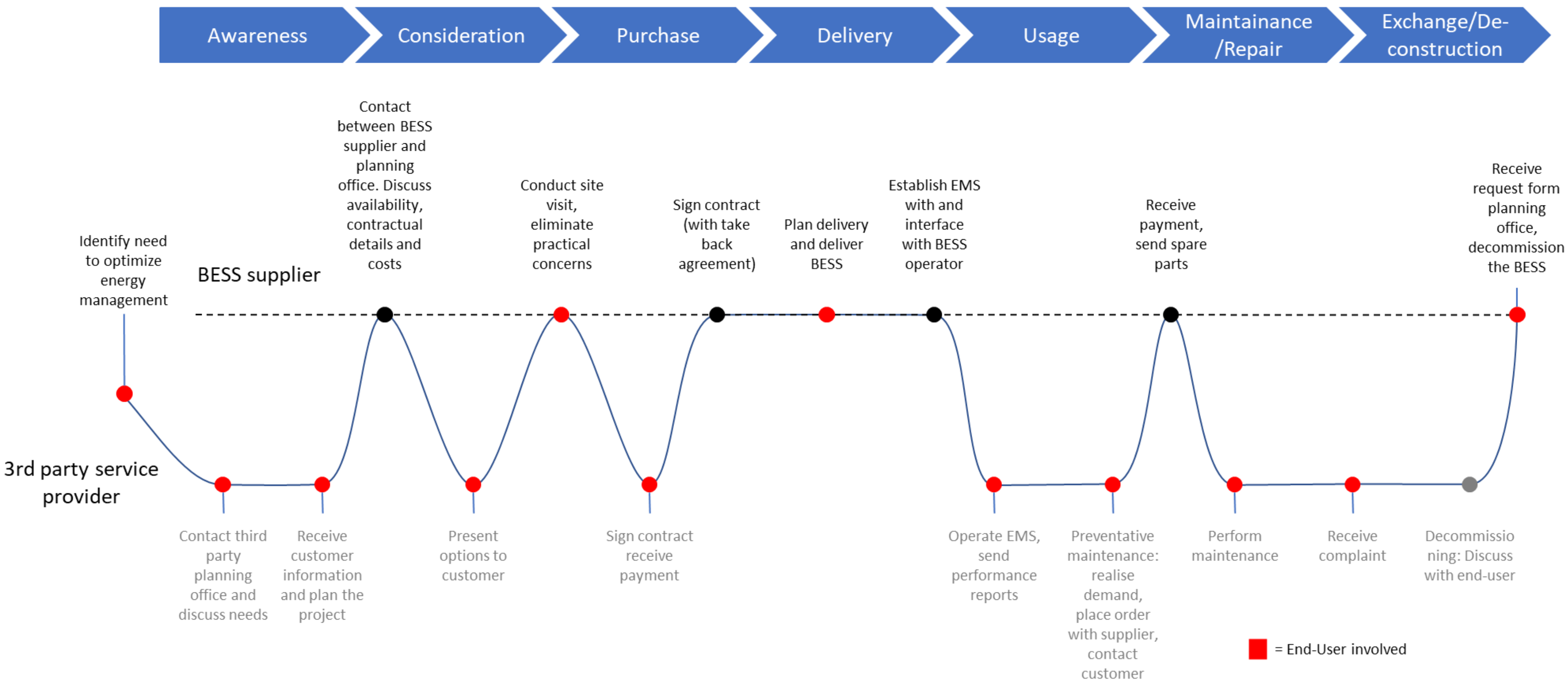
	Jörgen	Christopher	Eva
Basic Profile	- CEO - Mining Company - 200+ employees - **Profitability** (grid services and arbitrage) - Male, 60-65 - Decision maker	- Head of Estate - Public Hospital - 200+ employees - **Energy security, cost cutting, revenue generation and future proof infrastructure** - Male, 55-60 - Decision maker through tender evaluation	- CEO - Hotel - Ca. 100 employees - **RES integration and peak shaving** - Female, 45-55 - Decision maker
Key quote	”The BESS proved to be more profitable than expected. We want to scale it up!”	”Carbon is King.”	”We want to set up our infrastructure for longterm success.”
Interviewees	PM1, PM2, I1, I10	PM3, PM4, I3, I6, I11, I12	PM6, PM7, I4, I5, I7, I8, I9
Company´s total electricity demand			
Significance of electricity peaks to total costs			
Availability of funding			
Preference towards large, unproven OEM as service provider			
Importance of a sustainable offer			



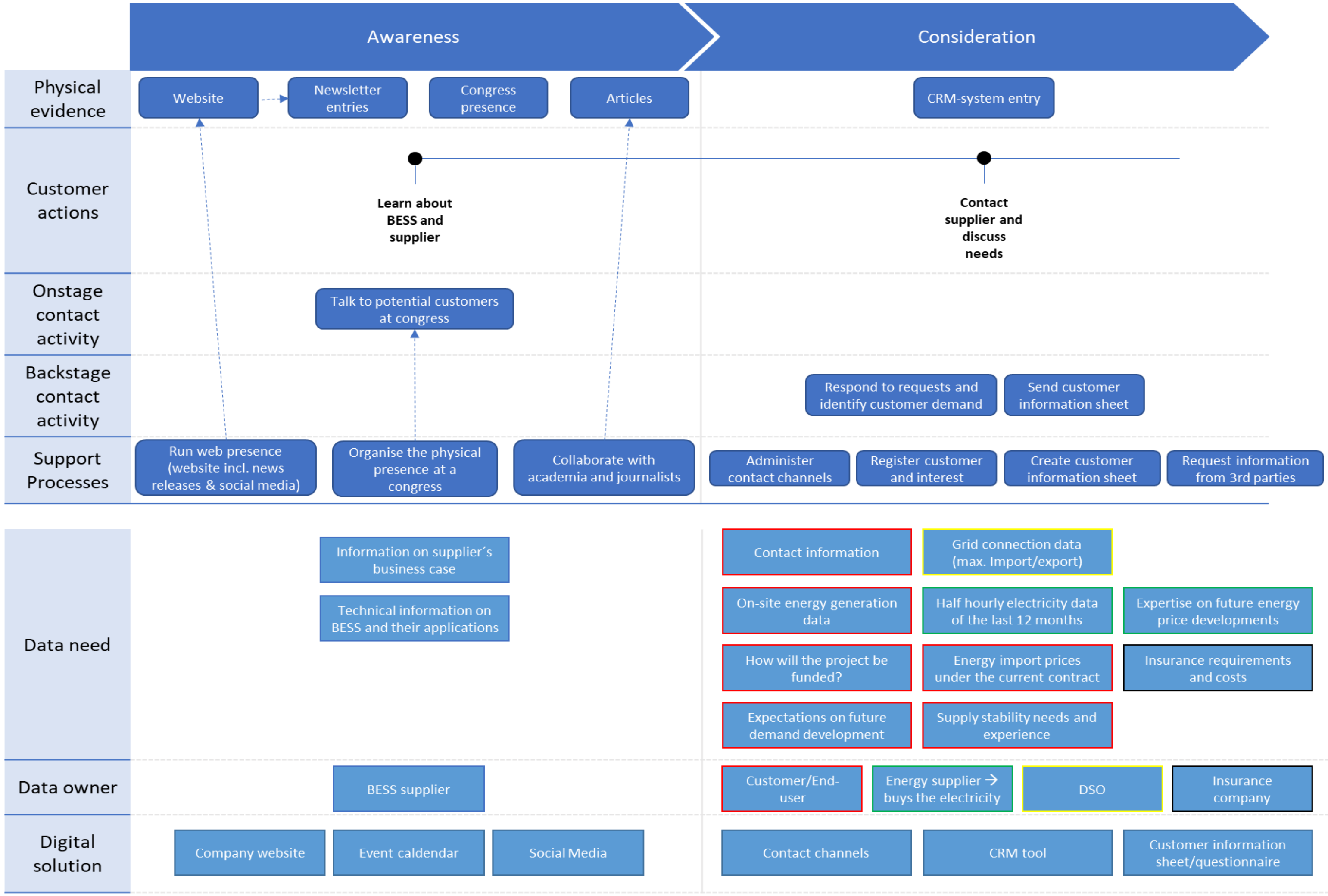
Appendix 6. Customer Journey all services integrated

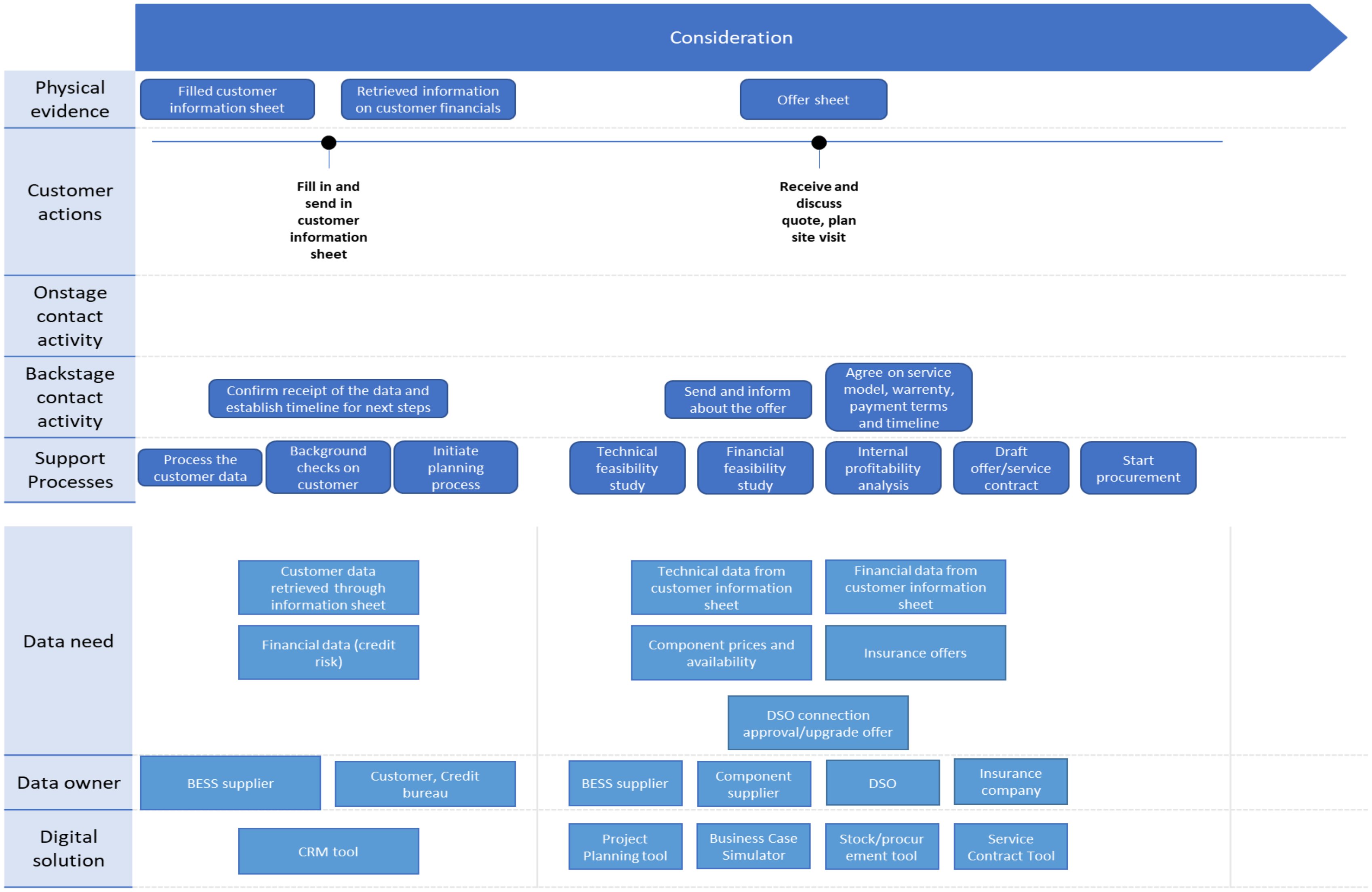


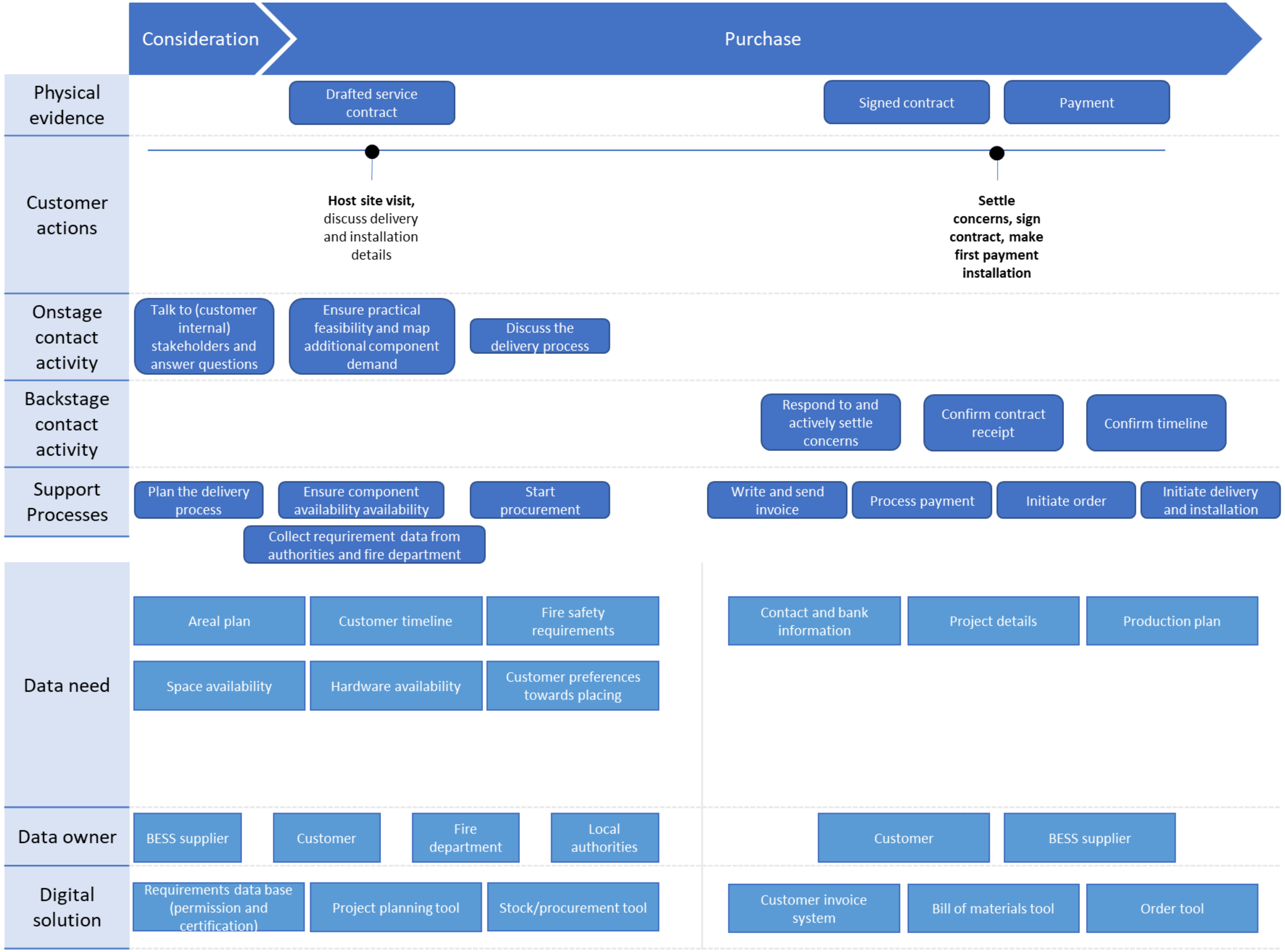
Appendix 7. Customer Journey all possible services outsourced

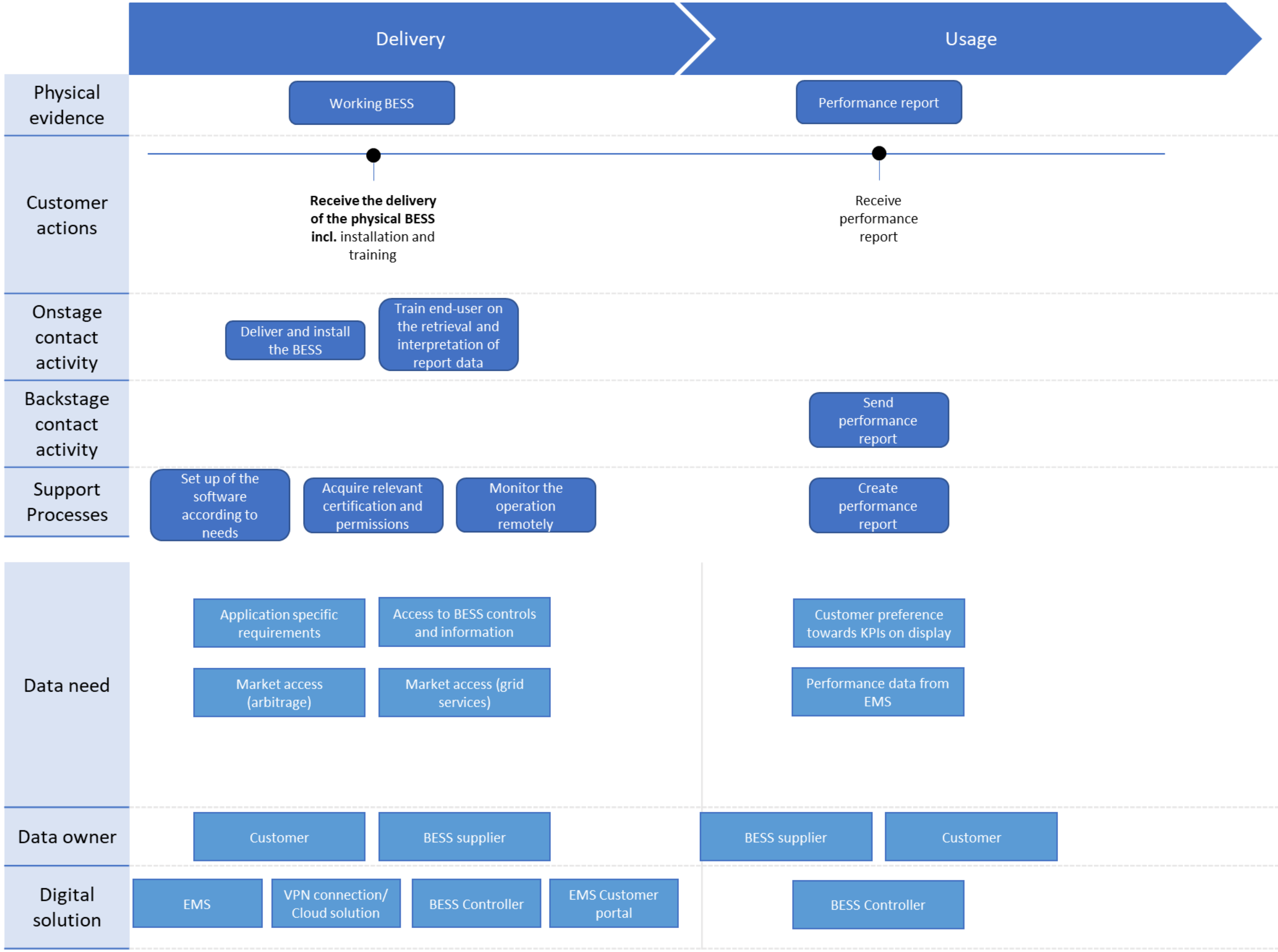


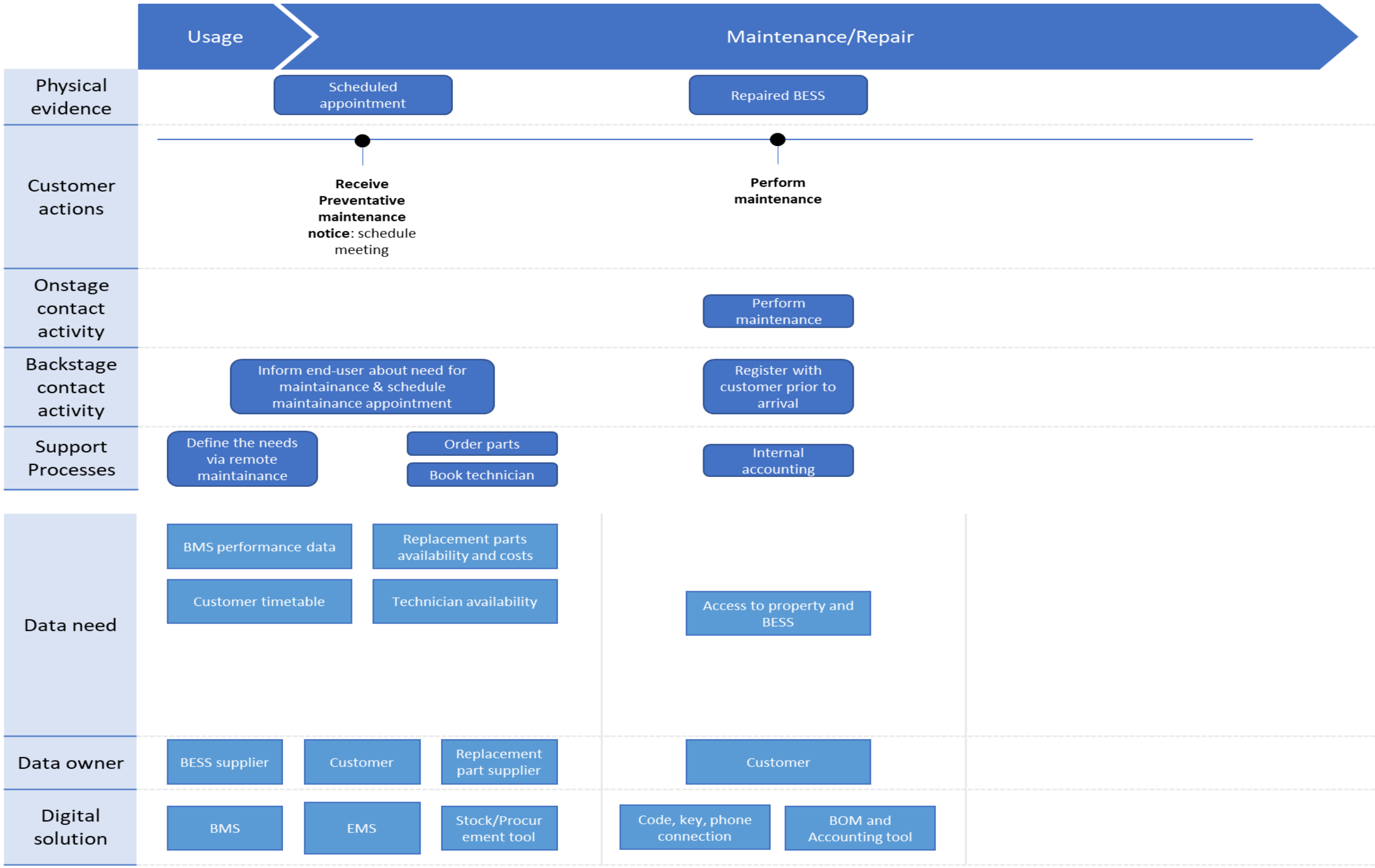
Appendix 8. Service blueprint with digital enabler map. All possible services integrated

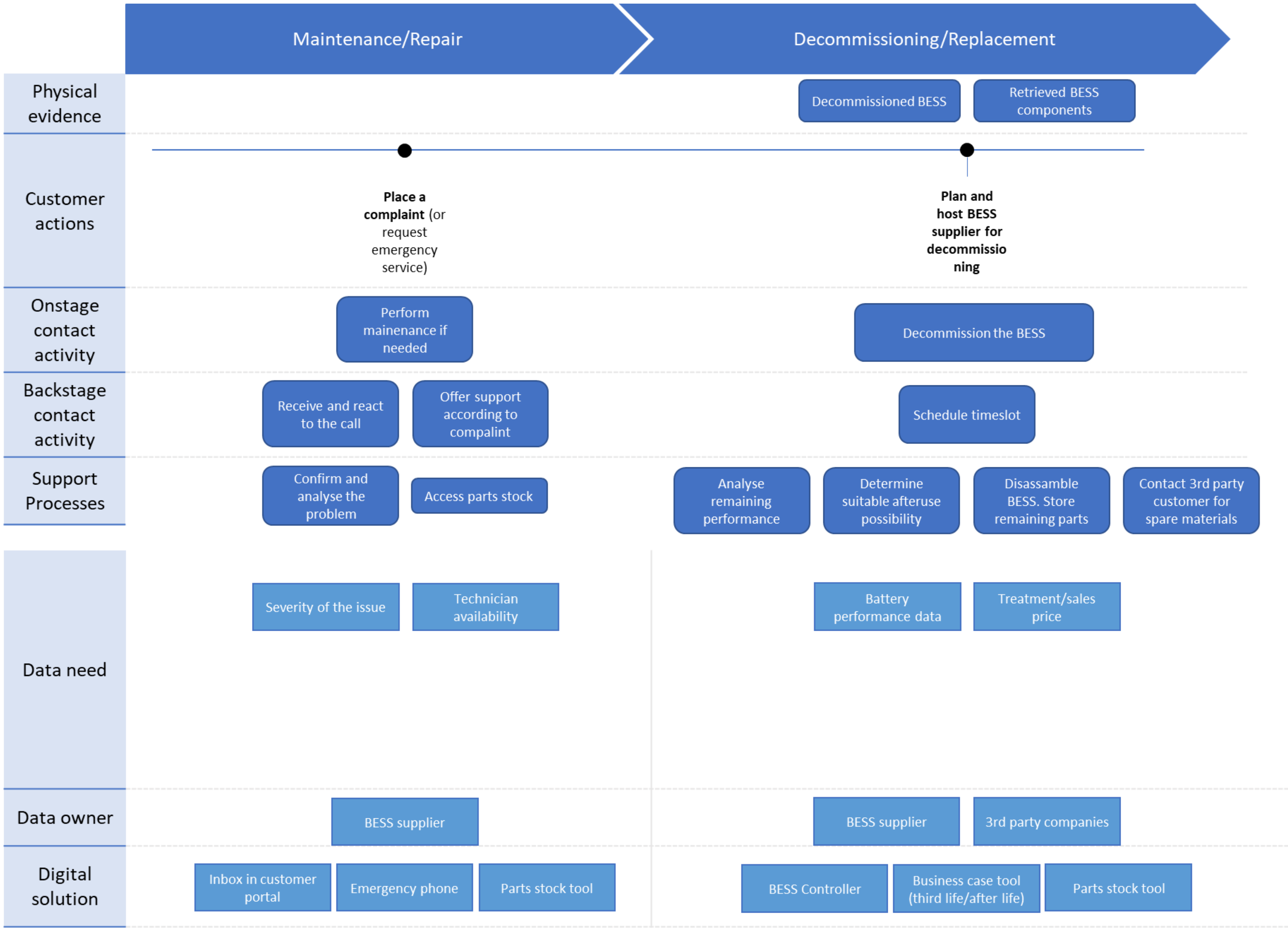



Consideration
Physical evidence
Filled customer information sheet
Retrieved information on customer financials
Offer sheet
Customer actions
Fill in and send in customer information sheet
Receive and discuss quote, plan site visit
Onstage contact activity
Backstage contact activity
Confirm receipt of the data and establish timeline for next steps
Send and inform about the offer
Agree on service model, warrenty, payment terms and timeline
Support Processes
Process the customer data
Background checks on customer
Initiate planning process
Technical feasibility study
Financial feasibility study
Internal profitability analysis
Draft offer/service contract
Start procurement
Data need
Customer data retrieved through information sheet
Financial data (credit risk)
Technical data from customer information sheet
Financial data from customer information sheet
Component prices and availability
Insurance offers
DSO connection approval/upgrade offer
Data owner
BESS supplier
Customer, Credit bureau
BESS supplier
Component supplier
DSO
Insurance company
Digital solution
CRM tool
Project Planning tool
Business Case Simulator
Stock/procur ement tool
Service Contract Tool


Consideration
Purchase
Physical evidence
Drafted service contract
Signed contract
Payment
Customer actions
Host site visit, discuss delivery and installation details
Settle concerns, sign contract, make first payment installation
Onstage contact activity
Talk to (customer internal) stakeholders and answer questions
Ensure practical feasibility and map additional component demand
Discuss the delivery process
Backstage contact activity
Respond to and actively settle concerns
Confirm contract receipt
Confirm timeline
Support Processes
Plan the delivery process
Ensure component availability availability
Start procurement
Collect requirement data from authorities and fire department
Write and send invoice
Process payment
Initiate order
Initiate delivery and installation
Data need
Areal plan
Customer timeline
Fire safety requirements
Space availability
Hardware availability
Customer preferences towards placing
Contact and bank information
Project details
Production plan
Data owner
BESS supplier
Customer
Fire department
Local authorities
Customer
BESS supplier
Digital solution
Requirements data base (permission and certification)
Project planning tool
Stock/procurement tool
Customer invoice system
Bill of materials tool
Order tool


Delivery
Usage
Physical evidence
Working BESS
Performance report
Customer actions
Receive the delivery of the physical BESS incl. installation and training
Receive performance report
Onstage contact activity
Deliver and install the BESS
Train end-user on the retrieval and interpretation of report data
Backstage contact activity
Send performance report
Support Processes
Set up of the software according to needs
Acquire relevant certification and permissions
Monitor the operation remotely
Create performance report
Data need
Application specific requirements
Access to BESS controls and information
Market access (arbitrage)
Market access (grid services)
Customer preference towards KPIs on display
Performance data from EMS
Data owner
Customer
BESS supplier
BESS supplier
Customer
Digital solution
EMS
VPN connection/ Cloud solution
BESS Controller
EMS Customer portal
BESS Controller


Usage
Maintenance/Repair
Physical evidence
Scheduled appointment
Repaired BESS
Customer actions
Receive Preventative maintenance notice: schedule meeting
Perform maintenance
Onstage contact activity
Perform maintenance
Backstage contact activity
Inform end-user about need for maintainance & schedule maintainance appointment
Register with customer prior to arrival
Support Processes
Define the needs via remote maintainance
Order parts
Book technician
Internal accounting
Data need
BMS performance data
Replacement parts availability and costs
Customer timetable
Technician availability
Access to property and BESS
Data owner
BESS supplier
Customer
Replacement part supplier
Customer
Digital solution
BMS
EMS
Stock/Procurement tool
Code, key, phone connection
BOM and Accounting tool


Maintenance/Repair
Decommissioning/Replacement
Physical evidence
Decommissioned BESS
Retrieved BESS components
Customer actions
Place a complaint (or request emergency service)
Plan and host BESS supplier for decommissioning
Onstage contact activity
Perform mainenance if needed
Decommission the BESS
Backstage contact activity
Receive and react to the call
Offer support according to compalint
Schedule timeslot
Support Processes
Confirm and analyse the problem
Access parts stock
Analyse remaining performance
Determine suitable afteruse possibility
Disassamble BESS. Store remaining parts
Contact 3rd party customer for spare materials
Data need
Severity of the issue
Technician availability
Battery performance data
Treatment/sales price
Data owner
BESS supplier
BESS supplier
3rd party companies
Digital solution
Inbox in customer portal
Emergency phone
Parts stock tool
BESS Controller
Business case tool (third life/after life)
Parts stock tool