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Enabling Second life Electric Vehicle Lithium-ion Batteries in the Norwegian Ecosystem

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Abstract: Electric vehicles (EV) adoption has accelerated rapidly over the past decade, driven by advances in battery technology, policy changes, and growing awareness of climate change. Lithium-ion batteries (LiBs) are central to this transition because of their high capacity, density, and long life span. However, several end of life (EOL) challenges arise as EV LiBs are typically retired at 70%-80% of their capacity, posing environmental and safety risks if not managed responsibly. Second life strategies, such as repurposing and recycling offer promising pathways to address these challenges and create additional value. This study employs a case study research design, using semi-structured interviews as a primary data and peer-reviewed articles and grey literature as secondary data. It applies a systems method 'SPADE' adapted to the second life EV LiB context. SPADE provides a systemic framework to categorise stakeholders, identify problems, map value chain configurations and develop a typology of sustainable business models.

Keywords: Sustainable business models; Ecosystems; Systems approach; Electric vehicles; Lithium-ion batteries; Recycling; Repurposing; Reusing; Second-life

1 Introduction

Climate change remains a persistent global issue throughout the world. The adopted '2030 agenda for sustainable development' that includes 17 sustainable development goals (SDGs), has provided a framework for Governments to follow (UN, 2015). As a result, transition towards renewable energy sources is accelerating, driven by strong decarbonization policies and advances in technologies (Hafner and Tagliapietra, 2020). This advancement is not only limited to technological innovations but also includes building better business practices and implementing sustainability in business models at both firm and system level (Bocken, 2023).

The road transport sector is considered one of the biggest polluters for the environment with emissions accounting for almost 77% of the total EU greenhouse gas (GHG), led by the fossil fuel based internal combustion engine vehicles (ICEV) (Dehkordi et al., 2024). Electrifying the road transport sector is considered key to achieving decarbonization and energy efficiency, and to reduce dependence on the fossil fuels based system (Creutzig et al., 2015; Zhang and Fujimori, 2020). EVs reduce GHG emissions as they are more energy efficient, and the electricity to power them can be produced using renewable sources (Holland et al., 2021; Singh and Strømman, 2013).

Norway leads this transition where 97% of the new cars sold in 2025 were EVs (Dow, 2026). This rapid adoption of EVs has led to an increased demand for Lithium ion batteries (LiBs) which are considered ideal for use in EVs because of their high capacity, increased density, and long life span (Wrålsen et al., 2021). The current LiB technologies require materials that are predicted to have a high supply risk in the future. Moreover, there is a growing concern of safety and pollution, if these batteries are handled irresponsibly after their first end of life (fEOL), since ideally, they are retired from the EVs once their capacity reaches 80% or less (Börner et al., 2022). The increased amount of fEOL EV LiBs can give rise to challenges such as supply chain bottlenecks, inefficient materials recovery, and energy waste. The challenges thus exist both at firm and value chain level. End of life strategies such as recycling, reusing and repurposing EV LiBs after their first life, has been put forward as key pathways to improve battery sustainability (Ma et al., 2022; Reinhardt et al., 2020). These pathways can prolong battery life, supported by business models that integrate sustainability at their core (Wrålsen et al., 2021). Repurposing these batteries in another second-life battery application (SLB) can be an important step for prolonging the battery life, while providing enough time for the recycling technologies to become more efficient and sustainable (Chirumalla et al., 2022; Reinhardt et al., 2020).

In recent years, ecosystem studies have started to gain increasing attention where stakeholders beyond the value chain are also considered such as governments, social activists, and indirect competitors (Ahmed et al., 2023). The EV LiB ecosystem is highly intricate, involving diverse set of actors that collaborate and compete to co- create, develop and capture value (Chirumalla et al., 2025). Moreover, implementing sustainable business models (SBM) comes forward as a possible approach to enable the second life pathways that can help battery circularity (Pantelatos et al., 2025). Researchers have proposed a wide range of business model patterns, themes and archetypes that can inform the configuration and innovation of business models within the battery value chain (Kulkov et al., 2025; Reinhardt et al., 2020; Wrålsen et al., 2021). However, existing research has mostly focused on the economic and technical aspects of battery circularity without considering BM elements that exist at both firm and ecosystem level (Ahmed et al., 2025; Hellström and Wrålsen, 2024).

This study is part of a larger sustainability project at the Norwegian University of Science and Technology named ‘HoLE LiB – Developing a holistic ecosystem for sustainable repurposing and/or recycling of LiBs in Norway.’ It builds on earlier work identifying second-life EV LiB value-chain structures and SBMs in Norway (Ahmed et al., 2025), and extends it by examining how systems level analysis can help enable second-life battery implementation. The study uses a systems method 'SPADE framework' adapted to the second life EV LiB context to structure a step by step analysis of actors, material flow, SBMs, value chain configurations, and barriers. It answers the following research question: How can value chain structures and associated sustainable business models enable the second life implementation of the EV LiBs in the Norwegian ecosystem?

2 Methodology

The study uses an exploratory case study research method, which is considered a suitable approach to investigate a relatively less known field (Yin, 2009), such as the emerging EV LiB second life ecosystem. The Norwegian ecosystem is selected for two primary reasons: 1) Norway has one of the highest EV adoption rate, and is actively building the LiB value chain and 2) The HoLE project is based in Norway, where the authors are also based making it convenient to access stakeholders. The data for the study is gathered from literature, and semi-structured interviews with the representatives of four selected companies in the EV LiB value chain. Three of these companies are in Norway while one is in the UK. The company in UK was selected based on its comparable role in the UK's EV LiB ecosystem.

The literature review was conducted using SCOPUS and Google scholar. A combination of keywords such as Electrification, Green transition, Business models, Sustainable business models, Systems approach, Electric vehicles, Lithium-ion batteries, recycling, repurposing, reusing, and second-life were used. Moreover, grey literature including news articles, press releases, and website analysis were also considered. The interviewees included extended producer responsibility organisation (EPR), repurposers, and producers. The companies and the representatives have been kept anonymous as per the request of the interviewees. The research is approved by Sikt (Norwegian agency for shared services in education and research). The interviewee profiles are shown in the table below:

Table 1 Interviewee Profiles

Company	***Interviewee position***	***Company's Value chain Position***	***Context***
Alpha	Compliance Manager	Extended producer responsibility	Norway
Beta	Product Manager	Battery Manufacturer	Norway
Gamma	Co-founder	Repurposer	UK
Delta	Sales Representative	Repurposer	Norway

Using SPADE as a Systemic Framework
Employing a systemic framework based on the systems approach such can help make sense of the complexity of the emerging Norwegian EV LiB ecosystem. A systemic framework 'SPADE' is thus adapted to the EV LiB context (Deshpande and Haskins, 2021) (figure 1). It emphasizes and supports a structured analysis through a stepwise framework by systematically identifying stakeholders, diagnosing problems, mapping value-chain structures, linking these to sustainable business models, and continously evaluating the changing system while providing iterations throughout ("INCOSE Systems Engineering Handbook," 2015).

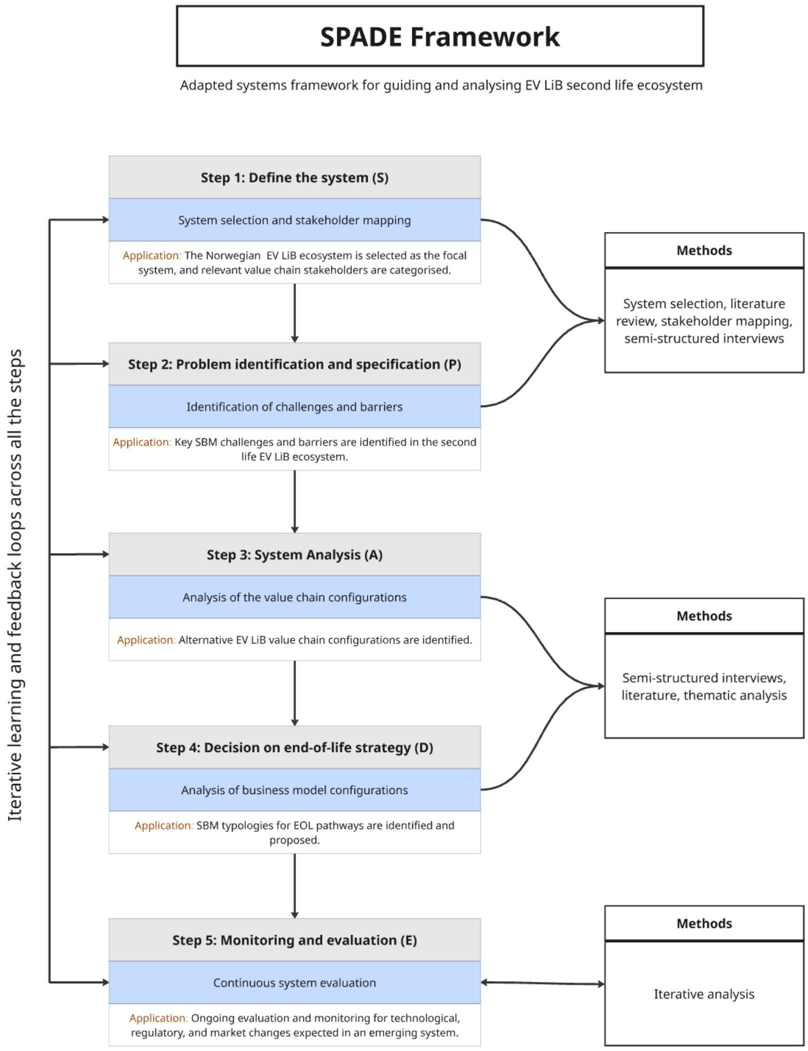

Figure 1 SPADE framework adapted to the Norwegian EV LiB ecosystem context from (Deshpande and Haskins, 2021)

3 Background

Transition to EVs and LiB End of Life Challenges

Electrifying the transport system has gained significant attention due to several reasons including environmental benefits, reducing air pollution and greenhouse gas emissions (Yuan et al., 2021). This has led to exponential growth in the adoption of the EVs globally and especially in Europe, driven by policy incentives, technological advancements, and market availability. Consequently, this uptake has led to an increase in the production of lithium-ion batteries, considered ideal for use in EVs because of their high density, high capacity, and longer life span (IEA, 2022; Winslow et al., 2018; Wrålsen et al., 2021).

However, electrification faces several challenges including high cost of LiBs, technological limitations, insufficient charging infrastructure, uncertain regulations, and market barriers (Agrawal et al., 2021; Ali et al., 2021). In addition, end of life (EOL) battery management remains critical to avoid waste and safety risks. EV LiBs are typically retired once they reach 80% or less of their capacity, consequently starting their second life – either through repurposing or recycling. The recycling processes, however, are not yet efficient and sustainable enough (Heelan et al., 2016) to handle the huge number of batteries expected to retire in the near future. Other challenges include workforce exploitation in developing countries, raw material scarcity, supply chain concerns, technological barriers and political challenges related to mining and transport (Börner et al., 2022).

Sustainable Business Models and Ecosystem Perspective

'Business models' has gained considerable attention in research and practice as a way of creating value for businesses (Bocken, 2023; Chirumalla et al., 2024; Dehkordi et al., 2024; Kulkov et al., 2025). A business model focuses on value creation, value delivery, and value capture for the stakeholders (Teece, 2018). Value creation entails the value proposition of the business, while value delivery and capture determine the channels used, the profits generated, and the cost incurred. In recent years, because of the climate crisis, sustainability has been increasingly seen as a part of business models, where social and environmental values are also integrated into its core functions (Bocken et al., 2019). These sustainable business models also promote increased stakeholder engagement, focusing on both the firm and systems level. At a firm level, creation of sustainable value is considered necessary to gain competitive advantage (Tarnovskaya, 2023). This becomes more prevalent when a holistic and systems perspective is considered, as business models are also a link between a firm and the ecosystem in which the firm operates (Zott et al., 2011), a view also supported by Chirumalla et al.,(2025)

An ecosystem approach provides a broader view of the firm, going beyond the value chain perspective, and including direct and indirect stakeholders in the analysis (Adner, 2017; Barquete et al., 2022; Hellström and Wrålsen, 2020; Kapoor, 2018; Peltoniemi and Vuori, 2008). The EV LiB ecosystem involves numerous actors collaborating and competing with one another. These actors include but are not limited to the mining industry for battery materials, battery producers, automotive manufacturers (OEMs), system integrators, repurposers, and recyclers etc. (Jiao and Evans, 2016; Wrålsen et al., 2021). These actors have differing business models, and yet a complex collaboration exists between them. Their business models exist in an institutional context and can interact with each other in varying ways (Bocken et al., 2019). These interactions take place at both an operation and value chain activities level, but also on the business model level, where change in the business model of one stakeholder can affect the business model of another stakeholder in the same ecosystem. On a BM level, these interactions are categorized as strategic, operational, and transactional – that may be sustainable or lead to sustainability of the batteries (Ahmed et al., 2026).

Stakeholders from different sectors and disciplines bring varied knowledge, skills, and perspectives. This multidisciplinary approach allows for a complete understanding of the challenges and opportunities (Chirumalla et al., 2022; Heemels and Muller, 2012). It helps in classifying possible connections, trade-offs, and unintentional consequences that may arise. Involvement of stakeholders to co-create value ensures that the barriers are thoroughly examined and addressed. Additionally, collaboration among stakeholders external to the battery value chain, including government agencies, industry players, research institutions, and civil society organizations, is essential for the battery circularity (Chirumalla et al., 2025, 2024; Reinhardt et al., 2019).

4 Results

The combined analysis of literature, semi-structured interviews and document analysis including grey literature reveals the presence of multiple stakeholders in the EV LiB ecosystem. The results are derived by employing SPADE framework adapted to the Norwegian EV LiB ecosystem. These have been categorized with company examples drawn from the Norwegian context. The analysis identifies key problems and barriers that hinders the adoption of second life EV LiBs. Additionally, the findings highlight two distinct types of value chain structures present in the Norwegian ecosystem along with a typology of associated sustainable business models (SBMs) that exist and/or are likely to exist for the second-life of the EV LiBs. The findings have been ascertained based on the SPADE method adapted to the second life EV LiB context.

Stakeholder categorisation in the second life EV LiB ecosystem : (S)

The first step of the study involved selecting and identifying the ecosystem. The stakeholders in the ecosystem are then systematically categorised and mapped across the value chain. Most of the literature related to EV LiBs is based on the value chain perspective. However, this can be limiting as it provides an understanding of the actors directly contributing towards the production, use, reuse, and recycling of the batteries without necessarily considering other actors like governments and activists that can also influence the value chain. Table 2 lists the stakeholders that go beyond the value chain:

Table 2 Categorization of Stakeholders in the Norwegian EV LiB Ecosystem

Stakeholder	*Description*	*Norwegian stakeholder example*
Energy Storage Providers	They provide energy storage services to grid operators, renewable energy developers, and commercial or residential customers	Ecostor, Evyon, Corvus energy etc.
Microgrid Developers and Operators	Microgrids are restricted energy systems that can operate independently or in connection with the main power grid. They offer consistent and resilient electricity supply.	Statkraft etc.
Renewable Energy Developers	They focus on developing and operating renewable energy projects, such as solar, wind, or hydroelectric power plants	Statkraft etc.
Grid owners and Operators	They focus on load levelling and frequency regulations	Stattnett, Aneo
System Integrators	They offer services like project development, sourcing, and system design. They ensure power quality and reliability	Pixii
Automotive OEMs/Importers/retailers	They produce EVs, and import and sell them to relevant markets.	Nissan, Kia, Tesla etc.
Battery Component and Pack Producers	They design and produce batteries.	Vianode, Morrow Batteries, Elinor batteries etc.
Raw materials	They mine for different raw materials that are used in the production of the LiBs	Nordic mining, Skaland Graphite, Alcoa, Glemcore, Elkem, Cenate
Policy Makers/Government	They make regulations and policies	Government plus municipality
Users	They use the products made by the businesses and have a significant role to play in driving policies.	EV user, repurposed batteries user - industrial and residential.
Battery recyclers	They recycle the EV LiBs	Hydrovolt, Morrow batteries, Fortum recycling, Stena recycling, ReSitec AS
Battery Repurposers	They repurpose the batteries in another application for example portable ESS products, household backup storage, and/or industrial context.	Ecostor, Eaton, Evyon, Hagal, Probatt, Alternativ Energi , and Battkomp etc.
Car Dismantlers	They dismantle the EOL car parts including batteries and provide them to the recyclers and repurposers.	Grønvold's AS, GBD Bildemontering etc
Extended producer responsibility (EPR)	They collect the EOL batteries and transport them to either the repurposing or recycling facilities.	Batteriretur, Norsirk

Problems within the system that hinders second life adoption (P):

The Problem stage of the adapted SPADE framework focuses on defining the core challenges that prevent second-life electric vehicle lithium-ion batteries (EV LiBs) from being widely adopted at scale. In this study, the fundamental problem can be characterized as a misalignment between second-life potential and the regulatory, market, and technical conditions required to realize it. This step in the SPADE framework supports a structured analysis of firm and system level challenges. Building on previous research, technological, legislative, market and social aspects were identified as crucial barriers (Ahmed et al., 2023). For instance, legislation mostly favour recycling over repurposing as for now. Moreover, the rapid technological development and increased scale of production is decreasing prices for the new EV LiBs where the competition is mainly arising from the first life batteries from China. This also poses a huge threat to the repurposed batteries where the prices have been increasing because of battery design variability, lack of standardization and increased labour cost. The interviewees were apprehensive that if this trend continues, the cost of repurposed batteries may become more than the new batteries, making the market less appealing. This is in line with the previous research where the market and legislative barriers have been ranked of highest importance (Wrålsen et al., 2021). The problem categories and barriers listed in Table 3 are adapted from previous research conducted as part of the HoLE LiB project (Ahmed et al., 2023), where they were empirically identified and validated.

Table 3 Problem categories and barriers

Problem Category	*Barriers*
Technological	1. Variable battery design, chemistry, and management system
	2. High optimization for first life leads to mismatch for second life.
	3. Limited data sharing between OEMs and Repurposers
	4. Unclear state of health
	5. Energy inefficiency in recycling processes
Market	1. Raw materials supply considerations
	2. Supply chain factors – Communication barriers, different geographical locations, and lack of data sharing.
	3. Battery availability (economies of scale)
	4. Disassembly and repackaging costs.
	5. Unclear value proposition
	6. Transportation costs
Social	1. Safety and reliability uncertainty
	2. Lack of awareness and information
	3. Unclear user incentives
Legislative	1. Policy incentives unclear
	2. Lack of legislation
	3. More incentives for recycling than repurposing.

Analysis of the Norwegian EV LiB Ecosystem (A)

Systems level analysis identifies and maps several stakeholders within the Norwegian EV LiB ecosystem., who are connected in a complex structure (Peltoniemi and Vuori, 2008). Figure 2 and 3 illustrate the 'Analysis' part of the SPADE framework, combining battery material flows with institutional and market influences. The value chain follows the battery lifecycle from raw material extraction by mining companies, through battery production and integration by OEMs, to vehicle retail, use, and end of life phase. Charging infrastructure and energy suppliers support the use phase, highlighting the interdependence between mobility and energy systems. While the external stakeholders such as EU-level regulation, national policy frameworks, activist groups, and broader societal concerns related to climate change and sustainability. These actors exert systemic influence on the entire ecosystem.

In Norway, once the batteries reach their fEOL, they are predominantly handled by third-party actors rather than OEMs. After an EV battery pack reaches EOL, it is removed and subjected to basic state-of-health (SOH) testing. Based on the results, batteries are directed either to repurposing or recycling. Collection, preliminary testing, and transport are typically managed by external producer responsibility (EPR) organizations that operate through contractual agreements with OEMs or retailers and/or importers. However, handling EV battery packs remains costly due to limited volumes, strict safety regulations, testing and logistics, making it difficult for smaller actors to compete. As a result, only a couple large actors are present in this market. Afterwards, batteries may be recycled, reused, or repurposed, depending on technical condition, regulatory requirements, and contractual arrangements. Recycling typically involves specialized recyclers, while repurposing leads to SLB applications such as energy storage systems for grid support, household use, or backup power. Reuse is shown as a pathway where batteries may be re-installed in vehicles.

Some repurposers have established direct contractual arrangements with OEMs, giving rise to two distinct value-chain configurations. In the first (figure 2), repurposers initiate the second-life value chain, including collection (directly or via third parties), testing, disassembly, and repurposing, with minimal OEM involvement beyond technical support. In the second (Figure 3), the OEM retains control over battery take-back system through the EPRs, testing, disassembly, and initial repurposing through via third party companies after which the repurposer integrates the batteries into second-life products and assumes product responsibility. The shaded section in figure 3 highlights configurations in which OEMs retain involvement beyond the first life, particularly in repurposing and reuse.

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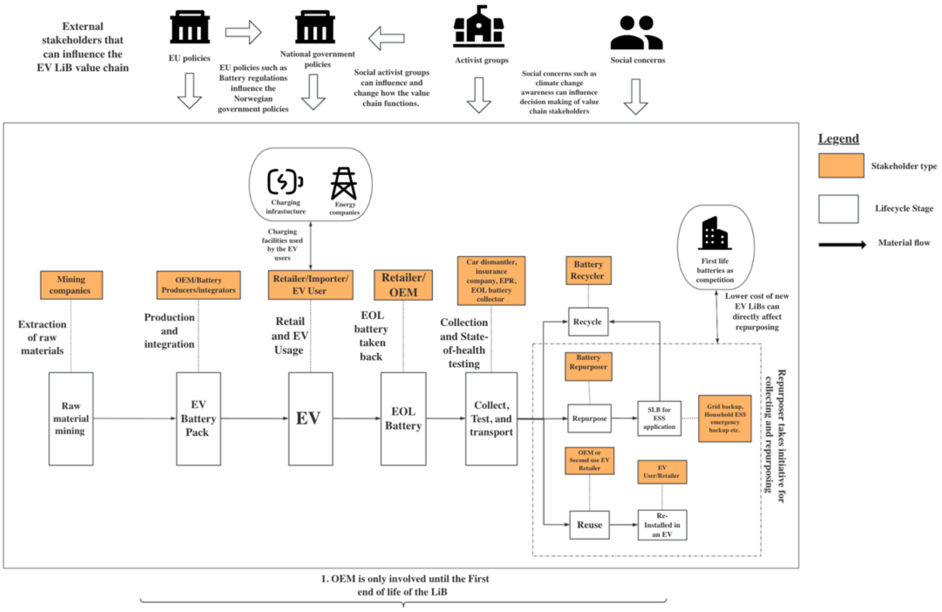

Figure 2 Repurposer led value chain structure for second life EV Libs in Norway

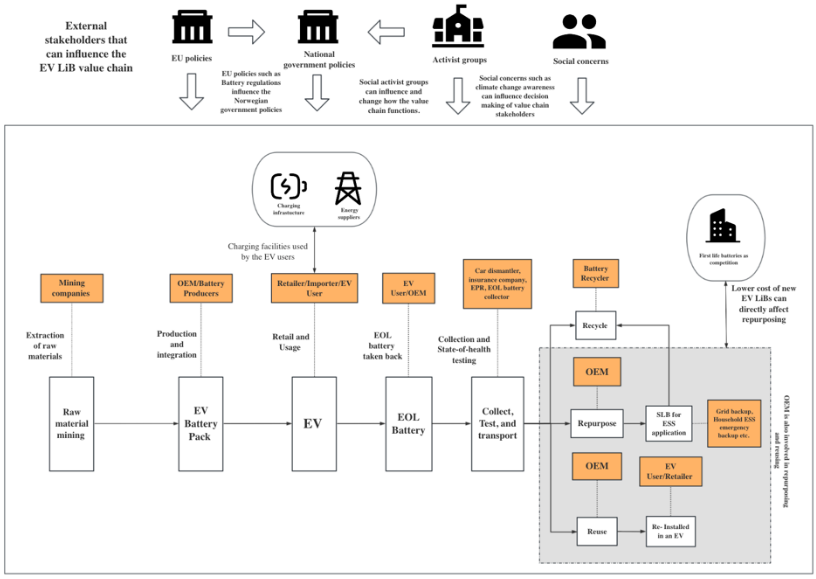

Figure 3 OEM controlled value chain structure for second life EV Libs in Norway

Typology of Existing and Likely Sustainable Business Models for the Second-life EV LiBs (D)

Figure 4 illustrates the Decision (D) stage of the SPADE framework, where alternative business models for implementing second life EV are evaluated to support strategic firm level decision making under ecosystem complexity. The insights are built on the SBM typology presented in the previous research (Ahmed et al., 2025). However, this typology considers the recycling aspect to address battery circularity.

The typology distinguishes between repurposing and recycling SBMs**,** presenting two core second-life pathways. Repurposing SBMs, derived from interview data include (1) repurposer-driven second-life battery (SLB) applications, (2) OEM-driven repurposing, and (3) OEM-controlled SLB applications. These models differ in terms of who controls batteries after fEOL, how value is created and delivered, and how responsibilities are allocated across the value chain. While recycling SBMs capture pathways driven either by regulatory requirements or by OEM control over material recovery. These SBMs emphasize closing material loops and securing access to critical materials, often with lower coordination than repurposing but more limited value creation potential.

By structuring the SBMs along value proposition, value creation and delivery, and value capture dimensions, the typology presents different ways firms can derive value from second life batteries. Within SPADE, this decision stage can help stakeholders to compare viable business model configurations and assess how ecosystem conditions can enable second-life EV LiB solutions.

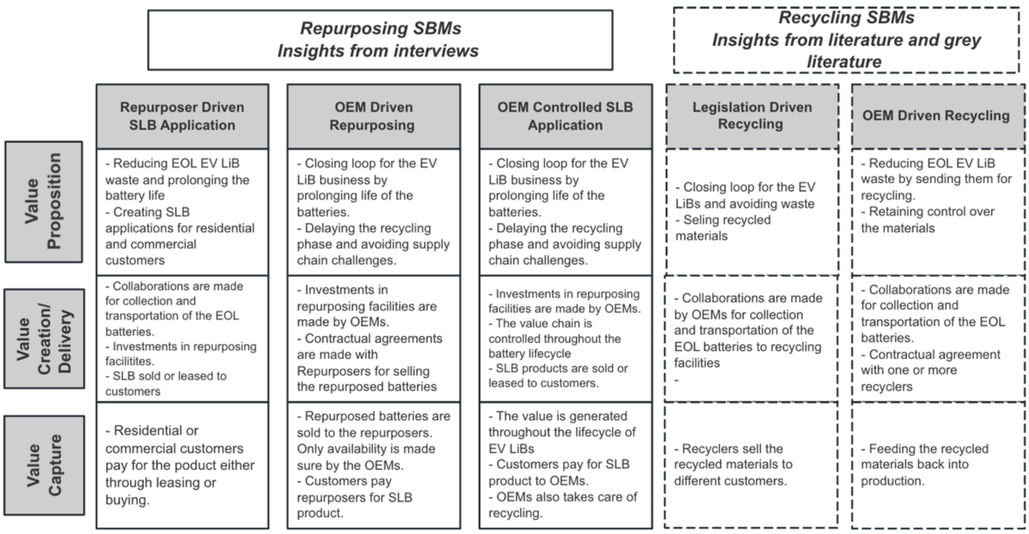

Figure 4 SBM typology for second life EV LiBs in the Norwegian ecosystem

Continuous Evaluation of the system (E)

The EV lithium-ion battery ecosystem is highly dynamic, shaped by rapid technological advancements, evolving regulatory frameworks, and increasing market competition. At the same time, growing circular economy ambitions such as Ecodesign principles, are placing additional pressure on firms to design batteries that can be reused, repurposed, and recycled. In this context, business model decisions and ecosystem formation cannot

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be treated as static. Continuous evaluation and monitoring is therefore a critical element of the SPADE framework. Organizations operating across the EV LiB value chain need to regularly monitor ecosystem developments to adapt to changing conditions. Proactively adapting to emerging policies and environments allows firms to align their SBMs with regulatory requirement while maintaining economic viability. By implementing continuous evaluation into decision-making, stakeholders can iteratively configure their business models, manage uncertainty, and make second-life EV LiB solutions viable.

5 Discussion

The industry for second-life EV LiB ecosystem is still emerging and is complex owing to the constant changes taking place at both the technological and regulatory level, but also on the firm level. Moreover, there is paucity in the literature when it comes to the value chain structures, the associated business models, and the overall ecosystem that includes the influences of other indirect stakeholders that either positively or negatively affect the value chain. Such emerging ecosystems require strategic and operational alignment.

Contribution to theory

This study is built on previous research (Ahmed et al., 2025, 2023), and offers three valuable contributions: First, it uses SPADE as a systemic framework thus providing a holistic approach to build a thorough understanding of the EV LiB ecosystem through categorization of the stakeholders and the associated problems and barriers. Secondly, it maps the Norwegian ecosystem and presents two distinct different value chain structures depending on the role the OEM and the repurposers take. The results show that currently two value chain structures exist in the Norwegian market, where in one the EV LiB is collected by the repurposer after the first end of life through contractual agreement with a third party, while in the second structure the OEM is involved also in the repurposing of the batteries through different contractual agreements with the repurposers. Third, it builds on the typology and archetypes of SBMs presented in previous research (Ahmed et al., 2025; Chirumalla et al., 2024; Reinhardt et al., 2020) by developing three repurposing oriented SBMs and two recycling oriented SBMs. The aspects of these SBMs determine how a firm operates in the ecosystem. The first two repurposing SBMs namely 1) repurposer driven SLB application and 2) OEM driven repurposing, already exist in the market albeit not yet commercialized on a large scale. Similarly, the recycling SBM ‘Recycling driven SBM’ already exists in the market where the main stakeholders are the OEMs, collectors, and the recyclers. However, the repurposing SBM ‘OEM controlled SLB application’ and recycling SBM ‘OEM driven recycling’ are expected to take form in the future. The study thus contributes to theory by combining systems perspective with the SBM lens to better understand how second life of EV LiBs can be enabled.

Contribution to Practice

The results from the study are valuable for the EV LiB stakeholders. The study shows multiple challenges that hinder the adaption of the second life of batteries. Addressing these challenges require collaboration among the EV LiB ecosystem stakeholders (Ahmed et al., 2026; Reinhardt et al., 2020). The traditional value chain is limited as it only focuses on the stakeholders that are directly involved in the production, usage, and end-of-life phase of the batteries and does not consider the indirect stakeholders that can affect how the value chain structures operate. Moreover, using only the BM perspective limits the understanding of the holistic ecosystem considerations. Mapping the EV LiB ecosystem thus provides a categorization of the different Norwegian EV LiB stakeholders and gives an account of how these stakeholders are connected across the value chain. Categorising the stakeholders and providing an overview of the ecosystem provides the current and upcoming stakeholders an opportunity to understand the battery material flow, and roles and responsibilities of different stakeholders in the ecosystem. It also shows the interconnections between the stakeholders, and can possibly unearth gaps and opportunities that can make the ecosystem more viable.

At the same time, the development of the SBM typology can support the stakeholders in understanding different pathways in which value can be proposed, delivered and captured. Practitioners can use the SBM typology as a guide to evaluate their business models. Moreover, these SBMs can show a firm’s activity, and combination of other SBM archetypes can be developed (Chirumalla et al., 2024; Wrålsen et al., 2021). This can help firms configure SBMs according to the conditions they operate in. However, the interconnectedness of the stakeholders, as shown in the ecosystem map, also implies the interdependencies of some of the elements of the SBMs. For instance, repurposers can be highly dependent on the OEMs for their batteries (Ahmed et al., 2026). This entails that stakeholders require better collaboration and communication at both the firm, value cain, and ecosystem level to enable battery second life. Additionally, the study also shows how a systems approach such as using the SPADE method can support practitioners in performing a step by step structured analysis of a complex ecosystem. Such an approach can be particularly useful for managers operating in complex and uncertain environments.

5 Conclusion

This study set out to understand and investigate how value chain structures and the associated sustainable business models enable the implementation of second life pathways for the EV LiBs. By employing an exploratory case study research design and a systems approach ‘SPADE Framework’ the study provides a holistic and structured analysis of EV LiB value chain structures, highlighting the interdependencies between stakeholders, the barriers and challenges and the business model choices. Rather than seeing the implementation of the second life, as purely a technological challenge, the study highlights how second life can be enabled through a systemic framework where the value is co-created, delivered, and captured by multiple stakeholders.

The findings reveal the Norwegian EV LiB ecosystem is characterized by a complex network of stakeholders and alternative value chain structures led by either the OEMs or the repurposers, each associated with distinct SBM configurations. These SBMs illustrate different value creation, delivery, and capture mechanisms, and highlight how business model choices are shaped by a broader system rather than just firm level strategies alone. However, the results indicate that although the second life ecosystem is emerging and multiple SBMs are being implemented by the stakeholders, there are still numerous barriers and problems that hinder second life battery adoption. These barriers include but are not limited to regulatory preferences for recycling, declining prices of new batteries, lack of battery standardization, limited data sharing, and coordination challenges across the value chain.

Limitation and future work

Despite its contributions, this study has several limitations. First, the research is based on an exploratory case study with a limited number of interviews, which constrains the generalizability of the findings. While the selected stakeholders represent key positions within the EV LiB ecosystem, additional perspectives from policymakers, grid operators, insurance companies, and end users could have provided a more comprehensive view. Moreover, the ecosystem mapping in the 'Analysis' part of the SPADE framework provides a conceptual and limited overview of the Norwegian ecosystem excluding additional actors that can influence the value chain, thus minimizing the real complexity of the system. Second, the study focuses primarily on the Norwegian context, which is characterized by unique conditions such as high EV penetration, strong policy support, and a relatively mature renewable energy infrastructure. As a result, the value chain structures and business models identified may not be directly transferable to other geographical contexts. Third, the analysis relies predominantly on qualitative data, complemented by secondary and grey literature. While this approach is well suited for capturing emerging phenomena, it limits the ability to quantitatively assess the economic viability, environmental impacts, and scalability of the identified SBMs. Finally, the application of the SPADE method and the results from the interviews have not been validated through a second round of interviews or a workshop with the stakeholders. In future research, focus should be put on an in-depth analysis of BM elements while also including a comprehensive overview of all the actors that can directly or indirectly influence the value chain at each interaction between the stakeholders. Moreover, future research could also explore and validate the implementation of SPADE framework in emerging ecosystems while also getting feedback from practitioners to see its validity. This study, nonetheless, provides a starting point for future studies combining systems approach with business model perspectives.

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