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RESEARCH ARTICLE

Repurposing Electric Vehicle Lithium-ion Batteries for the Household Context: A Delphi Study

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Abstract

The shift towards circular economy is accelerating, driven by policies incentivising circularity, and industry adapting sustainable business models. In Europe, the European Green Deal is a catalyst, including the new battery regulation adopted in 2023, which sets requirements for reuse, repurposing, and recycling of electric vehicle (EV) Lithium-ion Batteries (LiBs). These steps are particularly relevant because of the widespread adoption of EVs which is expected to increase the number of First End-of-Life (FEoL) LiBs in the near future. Repurposing these batteries, for example in energy storage systems (ESS), can extend their useful life before being recycled. This study explores the likelihood and feasibility of repurposing FEoL EV LiBs in the household context across short-, mid-, and long-term perspectives. It uses the Delphi method to gather expert opinions on key aspects such as the share of repurposed batteries in the future, value chain structures, emerging sustainable business models, drivers and barriers, and customer willingness to adopt repurposed batteries. The findings suggest that while technical feasibility is promising in the short-term, opinions about economic feasibility are polarised. Factors such as declining prices of new LiBs and alternative battery chemistries may challenge the adoption of repurposed EV LiBs for the household context.

Keywords Repurposing Lithium-ion Batteries · Sustainable Business Models · Value chains · User Perspectives · Household Context.

1. Introduction

The global economy is shifting away from the take-make-dispose model (Kanda et al., 2021) towards a circular economy (CE) model which provides a framework for sustainable production and consumption. The CE aims to promote economic growth while minimising resource depletion and environmental degradation through different pathways such as reusing, repurposing, and recycling products. It builds on both bottom-up and top-down approaches where policy initiatives such as the UN Sustainable Development Goals and the European Green Deal are main drivers (European Commission, 2019). Within the latter framework, the Critical Raw Materials Act (Critical Raw Materials Act - Internal Market, Industry, Entrepreneurship and SMEs, 2024) identifies different raw materials and value chains as sensitive, requiring circularity initiatives. These include but are not limited to renewable energy technologies such as photovoltaic (PV) cells and batteries. Among these, Electric Vehicle (EV) Lithium-ion Batteries (LiBs) provide a promising opportunity for achieving circularity goals by prolonging battery life through repurposing in different applications such as energy storage

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systems (ESS) after their First End-of-Life (FEoL). Potential is seen to extract both economic and material value from the EV LiBs beyond their FEoL and before recycling, while also decreasing the environmental cost. Most promising solutions for repurposing these batteries include the household and industrial context (Reinhardt et al., 2019a).

The interest in repurposing LiBs from EVs for household ESS is an outcome of two significant trends in the current energy transition. Firstly, the widespread adoption of EVs as an alternative to internal combustion engine vehicles has been accelerated by government and policy incentives, leading to exponential sales growth (Paoli & Bennett, 2019; Stefan & Chirumalla, 2025). For instance, in Norway, EVs held an 88% new passenger car market share at the end of 2024, largely driven by taxation rules and other incentives (Ministry of Transport Norway, 2025). Secondly, there is an increase in installations of PV and ESS in households, driven by high energy costs and a desire for energy security and self-sufficiency (BloombergNEF, 2023; Colthorpe, 2021). Relevant questions arise to what extent repurposed LiBs could fulfil a societal need within households while utilising FEoL LiBs for longer. Although industrial or large-scale applications are considered more economically viable and sometimes preferred in terms of safety (Börner et al., 2022), the household context represents a growing segment of ESS and a potentially huge and promising market.

EV LiBs are typically retired when their state-of-health (SOH) drops to around 80%, depending on factors such as charge and discharge cycles, driving patterns, and calendar aging (Prenner et al., 2024). This is foreseen to result in a growing number of FEoL LiBs requiring treatment in the near future. Repurposing these batteries for second life in less demanding applications, such as stationary energy storage, can extend their useful life before recycling, aligning with waste hierarchy principles and supporting the transition to decarbonised energy systems (Harper et al., 2019; Jian et al., 2018; Reinhardt et al., 2019b).

Despite the technical feasibility of using repurposed EV LiBs for household ESS being demonstrated (Heymans et al., 2014; Martinez-Laserna, Gandiaga, et al., 2018; Thakur et al., 2022), several barriers exist, including cost of repurposing, limited supply of FEoL batteries, and safety concerns (Börner et al., 2022; Hossain et al., 2019; Hu et al., 2022). Additionally, while research on FEoL batteries has predominantly focused on economic and technical aspects, it often overlooks circular business models (CBMs) based on CE principles (Wrålsen et al., 2021), and user perspectives relevant to the acceptance of such solutions (Bräuer, 2016; Pantelatos et al., 2025). CBMs represent a sub-category of Sustainable business models (SBM). While CBMs emphasise on circularity, SBMs also consider social, environmental, economic, and intellectual challenges (Boons & Lüdeke-Freund, 2013), and can enable strategies such as repurposing as a viable option for businesses beyond the technical dimension of circularity.

This article presents the findings of a Delphi study investigating the future of repurposing EV LiBs for household ESS from a market perspective across a short-, medium-, and long-term periods. It addresses key questions regarding market development, sustainable business models, and user perspectives, including factors influencing the adoption of repurposed EV batteries in the household context. More specifically, it addresses the following research questions:

1. How will the market of repurposed EV LiBs for the household context evolve over time in terms of
    a. Market share?
    b. Second-life applications?
    c. Feasibility?
2. What business models and value chain structures are likely to support repurposing for the household context?
3. Which factors will influence repurposing of EV LiBs for the household context over time in terms of
    a. Key drivers?
    b. Key challenges?
    c. Customer willingness to adopt?

By gathering expert opinions through multiple rounds of questionnaires (Okoli & Pawlowski, 2004), the study aims to provide a comprehensive understanding of the potential and challenges associated with repurposing EV batteries for home energy storage.

The remainder of the article is structured as follows: section 2 discusses relevant literature on repurposing batteries for the household context, and on sustainable business models for EV LiB repurposing, which has informed the questionnaires that were shared with the panel experts. Section 3 presents methodology considerations, followed by results and discussion (Section 4) based on the Delphi study. Lastly, section 5 provides concluding remarks.

2. Repurposing EV LiBs for the Household Context

This section provides a brief overview of repurposing EV LiBs for the household context. First it explores availability of FEoL LiBs, emerging second-life applications, and associated business models, followed by the regulatory considerations for battery repurposing and an examination of technical, economic and environmental perspectives that determine the viability of the repurposed EV LiBs. Furthermore, literature on drivers and challenges is presented, along with a brief introduction to user perspectives to understand the perceived value and challenges of such applications.

2.1. Availability of FEoL LiBs and likelihood of applications

The availability of FEoL LiBs from EVs would be a prerequisite for fulfilling the potential of repurposing these batteries for the household context. With global EV adoption accelerating, the International Energy Agency (IEA) projects a substantial increase in EV battery demand and subsequent retirement volumes, projecting the share of EVs in overall car sales to exceed 40% in 2030 (IEA, 2025). However, not all retired batteries would be suitable for second-life applications, depending on factors such as SOH, internal resistance, physical damage and calendar age (Martinez-Laserna, Sarasketa-Zabala, et al., 2018). It is expected that 3.4–5.4 million FEoL batteries will be available by 2040 for a second life within the EU (Kastanaki & Giannis, 2023). Despite general estimates of repurposing potential, specific projections for household applications are currently not prevalent in literature. On the other hand, the demand side presents itself as promising. In Germany for instance, the residential battery storage market is experiencing a strong growth. By the end of 2022, 650,000 ESS with an accumulated energy of 5.49 GWh were installed in German households often in combination with PV (Figgener et al., 2023).

In literature, various applications for repurposed LiBs within the household context have been proposed, and some even tested. This includes residential ESS for load-leveling purposes (Heymans et al., 2014; Ioakimidis et al., 2019) and residential ESS connected to renewable energy sources such as PV (Assunção et al., 2016; Thakur et al., 2022). Mobile power stations for outdoor or leisure time use have been identified as another possible application (Michelini et al., 2023). More peripheral, but still connected to the household domain, is extending the batteries' lifetime within the original car, where the car is sold onwards to users with lower range requirements (Börner et al., 2022).

2.2. Business models and value chains

Innovative business models that promote circularity are considered to be important in making repurposing viable. Bocken et al. (2019) propose adopting SBMs - business models that go beyond economic value and integrate environmental and social considerations in the value creation and delivery processes. Toorajipour et al.(2024) argue for integrating CE principles in the business models to implement and sustain second-life batteries. Various scholars have proposed different SBM archetypes including approaches focused on optimising the use of materials and energy, as well as strategies aimed at extending product lifecycles and enhancing circularity (Bocken et al., 2019; Reinhardt et al., 2020). Additionally, researchers have outlined different SBM typologies related to battery second-life. These include second-life battery initiatives led by repurposing firms, OEM driven repurpose strategies, and OEM-managed second-life battery applications. The SBMs are associated with diverse configurations of value chain structures where either the OEM or the repurposer has a more prominent role (Ahmed et al., 2025; Albertsen et al., 2021; Bocken et al., 2019; Reinhardt et al., 2020; Wrålsen et al., 2021). Different value chains have also been discussed focusing on a comprehensive business model framework where value proposition, creation, and delivery elements are emphasised. These include offerings and activities such as battery leasing, marketplace platforms, logistics and supply, and battery testing. These offerings and activities vary based on different battery ownership models (Kulkov et al., 2025). While the value chain structures focus on the sequence of activities, stakeholder configuration and role, and material and knowledge flow (Ahmed et al., 2025; Rönkkö et al., 2024; Stefan & Chirumalla, 2025), SBMs emphasise the business and strategic logic of the individual firms in the value chain (Boons & Lüdeke-Freund, 2013).

2.3. Regulations on battery repurposing

In terms of waste hierarchy, repurposing is considered a key strategy that precedes recycling. From a CE perspective, repurposing extends the product's lifecycle, reduces waste and addresses the challenge of resource scarcity. Regarding regulations for FEoL LiBs, the European Union has taken a leading role with the adoption of the new EU Batteries Regulation 2023/1542, which entered into force in August 2023. This regulation introduces a framework that governs the entire lifecycle of batteries from design and production to collection, repurposing and recycling. While recycling gets addressed with specific quantitative targets as for cobalt, lead, lithium and nickel, repurposing is addressed more conceptually, by defining it as "Any operation that results in a battery, that is not a waste battery, or parts thereof being used for a purpose or application other than that for which the battery was originally designed." (EU Parliament, 2023). This definition formally recognises second-life applications, such as using EV LiBs as ESS. However, the regulation does not provide direction for specific fields of applications, nor does it prescribe a standardised industrial procedure for repurposing. Instead, it leaves room for interpretation, evidenced by a variety of repurposing approaches in industry (Pantelatos et al., 2025). These policies align with the broader EU regulations such as the EU Green Deal and the Critical Raw Materials Act that aim to secure resources and promote circularity (Critical Raw Materials Act - Internal Market, Industry, Entrepreneurship and SMEs, 2024; European Commission, 2019).

International standards that have begun to emerge include the UL 1974 (updated in 2023), which provides safety and evaluation criteria for repurposing and remanufacturing batteries, including sorting, grading and testing protocols (UL Standards & Engagement, 2023). Furthermore, the IEC 63338:2024 offers a general guidance on reuse and repurposing of secondary cells and batteries, covering safety, environmental impact and suitability assessments (European Standards, 2024). Despite these developments, a universally adopted standard in industry is still lacking.

2.4. Technical, economic and environmental perspectives

The field of repurposing EV LiBs for the household context has mostly been studied from an economical, technological and environmental perspective. For instance, within a Swiss household context, Thakur et al. (2022) found that repurposed EV LiBs could serve as ESS in household context for an additional 3-5 years. Depending on the solar PV installations and feed-in tariffs, i.e. payment of selling electricity back to the grid, households could achieve economic savings of 24-77%. However, in a Canadian context, Heymans et al. (2014) found that employing LiBs within the household solely for load leveling, i.e. smoothing out the fluctuations in electricity usage, and peak shaving, i.e. reducing consumption from the grid when electricity rates are highest by using stored energy, would not to be viable without any incentives. On a general note, the high manual labour cost along with expenses for expired warranties and re-certifications is seen to impede the economic viability of repurposing (Prenner et al., 2024). This is especially the case when declining prices of new LiBs (Kamath et al., 2023) and the competition to household ESS based on them (Pantelatos et al., 2025) are taken into consideration. In terms of technical feasibility, in Belgium, Philippot et al. (2022) reported that repurposed batteries could last another ten years in households. Heymans et al. (2014) noted that a 10-kWh repurposed ESS in a Canadian home could be used to cover 2-3 hours of electricity use when electricity prices are high. From an environmental perspective, Spindlegger et al. (2025) conducted lifecycle assessment of different repurposing strategies compared to the use of new batteries for energy storage within the household context, demonstrating several environmental benefits across various impact categories by using FEoL LiBs. Furthermore, Philippot et al. (2022) found that repurposing an EV LiB for PV self-consumption reduces impact on climate change by 16%.

2.5. Drivers and challenges

Wrålsen et al. (2021) identified and ranked several drivers for repurposing EV LiBs in general – regardless of context – such as national and international regulation and policies, potential profits from reuse or remanufacturing and raw material availability. While these factors are undoubtedly relevant, there appears to be limited exploration of drivers for the household context specifically. For instance, context-specific factors may influence the uptake of repurposed LiBs within the household context. These could be increasing consumer interest in home ESS – particularly in markets like Germany (BVES, 2024; Figgener et al., 2023), Rising household energy cost (Guan et al., 2023) , and growing environmental awareness (Khatibi et al., 2021) may play a significant role.

Despite the potential growth in the repurposed FEoL batteries, the market remains niche and faces several challenges. Examples of challenges include economic feasibility (Prenner et al., 2024), safety concerns (Börner et al., 2022), a high variety of battery designs, chemistries, sizes, electrical connections, and packaging formats (Hellmuth et al., 2021), and unclear regulations and policies (Wrålsen et al., 2021).

2.6. User perspectives

The success of business models concerning repurposed EV LiBs in the household context will largely depend on user acceptance, both objective and subjective perceptions taken into account. However, studies focusing on user perspectives remain scarce (Bräuer, 2016; Pantelatos et al., 2025). Although specific insights on user perspectives regarding EV LiB repurposing is lacking, established theories such as the Technology Acceptance Model (TAM) (Davis, 1989) and the Diffusion of innovations Theory (Rogers, 1983) provide relevant conceptual frameworks on how users evaluate and adopt new technologies. These models highlight factors such as perceived usefulness, ease of use, social influence, and compatibility with existing practices as critical to adoption decisions.

Prior research in the broader context of household renewable energy installations has emphasised environmental motivation, economic considerations, and user awareness of relevant technologies as key drivers (Billanes & Enevoldsen, 2022; Große-Kreul, 2022; Hasselqvist et al., 2022; Palm & Tengvard, 2011). Similarly, end-user acceptance of repurposed LiBs may be influenced by perceived safety risks, particularly due to their hazardous chemical composition and potential for thermal instability (Börner et al., 2022). Börner et al. (2022) explicitly reference the Samsung Galaxy Note 7 case, where widespread battery fires led to a global recall, substantial financial losses, and a significant erosion of consumer trust. Although the impact was severe for Samsung, the incident also prompted broader concerns about battery safety across the smartphone industry, which underlines the importance of perceived safety.

In summary, literature has described various dimensions of repurposing EV LiBs for the household context as having potential, although several challenges have been identified. Further investigation is needed to understand how these dimensions specifically apply to ESS solutions based on repurposed EV LiBs, and how user perceptions may affect their adoption.

3. Methodology

This study employed the Delphi method, introduced by Dalkey & Helmer (1963), which is a systematic approach to gather expert opinions on complex issues through a collective and anonymised process. It is widely used to converge expert opinions on probable futures (Hsu & Sandford, 2007), and is particularly used for topics where there is uncertainty and a need to forecast what the future might look like (Büchel & Spinler, 2024). The Delphi method has helped forecast trends and future occurrences for different evolving and nascent industries (Lombardi et al., 2025). As the EV LiB industry is still emerging, with continuously evolving industrial and policy landscape, the Delphi method is considered to be an appropriate choice to get expert opinions on the short-, mid- and long-term future. Typically, the method involves iterative rounds where the panel experts anonymously answer questionnaires. In subsequent rounds, the panel experts review anonymised responses from their peers, allowing them to refine and adapt their initial answers (Niederberger & Spranger, 2020). A minimum of 10 respondents is recommended for obtaining representative results (Okoli & Pawlowski, 2004).

Prior to the Delphi study, the authors conducted exploratory semi-structured interviews with experts in the EV LiB industry to gather preliminary insights. The experts represented different parts of the Norwegian battery value chain such as production, collection, second life applications, and recycling. These experts brought diverse expertise in areas such as system optimisation, lifecycle management, battery production and design, second life etc. (Table 1). Their perspectives helped in identifying real-world emerging opportunities, challenges, and perspectives related to the FEoL EV LiBs, particularly for the household context (Ahmed et al., 2025; Pantelatos et al., 2025). The interviews were a preparatory step for informing the Delphi study, defining relevant themes and questions that reflected the real-world concerns in the second-life EV LiB industry. The Delphi panel members were recruited from the list of interviewed experts and complemented by additional experts identified through relevant scientific publications, conferences, media coverage, and existing contacts. Our primary focus was on the European Economic Area (EEA), given recent regulatory developments such as the revised EU Battery Directive (EU Parliament, 2023).

Table 1. Participants answering both rounds of the Delphi study

Field of Expertise *(Self-stated)*	**Sector of work or experience** *(Listed options)*	**Expertise in the battery value chain**	**Years of relevant working experience**	**Highest level of formal education**	**Geographical perspective** *(Listed options)*	**Countries specified** *(Self-stated)*	**Code**
Systems engineering	Industry University Research organisation	Architectural frameworks, system optimisation, and lifecycle management of EV battery value chains	45	Doctoral degree	European perspective	Nordic and the Netherlands	EAV6
Battery system expert	Industry	Battery production	25	Doctoral degree	Nordic perspective	Norway	HBI11
Economics	University	Battery recycling and repurposing	30	Doctoral degree	Global perspective	UK, Europe, US, China	SNW6
Sustainability Management (Product level)	University	Digitalisation and circularisation of EV battery value chains	4	Doctoral degree	European perspective	Germany, Austria, Belgium	VKA6

Table 1 (cont.). Participants answering both rounds of the Delphi study

Field of Expertise *(Self-stated)*	Sector of work or experience *(Listed options)*	Expertise in the battery value chain	Years of relevant working experience	Highest level of formal education	Geographical perspective *(Listed options)*	Countries specified *(Self-stated)*	Code
Life cycle engineering	University	Environmental assessment of battery systems	15	Doctoral degree	Asian perspective	Japan	SSH2
Battery research	Research organisation	Battery production, Second life, and recycling	20	Doctoral degree	European perspective	Norway, Nordic countries and EU	AHØ16
Repurposing and recycling used EV batteries	University	Battery Second life	1.5	Master degree	European perspective	Switzerland	GMM3
Environmental engineer	University	Battery pack design, integration and dismantling	2	Master degree	European perspective	EU27+4	BOB1
Automotive	University	Overall automotive industry	35	Doctoral degree	Global Perspective	EU and China	HCE8
Batteries, electromobility and renewable energies	Industry University	Battery production design, and Second life	30	Doctoral degree	European Perspective	Germany, France, Great Britain, Norway, Sweden	MMI19
Design, manufacturing and repair of Lithium-ion batteries	Industry	Battery production and design, battery second life	26	High school	European perspective	France and EU	ATG44
Battery aging	Research organisation	Battery production and design	14	Bachelor degree	Global perspective	China, Germany, Switzerland	TBA42

Gathering robust empirical data can be challenging in emerging nascent industries where there is high uncertainty, such as in the second-life EV LiB industry, as noted by Erikson et al. (2015). These considerations were especially relevant in our study given the high uncertainty and evolving stakeholder roles, which likely limited the invited experts' willingness to participate. The resulting Delphi panel experts for this study included professionals from academia, industry, research organisations, and regulatory bodies, summarised in Table 1. All the participants were informed about the purpose of the study, and given the right to withdraw at any time. Moreover, they were informed that the results of the study would be published in a reputed academic journal to maintain transparency. Initially, 167 experts were approached, with 17 responding in the first round and 12 in the second. The final panel was diverse in gender, relevant professional experience (mean: 19.9 years), and geography, though predominantly European. To ensure a broader perspective and capture insights from globally relevant stakeholders, also experts from outside the EEA who are part of established international collaboration networks with European partners were invited. In the final panel, one expert from Asia participated, offering a Japanese perspective. In our analysis, we accounted for this geographic and regulatory difference: in cases where this expert's ratings diverged significantly from the panel's consensus, these instances are explicitly discussed in the results section.

Table 2. Brief overview of questions included in the Delphi questionnaire

Q1 Shares of FEoL LiBs available for repurposing	Shares in a) general, b) specifically for household context.
Q2 Likelihood of different second-life applications within the household context	a) Household ESS, b) household ESS+PV, c) portable power packs, d) prolonged use of LiBs in cars, e) open option for other suggested applications.
Q3 Likelihood of different value chain structures to succeed.	Responsibility for collection, treatment, and repurposing of end-of-life EV batteries assigned to different actors: a/b) OEMs (full or partial responsibility), c) repurposers, d) insurance companies, or e) car dismantlers, f) open option for other suggested value chain structures.
Q4 Likelihood of different business models to emerged for OEMs.	OEM business model options: a) OEM retains ownership throughout lifecycle to capture value; b) OEM takes back end-of-life batteries and sells untreated to repurposers; c) OEM provides treated batteries to repurposers for second-life products, d) open option for other suggested sustainable business models.
Q5 Feasibility of repurposing EV LiBs for the household context.	a) Technical feasibility, b) Economical feasibility for user and industry, c) Contributing to sustainability.
Q6 Importance of drivers.	a) Regulatory and policy support, b) growing market interest in household energy storage, c) profitability for repurposers, d) raw material scarcity, e) environmental awareness, f) large volumes of FEoL batteries available, g) automation technology development for disassembly, h) EU market protectionism, i) household self-sufficiency goals to relieve the grid, and j) rising energy costs, k) open option for additional drivers.
Q7 Importance of challenges.	a) Low consumer awareness of sustainable options, b) Price reduction of new LiBs, c) Low performance of repurposed batteries vs. new LiBs, d) Higher value of repurposed LiBs in other markets, e) High transportation costs for end-of-life LiBs, f) Low availability of first end-of-life LiBs, g) OEM liability for safety hazards, h) Lack of regulations for safe/sustainable repurposing, i) Diverse EV battery designs across OEMs, j) Lack of design for repurposing, k) Open option for other likely challenges.
Q8 Importance of factors affecting customer willingness.	a) Customer willingness to buy a reduced product, b) Perceived safety of repurposed EV LiBs, c) Desire for household self-sufficiency and reliable power, d) Motivation to demonstrate climate responsibility, e) Installing repurposed LiBs as a tangible climate action, f) Potential savings on electricity bills, g) Open option for other factors affecting adoption.

The study was designed for two rounds, unless potential for significant further convergence of opinions would be identified, which turned out not to be the case. As significant changes did not appear, a third round was not pursued. Additionally, participant fatigue was considered a concern as extending the process would likely have reduced the engagement, response rate and quality.

Eight main questions were formulated based on input from the previous exploratory interviews, as well as peer-reviewed literature, grey literature – media articles, press releases, etc. and brainstorming. Topics included the future of EV LiBs, technical feasibility, economic viability, sustainability, value chains, business models, and customer adoption factors. A brief overview is listed in Table xx, while an exhaustive table can be found in Appendix A1. Although no direct customer data has been collected, this Delphi was seen as a starting point for experts to identify key developments likely to influence repurposing EV LiBs for the household. Questions were presented in a matrix format for the years 2025, 2030, and 2045, with responses in percentages or on a 7-point Likert scale. Participants could elaborate on their answers in open text fields. Responses were collected via the digital tool 'Nettskjema', which offers data analysis and security features. The first round of questionnaires was conducted from March 12th to April 28th, 2024, while the second round took place between May 13th and June 5th, 2024.

Answers from the first round were summarised and sent back to the panel experts, who were given the opportunity to revise their first-round answers and provide further considerations in open text fields. One participant handed in a blank form; this participant's answers from the first round were considered as final answers. After the second round the results were analysed for the average and median. Consensus was defined as at least 67% of the experts' responses falling within two consecutive points on the 7-point Likert scale, equivalent to 8 out of 12 experts in round 2, This aligns with the widely used 70% criterion for consensus (Hsu & Sandford, 2007). Remarks from both rounds were analysed thematically (Braun & Clarke, 2006). Throughout the paper, where possible and relevant, the opinions of the panel experts are put side to side with what literature has mentioned about the topic at hand.

In terms of interpreting the quantitative means from the questions presented in the Delphi questionnaire, we interpreted the results according to the ranges suggested in Table 2.

Table 3. Interpretation of quantitative means

Range	Interpretation
1.0 – 1.9	Very unlikely/ Not important at all
2.0 – 2.9	Unlikely / Not important
3.0 – 3.9	Slightly unlikely/ Slightly important
4.0 – 4.4	Neutral
4.5 – 5.4	Slightly likely/ Slightly important
5.5 – 6.4	Likely/Important
6.5 – 7.0	Very likely/Very important

4. Results and Discussion

In this section the results after round two are presented. The questionnaire results are presented from the second and last round, whereas relevant remarks and comments are presented from both rounds. Only parts of the questions are presented in the text, a complete overview of the results can be found in the appendix. A graphical summary of the main insights is presented in Figure 1.

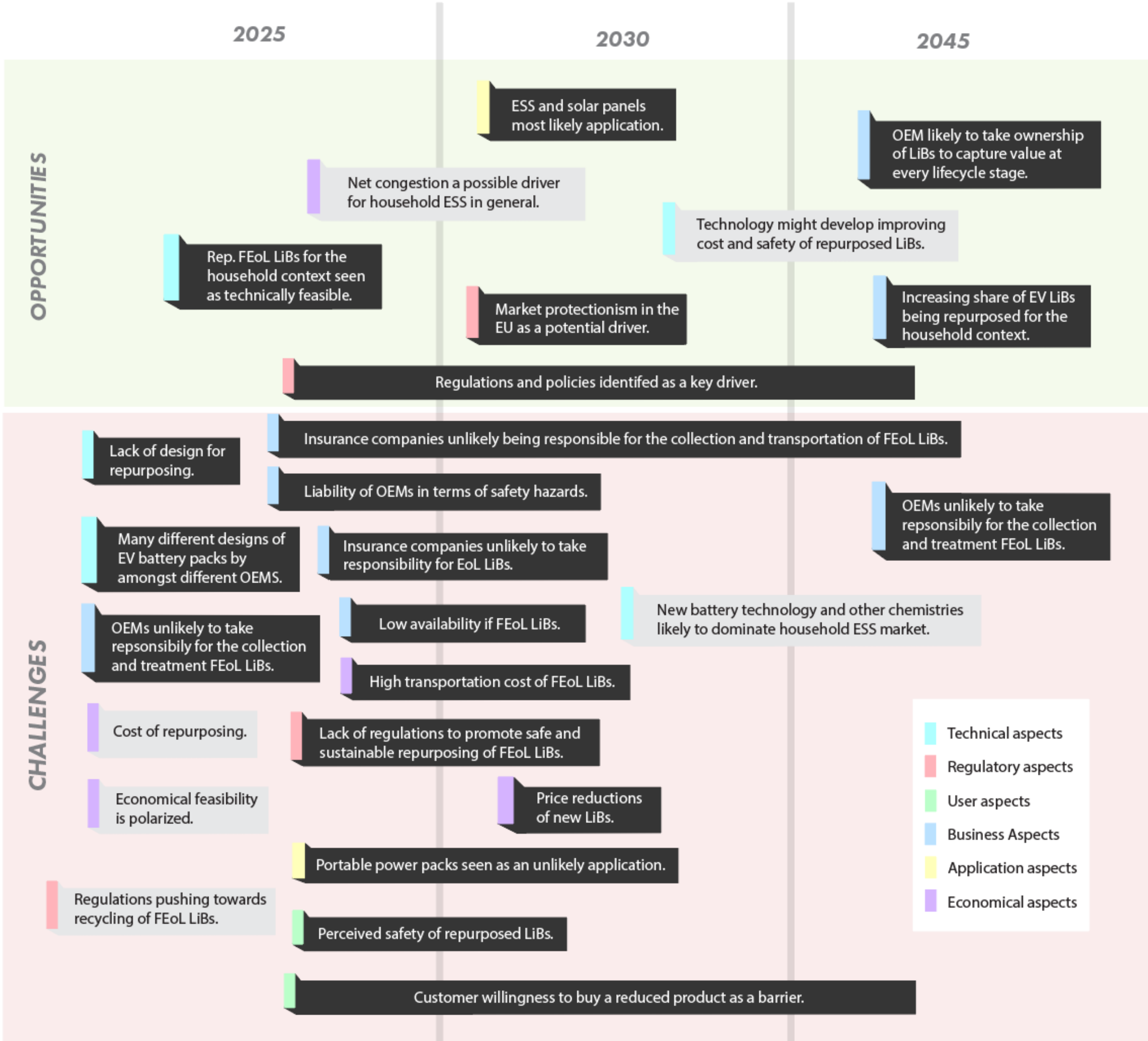

Figure 1. Overview of insights on the future of Repurposing LiBs for the household context. Black bricks represent aspects that were in consensus from the questionnaires, while grey bricks represent aspects suggested by the panel

4.1. Share of repurposed LiBs

Given the continuously rising demand for EV batteries (IEA, 2024), the panel experts were asked to estimate the future share of available EV lithium-ion batteries (LiBs) that could be repurposed for both general applications and household-specific contexts.

For repurposing regardless of application, the panel experts reached consensus that less than 20% of available EV LiBs would be repurposed in the short-term (mean score 14.3%). Although not in consensus, projections show an increase to 40.5% by 2045 (Fig. 2a). This is much lower than estimations of 75% of FEoL batteries which would be eligible for second-life by 2025 (Melin, 2017; Pagliaro & Meneguzzo, 2019). For the household context specifically, the short-term expectation is even lower (mean: 5.3%) but is expected to rise to 18.6% by 2045 (Fig. 2b). Overall, the trend suggests a growing share for the household context, with some variability in expectations for the near future.

a) share of EV LiBs repurposed regardless of application.

	2025	2030	2045
NA	8 %	8 %	8 %
0 %	0 %	0 %	0 %
1-10%	50 %	17 %	8 %
11-20%	25 %	33 %	8 %
21-40%	25 %	33 %	33 %
41-60%	0 %	17 %	33 %
61-80%	0 %	0 %	17 %
81-100%	0 %	0 %	0 %
Mean	***14,3***	***24,7***	***40,5***

b) share of EV LiBs repurposed for the household context, specifically.

	2025	2030	2045
NA	8 %	0 %	8 %
0 %	42 %	25 %	17 %
1-10%	42 %	33 %	0 %
11-20%	0 %	33 %	50 %
21-40%	8 %	0 %	17 %
41-60%	0 %	8 %	8 %
61-80%	0 %	0 %	0 %
81-100%	0 %	0 %	0 %
Mean	***5,3***	***11,2***	***18,6***

Figure 2. Estimated shares of used EV LiBs to be repurposed. Yellow indicates consensus over two adjacent cells

4.2. Likelihood of different applications within the household context

As pointed out in section 2.1, literature proposes several household applications for repurposing EV LiBs, including stationary energy storage, with or without PV (Heymans et al., 2014), and mobile energy storage (Manthey, 2023). Another alternative discussed is extending the battery's life within the car and reselling it as a low-performance car (Börner et al., 2022). The panel experts generally considered repurposing EV LiBs for household energy storage unlikely in the short-term, both with and without PV (Fig. 3a, 3b). For long-term ESS combined with PV, the expert panel experts were divided, though on average overall somewhat more positive (Fig. 3b). It was noted that while most experts anticipate gradual progress in adaptation, the Japanese expert was much more pessimistic.

The latter combination is also the most prominently addressed in research (Pantelatos et al., 2023). Market trends indicate a growing link between household LiB installations and PV installations, particularly in countries like Germany (BloombergNEF, 2023). However, repurposed EV LiBs may only meet a limited portion of the increasing demand for household ESS.

Application in portable power packs is considered unlikely in the short- and medium-term (Fig. 3c). The panel experts expressed scepticism regarding this application, suggesting limited scalability for mobile applications, and therefore likely to remain a niche rather than a mainstream second-life pathway. However, a few examples are already available in the market including a JVC Kenwood/Nissan product for sale in Japan, and Reusable Technologies in Slovenia offering a mobile power bank based on e-scooter batteries.

The panel experts did not reach consensus on further usage of the battery in EVs as argued for by Börner (2022), showing polarisation across the different time horizons (Fig. 3d). However, optimism increases from a mean of 3.8 in 2025 to 4.3 in 2045, making this ‘secondary’ application to be considered most likely in comparison with other suggested applications. We hypothese that the lack of consensus might reflect competing priorities within the battery value chain. Safety-focused perspectives, often aligned with OEM-strategies, emphasise risk mitigation, warranty compliance, and liability, presented in the supplementary experts insights section. In contrast, CE advocates prioritise maximising resource efficiency by extending battery use in vehicles as a sustainability measure. Technological optimists highlight advances in battery management systems (BMS) and predicative analytics that could enable safe life extension. In literature, Saxena et al. (2015) find that even with a lower SOH of the EV battery pack, an EV would still serve the daily travel needs of a substantial number of car drivers. In general, the commonly referenced narrative about the FEoL threshold of 80% stems from the 1990s when EVs were mostly based on lower energy and power density nickel-based batteries (Hunt, 1996). As battery technology has developed substantially since then, this 80% threshold might not be applicable anymore (Patel et al., 2024). Successfully challenging this threshold may have relevant implications as extending in-vehicle battery life could become a second-life strategy, which may offer significant environmental benefits by reducing the need for new LiBs and maximising resource efficiency. However, this approach might also decrease the volume of batteries available for household ESS and potentially influence business models.

a) ESS based on repurposed EV LiBs solely for load-leveling and peak-shaving in a household context:

	2025	2030	2045
Not answered	0 %	0 %	0 %
1 - Very unlikely	42 %	17 %	8 %
2	33 %	25 %	17 %
3	8 %	42 %	33 %
4	17 %	8 %	33 %
5	0 %	8 %	0 %
6	0 %	0 %	8 %
7 - Very likely	0 %	0 %	0 %
Mean	*2,0*	*2,7*	*3,3*

b) ESS based on repurposed EV LiBs for load-levelling and peak-shaving in combination with solar panels in a household context

	2025	2030	2045
Not answered	0 %	0 %	0 %
1 - Very unlikely	25 %	8 %	0 %
2	50 %	25 %	8 %
3	8 %	25 %	17 %
4	8 %	33 %	50 %
5	8 %	8 %	17 %
6	0 %	0 %	8 %
7 - Very likely	0 %	0 %	0 %
Mean	*2,3*	*3,1*	*4,0*

c) Application of repurposed EV LiBs in portable power packs in a household context:

	2025	2030	2045
Not answered	0 %	0 %	0 %
1 - Very unlikely	58 %	33 %	25 %
2	25 %	50 %	33 %
3	8 %	0 %	25 %
4	0 %	8 %	8 %
5	8 %	8 %	8 %
6	0 %	0 %	0 %
7 - Very likely	0 %	0 %	0 %
Mean	*1,8*	*2,1*	*2,4*

d) EV batteries will reach their end-of-life in the same application by EVs changing the hands of users with lower range and speed requirements:

	2025	2030	2045
Not answered	0 %	0 %	0 %
1 - Very unlikely	25 %	8 %	8 %
2	17 %	25 %	17 %
3	17 %	25 %	8 %
4	0 %	0 %	25 %
5	8 %	17 %	8 %
6	8 %	0 %	8 %
7 - Very likely	25 %	25 %	25 %
Mean	*3,8*	*3,9*	*4,3*

Figure 3. Likelihood of secondary applications within the household context

In summary, the most likely application using ranking of means as criterion, is prolonged use of the EV LiB in the original car (Fig. 3), followed by repurposed as ESS with PV (Fig. 3b), ESS for load-levelling and peak shaving (Fig. 3a), and lastly portable power packs (Fig. 3d). The rankings remain consistent over time but are not necessarily in consensus.

4.3. Value chain structures and their likelihood to succeed

The panel experts were asked about the likelihood of five plausible value chain structures that may facilitate repurposing EV LiBs in the future. These were identified through preparatory interviews and literature (Ahmed et al., 2025; Wrålsen et al., 2021). The first option, where OEMs are responsible for collection, treatment, and repurposing of the batteries, is considered unlikely in the short-term, by consensus. No consensus was reached for the long-term, but the mean increased from 2.2 to 2.7 (Fig. 4a). Literature suggests that OEMs benefit from maintaining control over batteries throughout their lifecycle, as seen in strategies by Daimler and Renault where solutions are implemented by incorporating second-life EV LiBs into the energy sector (Albertsen et al., 2021; Stefan & Chirumalla, 2025). Furthermore, OEMs may prefer close collaboration with third-party stakeholders to ensure battery circularity, exemplified by Nissan and BMW's partnerships with energy companies (Bonsu, 2020).

For the second-option (OEMs are responsible just for collection and treatment of the FEoL batteries), the panel experts reached consensus on this being unlikely for both short- and long-term (Fig. 4b). For the third option (repurposers are responsible for collection, treatment, and repurposing of the FEoL batteries) no consensus was reached, as indicated in Fig. 4c. This suggests uncertainty around repurposer-led value chains. This is also reflected in previous research, where technical, economic, and regulatory barriers are suggested to hinder repurposers to take the leading role (Huether, 2025). Moreover, geographical context may amplify scepticism. The response from the Japanese expert, who was more sceptical than average, also signals limited confidence in repurposer-led value chains. For instance, this is aligned with Japan's second-life market which is mostly OEM led, as indicated by Nissan's 4R model (Reuse-Refabricate-Resell-Recycle), where Nissan controls the battery lifecycle.

For the fourth option (where insurance companies bear responsibility for collection and transportation of the FEoL batteries), there is clear consensus for both the short-term and long-term about this being unlikely (Fig. 4d). However, we hypothesise that the insurance companies might handle batteries from EVs involved in accidents without significant battery damage, a view supported by Hellström and Wrålsen (2024). No consensus was reached for the fifth option (Fig. 4e), where car dismantlers are responsible for the collection and transportation of FEoL batteries. Although the mean increase from 3.3 in the short-term to 4.1 in the long-term. This is to some extent in line with literature emphasising that car dismantlers will play a crucial role in the battery value chains, as they have a significant responsibility to redirect the FEoL batteries to the relevant stakeholders such as insurance companies (Hellström & Wrålsen, 2024). The responses to the five options suggest that no single value chain structure is considered significantly more plausible than the others. However, OEM-led and dismantler-supported models appear most promising over time.

a) OEMs are responsible for the collection, treatment, and repurposing of the first end-of-life batteries

	2025	2030	2045
Not answered	0 %	0 %	0 %
1 - Very unlikely	33 %	25 %	25 %
2	50 %	33 %	25 %
3	0 %	25 %	8 %
4	8 %	8 %	42 %
5	0 %	8 %	0 %
6	8 %	0 %	0 %
7- Very likely	0 %	0 %	0 %
Mean	2,2	2,4	2,7

b) OEMs are responsible for the collection and treatment of the first end-of-life batteries

	2025	2030	2045
Not answered	0 %	0 %	0 %
1 - Very unlikely	17 %	8 %	0 %
2	25 %	33 %	25 %
3	33 %	8 %	33 %
4	8 %	25 %	17 %
5	8 %	25 %	25 %
6	8 %	0 %	0 %
7- Very likely	0 %	0 %	0 %
Mean	2,9	3,3	3,4

c) Repurposers are responsible for the collection, treatment, and repurposing of the first end of life batteries

	2025	2030	2045
Not answered	0 %	0 %	0 %
1 - Very unlikely	33 %	17 %	8 %
2	17 %	8 %	8 %
3	17 %	17 %	8 %
4	8 %	25 %	17 %
5	8 %	8 %	8 %
6	17 %	25 %	42 %
7- Very likely	0 %	0 %	8 %
Mean	2,9	3,8	4,7

d) Insurance companies are responsible for the collection and transportation of the first end-of-life batteries

	2025	2030	2045
Not answered	0 %	0 %	0 %
1 - Very unlikely	75 %	67 %	67 %
2	25 %	33 %	25 %
3	0 %	0 %	0 %
4	0 %	0 %	0 %
5	0 %	0 %	0 %
6	0 %	0 %	0 %
7- Very likely	0 %	0 %	0 %
Mean	1,3	1,3	1,3

e) Car dismantlers are responsible for the collection and transportation of the first end-of-life batteries

	2025	2030	2045
Not answered	0 %	0 %	0 %
1 - Very unlikely	33 %	25 %	17 %
2	8 %	8 %	0 %
3	0 %	0 %	8 %
4	33 %	33 %	33 %
5	8 %	17 %	17 %
6	17 %	17 %	25 %
7- Very likely	0 %	0 %	0 %
Mean	3,3	3,6	4,1

Figure 4. Likelihood of different Value Chain Structures of FEoL EV LiBS

4.4. Sustainable business models and their likelihood to succeed

The panel experts evaluated three SBMs with varying degrees of OEM battery ownership, based on the SBM typology proposed by Ahmed et al. (2025). The SBMs are focused on the OEMs because of their integral role in the battery value chain (Reinhardt et al., 2019b; Stefan & Chirumalla, 2025). The panel experts agreed that SBMs where the OEM retains battery ownership throughout its lifecycle are perceived to be more viable in the long-term, despite short-term challenges (Fig. 5a). This finding aligns with Reinhardt et al. (2019a) who forecast that OEMs will increasingly take back retired batteries to provide valuable ESS services, despite higher costs. However, the Japanese expert diverges and remains sceptical, rating this SBM as (2) on the Likert scale in the long-term. This divergence may reflect the difference between OEM-led business model such as the Nissan 4R, and full battery ownership which assumes long-term responsibility instead of efficiency.

No consensus was reached for the SBM where the OEM sells FEoL batteries to repurposers, despite a mean increase from 2.9 to 4.2, indicating increasing viability over time. (Fig. 5b). Some panel experts favoured this model in the long-term while others found it to be unlikely, reflecting polarisation and persistent doubts about its potential to succeed. Similarly, the SBM where the OEM collects, treats, and provides FEoL batteries to repurposers for second-life products also lacked consensus, despite the mean increase from 2.3 to 3.3 (Fig. 5c). We hypothesise that this polarisation likely stems from doubts related to cost and logistical complexity associated with the treatment process of the batteries, and more specifically related to high initial investments needs in infrastructure, as pointed out by Gu et al. (2024). These concerns are also pointed out by, Toorajipour et al.(2024) where they emphasise that unclear roles and responsibilities, lack of guarantees, and communication between the stakeholders hinder the adoption of second-life EV LiBs. Despite no consensus among the panel experts, previous research highlights the emergence of collaborative SBMs between repurposers and OEMs (Ahmed et al., 2025), which may indicate a gradual shift towards these models in the industry.

a) OEM owns the battery throughout its life cycle and aims to capture value at every lifecycle stage

	2025	2030	2045
Not answered	0%	0%	0%
1- Very unlikely	25%	8%	8%
2	42%	8%	8%
3	33%	58%	8%
4	0%	8%	25%
5	0%	17%	50%
6	0%	0%	0%
7- Very likely	0%	0%	0%
Mean	2.1	3.2	4

b) OEM takes back the first end of life batteries and then sells them untreated to the repurposer

	2025	2030	2045
Not answered	0%	0%	0%
1- Very unlikely	25%	8%	8%
2	17%	17%	0%
3	17%	8%	17%
4	25%	50%	42%
5	17%	8%	17%
6	0%	8%	8%
7- Very likely	0%	0%	8%
Mean	2.9	3.6	4.2

c) OEM provides treated batteries to the repurposer who makes different second-life battery products

	2025	2030	2045
Not answered	0%	0%	0%
1- Very unlikely	33%	17%	8%
2	25%	25%	25%
3	25%	25%	17%
4	8%	25%	33%
5	8%	8%	17%
6	0%	0%	0%
7- Very likely	0%	0%	0%
Mean	2.3	2.8	3.3

Figure 5. Sustainable business models that are likely to succeed

4.5. Feasibility of repurposing LiBs for the household context

The economic and technological feasibility of repurposing EV LiBs for household use is critical for the success of viable business models and value chains. Therefore, the panel experts were asked to estimate when repurposing would be economically and technologically feasible for users and industry. Additionally, the panel experts were asked when repurposed second-life solutions could start contributing to sustainability. The panel experts agreed that technical feasibility for household repurposing is achievable in the short-term (Fig. 6a). In literature, a number of studies investigating ageing of second-life batteries within a household context finds that a repurposed LiB can be used for an additional 3-10 years, depending on chemistry and contextual use profiles (Casals et al., 2019; Thakur et al., 2022).

However, there was no consensus on economic feasibility; half of the panel experts expect it by 2030, while a quarter, including the Japanese expert, believe it may never be economically viable (Fig. 6b). This reflects a cautious outlook due to the higher costs associated with repurposing as stated in the supplemented expert insights. Regarding sustainability, treating "never" as the highest category when calculating the median resulted in a panel's estimate of 2030, indicating medium-term feasibility (Fig. 6c). Here the Japanese expert expected contribution to sustainability as early as 2025, even though the economic viability remains doubtful.

	2025	2030	2045	Later	Never	NA	*Median*
a) Technically feasible?	75 %	17 %	0 %	0 %	8 %	0 %	*2025*
b) Economically feasible for user and industry?	17 %	33 %	8 %	17 %	25 %	0 %	*2037*
c) Contributing to sustainability?	42 %	17 %	8 %	17 %	17 %	0 %	*2030*

Figure 6. Feasibility in terms of technology, economy and contribution to sustainability

4.6. Drivers for repurposing LiBs for the household context

To assess the relative importance of different potential drivers for repurposing EV LiBs for the household context, the panel experts were asked to rate the importance of ten drivers gathered from scientific and grey literature detailed in Appendix A1. A full overview of the results is provided in Appendix A2. The panel experts reached consensus for three drivers. First, national and international regulations and policies to promote repurposing of LiBs are seen as very important for short-, medium- and long-term feasibility (Fig. 7a). This confirms findings by Wrålsen et al. (2021) regarding drivers for general further use of FEoL LiBs. Secondly, the panel experts were also in consensus that vast amounts of EV LiBs would need to become available for treatment in the short-term. For the medium- and long-term no further consensus was reached, but the mean answer increased to 4,8 in 2045 (Fig. 7f). A third driver deemed important is market protectionism in the EU (Fig. 7h), where demand for repurposed batteries can increase due to reduced imports. This aligns with EU battery regulation, which emphasises CE and sustainability of the batteries while highlighting the importance of reducing reliance on imported raw materials from third countries (EU Parliament, 2023) .

a) National and international regulations and policies to promote repurposing of LiBs

	2025	2030	2045
Not answered	0 %	0 %	0 %
1 - Not important	17 %	8 %	8 %
2	8 %	0 %	0 %
3	0 %	8 %	0 %
4	0 %	0 %	8 %
5	0 %	0 %	0 %
6	17 %	17 %	17 %
7 - Very Important	58 %	67 %	67 %
Mean	*5,4*	*6,0*	*6,1*

f) Vast amounts of first-end-of-life LiBs piling up in need of treatment

	2025	2030	2045
Not answered	0 %	0 %	0 %
1 - Not important	25 %	0 %	0 %
2	42 %	17 %	8 %
3	8 %	25 %	8 %
4	8 %	25 %	25 %
5	17 %	33 %	25 %
6	0 %	0 %	17 %
7 - Very Important	0 %	0 %	17 %
Mean	*2,5*	*3,8*	*4,8*

h) Market protectionism in the EU

	2025	2030	2045
Not answered	0 %	0 %	0 %
1 - Not important	8 %	0 %	0 %
2	33 %	17 %	17 %
3	0 %	8 %	8 %
4	42 %	42 %	42 %
5	8 %	25 %	17 %
6	0 %	0 %	8 %
7 - Very Important	8 %	8 %	8 %
Mean	*3,4*	*4,1*	*4,2*

Figure 7. Excerpt showing drivers reaching consensus within the expert panel

Ranking the results in terms of means, national and international regulations came forward as the driver with highest importance for repurposing LiBs for the household context across all time frames, followed by potential profit for repurposers (Appendix A3). However, the ranking is not necessarily in consensus. See Appendix A3 for the complete ranking.

4.7. Challenges for repurposing LiBs for the household context

The panel experts were also asked to rate a set of potential challenges for repurposing EV LiBs in household context applications. The challenges were identified through scientific and grey literature. In total 10 challenges were presented, and consensus was reached for 7 of these (Fig. 7). An overview of all challenges can be found in Appendix A4.

In the short- and medium-term, the panel experts found consensus on the following challenges: high transportation costs of end-of-life LiBs (Fig. 7e), low availability of FEoL LiBs (Fig. 7f), OEM liability (Fig. 7g), and lack of regulations (Fig. 7h). For challenges like diverse EV battery designs (Fig. 7i) and lack of repurposing design (Fig. 7j), consensus was only reached for the short-term. There was consensus about price reduction of new LiBs being a challenge in the medium-term (Fig. 7b). No long-term challenges reached consensus within the panel. Interestingly, the Japanese expert rated the availability of FEoL LiBs in 2045 as important (6), well above the panel average. This might reflect that Japan's export-heavy used EV market, where used EVs are exported to other countries such as Russia and New Zealand, poses a challenge for domestic

b) Price reduction of new LIBs

	2025	2030	2045
Not answered	0,0	0,0	0,0
1 - Not important	8 %	0 %	0 %
2	0 %	0 %	0 %
3	0 %	0 %	0 %
4	8 %	17 %	17 %
5	25 %	8 %	25 %
6	25 %	42 %	25 %
7 - Very Important	33 %	33 %	33 %
Mean	5,5	5,9	5,8

e) High transportation cost of end-of-life LiBs

	2025	2030	2045
Not answered	0	0	0
1 - Not important	8 %	0 %	0 %
2	0 %	0 %	0 %
3	8 %	17 %	33 %
4	17 %	17 %	8 %
5	50 %	50 %	42 %
6	17 %	8 %	8 %
7 - Very Important	0 %	8 %	8 %
Mean	4,5	4,8	4,5

f) Low availability of first end-of-life LiBs for repurposers

	2025	2030	2045
Not answered	0	0	0
1 - Not important	8 %	8 %	17 %
2	0 %	0 %	17 %
3	0 %	17 %	25 %
4	0 %	8 %	17 %
5	25 %	50 %	17 %
6	42 %	17 %	8 %
7 - Very Important	25 %	0 %	0 %
Mean	5,6	4,4	3,3

g) Liability of OEMs in terms of safety hazards of repurposed LiBs

	2025	2030	2045
Not answered	0	0	0
1 - Not important	8 %	0 %	0 %
2	0 %	8 %	8 %
3	0 %	0 %	0 %
4	8 %	0 %	8 %
5	0 %	8 %	25 %
6	42 %	58 %	33 %
7 - Very Important	42 %	25 %	25 %
Mean	5,8	5,8	5,5

h) Lack of regulations to promote safe and sustainable repurposing of LiBs

	2025	2030	2045
Not answered	0	0	0
1 - Not important	8 %	0 %	0 %
2	0 %	17 %	25 %
3	8 %	0 %	0 %
4	0 %	0 %	8 %
5	8 %	17 %	17 %
6	25 %	25 %	17 %
7 - Very Important	50 %	42 %	33 %
Mean	5,8	5,6	5,0

i) Many "different" designs of EV battery packs by different OEMs

	2025	2030	2045
Not answered	0	0	0
1 - Not important	0 %	0 %	0 %
2	0 %	0 %	8 %
3	8 %	8 %	17 %
4	8 %	8 %	17 %
5	0 %	17 %	17 %
6	33 %	33 %	25 %
7 - Very Important	50 %	33 %	17 %
Mean	6,1	5,8	4,8

j) Lack of design for repurposing of EV LiBs

	2025	2030	2045
Not answered	0	0	0
1 - Not important	0 %	0 %	0 %
2	0 %	0 %	0 %
3	8 %	8 %	25 %
4	8 %	8 %	17 %
5	8 %	33 %	42 %
6	25 %	17 %	0 %
7 - Very Important	50 %	33 %	17 %
Mean	6,0	5,6	4,7

Figure 7. Excerpt showing challenges reaching consensus within the expert panel

CE goals related to battery reuse and recycling, also in the long-term (Farmer & Watkins, 2023). In contrast, the expert consistently rated OEM liability and lack of regulation as unimportant across all time frames, and gave a neutral rating (4) to the challenge of diverse EV battery designs. These lower ratings may reflect regional differences in regulatory environments, market maturity, or expectations around industry-led standardisation.

Ranking the results by mean, in the short-term, the variety of EV pack designs was seen as the main barrier. Price reductions of new LiBs were highlighted as the most important in medium- and long-term, resonating with literature where the price advantage of second-life batteries is expected to diminish without subsidies (Patel et al., 2024; Sun et al., 2018). Furthermore, in the long-term, the higher value of repurposed EV LiBs in other markets was seen as the most important barrier. The ranking is however not necessarily in consensus. The complete ranking can be found in Appendix A5.

4.8. Factors affecting customer willingness to implement repurposed LiBs in the household context

An important, yet underexplored stakeholder perspective in the household context is that of the end user of products based on repurposed batteries. As noted by Pantelatos et al. (2025), addressing both rational and irrational factors perceived by end users are crucial for the success of business models involving second-life LiBs in households. The panel experts evaluated six factors affecting customer willingness to adopt repurposed LiBs, derived from literature (Appendix A1). Fig. 8 highlights the consensus on these factors, with a complete overview available in Appendix A6.

a) Customer willingness to buy a reduced product

	2025	2030	2045
Not answered	8 %	8 %	8 %
1 - Not important	0 %	0 %	0 %
2	0 %	0 %	0 %
3	8 %	0 %	0 %
4	0 %	8 %	8 %
5	8 %	8 %	25 %
6	58 %	58 %	42 %
7 - Very Important	17 %	17 %	17 %
Mean	**5,8**	**5,9**	**5,7**

b) Perceived safety of repurposed EV LiBs

	2025	2030	2045
Not answered	8 %	8 %	8 %
1 - Not important	0 %	0 %	0 %
2	8 %	8 %	8 %
3	0 %	0 %	17 %
4	0 %	8 %	0 %
5	8 %	8 %	0 %
6	17 %	17 %	33 %
7 - Very Important	58 %	50 %	33 %
Mean	**6,2**	**5,9**	**5,5**

Figure 8. Excerpt showing factors affecting customer willingness reaching consensus within the expert panel.

The panel experts found consensus for the importance of customer willingness to buy a reduced product, in terms of ageing, based on repurposed batteries, across all the different time horizons (Fig. 8a), and regarding perceived safety of LiBs, in a short- and medium-term perspective (Fig. 8b). The literature underscores the importance of safety within the household context (Börner et al., 2022; Bräuer, 2016). Pantelatos et al. (2025) also identified varying perceptions of what constitutes safety amongst repurposers of second-life batteries. However, in 2024, the standards IEC 63330 and IEC 63338 were published, addressing second life use of LiBs. IEC 63330 focuses on assessing the safety and suitability of second-life LiBs, while IEC 63338 provides high-level guidance on their safe and environmentally friendly reuse (Christensen et al., 2023). Interestingly the Japanese expert was an outlier to this question, rating perceived safety consistently as not important (2) across the time frames. This may be interpreted as confidence in existing systems and industry practices rather than a disregard for safety.

Ranking the results by mean revealed that perceived safety of repurposed EV LiBs was seen as the most important factor in short-term and medium-term. In medium-term and long-term, customer willingness to buy a reduced product is ranked most important. Although not by consensus, potential savings on electricity bills are also seen as an important factor, which resonates with market studies which find that consumers of new battery storage systems are seen to be price-sensitive (BVES, 2024), and that savings on electricity bills are the most important motivation for acquiring an ESS (BloombergNEF, 2023). Nevertheless, there may be distinctive differences between consumers who opt for storage systems utilising new batteries and those who might prefer systems based on repurposed batteries. These rankings are not necessarily in consensus, and a full overview can be seen in Appendix A7.

4.9. Supplementary expert insights

The panel experts provided supplementary insights as 'further remarks' to several questions presented above. The results from analysing those further remarks which have not yet been included in the discussion above, are presented thematically in this section.

4.9.1. Safety concerns Safety concerns emerged as a dominant theme throughout the remarks. Experts repeatedly emphasised the risks associated with battery failure inside homes. They noted that while technical feasibility is achievable the consequences of failure could be severe. One panel expert remarked:

> *"The issue of technical feasibility is clouded somewhat by the risks associated with the consequences of failure in the battery pack when inside a home. If it shorts out and starts to ignite ... so maybe the insurance industry will be key; and maybe consumers will be very cautious (note e.g. e-bike fires)" – Expert HCE8.*

This perspective underscores the importance of liability frameworks and insurance coverage, which several experts pointed out to be critical for consumer confidence. Although some panel experts expressed optimism that safety solutions will emerge as technology matures, others stressed that without robust standards and clear responsibilities, adoption will remain limited.

4.9.2. Economic and technical feasibility Economic feasibility was another recurring concern. One expert noted that current EV batteries are not designed for second-life applications, and even claimed that certain EV manufacturers design batteries in order to avoid reuse. Grey and scientific literature observes a shift towards cell-to-pack and cell-to-body design (Kohs & Brachtendorf, 2023; Samsung SDI, 2025). These architectures eliminate traditional modules by bonding cells directly into the EV pack or chassis using adhesives and welding. The goal is to improve energy density and reduce weight (Kohs & Brachtendorf, 2023; Pampel et al., 2022). While effective for performance, this approach creates major barriers for circular strategies. Dismantling becomes labor-intensive, hard to automate, and costly to repurpose (Kohs & Brachtendorf, 2023).

A few remarks also problematised high repurposing cost in favour of larger-scale ESS for neighbourhoods or industrial applications, where economies of scale reduce cost per kWh echoed in literature (Kamath et al., 2020). Proposed applications by the experts purely revolved around industrial applications which included metal processing with high energy demands and short-term high demand scenarios like ESS in stadiums. Smaller-scale applications mentioned, included forklifts and automated guided vehicles. Two experts suggested that FEoL LiBs could remain in vehicles to meet everyday needs at lower cost, as in (Börner et al., 2022), rather than being dismantled for household use. Additionally, falling prices of new LiBs and competition from inexpensive Asian products were seen to threaten the viability of repurposed batteries. Pantelatos et al. (2025) note that required dismantling levels vary amongst repurposers, affecting costs. One company in the aforementioned study repurposed entire EV packs, saving on dismantling costs and reusing several components, while other actors were skeptical about ensuring safety without dismantling and inspecting individual parts. This relationship between safety and cost is also mentioned by Hu et al. (2022). In light of the latter, the attractiveness of repurposing would depend on reduced costs whilst ensuring safety and longevity.

Technological development is viewed as both a driver and a disruptor in the future potential of repurposing EV LiBs for household use. On one hand, remarks underlined opportunities to improve the efficiency and safety of repurposed battery systems through learning, innovation, and better design. The remarks included that automating the treatment process would be key for making repurposing a cost-effective alternative and ensuring quality in the process. Furthermore, the process must be adapted to the high diversity in battery packs currently on the market. Examples from literature suggest that by combining automated dismantling with the use of artificial intelligence and machine learning, challenges such as the huge variety of battery packs and uncertainty can potentially be overcome (Meng et al., 2022). On the other hand, rapid advancements in battery chemistries and recycling technologies pose a challenge, potentially making repurposing less relevant or economically viable. Specifically, sodium-ion batteries can become viable for household ESS due to their lower production costs, reduced environmental impact, and enhanced safety (Wu et al., 2024), if their life cycle improves.

4.9.3. Policy and regulations Regulatory frameworks were seen to add another layer of complexity. Firstly, as presented in section 4.6, the panel experts rank regulation and policy to be the most important driver. Some panel experts made remarks considering new regulations to protect the market from inexpensive products from Asia, as well as legislation to promote repurposing before recycling. These were considered as important drivers for repurposing LiBs for the household context. In literature, potential is seen in digital battery passports, which could contain status and performance data from the FEoL EV LiB, made available to repurposers and thereby reduce costs and complexities in testing and sorting modules or cells for second-life applications (Berger et al., 2022). On the other hand, regulations were also seen to work against repurposing: two panel experts pointed out that EU regulations currently incentivise recycling over repurposing by mandating recycled content in battery materials. Literature echoes this concern, suggesting that policies must shift to incentivise repurposing before recycling (Seika & Kubli, 2024). Some experts further emphasised the pivotal role of OEMs in the collection and repurposing of FEoL LiBs. OEMs were seen as central actors due to their access to proprietary data, technical expertise, and their ability to standardise processes, factors that can help overcome significant barriers in battery repurposing. However, some experts also highlighted liability concerns remaining a major obstacle to collaboration with third-party repurposers. These concerns included safety risks, unclear responsibility for reused batteries, and potential legal exposure in case of failure or accidents. These observations align with the current regulatory landscape. While the EU Battery Regulation (2023/1542) provides a framework for the end-of-life management of batteries, including reuse and repurposing, it does not yet set specific quantitative targets or thresholds for repurposed LiBs. The regulation focuses more on recycling efficiency, recovery rates, and minimum recycled content (EU Parliament, 2023), leaving repurposing as a recommended but underdefined pathway.

4.9.4. Emerging Value chain structures and sustainable business models Besides reflecting on the potential value chain structures included in the questionnaire, the panel experts also considered the emergence of other alternatives. For instance, opportunistic repurposers may specifically acquire used EVs to extract and repurpose batteries. EV LiBs may also be sold and exported to other countries. Additionally, the panel suggested that in some cases, OEMs may take back batteries, test and design them for repurposing and directly sell to end users for ESS. Furthermore, it was suggested that collection companies, in cooperation with and funded by OEMs, can collaborate with specialised treatment facilities to manage these batteries. This is exemplified in the aforementioned 4R Energy case, where Nissan and Sumitomo corporation collaborate to give second-life to FEoL EV LiBs from Nissan Leaf car models. Furthermore, OEMs implement cross-sector collaborations across the value chain. For example, Nissan and Eaton collaborate to offer X-storage, a repurposed ESS for households (Reinhardt et al., 2020) while Mercedes provides second-life batteries to Evyon for industrial ESS (Evyon, 2022). These collaborative approaches can help enable battery circularity by improving conditions for data traceability of the BMS, which is also discussed in the literature on OEMs retaining second-life battery revenue streams (Albertsen et al., 2021; Nurdiawati & Agrawal, 2022). The panel experts also mentioned the importance of geographical location of where the EV was initially sold, as it can also influence the repurposing process, mainly due to market factors and regulatory environment.

Several panel experts suggested two other stakeholders which may take a prominent role in emerging value chains, namely material recyclers car leasing companies. Panel expert VKA6 mentioned that the stakeholder's role depends on factors such as regulatory frameworks and potential incentives. This highlights the significance of policies and regulations, in line with literature (Reinhardt et al., 2019b; Wrålsen et al., 2021).

"The responsibilities in the value chain are highly dependent on regulatory frameworks…. However, the responsibility over the battery in case of accidents, malfunctions needs to be covered by the third-party insurance. Otherwise, an OEM might not have the incentive to provide their asset [e.g. a] battery" – Expert VKA6

Other elements of SBMs suggested by the panel experts include vertical integration, whereby OEMs take control of the battery from raw material extraction to recycling, and work with their battery supplier to create second-life products, e.g. in the form of batteries-as-a-service models paired with battery swapping infrastructure. These business models have been discussed in different contexts in literature (Stefan & Chirumalla, 2025; Zhu et al., 2021). In the ESS context, these SBMs could lower costs for users but may bring challenges, such as the need for efficient stakeholder collaboration and costs related to insurance (or lack thereof) (Colarullo & Thakur, 2022; Toorajipour et al., 2024). Battery swapping systems may require additional infrastructure investments, and while they exist in mobility solutions like e-bikes and scooters (Mårtensson & Renmarker, 2024) they are not yet commercialised for second-life EV LiBs in ESS, especially in the household context. However, a study by Sindha et al. (2023) suggests that second-life battery swapping systems can become technically and economically feasible in the near future.

Additionally, the one panel expert proposed a marketplace business model for repurposed batteries, connecting sellers and buyers. A Swedish startup called 'Clingsystems' is already employing this BM. However, this can lead to safety and legal concerns, such as product guarantees, liability issues, and safe installation in households. These factors are frequently discussed in the context of e-marketplaces (Kian Chong et al., 2010; Murtaza et al., 2004), but not specifically for second-life EV LiBs.

4.9.5. Sustainability considerations Spindlegger et al. (2025) find that repurposed LiBs have significant environmental advantages compared to use of the same new battery cells within a German household context. Philippot et al. (2022) highlight repurposing LiBs for household energy storage as environmentally beneficial opposed to reusing them in another vehicle. Interestingly, the panel experts do not further address potential sustainability contributions of repurposing EV LiBs, possibly due to the emphasis on highlighted challenges or the implicit nature of the sustainability potential.

4.9.6. User perspectives and adoption In terms of user perception and adoption, the experts' remarks primarily focused on perceived safety risks, as discussed earlier. Additionally, the end users would need to be informed and educated to build trust and willingness to adopt second-life solutions. Furthermore, perceived inferiority of repurposed batteries, regardless of actual performance, can undermine market acceptance, especially in household contexts, as reflected by the following expert quote:

"…also "perceived" lack of performance could be an issue. [So,] maybe the [battery second use] application works rather well, but because it is second-life some consumers might have second thoughts (in particular with products such as batteries which have as of now a rather bad reputation)." – Expert VKA6

Moreover, a few panel experts suggested that public visibility and symbolic value may play only a minor role in household adoption of ESS based on repurposed LiBs. It was suggested that showcasing them in public or commercial settings could enhance environmental credibility for municipalities and industry actors.

In terms of practical constraints, some experts remarked several additional contextual factors that limit the suitability of ESS based on repurposed LiBs in a household context. Firstly, as more people reside in smaller urban dwellings, the physical space required for battery installations becomes a significant barrier. Furthermore, in countries like the Netherlands and Germany, where electricity tariffs remain relatively flat, the economic incentive to store energy for later use is reduced. Without dynamic pricing models, the financial case for household energy storage weakens. Finally, the lack of clear standards and guarantees for second-life batteries contributes to consumer uncertainty, further complicating adoption.

4.9.7. Future outlook Looking ahead, expectations for uptake of repurposed EV LiBs in household contexts can be considered modest, unless costs decrease and safety improves. Automation, standardisation, and OEM-led solutions could enhance feasibility, but demographic trends and falling electricity prices due to renewables and nuclear energy may reduce demand:

"Costs will matter but more nuclear and renewables hence cheaper electricity means LiBs not needed in houses unless very cheap (and safe). Jevon's paradox may kick in of course." – Participant SNW6.

Ultimately, rational factors such as cost savings are likely to dominate over intrinsic motivations like sustainability or climate action. The panel experts had mixed views about the role of motivations such as ensuring reliable power during grid outages or building a sustainable image, but agreed on the importance of economic considerations and that they will be prioritised over emotional or ideological drivers. This suggests that the success of repurposed EV LiBs in the household context will depend on pragmatic solutions that address cost, safety, and regulatory barriers, rather than solely relying on environmental awareness or other intrinsic motivations.

5. Conclusion

The increasing adoption of EVs is creating a sustainability challenge where a growing number of FEoL LiBs are entering the market. Repurposing these batteries before recycling is widely recognised as a critical step to advance circularity, reduce environmental impact, and extract additional value. However, several barriers must be addressed for this scenario to become feasible. This Delphi study sought expert opinions on the likelihood of repurposing FEoL EV LiBs as household ESS and explored opportunities and challenges shaping this future. In light of the results, we conclude with the following:

5.1. Market and applications

Experts anticipate modest growth in repurposing for the household context. While overall repurposing of EV LiBs may rise from ~14% in the short-term to ~40% by 2045, household-specific applications are expected to remain niche, increasing from ~5% to ~19%. Among proposed applications consensus was found for a neutral likelihood for household ESS combined with PV systems in long-term. When ranking by mean scores, prolonged use of EV LiBs within the original vehicle emerged as the highest-rated option across time horizons. However, the panel experts did not reach consensus on this application, indicating divergent views and uncertainty about its future role compared to other second-life pathways. Portable power packs and other niche uses are viewed as less probable. These findings suggest that household ESS based on repurposed EV LiBs will complement, rather than dominate, a growing household energy storage market.

5.2. Business models and value chain structures

No single value chain structure emerged as dominant. OEM-led models, particularly those retaining battery ownership throughout its lifecycle, are perceived as most viable in the long-term, enabling control over safety and data. Collaborative approaches between OEMs and repurposers, supported by digital battery passports, may reduce costs and improve traceability. However, logistical complexity, liability concerns, and high upfront costs remain barriers. Emerging business models such as vertical integration and marketplace platforms could reshape the battery industry landscape.

5.3. Drivers, challenges, and user factors

Regulatory frameworks and policies promoting repurposing are seen as the strongest drivers, alongside market protectionism and availability of FEoL batteries. Conversely, declining prices of new LiBs, diverse battery designs, and unclear liability frameworks pose significant challenges. From a user perspective, perceived safety and willingness to purchase reduced-performance products are critical for adoption. Economic incentives and transparent guarantees will be essential to build trust.

5.4. Contributions to literature

this study makes three main contributions to literature. First, it offers expert opinions on the short-, medium- and long-term contexts, providing a market outlook for EV LiB repurposing and addressing a gap identified from previous research. Second, it provides insights into the likelihood of different value chain structures and associated SBMs to succeed in the EV LiB context, and adds new SBM configurations that could emerge in the future. Third, it highlights user perspectives on second-life EV LiBs adoption, as well as it underscores regulations that incentivise repurposing and cost considerations as critical drivers, specifically for the household

5.5. Limitations and future research

The study presents several interesting findings, whilst it acknowledges some limitations. Only 12 of 167 invited experts completed both Delphi rounds, limiting representativeness. Greater participation from OEMs, policymakers, and repurposers would strengthen findings. The panel's predominantly Northern European perspective means results are most relevant for this region, where regulatory harmonisation and EV adoption rates vary, influencing the feasibility of second-life applications. The lack of consensus on several questions underscores uncertainty about future applications and market viability.

Future research should explore niche applications to realise the sustainability potential of repurposing LiBs and conduct in-depth analysis of existing business models and value chain structures to improve generalisability. Policy and regulatory aspects warrant attention, including economic incentives and mandatory repurposing targets for automotive manufacturers. As long as recycling routes remain immature, research on repurposing strategies will be critical.

End-user perspectives also require explicit investigation. Quantitative methods such as surveys and conjoint analysis can reveal preferences regarding price, safety, performance, and sustainability, while qualitative approaches—interviews, focus groups, and workshops—can provide nuanced insights into household adoption. These efforts will help stakeholders make informed decisions on technical and economic feasibility, sustainability implications, and strategies for user acceptance.

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Data availability The data that support the findings of this study are available from the corresponding author upon request.

Declarations

Competing interests The authors declare no competing interests.

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