CIRCUlar economy innovations for resilient, competitive and sustainable BATTery technologies

D1.1 Assessment Methodology Framework Report

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Document History

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1.0	20/03/2025	UoG	First draft - UoG
2.0	25/03/2025	UoG	Second draft – UoG; Comments from UESSEX, ISL and Battronics
3.0	26/03/2025	UoG	Added an example of Model-specific Score calculations in Section 2.4.4 – UoG
4.0	28/03/2025	UoG	Finalised version

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List of acronyms

AI - Artificial Intelligence

BaaS - Battery-as-a-Service

CE - Circular Economy

CIRCUBATT - CIRCUlar economy innovations for resilient, competitive and sustainable BATTery technologies

CO_2 - Carbon Dioxide

CILT - Chartered Institute of Logistics and Transport

EV - Electric Vehicle

KPI - Key Performance Indicator

LCA - Life Cycle Assessment

MCDA - Multi-Criteria Decision Analysis

MCI - Material Circularity Indicator

MSW - Municipal Solid Waste

OBJ - Objective

S-LCA - Social Life Cycle Assessment

SME – Small and Medium Enterprises

TBL - Triple Bottom Line

TCO - Total Cost of Ownership

TEA - Techno-Economic Analysis

TRL - Technology Readiness Level

WoS - Web of Science

WP – Work package

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Executive Summary

This report establishes a comprehensive assessment methodology framework designed to evaluate innovative business models within the European battery value chain. In response to the urgent need for standardised evaluation methods that not only guide the transition towards circular and sustainable practices but also ensure economic viability, this framework synthesises cutting-edge academic research, best industry practices, and direct stakeholder engagement.

At its core, the framework evaluates new battery business models across three critical dimensions: economic resilience and adaptability, environmental circularity, and social sustainability. Economic resilience and adaptability are examined through the lens of a business model's ability to maintain financial viability amidst market fluctuations and technological advancements. Environmental circularity is assessed by scrutinising the lifecycle of batteries, emphasising waste minimisation, resource efficiency and the closed-loop utilisation of materials. Social sustainability considers the ethical, inclusive, and community-focused dimensions inherent in the battery value chain.

Methodologically, the framework is developed through a rigorous process that includes content analysis of academic literature and industrial reports and white papers, quantitative and qualitative validation via surveys and in-depth interviews, and the application of multi-criteria decision analysis (MCDA) to integrate diverse indicators.

By providing a robust, evidence-based tool for evaluating battery business models, this report not only supports informed decision-making for businesses, policymakers and researchers but also contributes to the broader European objectives of achieving sustainability, circular economy principles and strategic autonomy in critical raw materials. Ultimately, the framework serves as a pivotal resource for guiding the battery sector towards a resilient, competitive and sustainable future.

1.Introduction

1.1. Overview and scope

This report serves as a key deliverable for Work Package 1 (WP1) of the CIRCUBATT project, which focuses on developing a novel Battery as a Service (BaaS) business model for end-of-life batteries. The BaaS approach here is a broad business view which includes but not limited to "Battery as a product", "Battery as an energy service", "Battery as a lease", "Battery as a swap", "Battery data as a service", "Battery as a pay-as-you-go", "Battery as a sharing economy", and many others.

The initiative aims to promote environmental, social, and economic sustainability, while evaluating lifecycle options such as retrofit, second life, and recycling. As the first deliverable D1.1 of WP1, for developing a robust assessment methodology framework, this report presents a systematic and comprehensive review of best practices and academic research to develop a framework for evaluating business models. This framework assesses sustainability, circularity, and adaptability within the battery value chain, integrating insights from academic research, industry reports, and expert feedback. By involving stakeholders from various sectors—such as policymakers, industry professionals, and community representatives—this task ensures that the framework addresses real-world challenges and opportunities. The main outcome of this task is an assessment methodology framework with quantifiable metrics, designed to evaluate new business models for end-of-life BaaS in D1.2 and D1.3 under WP1.

The transition to electrification, particularly within the transport sector, has positioned batteries as a critical element in Europe's sustainable energy future (European Commission, 2021). In pursuit of climate neutrality by 2050, the European Union has set ambitious targets for reducing greenhouse gas emissions, increasing renewable energy adoption, and transitioning to a circular economy (European Commission, 2020). The battery sector plays a key role in these efforts, offering both significant opportunities and substantial challenges (Gebhardt et al., 2022). However, the rapid development of the electric vehicle (EV) industry, particularly the growing demand for batteries, have intensified concerns about resource scarcity, environmental impacts, and social implications throughout the supply chain (Bobba et al., 2020). As a result, there is an urgent need to develop sustainable and innovative business models that embrace circular economy principles while ensuring economic viability and social responsibility.

The battery value chain encompasses multiple stages from raw material extraction and processing to manufacturing, use, and end-of-life management (Johansen et al., 2022). Each stage involves a range of stakeholders, technologies, and processes, creating a complex ecosystem that requires holistic assessment frameworks. The current landscape of assessment frameworks for business models in the battery sector is fragmented and incomplete. Existing approaches typically focus narrowly on specific aspects such as economic performance, environmental impact, or technical specifications, without integrating these elements into a cohesive evaluation system (Ahmed et al., 2022; Prenner et al., 2024). Additionally, many traditional business models in this sector have followed linear approaches, focusing on production efficiency and cost reduction without adequately addressing sustainability, circularity, or adaptability to market disruptions (Geissdoerfer et al., 2017).

In response to these challenges, BaaS business models have emerged as promising alternatives that separate battery ownership from product ownership, facilitating more efficient use, better maintenance, and more effective end-of-life management (Kley et al., 2011). However, the emergence of new business models, especially those related to battery leasing, recycling, and second-life applications, has highlighted the need for comprehensive assessment methodology frameworks that can capture their impacts across economic, environmental, and social dimensions.

The motivation behind this work also stems from the need to create standardised methodologies that guide wider industry stakeholders in adopting, refining, and scaling innovative battery business models. The transition to a more sustainable and circular battery value chain also requires collaboration among diverse stakeholders (Howard et al., 2019). The introduction of business models can drive EVs adoption and reduce environmental impact, but to ensure their long-term success, an evidence-based framework is essential. A standardised assessment framework can also facilitate communication, establish common ground for evaluation, and promote shared understanding of the challenges and opportunities within the battery sector. The report, therefore, will develop a comprehensive framework to assess these business models and offer a step-by-step guide for implementation that integrates stakeholders' opinions and real-world data, ensuring that business models contribute to a sustainable and circular battery value chain.

1.2. Aim and objectives

The primary aim of this report is to develop a comprehensive assessment methodology framework for assessing new business models tailored to the battery sector, ensuring their alignment with sustainability, circularity and adaptability. The framework focuses on identifying and assessing key performance indicators (KPIs) that reflect the multifaceted nature of battery business models, particularly within the transport sector. By doing so, this report seeks to provide practical insights that can help stakeholders make informed decisions regarding the adoption and optimisation of battery business models. To achieve this, three specific objectives are outlined as follows:

Objective 1 (OBJ1): Identify and measure relevant KPIs for assessing new business models within the battery value chain

The OBJ1 aims to identify and measure the KPIs that are most relevant for evaluating battery business models. These KPIs will cover three dimensions, including economic resilience and adaptability, environmental circularity, and social sustainability. They will be defined through a combination of extensive academic literature, industry documents, and expert input, ensuring their relevance to the battery value chain and broader sustainability goals.

Objective 2 (OBJ2): Validate and weigh identified KPIs through input from academic and industrial stakeholders

The OBJ2 focuses on validating the identified KPIs and assigning appropriate weights based on feedback from stakeholders, such as academic researchers, business managers, industry professionals. This step will ensure that the framework reflects the real-world applications and priorities of those working in the battery sector, and stakeholder feedback will be gathered through surveys and interviews.

Objective 3 (OBJ3): Develop a practical, step-by-step guideline for implementing the assessment framework in a real-world scenario

The OBJ3 aims to develop a practical implementation guide that outlines how the assessment framework can be applied in real-world contexts. This guide will offer stakeholders clear, actionable steps to assess and refine their business models, ensuring alignment with sustainability goals.

The assessment framework development for the battery business model is led by the UoG, with contributions from the consortium partners ISL, E-F, and UESSEX. Throughout the development and validation process, the framework has been co-created with input from external stakeholders, including academics, industry professionals, and policymakers. Their involvement and feedback have ensured that the framework is comprehensive, practical, and effectively reflects real-world needs and challenges. The scope of this framework encompasses the battery value chain, with a particular focus on batteries used in electric vehicles, as these represent a significant and growing market with substantial environmental and social implications. However, the framework's principles can be adapted to other battery technologies and applications as needed.

The assessment framework presented in this report also supports decision-making processes for a variety of stakeholders, including battery manufacturers, service providers, policymakers, and investors. It offers a structured approach to evaluating new business models, identifying areas for improvement, and guiding strategic decisions that align with both business objectives and broader societal goals, thereby supporting the advancement of the European battery sector toward greater sustainability, circularity, and competitiveness.

1.3. Assessment methodology framework

Given the motivation and objectives of this report, the following section presents the assessment methodology framework developed for assessing battery business models, as illustrated in

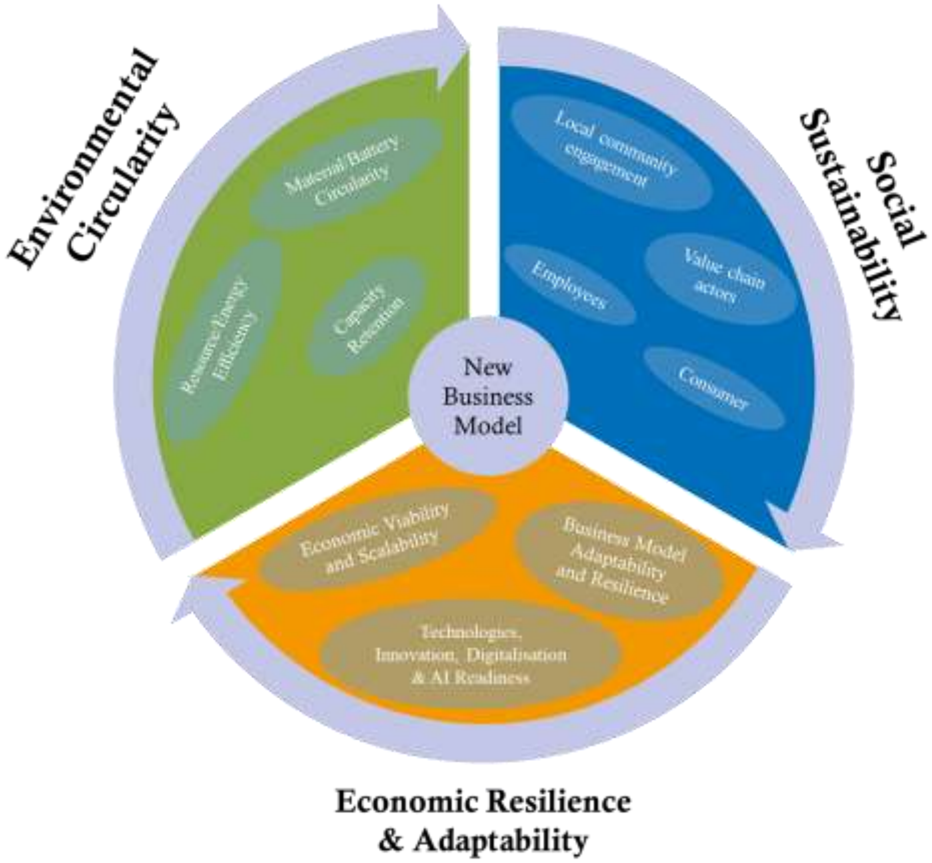

Figure 1. This framework is structured around three key domains:

- **Economic Resilience and Adaptability**: The ability of a business model to generate sustainable financial returns while remaining flexible and responsive to market dynamics, technological advancements, and external disruptions.
- **Environmental Circularity**: A regenerative approach to resource use that prioritises waste minimisation, material reuse, recycling, and sustainable production processes to reduce environmental impact. This ensures that products, materials, and energy remain in continuous use, promoting long-term ecological balance.
- **Social Sustainability**: The commitment of a business to ethical, inclusive, and community-oriented practices that enhance social well-being. This includes fair labour conditions, diversity and inclusion, consumer well-being, and positive contributions to local and global communities.

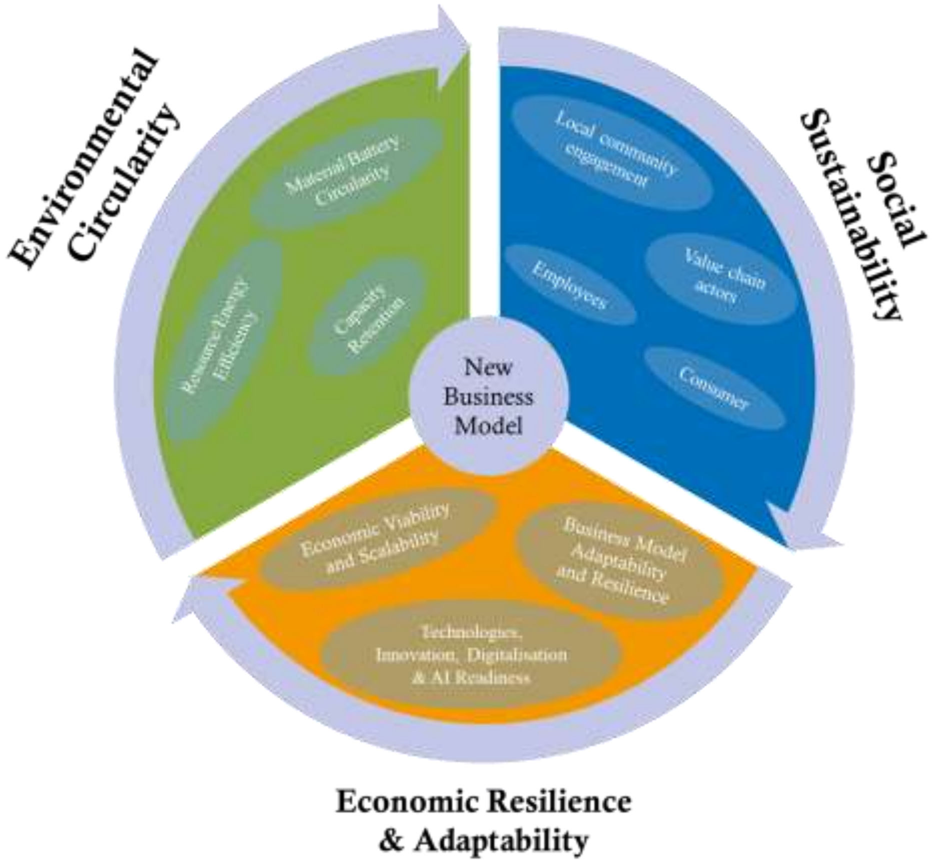

Figure 1. A comprehensive assessment framework for business models within the battery value chain

1.4. Assessment KPIs, measures and implementation

Our framework systematically evaluates battery business models by organising each domain into specific sub-dimensions and KPIs, ensuring alignment with sustainability, circularity, and adaptability across the battery value chain (see Figure 2). To provide comprehensive and flexible measurement, each KPI is supported by a set of quantified metrics, detailed further in section 3.

To implement the framework, we propose a cyclical, six-step process to guide organisations through effective deployment: (1) Define scope & objectives, (2) Gather data & prepare KPIs, (3) Apply the framework & measure performance, (4) Evaluate & identify improvement areas and potential opportunities, (5) Implement changes & track progress, and (6) Re-assess & refine. More details can be found in section 4.1.

Additionally, this framework will be available as a self-assessment tool with result visualisation (e.g., RADAR charts) and AI-generated diagnostics reports on the CIRCUBATT project online platform. This tool will allow users to simply input KPI values and instantly analyse their performance, strengths, and areas for improvement without requiring a great effort of the calculations.

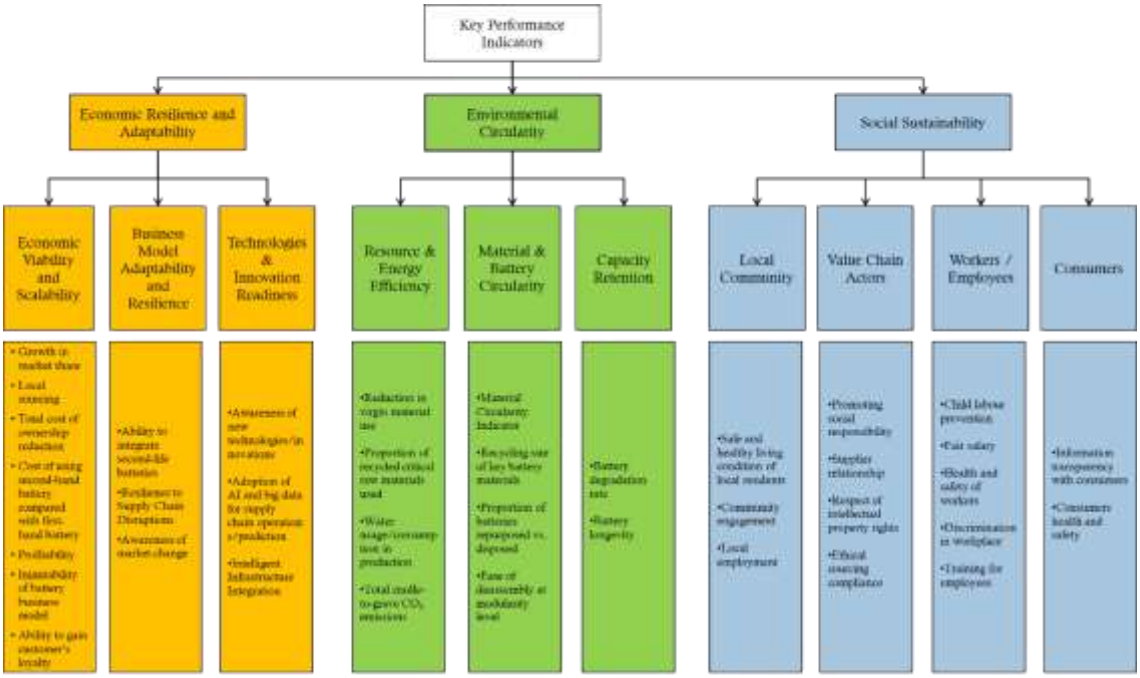

Figure 2. A first glance of our comprehensive KPIs list in each sub-dimension

1.5. Report structure

The structure of the report is as follows:

- Section 2 describes the methodology used to develop the assessment methodology framework, including the research methods and processes involved.
- Section 3 presents the results of the content analysis, field research and the final assessment framework, detailing the key components and their alignment with sustainability, circularity, and adaptability.
- Section 4 provides guidance on how to implement the assessment framework, along with a feasibility test of the framework using case studies to validate its real-world applicability.

2.Framework Development Approach

2.1. Overview of the approach

To develop the assessment framework, we integrate, adapt and advance the research methods from Ahmed et al. (2022); Cardeal et al. (2020); and Singh et al., (2024) which assess the sustainability, circularity and adaptability for both business models and strategies. Our framework development approach consists of 4 main steps (see Figure 3): (1) review academic literature and industry documents to identify the relevant KPIs to battery-related business models using content analysis, (2) validate and weigh the importance of identified indicators using survey and semi-structured interviews, (3) quantitatively synthesise all indicators using multi-criteria decision analysis, (4) develop the implementation guidance and conduct a pilot test to the proposed assessment methodology framework using case studies.

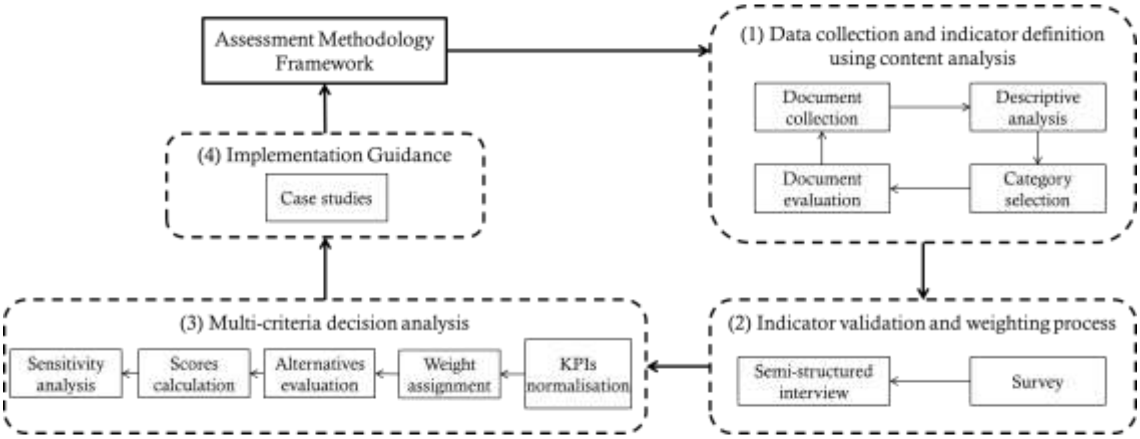

Figure 3. Framework Development Approach

2.2. Content analysis

We utilised the well-established content analysis process outlined by Mayring (2010) and Mayring & Fenzl (2019). This systematic, rule-governed, and theory-driven approach enables a comprehensive literature review by extracting complex latent information essential for content analysis (Ambilkar et al., 2022). Content analysis has been widely employed in research to derive comprehensive lists of key performance indicators or extract key research themes (Ahmed et al., 2022; Duong et al., 2022; Howard et al., 2019; Nguyen et al., 2018; Singh et al., 2024). The process encompasses 4 main steps:

2.2.1. Document collection

The research team conducted an extensive review of academic and industry sources, including Google Scholar, Scopus, Web of Science, ABI/Informs, and Google. Using relevant keywords such as *"sustainability," "circularity," "circular economy," "assessment framework", "adaptability," "social sustainability", and "assessment for business model"*, the search covered both general contexts and the specific domain of EV batteries. Additionally, to ensure a comprehensive collection of relevant materials, we applied backward and forward snowballing techniques by examining the references and citations of the initially gathered literature.

2.2.2. Descriptive analysis

Our analysis includes 12 from academic sources and 8 frameworks/documents from industry, all of which are highly relevant to developing our assessment framework for evaluating new business models. Annex 1 presents the descriptions of the reviewed frameworks.

2.2.3. Category selection

In the context of assessing battery business models, the three main aspects of Circularity, Sustainability, and Adaptability are foundational to understanding the broader framework's strategic approach. These aspects ensure that battery-related business models align with long-term goals for environmental protection, social responsibility, and economic success.

- **Sustainability:** refers to a practice of conducting business in a way that minimises harm to the environment, society, and local communities, ensuring long-term ecological and social well-being (Spiliakos, 2018).

- **Circularity:** refers to a strategic practice that maximises resource efficiency and minimises waste throughout the entire production and consumption lifecycle, promoting both sustainability and economic resilience (McKinsey & Company, 2024).
- **Adaptability:** refers to the capacity of a business to effectively adjust and respond to evolving changes in a dynamic external environment, ensuring resilience and long-term success (Reeves and Deimler, 2011; Tuominen et al., 2004).

However, in reviewing collected documents and developing the assessment framework, we identified significant overlap between circularity and sustainability. This overlap arises because sustainability, as defined by the triple bottom line (TBL) (People, Planet, and Profit), encompasses economic, environmental, and social dimensions, while circularity is primarily concerned with environmental benefits. Additionally, adaptability strongly correlates with the economic aspect of sustainability, further increasing the risk of conceptual overlap (see Figure 4).

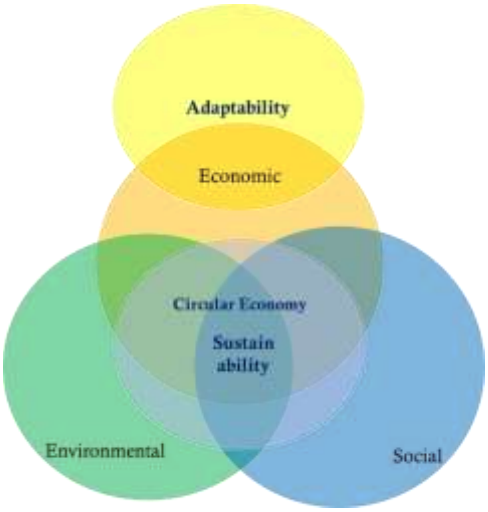

Figure 4. The traditional concepts of sustainability, circularity and adaptability

While overlapping KPIs can ensure that critical performance aspects are not neglected, they may also cause confusion among stakeholders when it comes to evaluating these KPIs and establishing appropriate measurement criteria. To address this challenge and ensure that assessment framework comprehensively encompasses all three key aspects, we have regrouped and redefined our dimensions as follows (see Figure 5):

- **Economic Resilience & Adaptability**: This dimension focuses on the economic viability, scalability, and adaptability of business models in response to market changes. Through this dimension, the framework evaluates whether the business model has sustainable economic growth potential and can maintain competitiveness in an uncertain market environment.
- **Environmental Circularity**: This dimension focuses on evaluating the performance of business models in terms of resource use, energy efficiency, material recycling, and waste management, ensuring the battery industry aligns with sustainable development goals.

- **Social Sustainability**: This dimension evaluates the contributions of business models in terms of social responsibility and social welfare, particularly in the areas of community, employees, and consumers, ensuring that the battery industry not only meets economic and environmental goals but also promotes social equity and welfare.

This regrouping reduces conceptual overlap while maintaining a holistic approach to business model assessment. It also aligns with the TBL framework in a more structured and practical manner.

Figure 5. Our proposed conceptual framework

Next, we categorised sub-dimensions within each aspect in Step 2 (see Figure 6). These sub-dimensions were also cross-checked among the consortium members to ensure consistency and relevance.

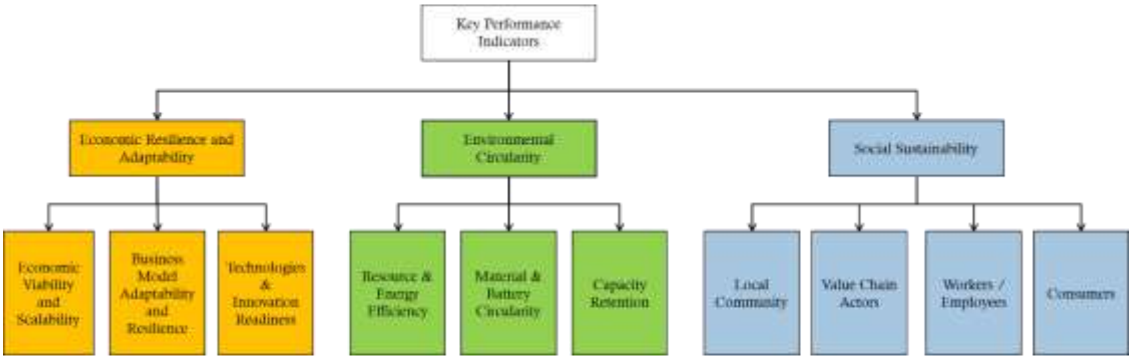

Figure 6. Sub-dimensions for KPIs

2.2.4. Document evaluation

In this step, we focus on evaluating documents by conducting an in-depth analysis of various frameworks to determine suitable indicators for assessing new business models in the battery value chain (OBJ1). This involves naming and defining each indicator, identifying their corresponding measures, where one indicator may have multiple measures, and classifying them into the predefined sub-dimensions. The results of this evaluation will be presented in Section

3.1.

2.3. Survey and interview as validation methods

After selecting and classifying the relevant KPIs, validation is a crucial step to ensure the accuracy and feasibility of the provisional assessment framework (OBJ2). This process involves verifying the relevance of the identified KPIs and refining them based on feedback from industry experts, including EV battery manufacturers, business owners, policymakers, and researchers. If certain KPIs are deemed unimportant, they will be removed, while additional KPIs may be incorporated based on expert recommendations. This approach is proved to be efficient in validating KPIs outlined by Singh et al. (2024).

To validate the framework, a two-step approach is applied. The first step involves designing a questionnaire that assesses the importance of each KPI on a Likert scale from 1 to 5. This questionnaire also gathers expert opinions on the framework's design across three key dimensions: (1) Economic Resilience and Adaptability, (2) Environmental Circularity, and (3) Social Sustainability. Experts are asked to evaluate the framework's coverage, applicability, and any missing or additional KPIs that should be considered. The questionnaire used for this validation can be found in Annex 2.

The second step consists of in-depth interviews with experts who completed the survey and expressed willingness to participate in a follow-up discussion. These interviews aim to explore the reasoning behind their ratings and provide deeper insights into their perspectives. For instance, if a KPI receives a low/high importance rating, the interview helps uncover the rationale behind this evaluation. The questions used in these interviews are available in Annex 3. This second step is essential for refining the assessment framework, as it allows for a more nuanced understanding of expert feedback. By integrating these insights, the framework can be further revised to enhance its accuracy, relevance, and effectiveness.

2.4. Multi-criteria decision analysis

In this project, we aim to establish a comprehensive framework for assessing various business models within the battery supply chain by utilising Multi-Criteria Decision Analysis (MCDA). MCDA is an analytical technique designed to evaluate and rank multiple options based on various criteria, facilitating decision-making when multiple, often competing, objectives need to be balanced (HM Treasury, 2020; Zanghelini et al., 2018). It has been widely used for sustainability assessments in energy management contexts.

In our study, MCDA provides a systematic and quantitative decision-making process, enabling the evaluation of business models based on a comprehensive set of criteria. These criteria are defined by various KPIs under the dimensions of Economic Resilience & Adaptability, Environmental Circularity, and Social Sustainability. Specifically, the MCDA framework allows us to assess multiple alternatives (i.e., business models) by assigning appropriate weights to the criteria (i.e., KPIs), based on their relative importance as determined by stakeholder feedback. These weighted scores are then used to compare and rank different business models.

Moreover, the data from the Likert survey are subjective judgments from various stakeholders.

The combination of subjective stakeholder feedback and quantitative analysis makes MCDA an ideal and effective approach for assessing business models in a dynamic and complex field like the battery supply chain (Zanghelini et al., 2018). Thus, MCDA is a suitable decision-making approach for evaluating multiple KPIs for battery business models.

To ensure the scientific integrity of our assessment framework, we follow a structured set of MCDA steps: (1) data collection and normalisation; (2) assigning weights; (3) evaluating alternatives (i.e., different business models); (4) score calculations; and (5) sensitivity analysis.

2.4.1. KPIs normalisation

To begin with, we use a survey that asks stakeholders to rate how well each KPI aligns with each of three key dimensions using a 1-5 Likert scale. Each stakeholder provides their judgments about the relevance and importance of the KPIs in the context of these dimensions. Once the survey responses are collected, we calculate the average score for each KPI. This average score reflects how important the stakeholders perceive each KPI in relation to its dimension. For example, if several stakeholders rated the importance of “Market share growth” as 4, 5, 3, and 4, the average score would be (4 + 5 + 3 + 4) / 4 = 4.0. Then, to ensure that multiple KPIs are on a comparable scale, we normalise each KPI’s average score to the 0-1 range using the formula:

$$Normalised\ scores = \frac{Average\ score - 1}{5 - 1}$$

For example, if the average score of a KPI is 4.0, the normalised score would be:

$$Normalised\ scores = \frac{4.0 - 1}{5 - 1} = 0.75$$

2.4.2. Assigning weights

Based on the normalised scores, we assign weights to each KPI. KPIs with higher normalised scores are assigned higher weights, reflecting their relative importance in the decision-making process. The weight for each KPI is calculated by dividing its normalised score by the sum of all normalised scores under different dimensions, using the formula:

$$Weight\ of\ KPI = \frac{Normalised\ score}{\sum Normalised\ scores\ of\ KPIs\ under\ each\ dimension}$$

For example, if the normalised score of a KPI is 0.75, and the sum of all normalised scores under Economic Resilience & Adaptability dimension is 4.0, its weight would be:

$$Weight\ of\ KPI = \frac{0.75}{4.0} = 0.1875$$

2.4.3. Evaluating alternatives (business models)

In this step, we evaluate each business model (alternative) based on its performance across each KPI. We determine the best and worst performances and then map each alternative’s performance to a 0-1 scale by using Min-Max normalisation. The formula for calculating the standardised score is:

$$Standardised\ score = \frac{Actual\ value - Minimum\ value}{Maximum\ value - \ Minimum\ value}$$

For example, if the best performance of the KPI “Market share growth” from the market is defined as 20% growth and the worst is defined as 0% growth, the difference is 20% (i.e., 20% - 0%). If an alternative achieves a 6%, the score would be:

$$Standardised\ score = \frac{6-0}{20-\ 0} = 0.3$$

2.4.4. Full framework and Model-specific scores’ calculations

- **Full framework score**

To compute the full framework score of each dimension for each alternative (i.e., business model), we calculate the weighted score for each KPI by multiplying its standardised score by the assigned weight. The total score of each dimension for each alternative is computed by summing the weighted scores for all KPIs under each dimension. This enables a comprehensive comparison of different dimensions across all KPIs, helping determine the best option of battery business model based on the weighted performance of each KPI. The formula is as follows:

$$Full\ framework\ score\ per\ dimension = \sum (Weighted\ scores\ of\ each\ KPIs\ per\ dimension)$$

This Full Framework Score serves as a comprehensive industry benchmark that reflects stakeholder priorities across the entire battery value chain. It measures each business model against all KPIs in the framework, including those that may not currently apply to their operations. By evaluating against the complete set of indicators, this score:

- Establishes a comprehensive industry standard that reflects stakeholder priorities across the entire battery value chain
- Identifies gaps and opportunities for business model evolution and innovation
- Encourages businesses to consider expanding their scope to address additional sustainability dimensions
- Provides a consistent benchmark that allows direct comparison across all business types
- Illustrates the distance between current specialised models and the ideal comprehensive sustainability model

Table 1. Weighting from 1-5 Likert survey under three dimensions

KPIs	Average score (1-5 Likert survey)	Normalised scores	Weights
Dimension 1: Economic Resilience & Adaptability			
A	4.0	0.75	0.246
B	3.5	0.625	0.205
C	4.5	0.875	0.287
D	4.2	0.8	0.262
Dimension 2: Environmental Circularity			
A	4.0	0.75	0.25
B	4.0	0.75	0.25
C	4.5	0.875	0.2917
D	3.5	0.625	0.2083

Dimension 3: Social Sustainability			
A	4.2	0.8	0.248
B	4.0	0.75	0.232
C	4.5	0.875	0.271
D	4.2	0.8	0.248

Table 2. Calculating weighted scores for Alternative(s) under three dimensions

KPIs	Standardised scores of Alternative 1 (Business Model 1)	Weights	Weighted scores
Dimension 1: Economic Resilience & Adaptability			
A	0.6	0.246	0.1476
B	0.5	0.205	0.1025
C	0.8	0.287	0.2296
D	0.7	0.262	0.1834
Dimension 2: Environmental Circularity			
A	0.6	0.25	0.15
B	0.6	0.25	0.15
C	0.8	0.2917	0.2334
D	0.7	0.2083	0.1458
Dimension 3: Social Sustainability			
A	0.7	0.248	0.1736
B	0.5	0.232	0.116
C	0.8	0.271	0.2168
D	0.7	0.248	0.1736

Table 1 and Table 2 provide calculations examples of the normalised scores and weights for each KPI under three dimensions (Economic Resilience & Adaptability, Environmental Circularity, and Social Sustainability), along with the weighted scores for the alternative (Business Model 1) based on those weights.

Next, we sum the weighted scores from all dimensions for Alternative 1 (Business Model 1):

- Economic Resilience & Adaptability: 0.1476 + 0.1025 + 0.2296 + 0.1834 = 0.6631
- Environmental Circularity: 0.15 + 0.15 + 0.2334 + 0.1458 = 0.6792
- Social Sustainability: 0.1736 + 0.116 + 0.2168 + 0.1736 = 0.68

Figure 7 illustrates the current performance of business model 1 in three main dimensions. This RADAR chart can be used to compare the strengths and weaknesses across different new business models.

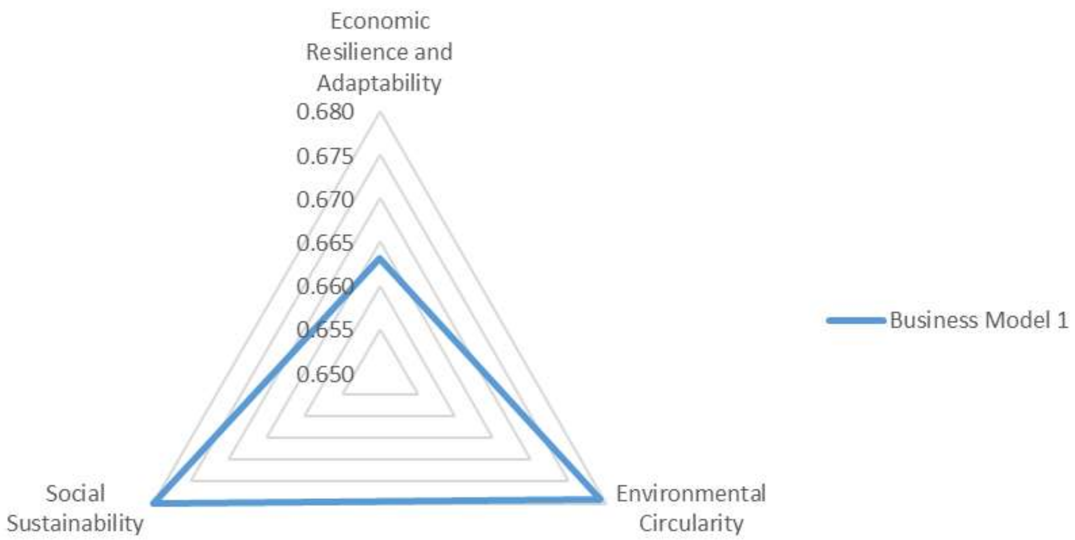

Figure 7. Example of RADAR chart for business model 1

- **Model-specific score**

To provide stakeholders with a comprehensive understanding of business model performance in the battery value chain, we have developed another complementary scoring method, named 'Model-specific score'. While the Full Framework Score provides a comprehensive evaluation, it may not always reflect the operational reality of specialised business models. For example, digital service providers in the battery value chain may have limited applicability to material-focused KPIs, resulting in artificially lower scores in certain dimensions. To address this limitation, we introduce a complementary Model-Specific Performance score.

This score evaluates each business model based solely on KPIs that are directly applicable to its current operations. The calculation adjusts the Full Framework Score to account only for relevant KPIs:

$$Model - specific\ Score\ per\ dimension = (Full\ Framework\ Score / \sum(weights\ for\ applicable\ KPIs)\ X \sum(all\ weights\ in\ the\ dimension)$$

For example, a company has a Full Framework Score of 0.70 under Economic Resilience and Adaptability dimension. The total weight for this dimension is 1.0, but the sum of applicable KPI weights for the company is 0.5. Then, the Model-specific Score for Economic Resilience and Adaptability dimension will be calculated as follows:

$$\frac{0.7}{0.5} \times 1.0 = 1.40$$

Please note this numerical example is only illustrative; appropriate realistic figures should be used.

Businesses can select relevant KPIs based on their actual operational context and apply this formula to flexibly adjust scores, enabling a personalised assessment. Specifically, by focusing only on relevant metrics, this score:

- Provides an accurate reflection of how well a business is performing within its existing scope and limitations
- Enables fair comparison between different types of business models (e.g., digital services vs. physical manufacturing)
- Highlights immediate strengths and weaknesses within a business's current operational parameters
- Facilitates targeted improvements in areas where the business is already engaged
- Helps identify which businesses are optimising their current model most effectively

In summary, both scores serve valuable but different purposes in our assessment. The *Model-Specific Score* answers, "How well is this business doing what it currently does?" while the *Full Framework Score* addresses "How comprehensively does this business address all aspects of battery sustainability?". Together, these two scoring approaches offer stakeholders a balanced view of business model performance, addressing both current operational performance assessment and comprehensive sustainability impact. That is, a business might excel in its *Model-Specific Score* while having a lower *Full Framework Score*, indicating they are operating efficiently within their niche but could explore expanding their sustainability impact. Conversely, a business with average scores in both metrics might benefit from focusing on optimising their current operations before expanding further. This dual approach ensures our assessment framework serves both as an evaluation tool and a roadmap for future development across the battery value chain.

2.4.5. Sensitivity analysis

To ensure the robustness and reliability of assessment framework, we perform a sensitivity analysis by verifying if there are changes in the weights of KPIs across various professional perspectives. Different backgrounds among participants (stakeholders) may lead to varying opinions on the importance of KPIs. If the weights are consistent across different groups, it shows that the framework is aligned with the collective understanding of the stakeholders and has general applicability. If there are significant weight differences, it opens the opportunity for deeper analysis into why those differences exist and make further adjustments, such as considering specific needs and considerations based on professional backgrounds.

First, we group all survey participants based on different professional roles, which helps assess whether different roles or backgrounds lead to different assessments of the same KPIs. Second, we calculate the KPI's weight for each group followed our steps in section 2.4.1 and 2.4.2. Finally, to verify the consistency, we apply Pearson correlation to measure the linear relationship between the KPI weightings across different stakeholder groups. It helps us understand how strongly the group assessments align.

A high Pearson correlation value would suggest that the groups share similar perspectives, indicating that the framework is robust and widely applicable across different professional viewpoints. Conversely, a low Pearson correlation may indicate great differences in the way KPIs are valued, signalling that the framework may need refinement to account for differing stakeholder priorities.

3. Assessment Methodology Framework: Key Components and Validation

3.1. Key performance indicators

Table 4 presents the KPIs selected during the Document Evaluation step in section 2.2.4. The table includes a description of each KPI, multiple measures associated with each, and their respective sources. Additionally, we conducted a survey to collect opinion from EV battery-related experts aiming to validate and potentially enrich our list of KPIs discussed in section 2.3.

To gather feedback on the framework and to ensure that the framework benefited from a diverse range of expert opinions, a purposive sampling strategy was adopted. The survey was disseminated among key stakeholders within the battery sector, leveraging the network of CIRCUBATT consortium partners as well as external contacts. First, we directly emailed 120 companies from the NAATBatt database[1], which covers key players in the battery supply chain, along with 100 additional battery-related companies identified online[2]. Additionally, the survey was shared with members of various organisations, including BEPA, the EV Lithium-Ion Battery Global Manufacturer group, the Chartered Institute of Logistics and Transport (CILT), the Small Business Research and Enterprise Centre based in the City of London, The Federation of Small Businesses, the European DIGITAL SME Alliance, and participants and contributors from the Battery Pass consortium, as well as through CIRCUBATT's own LinkedIn page, which has over 200 followers. The recruitment process was designed not only to target those directly involved in battery manufacturing, technology, and sustainability but also to capture insights from academic and research institutions, thereby ensuring a balanced representation of technical, commercial, and policy perspectives. Respondents were encouraged to share the survey within their professional networks to broaden the pool of feedback.

For in-depth qualitative insights, a subset of survey respondents (selected on the basis of their expertise and the richness of their responses) were invited to participate in follow-up interviews. Experts from the consortium were also specifically invited to these interviews to ensure that the framework development benefitted from their deep domain knowledge and practical experience. The interviews were designed to delve deeper into the nuances of the KPIs, exploring issues such as indicator normalisation, weighting methods, and the practical challenges of applying the assessment framework in real-world scenarios.

This integrated approach to sampling ensures that the validation process is both comprehensive and reflective of the varied perspectives within the EV battery value chain. The robust and diverse input from industry experts, business representatives, researchers, policymakers, and consortium experts act together to provide a solid foundation for refining the assessment

[1] NAATBatt Lithium-Ion Battery Supply Chain Database | Transportation and Mobility Research | NREL
[2] The list can be made available upon request

framework and enhancing its relevance to both practice and policy.

- **Descriptive analysis**

Table 3. Descriptive analysis of survey respondents by Role/Position, Industry/Domain, and Years of Experience

Part A. Role/Position	Frequency (%)
Industry expert (e.g., engineer, technical specialist)	13(30%)
Scholar/Researcher	12(27%)
Business representative/Manager	13 (30%)
Policymaker	1 (2%)
Other	5 (11%)
Part B. Industry/Domain	**Frequency (%)**
Academic or Research Institution	13 (24%)
Battery Manufacturing & Technology	15 (27%)
Sustainability/Environmental Policy	5 (9%)
Electric Vehicles (EVs)	9 (16%)
Battery Recycling	7 (13%)
Other	6 (11%)
Part C. Years of Experience	**Frequency (%)**
Over 10 years	17 (41%)
5-10 years	11 (27%)
1-5 years	10 (24%)
Less than 1 year	3 (7%)

As a result, we have collected responses from 41 experts. Table 3 presents the frequency of their role/position, industry/domain, and years of experience. In Part A - Role/Position, the largest groups of respondents were Industry experts (30%), such as engineers and technical specialists, and Business representatives/Managers (30%), which indicates a strong involvement of professionals directly working with business operations and technical expertise. Scholars/Researchers comprised 27% of the respondents, while policymakers represented a small proportion of 2%.

In Part B - Industry/Domain, Battery Manufacturing & Technology was the most represented industry, with 27% of respondents coming from this sector. This was followed by respondents from Academic or Research Institutions (24%) and those involved with EVs (16%). A smaller group of respondents came from Sustainability/Environmental Policy (9%), Battery Recycling (13%), and other industries (11%). It is important to note that the frequencies in Part A and Part B may exceed 41, as some respondents hold cross-role or cross-industry positions.

Part C - Years of Experience reveals that the majority of respondents have significant experience, with 41% having over 10 years of experience, and 27% having between 5-10 years. Another 24% have between 1-5 years of experience, while a smaller portion, 7%, have less than one year of experience.

This diverse range of experts in various organisations ensures that the insights gathered are comprehensive and representative of various perspectives, all of which contribute to the robustness of the assessment framework.

- **KPIs validation and consolidation**

Our experts rate the average level of importance of all KPIs above 3.0 in the range from 1 (extremely not important) to 5 (extremely important). Furthermore, majority of stakeholders said this framework is applicable to assess new business models (46% highly, 51% somewhat). Hence, we have chosen to keep all our current KPIs.

In our survey, we asked a further set of three open-ended questions to double check our coverage and to explore the potential of any other uncovered KPIs as below:

- *"Do you think business models in the battery value chain can be sufficiently evaluated by three aspects: (1) Economic Resilience & Adaptability, (2) Environmental Circularity, and (3) Social Sustainability? If not, why?".*
- *"Do you have any additional suggestions or comments for our assessment framework?".*
- *"Are there any other KPIs that you think are closely related to measuring the above three aspects (1) Economic Resilience & Adaptability, (2) Environmental Circularity, and (3) Social Sustainability of the battery business model?".*

We have received many detailed answers, and we have analysed them in Annex 4. Overall, our list of KPIs is considered to be appropriately comprehensive, and the experts' detailed responses have also helped us to enrich the measure metrics of our KPIs. The newly added measures from domain experts are noted in Table 4.

To complement the survey results and deepen our understanding of the relevance of the framework, we conducted 4 semi-structured interviews with relevant stakeholders. Participants were invited to elaborate on their survey responses, providing context and nuance to the quantitative data. The interviewees discussed both strengths and limitations of the current KPIs, and their discussions helped clarify the rationale behind key indicators. For example, several experts emphasised the critical role of profitability and supply chain resilience in economic sustainability, while others highlighted the importance of battery longevity and degradation rate as core components of environmental circularity. The semi-structured format allowed for both generic questions, mirroring those in the survey, and specific probes to capture additional insights. Overall, the interviews confirmed our survey findings while also uncovering new dimensions that warrant further exploration, thus reinforcing the overall robustness and practical relevance of the assessment framework.

Table 4. The description and measures of key performance indicators across three dimensions

Code	Performance indicators	Description	Measures	Sources
Economic Resilience and Adaptability				
E1	Growth in market share	Evaluates the business model's success in expanding its market presence over time.	• Percentage of increase in market share per specific period of time • Estimated potential increase rate in market share in 5 years/10 years* • Total Addressable Market*	Lukas (1999)
E2	Local sourcing	Measures the contribution of the business model to local economic development.	• Likert scale (1-5) based on their importance • Likert scale (1-5) based on their ease of implementation	Gebhardt et al. (2022)
E3	Total Cost of Ownership (TCO) reduction	Assesses cost-effectiveness by measuring lifecycle costs of products/services.	• Percentage of decrease in lifecycle costs (%) • Estimate of overall cost for owning and operating second-hand battery	Prenner et al., (2024); Weiller et al. (2015)
E4	Cost ratio second life to first-life	Evaluates cost savings when using second-life batteries compared to new ones.	• % of the cost of using second-life batteries compared to first-life batteries from users' perspective • Capital expenditure for second-life battery* • Cost efficiency for service-related activities of second-life battery compared with first-life battery*	Prenner et al. (2024)
E5	Profitability	Measures the ability of the business model to generate profit.	• Gross Profit Percentage (%) • Gross Profit Margin*	Hoopes et al., (2003); Lukas (1999)
E6	Inimitability of battery business model	Assesses how unique and difficult to replicate the business model is	• Likert scale (1-5) on the uniqueness of the business model over their competitors from	Amit & Zott (2001); Hoopes et

		compared to competitors.	customers' perspective	al. (2003)
E7	Ability to gain customer's loyalty	Evaluates the business model's effectiveness in retaining customers.	• Likert scale (1-5) on the level of services to boost customer's loyalty such as loyalty programmes, promotion, customised/personalised offerings	Amit & Zott (2001)
E8	Ability to integrate second-life batteries	Measures the ease of technological adoption for second-life battery usage.	• Likert scale (1–5) on technological integration ease for second-life battery	Chirumalla et al. (2023)
E9	Procurement Resilience to Supply Chain Disruptions	Assesses the model's ability to secure supplies from diverse sources and minimize risks.	• % of supply secured from diverse sources	Szczepański (2021)
E10	Awareness of market change	Measures the business model's responsiveness to evolving customer and competitor behaviours.	• Likert scale (1–5) on the awareness towards customers' and competitors' needs and behaviours • Likert scale (1–5) on the understanding towards customers' needs and behaviours*	Tuominen et al., (2004); Weiller et al. (2015)
E11	Awareness of new technologies/innovations	Assesses how well the business integrates emerging technologies and innovations.	• Likert scale (1–5) on new technologies adoption, patent protection on business level and product level	Tuominen et al. (2004)
E12	Adoption of AI and big data for supply chain operations	Evaluates the extent to which AI and big data are leveraged for operational efficiency.	• % of AI-driven decisions in operations and Technological Readiness Level*	Lanzalonga et al. (2024)
E13	Intelligent Infrastructure Integration	Measures the level of integration with smart grids and charging networks.	• Score (0-5) on integration with smart grid and charging systems • Technological Readiness Level*	Kley et al. (2011); Weiller et al. (2015)
Environmental Circularity				
C1	Reduction in virgin	Assesses the business model's	• % of Decrease in new material dependency	Ziemann et al.

	material use	effectiveness in reducing reliance on new raw materials.		(2018)
C2	Proportion of recycled critical raw materials used	Evaluates the use of recycled materials in battery production.	• % of recycled materials in new batteries • Compliance with recycling regulations (0: No and 1: Yes)	European Commission, (2023b), (2023a)
C3	Water usage/consumption in production	Measures the water efficiency of the business model compared to industry standards.	• m³/kWh or % of water reduction compared to industry average	Hoekstra et al., (2011); Prenner et al. (2024)
C4	Total cradle-to-grave CO_2 emissions	Assesses the carbon footprint of the business model throughout the product lifecycle.	• kg CO_2-eq per kWh • Compliance with the ISO 14067 • ∑ CO2 equivalent (kg) • % of reduction in CO2 emissions	ISO (2006); Prenner et al., (2024); Schöggl et al. (2016)
C5	Material Circularity Indicator	Measures how effectively materials are reused within a circular economy model.	• Scale (0–1) • OEE materials effectiveness* • Percentage of compliance with ISO59010 • Weight of materials that are renewable/Total weight of materials	Ellen Macarthur Foundation, (2021); ISO (2024); Schöggl et al. (2016)
C6	Recycling rate of key battery materials	Evaluates the recyclability of batteries at the end of their lifecycle.	• % of materials recycled vs. disposed	European Commission (2023a)
C7	Batteries repurposed vs. disposed	Measures how successfully batteries are repurposed instead of discarded.	• % of batteries successfully repurposed	Chirumalla et al. (2023)
C8	Ease of disassembly at modularity level	Assesses how easily battery components can be disassembled for reuse, recycling, or maintenance.	• Likert scale (1-5) on the ease of battery disassembly	European Union (2009)

C9	Battery degradation rate	Evaluates how quickly a battery loses its original capacity over time, affecting its lifespan and efficiency.	• Percentage (%) of original capacity retained after certain period of time • Number of years to reduce to 80% capacity	Buchmann, (2017); Prenner et al. (2024)
C10	Battery longevity	Measures the total lifespan of a battery in terms of charge-discharge cycles before it reaches its end-of-life threshold.	• Number of charge-discharge cycles before reaching end-of-life threshold • Number of charge-discharge cycles before reducing to 80% capacity • Number of cycles or years batteries obtain	Buchmann, (2017); Prenner et al. (2024)
Social Sustainability				
S1	Safe and healthy living condition of local residents	Assesses the impact of the business model on air and water pollution affecting to local residents.	• Likert Scale (1-5) on Pollution level adding to the country/region	Ciroth & Franze (2011)
S2	Community engagement	Measures the extent to which the business actively engages with local communities.	• Presence of policies regarding community engagement at organisational level (0: No, 1: Yes) • Likert Scale (1-5) on Extent of policies regarding community engagement at organisational level • Liker Scale (1-5) on extent of local governmental support*	Ciroth & Franze (2011)
S3	Local employment	Evaluates the business model's contribution to job creation in the region.	• % of spending on locally based suppliers • % of unemployment in the country/region. • % of work force hired locally	Ciroth & Franze (2011)
S4	Promoting social responsibility	Assesses efforts to ensure ethical supplier practices and labour rights compliance.	• % of suppliers the enterprise has audited regarding social responsibility. • Presence of codes of conduct that protect human rights of workers among suppliers (0:	Ciroth & Franze (2011)

			No; 1: Yes)	
S5	Supplier relationship	Measures the quality and fairness of supplier interactions.	• Likert scale (1-5) on the interaction of the company with suppliers (e.g., payment on time, sufficient lead time, reasonable volume fluctuations, appropriate communication, collaboration regarding quality issues)	Ciroth & Franze (2011)
S6	Respect of intellectual property rights	Evaluates compliance with intellectual property regulations.	• Number of violations of the company against intellectual property rights • Likert scale (1-5) on the respect level of intellectual property rights	Ciroth & Franze (2011)
S7	Ethical sourcing compliance	Measures the business's commitment to ethical procurement practices.	• Likert scale (1-5) on the commitment to ethical sourcing compliance	Gebhardt et al. (2022)
S8	Child labour prevention	Assesses the company's commitment to preventing child labour in the supply chain.	• Likert scale (1-5) on the commitment to child labour prevention • ∑ Incidents of child labour	Ciroth & Franze, (2011); Gebhardt et al. (2022); Schöggl et al. (2016)
S9	Fair salary	Evaluates how wages compare to living wages and industry standards.	• % of Wage level compared with living wage and/or minimum wage in the country/region	Gebhardt et al. (2022)
S10	Health and safety of workers	Evaluates workplace safety by tracking accident rates and proactive health assessments.	• Potential accident rate of the new business model • Number of days since last health and safety self-assessment • % of injuries relative to total hours worked per year	Ciroth & Franze, (2011); Schöggl et al. (2016)
S11	Discrimination in	Assesses workplace diversity and	• Percentage of women in the labour force in the	Ciroth & Franze

	workplace	incidents of discrimination, focusing on gender representation and fair treatment.	sector • % - Total number of incidents of discrimination/Total number of employees	(2011); Schöggl et al. (2016)
S12	Training per employee	Measures investment in employee development and skill-building initiatives.	• % - Total training hours per employees	Schöggl et al. (2016)
S13	Information transparency with consumers	Assesses how openly the company shares details about the battery lifecycle, ensuring informed consumer choices.	• Likert scale (1-5) on transparency of battery lifecycle information	Ciroth & Franze (2011)
S14	Consumers health and safety	Evaluates the risks associated with the product, focusing on safety complaints and incidents.	• Likert scale (1-5) on level of product/service safety based on complaints and accident	Ciroth & Franze (2011)
*: Added measures based on the open-ended questions in the survey				

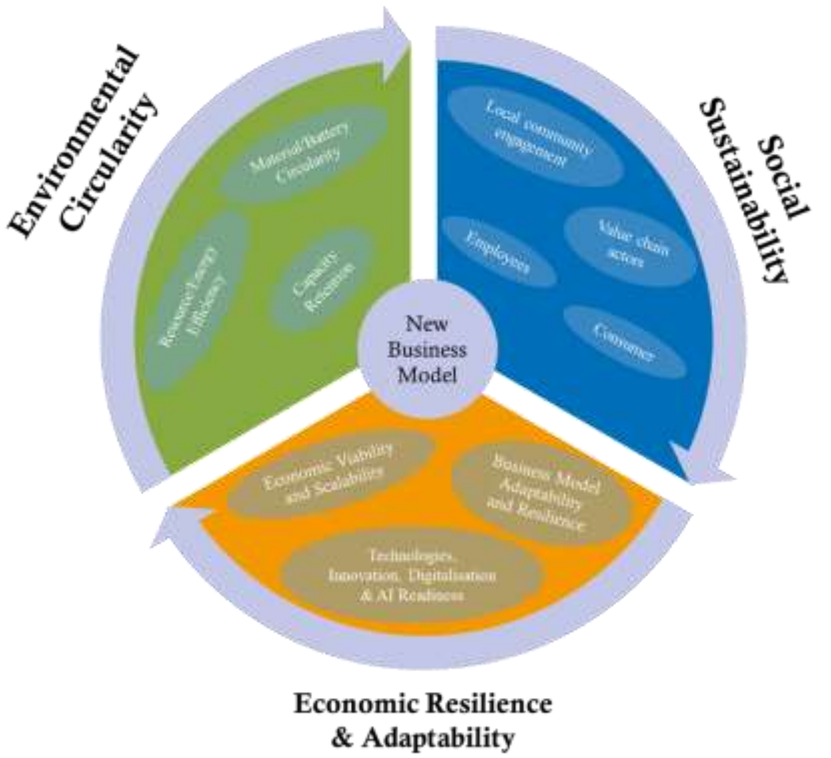

Figure 8. The overview of our assessment methodology framework

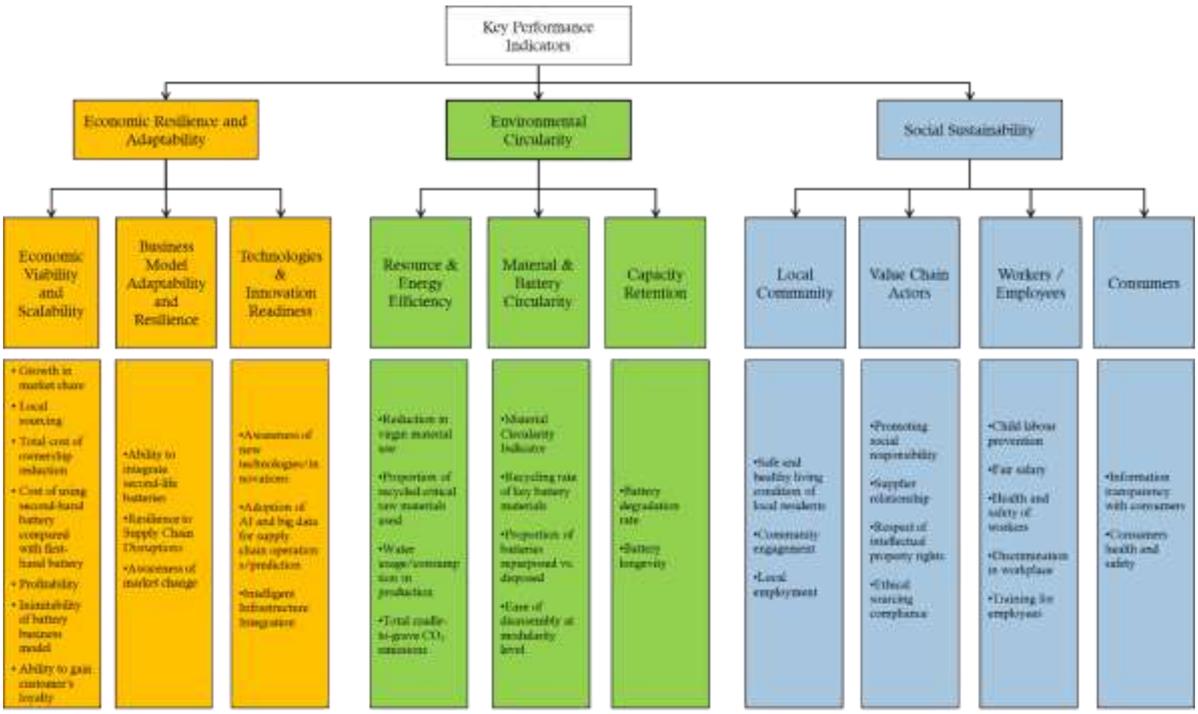

Figure 9. The allocation of KPIs into three main dimensions and sub-dimensions

Figure 8 presents the overview of identified KPIs that are further categorised into sub-dimensions within three main dimensions, as illustrated in Figure 9 – (1) Economic Resilience and Adaptability, (2) Environmental Circularity and (3) Social Responsibility.

To ensure objectivity, each research member conducted an independent review and evaluation, minimising potential human bias. The preliminary results were then presented to three additional partners involved in this WP for further discussion. This collaborative approach enhances the robustness, accuracy, and comprehensiveness of our KPIs.

3.2. KPIs normalisation and weight assignments

Next, using the importance ranking data from 41 respondents, we apply the KPIs normalisation and weight assignment as described in section 2.4.1 and 2.4.2. As a result, Table 5 presents the mean scores, normalised scores and assigned weights for each KPI.

Table 5. KPIs normalisation and weight assignments

Code	Mean	Normalised scores	Assigned weights
E1	4.171	0.793	0.087
E2	3.537	0.634	0.070
E3	3.902	0.726	0.080
E4	3.098	0.524	0.058
E5	4.439	0.860	0.095
E6	3.122	0.530	0.058
E7	3.878	0.720	0.079
E8	3.341	0.585	0.064
E9	4.317	0.829	0.091
E10	4.073	0.768	0.085
E11	4.415	0.854	0.094
E12	3.195	0.549	0.060
E13	3.878	0.720	0.079
C1	3.805	0.701	0.077
C2	4.000	0.750	0.082
C3	3.683	0.671	0.074
C4	3.756	0.689	0.076
C5	3.659	0.665	0.073
C6	4.098	0.774	0.085
C7	3.854	0.713	0.078
C8	3.878	0.720	0.079
C9	4.220	0.805	0.089
C10	4.439	0.860	0.095
S1	4.024	0.756	0.083
S2	3.268	0.567	0.062
S3	3.707	0.677	0.074
S4	3.634	0.659	0.072
S5	3.927	0.732	0.080
S6	3.976	0.744	0.082
S7	4.098	0.774	0.085

S8	4.317	0.829	0.091
S9	4.000	0.750	0.082
S10	4.415	0.854	0.094
S11	3.585	0.646	0.071
S12	4.049	0.762	0.084
S13	4.244	0.811	0.089
S14	4.610	0.902	0.099

The weights for certain KPIs can be better understood, based on the findings of the interviews. The semi-structured interviews (Annex 4) not only corroborated the survey results but also enriched them with contextual explanations that clarify why certain KPIs emerged as priorities. The following synthesises the key takeaways from all interviewees, organised by dimension:

Economic Resilience & Adaptability

Interviewees emphasised that supply chain resilience (E9), profitability (E5), and technology awareness (E11) are critical for sustaining a competitive battery business model in Europe. One expert noted, *"If we lose control over our supply of components, it becomes almost impossible to remain competitive",* underscoring the importance of resilient procurement practices. Profitability was frequently described as a *"baseline survival criterion"*, with several respondents stressing that positive cash flow is essential to avoid insolvency, even if overall profit margins appear satisfactory. In contrast, indicators such as the cost ratio between second-life and first-life applications (E4) and the inimitability of the business model (E6) received lower priority. Respondents explained that these aspects reflect an early-stage market where second-life applications are not yet fully developed, and where many manufacturing practices can be easily replicated.

Environmental Circularity

Within the environmental domain, the indicators for battery degradation rate (C9) and battery longevity (C10) emerged as the most critical. Interviewees consistently argued that a lower degradation rate directly translates into extended battery life, reducing the need for frequent replacement and thus lowering the overall environmental footprint. As one participant remarked, *"Extending the cycle life is the single most effective way to reduce raw material consumption"*. While recycling rate (C6) and material circularity (C5) remain important, they were seen as secondary in the current context, with durability regarded as a more immediate lever for environmental improvement.

Social Sustainability

For social sustainability, consumer health and safety (S14) stood out as the paramount indicator. Stakeholders were unanimous in their view that ensuring robust safety measures is indispensable, not only to comply with regulatory standards but also to safeguard public confidence. One interviewee stated, *"If an electric vehicle battery fails, the consequences can be catastrophic: it's a non-negotiable priority"*. Other social indicators, such as community engagement (S2), received lower ratings. This lower priority was attributed to a prevailing *"not-in-my-backyard"* sentiment, where companies are more focused on internal safety and compliance rather than actively engaging with local communities, particularly when production occurs outside Europe.

3.3. Sensitivity analysis

In this section, we conduct the sensitivity analysis to check whether the weighting has been done consistently among three distinct group of stakeholders [3] – 13 Industry experts, 14 Business representatives and 16 Researchers. The weight for each KPI has been calculated separately for three groups of stakeholders in Table 6.

Table 6. Calculated weighted scores for three groups of stakeholders and overall

Code	Industry Expert	Business representative/Manager	Scholar/Researcher, Policymaker, Consultant	Overall
E1	0.089	0.090	0.083	0.087
E2	0.072	0.073	0.069	0.070
E3	0.082	0.079	0.079	0.080
E4	0.047	0.056	0.065	0.058
E5	0.099	0.098	0.088	0.095
E6	0.053	0.060	0.062	0.058
E7	0.076	0.084	0.077	0.079
E8	0.057	0.063	0.070	0.064
E9	0.095	0.094	0.086	0.091
E10	0.091	0.083	0.081	0.085
E11	0.095	0.094	0.093	0.094
E12	0.059	0.054	0.067	0.060
E13	0.085	0.073	0.079	0.079
C1	0.096	0.092	0.097	0.077
C2	0.101	0.102	0.101	0.082
C3	0.091	0.100	0.086	0.074
C4	0.088	0.095	0.097	0.076
C5	0.085	0.087	0.095	0.073
C6	0.096	0.102	0.114	0.085
C7	0.088	0.105	0.099	0.078
C8	0.104	0.100	0.095	0.079
C9	0.124	0.100	0.105	0.089
C10	0.127	0.118	0.110	0.095
S1	0.068	0.077	0.070	0.083
S2	0.059	0.052	0.052	0.062
S3	0.070	0.064	0.062	0.074
S4	0.063	0.054	0.071	0.072
S5	0.076	0.064	0.071	0.080
S6	0.074	0.078	0.065	0.082
S7	0.070	0.070	0.079	0.085
S8	0.077	0.081	0.078	0.091
S9	0.074	0.078	0.065	0.082
S10	0.079	0.088	0.079	0.094

[3] We have 2 business representatives also an industry expert; We group 1 policymaker and 1 consultant into the researcher group as they have external view on battery manufacturing.

S11	0.059	0.067	0.060	0.071
S12	0.068	0.072	0.078	0.084
S13	0.074	0.073	0.084	0.089
S14	0.090	0.083	0.087	0.099

We also applied Pearson Correlation to statistically assess the consistency of weightings among the three stakeholder groups. Pearson Correlation ranges from -1 (strong negative correlation) to 0 (no correlation) to 1 (strong positive correlation). In Table 7, the results indicate that all groups, including the overall weighting, are significantly (p-value ≤ 0.001) and strongly correlated (Corr > 0.5). This confirms the homogeneity of weightings across the three groups, allowing us to consider the overall value as a robust representation of our KPI weighting.

Table 7. Correlation test among three stakeholder groups – Industry expert, Business representative and Researcher.

		Industry Expert	Business representative & Manager	Scholar, Researcher, Policymaker, Consultant	Overall
Industry Expert	Pearson Correlation	1	.898**	.859**	.672**
	Sig. (2-tailed)		<.001	<.001	<.001
	N	37	37	37	37
Business representative & Manager	Pearson Correlation	.898**	1	.875**	.634**
	Sig. (2-tailed)	<.001		<.001	<.001
	N	37	37	37	37
Scholar, Researcher, Policymaker, Consultant	Pearson Correlation	.859**	.875**	1	.544**
	Sig. (2-tailed)	<.001	<.001		<.001
	N	37	37	37	37
Overall	Pearson Correlation	.672**	.634**	.544**	1
	Sig. (2-tailed)	<.001	<.001	<.001	
	N	37	37	37	37

**. Correlation is significant at the 0.01 level (2-tailed).

4. Assessment Methodology Framework Implementation

4.1. Implementation guidance

Moving beyond theoretical considerations, this section provides a practical roadmap for organisations to apply the assessment framework. The process is structured into six interconnected phases. Drawing on the framework's KPIs and the data collection strategies described earlier in the report, we propose a cyclical, six-step process to guide organisations through effective deployment. Each step, from defining scope and objectives to reassessing and refining, builds upon the previous one, ensuring that insights gleaned from one assessment cycle inform the next. By following this structured approach and utilising visual tools such as RADAR charts, practitioners can continually evaluate their performance across economic, environmental, and social dimensions, fostering a culture of ongoing learning and improvement within the battery value chain.

Figure 10 illustrates how organisations can repeatedly assess, visualise, and refine their performance across economic, circularity, and social dimensions using tools such as radar charts.

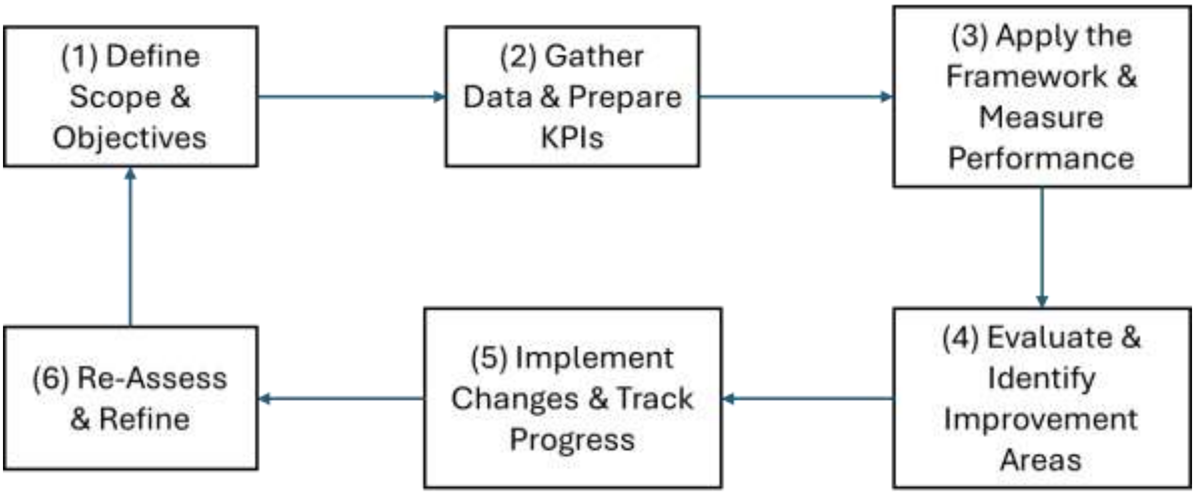

Figure 10. Six Implementation steps

1) Define Scope & Objectives

Begin by identifying the specific battery-related business model or process users intend to assess (e.g., second-life battery application, recycling initiative, or Battery-as-a-Service). Clearly outline the dimensions (i.e. economic, environmental, and social) that users will measure using the framework's Key Performance Indicators (KPIs). Establish clear objectives and performance targets to align stakeholder expectations with the scope of the report's methodology.

2) Gather Data & Prepare KPIs

Collect the relevant quantitative and qualitative data identified in the KPI tables (see Table 4). Ensure consistency in units, timeframes, and data sources to allow meaningful comparisons. Organise and normalise these data points so that each KPI reflects the battery value chain's current status and can be directly compared with future assessments.

3) Apply the Framework & Measure Performance

Use the assessment framework detailed in this report to analyse how well the selected business model meets each KPI. First, users can refer to table of KPI's weights in section 3.2 and performance calculation in section 2.4.3.

Then, they can apply both scoring methodologies to gain a comprehensive understanding of performance as outlined in section 2.4.4:

- ***Full Framework Score:*** Calculate weighted scores for all KPIs, including those that may not directly apply to your current business model. This provides a comprehensive view of how your business addresses all sustainability dimensions valued by stakeholders.
- ***Model-Specific Score:*** Calculate adjusted scores, focusing only on KPIs applicable to your business model. This offers insight into operational effectiveness within your current scope.

Plot these results on separate radar charts (or similar visualisations tool) to provide an at-a-glance comparison of performance across the economic, circularity, and social dimensions. This dual representation allows one to see both comprehensive sustainability coverage and operational effectiveness simultaneously.

4) Evaluate & Identify Improvement Areas

Interpret both scoring approaches and the radar charts, as well as supporting data to pinpoint gaps or underperforming areas.

- ***Full Framework Score analysis**:* Examine the performance against all KPIs to identify gaps in your sustainability coverage. This shows how comprehensively the business model addresses the complete battery value chain sustainability landscape. Lower scores in certain dimensions may indicate strategic opportunities to expand the business model's scope.
- ***Model-Specific Score analysis**:* Review the performance on applicable KPIs to understand operational effectiveness within the current business model. This reveals how well the business is executing within the existing parameters. Focus on dimensions where this score is lower for immediate improvement opportunities.

Then, compare both scores to determine the strategic position. High scores in both metrics indicate a comprehensive and well-executed business model. High *Model-Specific Score* with low *Full Framework Score* suggests effective execution in a specialised niche with potential for strategic expansion. Low scores in both metrics highlight fundamental issues requiring immediate attention. Moreover, benchmark the scores against industry peers and competitors operating similar business models. This comparative perspective provides valuable context for the performance metrics and helps identify industry best practices. Consider both sectoral averages and leading performers to establish appropriate benchmarks for each dimension. Significant gaps between the business scores and industry leaders identify specific areas where targeted improvements could yield competitive advantage.

Finally, involve relevant stakeholders to discuss the root causes behind these findings and prioritise interventions. By referencing the thresholds and benchmarks set in Step (1), the business can objectively determine where improvements are most urgently needed.

5) Implement Changes & Track Progress

Formulate action plans, whether policy adjustments, process enhancements, or technology upgrades, to address the issues identified through your Full Framework and Model-Specific Score analyses. These plans should account for both the internal performance gaps and the relative positioning compared to industry peers and competitors. When prioritising initiatives, the business should consider: (i) areas where the performance significantly lags industry benchmarks, (ii) dimensions where improvements could create distinctive competitive advantage, (iii) opportunities to adopt proven best practices from industry leaders, to develop a two-tiered improvement strategy based on the dual score analysis:

- **Operational improvements**: Based on the *Model-Specific Score*, formulate action plans to enhance performance on applicable KPIs. These represent immediate opportunities for improvement within the existing business model.
- **Strategic expansions**: Guided by the *Full Framework Score*, develop longer-term initiatives to address sustainability dimensions that are currently outside the business model's scope but align with stakeholder priorities in the battery value chain.

Allocate resources and responsibilities to ensure accountability for both operational and strategic initiatives. Establish clear timelines, with operational improvements typically taking priority for immediate implementation while strategic expansions follow a more gradual roadmap.

Continue monitoring both sets of KPIs over time, comparing ongoing data against the baseline scores to track overall progress in both operational effectiveness (*Model-Specific Score*) and comprehensive sustainability coverage (*Full Framework Score*), as well as industry benchmarks and competitor scores to evaluate relative improvement and assess market positioning. This dual tracking approach ensures balanced progress across immediate operational excellence and long-term strategic evolution, as well as to understand how your sustainability performance of the business model evolves relative to the broader market and changing industry standards.

6) Re-Assess & Refine

After an appropriate interval, repeat Steps (2) through (5) to measure progress and capture new data. Generate an updated radar chart to visualise improvements and reveal any remaining challenges. This cyclical approach enables continuous refinement of both the business model and the assessment framework itself, ensuring alignment with evolving market conditions, regulations, and strategic goals.

4.2. Case studies

To demonstrate the effectiveness of our assessment framework, we conducted three case studies. Our implementation process follows Steps 1 to 4, as Steps 5 and 6 require direct evaluation and judgment from the companies themselves.

1) Objective of case studies

The primary goal of these case studies is to assess three key dimensions of sustainability in emerging business models:

- Economic resilience & adaptability
- Environmental circularity
- Social sustainability

We apply this assessment to three SMEs, each with a unique business model.

2) Gather data

We gathered primary data from three SMEs each operating in a different sector[4]:

- Company A: Digital battery aging databases
- Company B: EV charging solutions
- Company C: Sustainable materials

As these business models are still in the early stages of development and implementation, our assessment framework serves as a valuable benchmarking tool. It helps these companies understand their current position relative to best practices while identifying and prioritising key areas for improvement—an essential process for SMEs with limited resources.

To collect data, we utilised our KPI Table (Table 4, section 3.1), requesting each company to provide relevant measures and detailed explanations via email.

3) Apply the Framework & Measure Performance

Our research team systematically analysed and evaluated each KPI, following the guidelines outlined in Sections 2.4.3 and 2.4.4. As the KPI weights were predefined in section 3.2, we applied these weights in our calculations. The KPIs calculation for each company is presented in Table 9.

4) Evaluate & Identify Improvement Areas

The final scores for each dimension are presented in Table 8. To further illustrate our findings, we

[4] Their identity has been kept anonymous upon request

visualise three business models using a RADAR chart in Figure 11. Our analysis reveals several key insights:

- *Strong social sustainability across all models:* Although these business models are newly developed, they demonstrate strong social sustainability. This is largely due to their origins—one company operates as part of a larger corporate group, while the other two are established firms introducing new business models rather than being entirely new SMEs. As a result, they inherit well-established social sustainability practices from their parent organisations or existing management structures.
- *Weaker performance in other aspects due to early-stage development:* The economic and environmental dimensions show significantly lower Full Framework scores, primarily because these business models are still in their infancy. Many KPIs have yet to be fully integrated into their operations. For instance, circularity-related KPIs are currently underdeveloped, but as these companies scale and expand their engagement with materials and battery manufacturing, improvements in environmental sustainability are expected.
- *Assessing qualitative data with a flexible framework:* Company B, specialising in EV charging solutions, provided only qualitative data, which typically presents challenges for quantitative assessment. However, our framework successfully accommodates such cases by incorporating multiple evaluation measures, including Likert scale assessments. This adaptability ensures a comprehensive and fair evaluation across diverse business models.
- The company A has low *Full Framework Scores* across all dimensions, indicating gaps in comprehensive sustainability coverage. However, its *Model-Specific Scores* are significantly higher, especially in Environmental Circularity **(0.928)** and Social Sustainability **(0.975)**, suggesting strong operational execution within a specialised niche. Expanding its business model to cover more sustainability aspects could be a strategic opportunity.
- The company B demonstrates strong *Model-Specific Scores* across all dimensions, particularly in Economic Resilience & Adaptability **(0.967)** and Social Sustainability **(1.098)**, indicating efficient execution. However, its low *Full Framework Score* in Environmental Circularity (0.158) suggests a major gap in circularity efforts, which could be a focus for improvement to enhance overall sustainability.
- The company C shows a balanced but moderate performance, with decent *Full Framework Scores* in Economic Resilience & Adaptability **(0.554)** and Social Sustainability **(0.818)** but a weaker score in Environmental Circularity **(0.197)**. While its *Model-Specific Scores* are generally strong, Environmental Circularity **(0.485)** is notably lower, highlighting an area for immediate improvement to enhance operational sustainability.

Overall, comparing these companies, Company B appears to be the most operationally efficient, while Company A has strong execution but a narrow focus, and Company C has room for improvement in circularity. Benchmarking against industry leaders can help pinpoint best practices for strategic improvements.

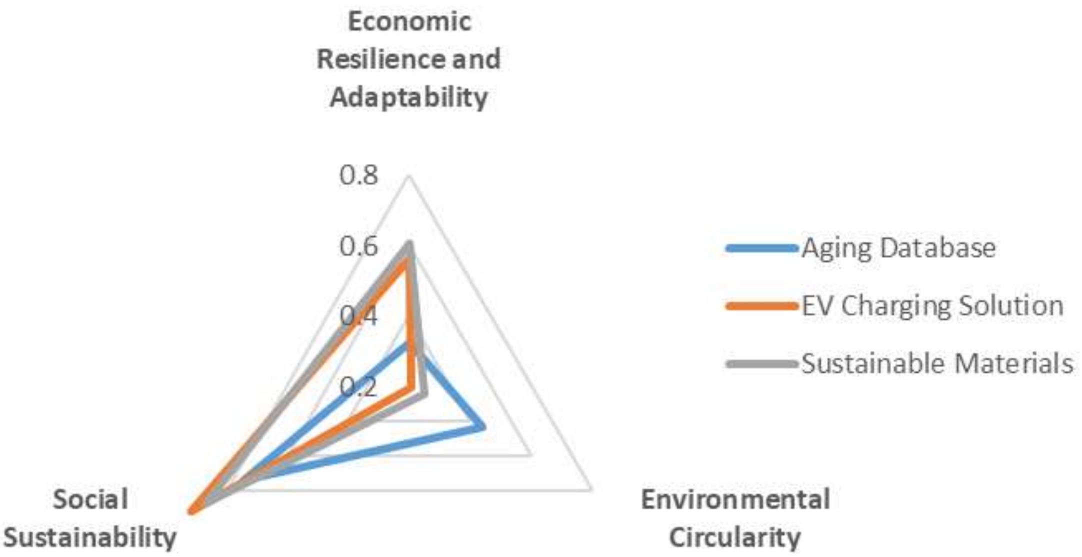

Figure 11. RADAR chart for full framework score of three example case studies

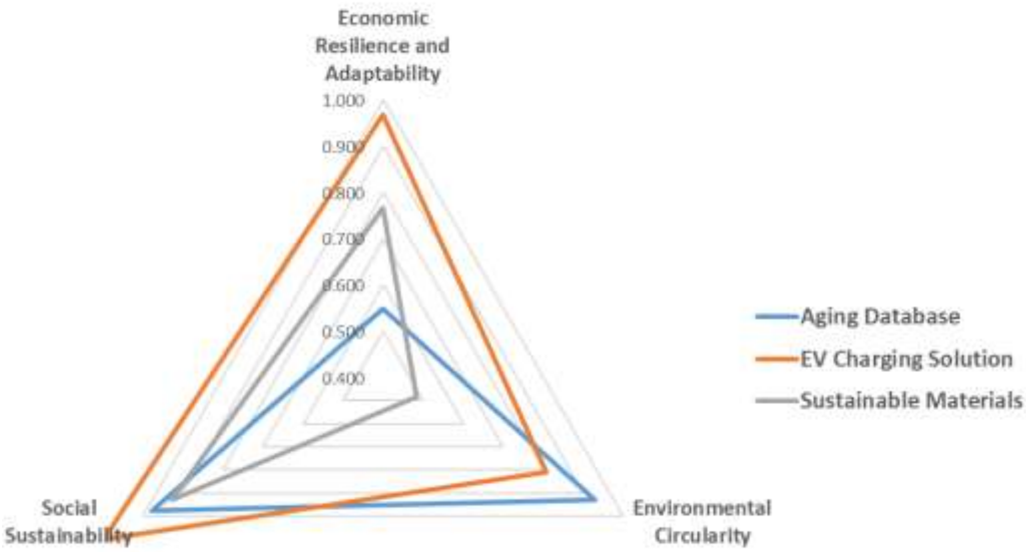

Figure 12. RADAR chart for model-specific score of three example case studies

Table 8. The final scores of three example case studies

	Aging Database (Company A)		EV Charging Solution (Company B)		Sustainable Materials (Company C)	
	Full framework score	Model-specific score	Full framework score	Model-specific score	Full framework score	Model-specific score
Economic Resilience and Adaptability	0.271	0.549	0.512	0.967	0.554	0.767
Environmental Circularity	0.388	0.928	0.158	0.808	0.197	0.485
Social Sustainability	0.693	0.975	0.868	1.098	0.818	0.928

Table 9. KPI calculation and explanation for three example case studies

Code	Weights	Best Practice	Battery Aging Database				EV Charging Solution				Sustainable Materials			
			Raw Data	Detail	Normalised Data	Score	Raw Data	Detail	Normalised Data	Score	Raw Data	Detail	Normalised Data	Score
E1	0.087	CATL in 2023 – 36.8%[5]	8%	Estimated	$\frac{(0.008-0)}{(0.368-0)} = 0.022$	0.002	0	N/A	0	0.000	5%	Estimated	$\frac{(0.005-0)}{(0.368-0)} = 0.014$	0.001
E2	0.070		Likert scale 2	Digital tools have low level for local development and difficult to implement	$\frac{(2-1)}{(5-1)} = 0.25$	0.018	Likert scale 4	Access to a network of suppliers and service providers as part of enterprise group	$\frac{(4-1)}{(5-1)} = 0.75$	0.052	Likert scale avg. 4	5 – on importance and 3 due to limited regional suppliers	$\frac{(4-1)}{(5-1)} = 0.75$	0.052
E3	0.080		0	KPI not applicable	0	0.000	0	N/A	0	0.000	0	Does not work directly with second-life batteries. Aiming integrates recycled lithium and iron phosphate	0	0.000
E4	0.058		0	0	0	0.000	0	N/A	0	0.000	0	N/A	0	0.000
E5	0.095	16% for BYD	12%	Estimated	$\frac{(0.12-0)}{(0.16-0)} = 0.75$	0.071	0	N/A	0	0.000	30%	Estimated	$\frac{(0.3-0)}{(0.16-0)} = 1.875$	0.177

[5] Electric vehicle industry in China - Wikipedia

		Seal model[6]												
E6	0.058		Likert scale 1	High chance of imitation	$\frac{(1-1)}{(5-1)} = 0$	0.000	Likert scale 5	The company's ability to design and integrate unique software solutions	$\frac{(5-1)}{(5-1)} = 1$	0.058	Likert scale 4	Competitors can produce LFP but may lack a sustainable, localized supply chain	$\frac{(4-1)}{(5-1)} = 0.75$	0.044
E7	0.079		Likert scale 1	High chance of switching	$\frac{(1-1)}{(5-1)} = 0$	0.000	Likert scale 5	Ongoing maintenance services, and energy management software contribute to strong customer retention	$\frac{(5-1)}{(5-1)} = 1$	0.079	Likert scale 4	Enhances customer loyalty through EU-based supply security, sustainable material integration, and tailored CAM solutions	$\frac{(4-1)}{(5-1)} = 0.75$	0.059
E8	0.064		Likert scale 4	Good integration of 2nd life and possible for calculations	$\frac{(4-1)}{(5-1)} = 0.75$	0.049	Likert scale 5	High capability for integrating second-life batteries	$\frac{(5-1)}{(5-1)} = 1$	0.064	Likert scale 3	Technological integration ease	$\frac{(3-1)}{(5-1)} = 0.5$	0.032
E9	0.091		0	N/A	0	0.000	0	N/A	0	0.091	60%	As today	$\frac{(0.6-0)}{(1-0)} = 0.6$	0.055
E10	0.085		Likert scale avg. 4.5	4 – Good customer awareness 5 – Good competitor	$\frac{(4.5-1)}{(5-1)} = 0.875$	0.071	Likert scale 5	Monitors regulatory changes, customer	$\frac{(5-1)}{(5-1)} = 1$	0.085	Likert scale 4	Closely monitors market trends,	$\frac{(4-1)}{(5-1)} = 0.75$	0.063

[6] How China's BYD went from bargain battery maker to Tesla's biggest rival - Nikkei Asia

				awareness				needs				customer preferences, and competitor strategies		
E11	0.094		Liker scale avg. 3.5	5 – Fast new technology 2 – Low patent protection	$\frac{(3.5-1)}{(5-1)} = 0.625$	0.057	Likert scale 5	Integrates smart energy software, AI-driven analytics, and emerging battery technologies	$\frac{(5-1)}{(5-1)} = 1$	0.094	Likert scale 4	IP awareness and technology adoption	$\frac{(4-1)}{(5-1)} = 0.75$	0.070
E12	0.060		0	As of 03/2025	0	0.000	0	AI adoption for supply chain operations is an area of potential growth	0	0.000	0	Currently no AI integration	0	0.000
E13	0.079		0	N/A	0	0.000	Likert scale 5	Grid-connected battery storage and solar PV solutions that integrate with smart grids, demand-response systems, and virtual power plants (VPPs)	$\frac{(5-1)}{(5-1)} = 1$	0.079	0	Does not interact directly with smart grids or charging infrastructure	0	0.000
C1	0.077	14% of lithium in Europe[7]	12%	Estimated	$\frac{(0.12-0)}{(0.14-0)} = 0.8571$	0.065	0	N/A	0	0.000	5%	Current rate	$\frac{(0.05-0)}{(0.12-0)} = 0.417$	0.032

[7] Europe set to miss potential for battery material recycling | Reuters

C2	0.082	Estimated 16% for nickel and cobalt[8]	0	N/A	0	0.000	1	Compliance with recycling regulations	1	0.082	5%	Current rate	$\frac{(0.05-0)}{(0.16-0)} = 0.313$	0.026
C3	0.074		0	N/A	0	0.000	0	N/A	0	0.000	0	Does not yet have full lifecycle CO_2 data but aims to track emissions across raw material sourcing, production, and transport	0	0.000
C4	0.076		0	N/A	0	0.000	1	Compliance with regulation	1	0.076	0.1	Current circularity indicator is estimated	0.1	0.008
C5	0.073		0	N/A	0	0.000	0	N/A	0	0.000	0	Does not recycle battery materials or handle end-of-life battery disposal	0	0.000
C6	0.085		0	N/A	0	0.000	0	N/A	0	0.000	0	Does not recycle battery materials or handle end-	0	0.000

[8] Europe set to miss potential for battery material recycling | Reuters

												of-life battery disposal		
C7	0.078	Only 5% of batteries is currently dealt at their end-of-life[9]	0.1	Estimated;	$\frac{(0.1-0)}{(0.052-0)} = 1.9$	0.145	0	N/A	0	0.000	0	Battery repurposing is not part of their operations	0	0.000
C8	0.079		0	N/A	0	0.000	0	N/A	0	0.000	0	Disassembly is not relevant to our business model	0	0.000
C9	0.089	The current best practice – 80% of original capacity retained	80%	Same as the current best practice – 80% of original capacity retained	$\frac{(0.8-0)}{(0.8-0)} = 1$	0.086	0	N/A	0	0.000	0	Does not produce batteries	0	0.000
C10	0.095	Best practise is 5000 cycles[10]	4500 cycles for LFP	4500 cycles for LFP	$\frac{(4500-0)}{(5000-0)} = 0.9$	0.083	0	N/A	0	0.000	7000 cycles	High-quality LFP CAM typically supports battery lifespans	$\frac{(7000-0)}{(5000-0)} = 1.4$	0.132
S1	0.083		Likert scale 5	No pollution	$\frac{(5-1)}{(5-1)} = 1$	0.082	Likert scale 4	Approximately 70% of its fleet to EV, installed solar panels and EV chargers to promote	$\frac{(4-1)}{(5-1)} = 0.75$	0.062	Likert scale 2	Estimated	$\frac{(2-1)}{(5-1)} = 0.25$	0.021

[9] Electric Car Batteries Lasting Longer Than Predicted Delays Recycling Programs
[10] Comparing Battery Cycle Counts Lead Acid vs Lithium-Ion

								sustainable energy use						
S2	0.062		0	No engagement	0	0.000	Likert scale 5	works closely with its local food bank, providing free EV charging solutions for their food delivery vehicle to ensure sustainable and efficient operations; donated an electric van to the Roy Castle Lung Cancer Foundation	$\frac{(5-1)}{(5-1)} = 1$	0.062	0	Does not currently have a formal community engagement policy	0	0.000
S3	0.074	64% of the batteries sourced for European-built EVs were from facilities in Europe[11]	50%	50% of spending on locally based suppliers	$\frac{(0.5-0)}{(0.64-0)} = 0.78125$	0.058	0	N/A	0	0.000	50%	50% on locally based suppliers	$\frac{(0.5-0)}{(0.64-0)} = 0.78125$	0.058
S4	0.072		50%	0% of suppliers the enterprise has audited regarding social responsibility. 1 - Presence of codes of conduct that protect human rights of workers among suppliers	$\frac{(0.5-0)}{(1-0)} = 0.5$	0.036	1	Ensures ethical supplier practices and prioritises socially responsible partnerships.	1	0.072	0	Not yet conducted formal supplier audits	0	0.000

[11] Northvolt shows Europe's battery makers face make-or-break moment

S5	0.080		Likert scale 4	Payment always on time, sometimes short lead times	$\frac{(4-1)}{(5-1)} = 0.75$	0.058	Likert scale 5	Strong, flexible supplier relationships	$\frac{(5-1)}{(5-1)} = 1$	0.080	Likert scale 4	Stable supplier relationships prioritized, focusing on fair trade and sustainable practices	$\frac{(4-1)}{(5-1)} = 0.75$	0.060
S6	0.082		Likert scale 5	Highly respect	$\frac{(5-1)}{(5-1)} = 1$	0.080	Likert scale 5	Full compliance with intellectual property laws	$\frac{(5-1)}{(5-1)} = 1$	0.082	Likert scale 5	Strict compliance with IP regulations. Zero recorded violations	$\frac{(5-1)}{(5-1)} = 1$	0.082
S7	0.085		0	N/A	0	0.000	Likert scale 4	Follows ethical procurement practices	$\frac{(4-1)}{(5-1)} = 0.75$	0.064	Likert scale 5	Ethical sourcing compliance is a key priority	$\frac{(5-1)}{(5-1)} = 1$	0.085
S8	0.091		0	N/A	0	0.000	Likert scale 5	Ensures compliance with anti-child labour regulations	$\frac{(5-1)}{(5-1)} = 1$	0.091	Likert scale 5	No child labour in the supply chain	$\frac{(5-1)}{(5-1)} = 1$	0.091
S9	0.082	Highest in Luxembourg, estimated 2.94[12,13]	2.8 times	Estimate 2.8 times minimum wage standards;	$\frac{(2.8-0)}{(2.94-0)} = 0.9523$	0.078	0	N/A	0	0.000	1 time	Wages at or above living wage standards	$\frac{(1-0)}{(2.94-0)} = 0.34$	0.028
S10	0.094		0	N/A	0	0.000	No accident	Following internationally	1	0.094	1	Strict safety protocols are	1	0.094

[12] Hourly labour costs ranged from €9 to €54 in the EU - News articles - Eurostat
[13] Minimum wage - Luxemburg - WageIndicator.org

								recognised ISO management systems				in place, with no incidents to date		
S11	0.071	Limited data but 25% of women in energy sector in the US[14]	0.3	30% of women	$\frac{(0.3-0)}{(0.25-0)} = 1.2$	0.084	No discrimination	Promotes workplace diversity and adheres to equal opportunity policies	1	0.071	67%	Workplace diversity	$\frac{(0.67-0)}{(0.25-0)} = 2.68$	0.191
S12	0.084	64h in 2021 globally[15]	16h per year		$\frac{(16-0)}{(64-0)} = 0.25$	0.020	0	N/A	0	0.000	15h per year		$\frac{(15-0)}{(64-0)} = 0.234$	0.020
S13	0.089		Likert scale 5	High transparency as data can be shared on platform	$\frac{(5-1)}{(5-1)} = 1$	0.088	Likert scale 5	Clear, accessible information	$\frac{(5-1)}{(5-1)} = 1$	0.089	Likert scale 4	transparent information about its LFP cathode active material (CAM)	$\frac{(5-1)}{(5-1)} = 1$	0.089
S14	0.099		Likert scale 5	No complaints	$\frac{(5-1)}{(5-1)} = 1$	0.098	Likert scale 5	Safe installation practices and offers warranties and aftercare services	$\frac{(5-1)}{(5-1)} = 1$	0.099	Likert scale 5	LFP materials are inherently safe	$\frac{(5-1)}{(5-1)} = 1$	0.099

[14] Gender Equality Can Drive the Electric Vehicle Industry Forward | Article | EESI
[15] Workplace training: training hours used per employee | Statista

5. Conclusions

This report presents a comprehensive framework for assessing business models within the battery value chain, addressing the growing need for sustainable, circular, and adaptable practices. By synthesising insights from academic research, industry practices, and stakeholder feedback, our methodology offers a robust and comprehensive tool for decision-makers. The framework evaluates battery business models across three critical dimensions: Economic Resilience & Adaptability, Environmental Circularity, and Social Sustainability. Each dimension is supported by specific KPIs, which were validated through comprehensive field research to ensure their relevance and applicability. Using the MCDA method, the framework quantifies the performance of different business models and provides a systematic score based on the weighted importance of each KPI, enabling decision-makers to make informed and objective decisions in evaluating business models.

The outcomes of this report also involve the development of an adaptable and practical guidance that can guide decision-makers in assessing the battery business models. The validation process confirmed the framework's applicability and relevance, positioning it as an invaluable tool for businesses, policymakers, and researchers striving to scale sustainable battery-related business models. The report provides step-by-step implementation guidance and case studies, demonstrating the framework's effectiveness in real-world applications and showcasing its potential for identifying key strengths and weaknesses.

The significance of this framework lies in its ability to assess existing business models and guide the development and optimisation of new business models. In the context of global efforts to advance CE and sustainable development, the framework provides actionable insights for enhancing resource efficiency, sustainability, and social responsibility within the battery sector.

In conclusion, the assessment methodology framework presented in this report offers a structured, systematic tool for stakeholders within the battery sector to foster a circular economy and a sustainable future. By supporting the broader European goals of building a resilient, competitive, and sustainable battery industry, this framework paves the way for future advancements in the sector.

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Annex 1. Summary of reviewed documents

Type	Framework/Title	Description	Reference
Academic literature	Strategic Type, Market Orientation, and the Balance between Adaptability and Adaptation	This study identified several indicators as the determinants for business performance such as profitability, business growth and market share. The study aimed to investigate the strategic type and market orientation impact the business performance	Lukas (1999)
	Determining requirements and challenges for a sustainable and circular electric vehicle battery supply chain: A mixed-methods approach	This paper examines the sustainability of the lithium-ion battery supply chain, which is critical for the transition to EVs and reducing greenhouse gas emissions from transportation. It identifies key limitations in existing sustainability assessments, including the lack of comprehensive evaluations across economic, environmental, social, and governance dimensions, as well as challenges in stakeholder engagement and information sharing. To address these gaps, the study investigates relevant sustainability 29 aspects, their prioritisation, and barriers to effective supply chain-wide assessments.	Gebhardt et al. (2022)
	Competing and Co-existing Business Models for Electric Vehicles: Lessons from International Case Studies	This study develops an assessment framework for evaluating the innovations of new EV business models in 4 key aspects – financial, customer, strategic and business. Additionally, the framework also helps identify customers adoption's barriers and model value creation and capture.	Weiller et al. (2015)
	Enabling Circular Business Models: Preconditions and Key Performance Indicators for the Market Launch of Repurposed Second-Life Lithium-Ion Batteries from Electric Vehicles	This study aims to identify key preconditions and performance indicators for selecting and repurposing end-of-first-life lithium-ion batteries (LIBs) to support second-life applications. Using a mixed-methods approach - including expert interviews, an exploratory workshop, and an online survey - researchers rated KPIs by importance on a Likert scale and introduced reference values. The study identified 12 preconditions and 12 KPIs, with "availability of battery specification information" and "compliance with standards" being critical, ultimately providing guidance for repurposing companies to enhance second-life market adoption.	Prenner et al. (2024)
	Resource-based view	This standard strategy theory posits that in a heterogeneous market where there are many competitors. For a firm to survive and thrive, it depends on their unique bundle of resources and capability. To show their ability to make profit, companies should have valuable, rare and Isolated from imitation or substitution resources and capability	Hoopes et al. (2003)
	NICE framework	NICE framework is a fundamental framework in assessing the ability to create value from businesses. The framework	Amit & Zott

Type	Framework/Title	Description	Reference
		suggests 4 independent dimensions: efficiency, complementarities, lock-in, and novelty as the backbone for a firm's business model.	(2001)
	Second life use of Li-ion batteries in the heavy-duty vehicle industry: Feasibilities of remanufacturing, repurposing, and reusing approaches	This case study explores sustainable strategies for repurposing Li-ion batteries within a top manufacturing company in the heavy-duty vehicle sector.	Chirumalla et al. (2023)
	The application of artificial intelligence in waste management: understanding the potential of data-driven approaches for the circular economy paradigm	The study explores how artificial intelligence (AI) can improve decision-making to support circular economy initiatives in the utility industry	Lanzalonga et al. (2024)
	Modeling the potential impact of lithium recycling from EV batteries on lithium demand: A dynamic MFA approach	This study evaluates the demand trends for lithium and the potential impact of automotive battery recycling using dynamic material flow analysis of the global lithium cycle.	Ziemann et al. (2018)
	How does adaptability drive firm innovativeness?	A conceptual framework of the adaptability construct for a firm to adapt to their environments and devise strategies to stay competitive and achieve high business performance. The framework consists of 7 dimensions of home market and technology sensing, customer and technology sensing, technology searching, global market monitoring, commitment of employees, interfunctional coordination, and incentive systems.	Tuominen et al. (2004)
	New business models for electric cars—A holistic approach	This study develops a holistic approach to help battery stakeholders create new business models for electric mobility. Better utilisation of vehicle capacity, extended utilisation concepts, secondary usage, increasing acceptance are the approaches proposed in the study.	Kley et al.2011)
	Sustainability Assessment in	This study develops a set of 69 sustainability indicators for the European automotive and electronics industries, based	Schöggl et al. (2016)

Type	Framework/Title	Description	Reference
	Automotive and Electronics Supply Chains	on literature review, expert interviews, and focus groups. It also explores software-based data exchange for sustainability assessment, aiming to enhance efficiency and industry-wide information sharing.	
Industry Documents	Battery Test Methods	This article discusses the growing demand for lithium-ion batteries and the need for advanced diagnostic methods to ensure their reliability, prevent failures, and predict their end of life. It highlights the complexity of battery testing, comparing it to medical diagnostics, and emphasises the importance of rapid-test technologies for accurate assessments. They have listed 8 battery testing methods – Voltage, Ohmic test, full cycle, rapid-test, BMS, Coulomb counting, read-and-charge, and SOLI.	Buchmann (2017)
	Water Footprint Assessment Manual	An assessment manual to measure the water footprint across various sources such as farm, living district or industry.	Hoekstra et al. (2011)
	ISO 14040:2006 Environmental management — Life cycle assessment — Principles and framework	ISO 14040:2006 establishes the principles and framework for life cycle assessment (LCA), covering key phases such as goal and scope definition, inventory analysis, impact assessment, interpretation, and reporting, while also addressing limitations and value choices. It applies to both LCA and life cycle inventory (LCI) studies.	ISO (2006)
	ISO 59010:2024 - Circular economy	ISO 59010 guides organisations in shifting from linear to circular value creation models. It provides business-focused strategies for implementing circular economy practices, complementing ISO 59004 with detailed guidance on assessing value chains and developing circular strategies. The standard supports sustainable business practices and a resilient global economy.	ISO (2024)
	Material Circularity Indicator (MCI)	The MCI tool helps evaluate and compare the 'circularity' scores of individual products, product portfolios, or entire companies. It can assist product designers in making informed design choices, support internal circular economy performance reporting, and guide procurement decisions.	Ellen Macarthur Foundation,2021)
	Life Cycle Assessment of an Ecolabeled Notebook	This study examines the social and environmental impacts of an EU Ecolabel-certified ASUS laptop throughout its life cycle, from raw material extraction to recycling. The research aims to identify sustainability hot spots, provide recommendations for companies and policymakers, and apply UNEP/SETAC guidelines for Social Life Cycle Assessment (S-LCA) to a complex product.	(Ciroth and Franze, 2011)
	European Regulation on	The documents outline EU battery regulations aimed at ensuring sustainability across the battery life cycle while	(European Commission,

Type	Framework/Title	Description	Reference
	batteries and Critical raw materials	fostering a competitive industry and reducing reliance on fuel imports. It also addresses the growing concern over secure access to raw materials, with the European Commission maintaining a list of Critical Raw Materials (CRMs) to safeguard supply chains and support Europe's economic and strategic interests.	2023a, 2023b)
	Resilience of global supply chains	This briefing discusses the challenges and solutions for the resilience of global supply chains. Global supply chains remain crucial to international trade, with the EU more deeply involved than the US and China, despite a decline in trade through these networks since the 2008-2010 crisis. The COVID-19 pandemic severely disrupted supply chains, creating bottlenecks that slowed economic recovery, impacted manufacturing, and fueled inflation. In response, the EU and other nations are working to enhance supply chain resilience through diversification, domestic capacity expansion, and international cooperation, though experts believe reshoring will have limited impact.	(Szczepański, 2021)

Annex 2. Survey for Business Model Assessment Framework Validation in Battery Value Chain

The CIRCUBATT project is funded by the EU, seeking to transform the European battery sector by integrating AI, data analytics, and sustainable practices across entire battery lifecycle to enhance competitiveness and sustainability.

This survey aims to gather insights from a diverse range of stakeholders to help develop an assessment framework for evaluating the adaptability, circularity, and sustainability of business models within the battery value chain. Your feedback will be valuable in ensuring that the framework is comprehensive, effective, and aligned with real-world challenges and opportunities.

Your responses will be kept confidential and used exclusively for this project. Your data will be stored securely with our encrypted location and will not be shared without your consent.

This survey would take approximately 3-5 minutes to complete.

If you have any questions about this survey or the CIRCUBATT project, please contact Prof. Li Zhou at li.zhou@gre.ac.uk or learn more here: https://cordis.europa.eu/project/id/101192383

Thank you very much for your contribution!

Demographics

What is your role/position?

- ☐ Industry expert (e.g., engineer, technical specialist)
- ☐ Business representative/Manager
- ☐ Policymaker
- ☐ Scholar/Researcher
- ☐ Other

What is your industry/domain?

- ☐ Battery Manufacturing & Technology
- ☐ Battery Recycling
- ☐ Electric Vehicles (EV)
- ☐ Sustainability/Environmental Policy
- ☐ Government/Regulatory Body
- ☐ Academic or Research Institution
- ☐ Other

How many years of experience do you have in the field?

- ○ Less than 1 year
- ○ 1-5 years
- ○ 5-10 years
- ○ Over 10 years

Do you think business models in the battery value chain can be sufficiently evaluated by three aspects: (1) Economic Resilience & Adaptability, (2) Environmental Circularity, and (3) Social Sustainability?

◯ Yes
◯ No

What else do you think it needs to capture?

KPIs Validation

Based on your understanding, please rank the importance of the following Key Performance Indicators (KPIs) in evaluating the 'Economic Resilience & Adaptability' of business models in the battery value chain. (1 = Not Important, 5 = Very Important)

	1	2	3	4	5
Growth in market share	◯	◯	◯	◯	◯
Local sourcing (Local economic development)	◯	◯	◯	◯	◯
Total cost of battery ownership reduction	◯	◯	◯	◯	◯
Cost of using second-hand battery compared with first-hand battery	◯	◯	◯	◯	◯
Ability to generate profit	◯	◯	◯	◯	◯
Inimitability of battery business model	◯	◯	◯	◯	◯
Ability to gain customer's loyalty	◯	◯	◯	◯	◯
Ability to integrate second-life battery	◯	◯	◯	◯	◯
Resilience to supply chain disruptions	◯	◯	◯	◯	◯
Awareness of market change (e.g., customers, competitors)	◯	◯	◯	◯	◯

Awareness of new technologies/innovations	◯	◯	◯	◯	◯
Adoption of AI and big data for supply chain operations	◯	◯	◯	◯	◯
Intelligent infrastructure integration	◯	◯	◯	◯	◯

Based on your understanding, please rank the importance of the following Key Performance Indicators (KPIs) in evaluating the 'Environmental Circularity' of business models in the battery value chain. (1 = Not Important, 5 = Very Important)

	1	2	3	4	5
Reduction in virgin material use	◯	◯	◯	◯	◯
Proportion of recycled critical raw materials used	◯	◯	◯	◯	◯
Water usage in production	◯	◯	◯	◯	◯
Total cradle-to- grave CO_2 emissions (Battery lifecycle carbon footprint)	◯	◯	◯	◯	◯
Material circularity indicator (MCI)	◯	◯	◯	◯	◯
Recycling rate of key battery materials (Recyclability)	◯	◯	◯	◯	◯
Proportion of battery repurposed vs. disposed	◯	◯	◯	◯	◯
Modularity and ease of disassembly (Eco-design integration)	◯	◯	◯	◯	◯
Battery degradation	◯	◯	◯	◯	◯

rate					
Battery longevity	○	○	○	○	○

Based on your understanding, please rank the importance of the following Key Performance Indicators (KPIs) in evaluating the 'Social Sustainability' of business models in the battery value chain. (1 = Not Important, 5 = Very Important)

	1	2	3	4	5
Safe and healthy living condition of local residents	○	○	○	○	○
Community engagement	○	○	○	○	○
Local employment	○	○	○	○	○
Promoting social responsibility	○	○	○	○	○
Supplier relationship	○	○	○	○	○
Respect of intellectual property rights	○	○	○	○	○
Ethical sourcing compliance	○	○	○	○	○
Child labour prevention	○	○	○	○	○
Fair salary	○	○	○	○	○
Health and safety of workers	○	○	○	○	○
Discrimination in workplace	○	○	○	○	○
Training for employees	○	○	○	○	○
Information transparency with consumers	○	○	○	○	○
Consumers health and safety	○	○	○	○	○

Are there any other KPIs that you think are closely related to measuring the above three aspects

(1) Economic Resilience & Adaptability, (2) Environmental Circularity, and (3) Social Sustainability of the battery business model?

General Questions

How applicable do you think the current assessment framework of batter value chain is to your industry/domain?

- ◯ Highly applicable
- ◯ Somewhat applicable
- ◯ Not applicable

Please explain why it is not applicable.

Do you have any additional suggestions or comments for our assessment framework?

Would you be interested in participating in follow-up consultations, interviews, or workshops related to this assessment framework and CIRCUBATT project?

- ◯ Yes
- ◯ No

Please provide your contact information (e.g., email address) here:

Thank you for your participation. Follow us on LinkedIn for more interesting and groundbreaking findings!

Annex 3. Interview questions

Semi-Structured Interview Guide for CIRCUBATT Project

Introduction (2-3 minutes)

Thank you for participating in this follow-up interview. In this interview I'd like to explore your perspectives on the battery business model assessment framework we're developing as part of the CIRCUBATT project. This interview will take approximately 30 minutes, and we're particularly interested in understanding the reasoning behind your survey responses and gaining deeper insights into your professional assessment of our proposed KPIs.

Background Context (1-2 minutes)

Based on your survey participation, I understand you're in the ……. with ……… of experience. Before we begin, could you briefly share your current involvement with battery technologies or circular economy initiatives?

General Framework Assessment (5-7 minutes)

The assessment framework we're developing has three key dimensions: Economic Resilience & Adaptability, Environmental Circularity, and Social Sustainability. In your view, how well do these dimensions capture the complexity of battery business models?

In the survey, we noticed varying importance ratings across different indicators. What factors do you consider when determining the importance of a particular KPI?

Dimension-Specific Questions (12-15 minutes)

- **Economic Resilience & Adaptability**
  - Among the economic indicators, Supply Chain Resilience (E9) and Technological Awareness (E11) scored particularly high. What makes these indicators especially critical from your perspective?
  - On the other hand, indicators like Cost Ratio of Second Life to First Life Batteries (E4) and Inimitability of Business Model (E6) received lower ratings. Could you elaborate on why these might be considered less crucial?
  - Given current industry trends, are there economic indicators you believe will become increasingly important over the next 5-10 years?
- **Environmental Circularity**
  - Battery Longevity (C10) and Battery Degradation Rate (C9) emerged as the highest-rated environmental indicators. Could you discuss why these lifecycle performance metrics seem to take precedence over other circularity measures?
  - What practical challenges do you see in implementing and measuring some of these environmental circularity indicators in real-world business operations?
  - Are there any environmental metrics or emerging considerations that you believe our framework should incorporate?
- **Social Sustainability**
  - Consumer Health and Safety (S14) received the highest overall rating across all indicators. Why do you think this particular aspect of social sustainability is perceived as so critical?

- Community Engagement (S2) received one of the lower ratings. Do you think this accurately reflects its importance, or are there contextual factors that might influence this rating?
- How do you see social sustainability metrics evolving in the battery industry, particularly as battery production scales globally?

Weighting and Implementation (5-7 minutes)

- Our analysis has assigned weights to each indicator based on the survey results. Looking at the weights shown here, do any particular values surprise you or seem misaligned with industry priorities?
- When implementing this framework in real business contexts, what challenges do you foresee in data collection and measurement?
- How might these weights and priorities differ across different parts of the battery value chain (e.g., manufacturing, repurposing/second life, recycling)?

Closing Questions (2-3 minutes)

- Based on our discussion, are there any additional indicators or considerations you believe should be included in the assessment framework?
- Do you have any recommendations for how we might improve the practical applicability of this framework for industry stakeholders?
- Would you be interested in reviewing the refined framework once we've incorporated feedback from these interviews?

Annex 4. Reflection to open-ended questions

- *"Do you think business models in the battery value chain can be sufficiently evaluated by three aspects: (1) Economic Resilience & Adaptability, (2) Environmental Circularity, and (3) Social Sustainability? If not, why?".*

Response	Our reflections
(1) Maybe covered in Economic Resilience & Adaptability but the business models need to avoid situations such as the collapse of British Volt. Also market certainty, demand creation and the skills required to roll out the required charging infrastructure & battery replacement.	Comment translation: Under Economic Resilience & Adaptability, it is essential to consider incorporating market volatility, demand forecasting, and infrastructure readiness into existing KPIs. Our reflection in existing framework: We have considered some relevant KPIs and added measurements in the corresponding KPIs, as follow: ->**E5 Profitability** reflects the profitability and financial health of the business. ->**E10 Awareness of market change** focuses on staying aware of market shifts, aligning well with the need to create demand and respond to market uncertainty.
(2) Actually, my answer is Yes, so long as mining/minerals extraction is taken into account in circularity.	Comment translation: Under Environmental Circularity, it is crucial to consider mining/minerals extraction. Our reflection in existing framework: We have considered some relevant KPIs and added measurements in the corresponding KPIs, as follow: ->**C1 Reduction in virgin material use** directly correlates with reducing dependency on mined materials and reducing the overall impact of mining. ->**C2 Proportion of recycled critical raw materials used** promotes the reuse of mined materials, reducing the demand for new mineral extractions. ->**C4 Total Cradle-to-Grave CO_2 Emissions** covers the environmental impact throughout the battery lifecycle, including the raw material extraction phase and the emissions linked to the mining and extraction process.
(3) This sounds cynical, but I think only #1 needs to be addressed to sufficiently evaluate a business model in the battery value chain. I believe #2 and #3 are important, but that they are aspirational, not necessary to build an economically viable business.	Comment translation: In the short term, the focus should perhaps remain more firmly on economic KPIs such as profitability, market growth, and cost reduction. Our reflection in existing framework: We have considered some relevant KPIs and added measurements in the corresponding KPIs, as follow: ->**E1 Growth in market share** also measures the success of a business model in expanding its market presence over time.
(4) Component and cell performance	Comment translation: This comment indicates that technical performance is vital for battery efficiency, energy retention, and durability, which should play an important role in the framework. Our reflection in existing framework:

	We have considered some relevant KPIs such as **C10 Battery longevity** and **C9 Battery degradation rate** under Environmental Circularity.
(5) Electric Vehicle and Passenger Auto Industry / Market Trends [>800B USD of cell production revenue in 2024 went to the EV Battery industry.]	<u>Comment translation</u>: This comment shows the growing market for EVs and their battery production. The expert suggests that understanding the market trends and the overall economic environment of the EV battery industry is crucial? <u>Our reflection in existing framework:</u> We have considered some relevant KPIs in terms of market trends and the economic impact of battery industry growth, such as **E1 Growth in market share** and **E5 Profitability**. For example: the comment mentions that most of the battery production revenue will flow to the electric vehicle industry, which is very relevant to the KPI of **E1 Growth in market share** as it emphasises the huge development potential of the EV battery market and shows the importance of battery production and market expansion.
(6) Economic Efficiency	<u>Comment translation</u>: considering economic efficiency as a dimension, it is essential to add KPIs like cost-benefit analysis/cost efficiency, operational ROI, and profit margins for operational efficiency and economic viability, making our framework more comprehensive from a financial sustainability perspective. <u>Our reflection in existing framework:</u> Economic efficiency is adequately covered by the existing KPIs, especially those related to cost reduction (**E3 TCO reduction**), profit generation (**E5 Profitability**), and cost ratio (**E4 Cost ratio -second life to first-life**).
(7) Technology sustainability	<u>Comment translation</u>: Technology sustainability is defined as how a company ensures the long-term sustainability of its technologies. It includes not only technological innovation, upgrades, and optimisations but also if the technology can adapt to environmental changes, reduce resource consumption, and remain sustainable over time. <u>Our reflection in existing framework:</u> The existing framework has covered some KPIs of technology sustainability, such as **E11 Awareness of new technologies/innovations**, **E12 Adoption of AI and Big Data for supply chain operations** and **E13 Intelligent infrastructure integration**, enhancing operational efficiency and sustainability.
(8) Economic Resilience and adaptability are to narrow - How about e.g. process efficiency, product performance.	<u>Our reflection in existing framework:</u> Existing KPIs have covered the aspects of economic resilience, such as **E1 Growth in market share**, **E2 Local sourcing**, and **E8 Ability to integrate second-life battery**. ->For process efficiency, the existing framework includes KPIs: **E4 Cost ratio - second life to first-life**, **E3 TCO reduction**, and **E8 Ability to integrate second-life battery**. ->Regarding product performance, we also covered KPIs like **C10 Battery longevity** and **C9 Battery degradation rate** under Environmental Circularity.
(9) Economic Resilience and Adaptability may fall short of	<u>Comment translation</u>: There should be a more comprehensive approach to environmental impact, including climate change, toxicity, and holistic

profitability, environmental circularity does not equal environmental friendliness in total (climate impact, toxicity etc.)	environmental impact assessments. Our reflection in existing framework: The existing KPIs focus on resource efficiency, such as **C1 Reduction in virgin material use**, **C2 Proportion of recycled critical raw materials used**, and **C3 Water usage/ consumption in production** across the lifecycle. We also consider climate impact in the KPI **C4 Total Cradle-to-Grave CO_2 Emissions** and toxicity in the KPI **S10 Health and safety of workers** and **S14 Consumers health and safety**
(10) Competitive positioning, quality of partnerships	Comment translation: competitive positioning is about a company's ability to maintain a strong position in the market relative to competitors, like market share, brand strength, unique selling propositions, and differentiation in the market. Our reflection in existing framework: The current framework has covered competitive positioning aspects through KPIs: **E1 Growth in market share**, **E6 Inimitability of battery business model**, and **E12 Adoption of AI and Big Data for supply chain operations** Comment translation: quality of partnerships is about the strength and value derived from business relationships, such as collaborations with suppliers, distributors, clients, and other stakeholders. Our reflection in existing framework: The current framework has included elements that touch on quality of partnerships, such as **S3 Local employment** and **S5 Supplier relationship**.

- *"Are there any other KPIs that you think are closely related to measuring the above three aspects (1) Economic Resilience & Adaptability, (2) Environmental Circularity, and (3) Social Sustainability of the battery business model?".*

Response	Our reflections
For economic wise, since there is boosted traffic on imported EV from China, this might be one of the issues? how it helps domestic economic should also be considered in my opinion.	Comment translation: this comment highlights the impact of imported electric vehicles on the domestic battery industry, such as evaluating how the battery production chain is influenced by market demand for imported electric vehicles. Our reflection in existing framework: We have considered some relevant KPIs and added measurements in the corresponding KPIs, as follow: -> **E1 Growth in market share** tracks market expansion. -> **E2 Local sourcing** touches on local battery production.
Other KPIs should include: adoption of EVs vs reduction in petrol/diesel vehicles; air quality improvements plus a wider view on modal shift to other forms of transport (including active travel, public transport, micromobility, shared mobility)	Comment translation: beyond the economic and environmental aspects of battery value chains, broader sustainability impacts should be considered, particularly the shift in transport modes. Our reflection in existing framework: We have considered some relevant KPIs and added measurements in the corresponding KPIs, as follow:

	-> Adoption of EVs vs reduction in petrol/diesel vehicles: **E1 Growth in market share** reflects the market penetration of EVs. -> Air quality improvements: **S1 Safe and healthy living condition of local residents** and **C4 Total Cradle-to-Grave CO_2 Emissions** (reflects the carbon footprint of the battery life cycle). -> A wider view on model shift to other forms of transport: **E8 Ability to integrate second-life battery** involves how to recycle batteries from EVs and apply them to other applications (such as energy storage systems), which is related to the recycling of batteries and the efficient use of resources.
Gross margin and CapEx spend are KPIs I pay very close attention to as well as Total Addressable Market from a global view.	Our reflection in existing framework: -> Gross margin - we have considered some relevant KPIs and added measurements in the corresponding KPIs: **E5 Profitability** is related to gross profit margin as it measures the overall profitability of the business model. ->CapEx spend refers to the investment made by a company to expand, maintain or update its infrastructure, assets and production capabilities. We have considered some relevant KPIs and added measurements in the corresponding KPIs: **E4 Cost ratio -second life to first-life** focused on the ability to integrate used batteries into the business model, which may involve the modification or expansion of production facilities. ->Total Addressable Market from a global view refers to the maximum market demand that a product or service can achieve worldwide. We have considered some relevant KPIs and added measurements in the corresponding KPIs: **E1 Growth in market share** can indirectly reflect the company's expansion potential in a specific market, which is indirectly related to TAM. The larger the TAM, the greater the potential room for market share growth.
Overall Equipment Effectiveness (OEE) materials effectiveness	Comment translation: OEE materials effectiveness measures the efficiency of materials in the production process Our reflection in existing framework: We have considered some relevant KPIs and added measurements in the corresponding KPIs: -> **C5 Material circularity indicator** focuses on recycling and utilisation efficiency of materials.
Collaboration with other stakeholders for adaptability and flexibility	Our reflection in existing framework: Existing framework has covered the KPIs about supplier relationship (**S5 Supplier relationship**), focusing on the cooperative relationship between business and suppliers. Other relevant KPIs include: -> **E8 Ability to integrate second-life battery,** indicating the collaboration with recyclers, recycling companies, technology providers, etc. to increase battery reuse and maximise resources -> **E9 Procurement resilience to supply chain disruptions**, indicating working together to address supply chain uncertainty.
Efficiency of Service provision	Comment translation: efficiency of service provision means the efficiency of

	service delivery/Resource utilisation efficiency during the service process Our reflection in existing framework: Existing framework has covered some relevant KPIs: -> **E4 Cost ratio -second life to first-life** involves how to reduce costs by effectively utilising resources and optimising processes, which can indirectly reflect the efficiency of service provision.

- *"Do you have any additional suggestions or comments for our assessment framework?".*

Response	Our reflections
The framework focuses a lot on the producing side (including workers), but I think a demand orientation (other than profit) would enhance the framework. I think potential customer/societal perception, and consumer adoption would be key KPI.	Comment translation: this comment emphasises demand orientation and consumer adoption as important supplements to the assessment framework Our reflection in existing framework: Existing framework has covered some relevant KPIs: ->**E10 Awareness of market change** is about understanding towards customers' needs and behaviours
Consider London's environment and transport strategy including healthy streets.	Comment translation: this comment is about health impacts of urban transport and the environment. Our reflection in existing framework: We have considered some relevant KPIs as follow: -> **C4 Total Cradle-to-Grave CO_2 Emissions** and **S1 Safe and healthy living condition of local residents** (focuses on the safety and health of the community, but it may be linked to the concept of healthy streets)
Techno-economic Analysis (TEA) and application-based TEA are important when targeting specific verticals.	Our reflection in existing framework: We have considered some relevant KPIs, such as **E13 Intelligent infrastructure integration, E3 TCO reduction (**focuses on reducing the total cost, but it also involves an analysis of economic benefits), and **E4 Cost ratio -second life to first-life** (the cost effectiveness of second life cycle batteries relative to first life cycle batteries)
Governmental support. Coopetition strategy that allows industry to involve academic institutions and minimize the gap between low and high TRL.	Our reflection in existing framework: We have considered some relevant KPIs and added measurements in the corresponding KPIs: -> Governmental support: **S2 Community Engagement.** -> Coopetition strategy, academic involvement and TRL: **E12 Adoption of AI and Big Data for supply chain operations** (relates to the actual application of technology) and **E13 Intelligent infrastructure integration** (related to the maturity of the technology)
How important is it to enable out of region sourcing when local supply chains do not exist? IOW, how to	Comment translation: regarding the globalisation of supply chains and the lack of regional supply chains, it is vital to consider how to promote the development of the battery industry in emerging markets through cross-

jump start EV Battery industry in emerging regions.	regional/boarder sourcing. <u>Our reflection in existing framework:</u> We have considered some relevant KPIs: -> **S5 Supplier relationship** builds strong partnerships with suppliers outside the region in the absence of a local supply chain. -> **E9 Procurement resilience to supply chain disruptions** can enhance the resilience of supply chains through cross-regional/boarder sourcing if emerging regions lack local supply chains.
It would be interesting to see this framework as an interactive tool to dynamically evaluate the business model over time and to be able to compare across companies	<u>Our reflection in existing framework:</u> Yes, this is our aim. We will measure new business models over time to see their growth as well as benchmarking with best industry practices.
Will this assessment framework produce a score? From the council, we would be interested in this	<u>Our reflection in existing framework:</u> Yes, we will produce three scores for three key dimensions and visualise them on RADAR charts.
There are some issues missing: Implementation cost, operations cost, as well the impact of attributes to objectives and impact of attributes to cost	<u>Our reflection in existing framework:</u> In our assessment framework, cost can be reflected in detailed analysis about market growth (**E1 Growth in market share**) and profitability (**E5 Profitability**).
Focus on generally accepted KPI (e.g. MCI is not), terms like "local" are unhelpful as local as the distinct place you are at a distinct point in time, so what does e.g. "local residents" refer to: mine, plant, use, recycling...?	<u>Comment translation and our reflection in existing framework:</u> MCI evaluates performance in material recovery and recycling. We have covered some related KPIs: **C3 Water usage/ consumption in production** and **C4 Total Cradle-to-Grave CO_2 Emissions.** We also covered some "local" related KPIs, such as **S2 Community engagement** and **S3 Local employment**.

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