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REUSE

Revitalise

STREAMS
SUSTAINABLE TECHNOLOGIES FOR REDUCING EUROPE'S BATTERY RAW MATERIALS DEPENDANCE

HighMag
High-energy, low-cost and scalable generation 5 magnesium-based batteries for mobility applications and beyond

WEBINAR

Sustainability in Focus: Batt-Bridge Projects Assessing recycling processes for a circular battery value chain

9 JULY 2026

10:30 CET

A FEW RULES

Participant audio and video are disabled

Post questions on Q&A Teams at any time

This session is being recorded

The recording will be shared on the RENOVATE website and social media

Funded by the European Union

Strengthening Europe’s battery research and innovation ecosystem: A centralised digital platform that connects research, industry, and policy, offering access to projects, funding, stategies and performance data

Fosters collaboration, supports evidence-based policymaking and aligns initiatives to boost Europe’s leadership in sustainable batteries

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High-energy, low-cost and scalable
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SUSTAINABLE TECHNOLOGIES
FOR REDUCING EUROPE'S BATTERY
RAW MATERIALS DEPENDANCE

Enhancing & optimising the entire battery lifecycle

Funded by the
European Union

AGENDA

10:30 **Introduction and framing**

Welcome and context setting of the webinar

10:40 **Session 1: Sustainability assessment approaches for innovative battery recycling**

Presentations, discussion among speakers, and Q&A session

RENOVATE: Pushpendra Chabrawal, KIT-HIU
CIRCUBATT: James Duong, University of Greenwich & Michael Hess, Battronics
REVITALISE: Violeta Vargas Parra, Eurecat
ReUSE: Alok Prasad, University of Bordeaux
STREAMS & HighMag: Daniel Dias, Imperial College London

11:10 **Session 2: Validating sustainability approaches**

Presentations, discussion among speakers, and Q&A session

11:50 **Conclusion & Wrap-up**

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SESSION 1

Sustainability assessment approaches for innovative battery recycling

Funded by the European Union

Michael Hess
Battronics

James Duong
University of Greenwich

Pushpendra Chabrawal
KIT-HIU

Violeta Vargas
Eurecat

Alok Prasad
University of Bordeaux

Daniel Dias
Imperal College London

CIRCUBATT

CIRCULAR ECONOMY INNOVATIONS FOR RESILIENT, COMPETITIVE AND SUSTAINABLE BATTERY TECHNOLOGIES

CIRCUBATT Sustainability Assessment

James Duong (UoG) & Michael Hess (Battronics)

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LCC & LCA of recycling vs 2nd life of LIB‘s

CIRCUBATT

Scenarios to cover for LCC & LCA:

I. Data gathering

1) Prices of materials and chemicals for recycling.

2) Cost information for battery recycling by geographical location (labor, electricity, landfill, etc.)

3) Environmental data by region (electricity mix)

II. Scenarios:

1) Low vs. high feedstock tonnage (1'000/10'000 t/y)

2) NMC vs. LFP

3) Cell vs. pack level recycling

4) Poland vs. France

5) Current price (Li, Ni, Co, P, Cu) vs. 5 years low/high

III. Output

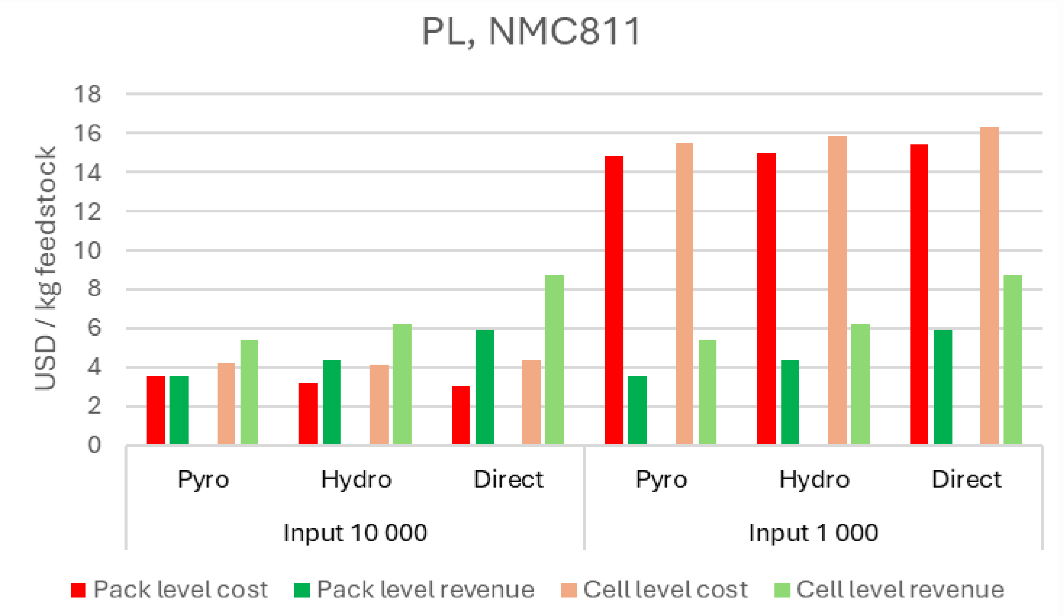
1) Pack to cell disassembly costs

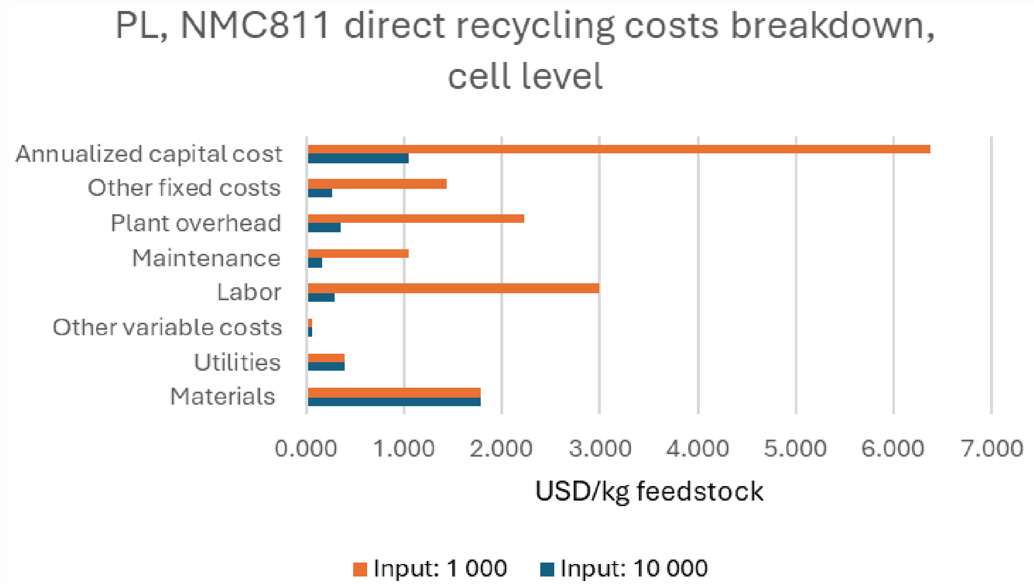
2) Recycling cost and revenue breakdown (pyro/hydro/direct)

3) Energy usage

4) Environmental impact (emissions)

Results LCC of recycling in Poland : NCM811

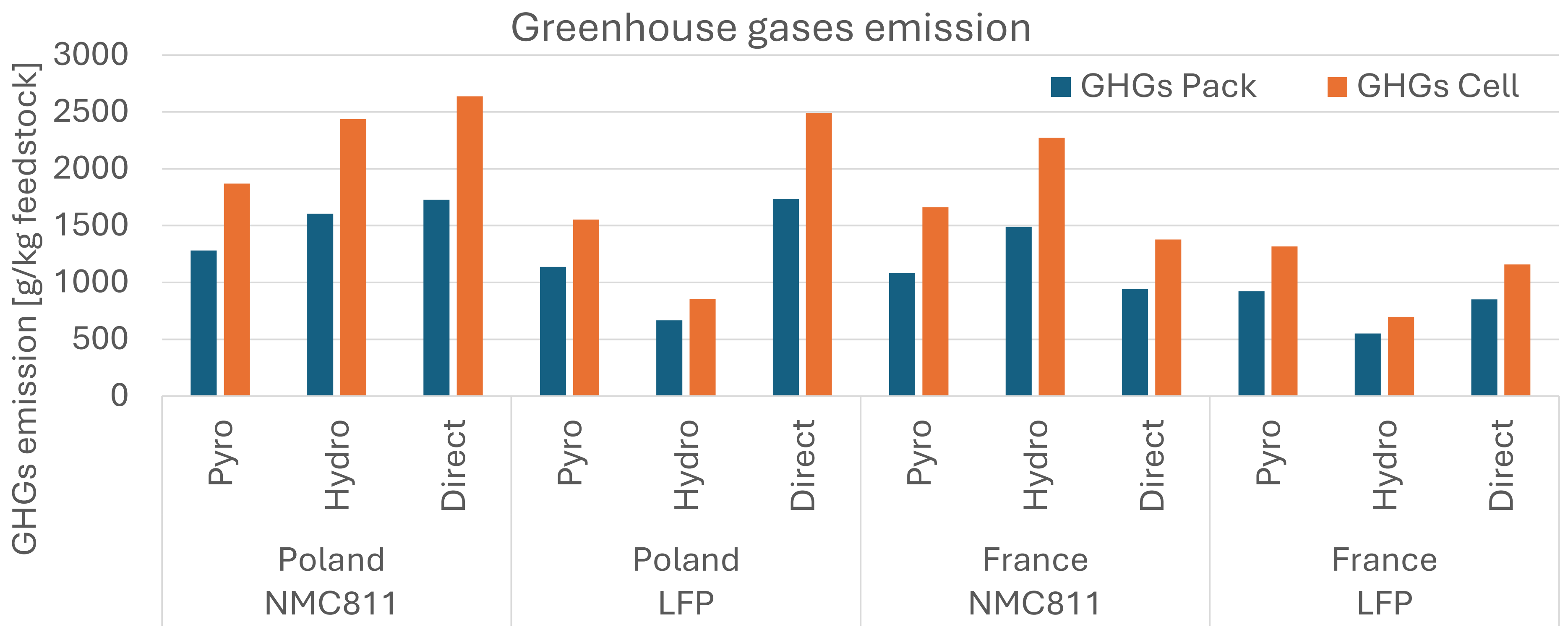




LCC & LCA of recycling vs 2nd life of LIB‘s

Results LCA Greenhouse gas emissions comparison

- For recycling, as expected, France has less Greenhouse gas emissions compared to Poland for same chemistry



Summary

- LIB Recycling is less profitable and even often a loss business in most recycling cases in France (e.g. LFP recycling) compared to Poland but slightly more CO_2 favorable in France as electricity has lower CO_2 footprint

BATT-BRIDGE Webinar
Sustainability in Focus: Batt-Bridge Projects – Assessing recycling processes for a circular battery value chain

Session 1:
Sustainability assessment approaches for innovative battery recycling

RENOVATE

A circular and chemistry-neutral approach for recycling and recovery of battery waste feeds

9 July 2026 (Online)

By: Pushpendra, Marcel Weil

Helmholtz Institute Ulm (HIU)/Karlsruhe Institute of Technology (KIT), Germany

Karlsruhe Institute of Technology

HELMHOLTZ INSTITUTE ULM
Electrochemical Energy Storage

Funded by the European Union

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101137745. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Innovation Council. Neither the European Union nor the granting authority can be held responsible for them.

Mission & Goals

Develop and demonstrate novel, innovative, and sustainable **recycling technologies at TRL4** (lab level validation) for the European battery value chain by recycling and **reusing 95+%** of end-of-life (EoL) batteries, battery components (e.g., metallic foil, graphite) and industrial side streams (e.g., waste chemicals, solvents, and scraps).

- Foster a **closed-loop circular approach**: reduce the demand for virgin materials, suppliers' dependency, waste generation and losses, create new added-value business cases for recyclers and battery materials users.
- Support the **net zero carbon** and **digital transformation**: increase the competitiveness and growth of the EU's battery industry while protecting health and environment.

Concept & Integration

RENOVATE

STEP 1

Collection

EoL cells (LFP & NMC-based)

Manufacturing scraps

Small Na-ion pouch cells

STEP 2

Non-CAM recycling

Electrolyte separation

HVF treatment

PVDF recovery

Graphite recovery and re-use

STEP 3

CAM recycling

LFP direct recycling

NMC solvometallurgy

Adaptability analysis

STEP 4

Product value, closed-loop, remanufacturing

Materials characterisation

Remanufacturing of cells

STEP 5

Transversal activities

Wastewater management and leaching solutions

Sustainability assessment

Digital architectures

Regulatory framework for scalability

LFP = Lithium Iron Phosphate; NMC = Nickel Manganese Cobalt; HVF = High Voltage Fragmentation; CAM = Cathode Active Materials; PVDF = Polyvinylidene fluoride

WP 6.1-6.3 Life cycle sustainability and safety assessment

The sustainability of the RENOVATE project is assessed through a **Safe and Sustainable by Design (SSbD)** approach that evaluates both **process safety** and broader **sustainability dimensions** - economic, environmental, and societal.

➢ Prospective Life Cycle Assessment (PLCA):

- ✓ The **RENOVATE** process is initially assessed through a **lab-scale LCA** to identify environmental hotspots and **generate targeted feedback** for technology partners.
- ✓ **Upscaling** of lab-scale LCIs using **detailed process engineering** and scale-up **assumptions** to support **benchmarking** at a more **representative** process scale.
- ✓ **Sensitivity analyses** on the **scale-up assumptions**, and **different scenarios** development to capture the **uncertainty** in the results.
- ✓ This **two-step approach** helps connect **early-stage experimental results** with a **clear view** of the process hotspot at low-TRL to steer the process with low efforts and **process's potential performance** under different (futuristic) industrial conditions.
- ✓ Parallel to the environmental LCA, **LCC,** and **social aspects** are considered, including the comparison of social impacts associated with primary materials versus recycled materials

➢ Process safety assessment:

1 Hazard assessment of the chemical/material (intrinsic properties)

- ✓ Substances classified from Level 0 (highly hazardous – requires substitution) to Level 3 (not considered intrinsically hazardous)

2 Human health and safety aspects in the chemical/material production and processing phase

- ✓ Occupational exposure is assessed through inhalation and dermal routes.
- ✓ Exposure levels compared with health-based reference values to calculate Risk Characterization Ratios (RCRs). If **RCR > 1**, additional risk management measures may be required.
- ✓ Environmental exposure linked to the processing phase is assessed in parallel, considering potential emissions to air, water or waste streams.

3 Human health and environmental aspects in the final application phase

- ✓ currently under evaluation! Exposure in the manufacturing stage (with recovered materials) is comparable to that of conventional/virgin batteries.

Research for Sustainable Energy Technologies (RESET)

RESET Team Members

Group Leader
Dr. Marcel Weil

RESET

Thanks for your attention!

BATT-BRIDGE

Revitalise

WEBINAR

Sustainability in Focus: Batt-Bridge Projects – Assessing recycling processes for a circular battery value chain

Session 1: Sustainability assessment approaches for innovative battery recycling

Violeta Vargas
Eurecat

HORIZON EUROPE Project

Revitalise

NOVEMBER 2023 - OCTOBER 2026

REVITALISE aims to:

• Develop pre-treatment and recycling technologies and cathode regeneration for EV batteries using green, low temperature and direct recycling process.

• Address NMC (High-Ni), LFP and Na-Ion post-production scrap and EoL batteries recycling (lab-scale to large production).

• Develop robust process to deal with heterogenous material input and cross contamination.

Eurecat performs the LCA and LCC tasks to evaluate the environmental and economic performance of the green recycling processes developed in REVITALISE.

The LCA will assess energy use, chemical consumption, and CO_2 emissions, demonstrating the sustainability and circularity of the proposed technologies.

The LCC will analyze investment, operation, and maintenance costs, proving the economic feasibility and competitiveness of the new recycling solutions for future industrial implementation.

NTNU

Watercycle Technologies

Iconiq Innovation

Universität Münster

VERKOR

eurecat Technology Centre of Catalonia

Hydro

UNIVERSITY OF BIRMINGHAM

meet

REELEMENTS

How it starts

The EU regulatory challenge

Rapid EV growth demands critical raw material recovery.

EU Battery Regulation pushes circularity and recycled content.

REVITALISE recovery target

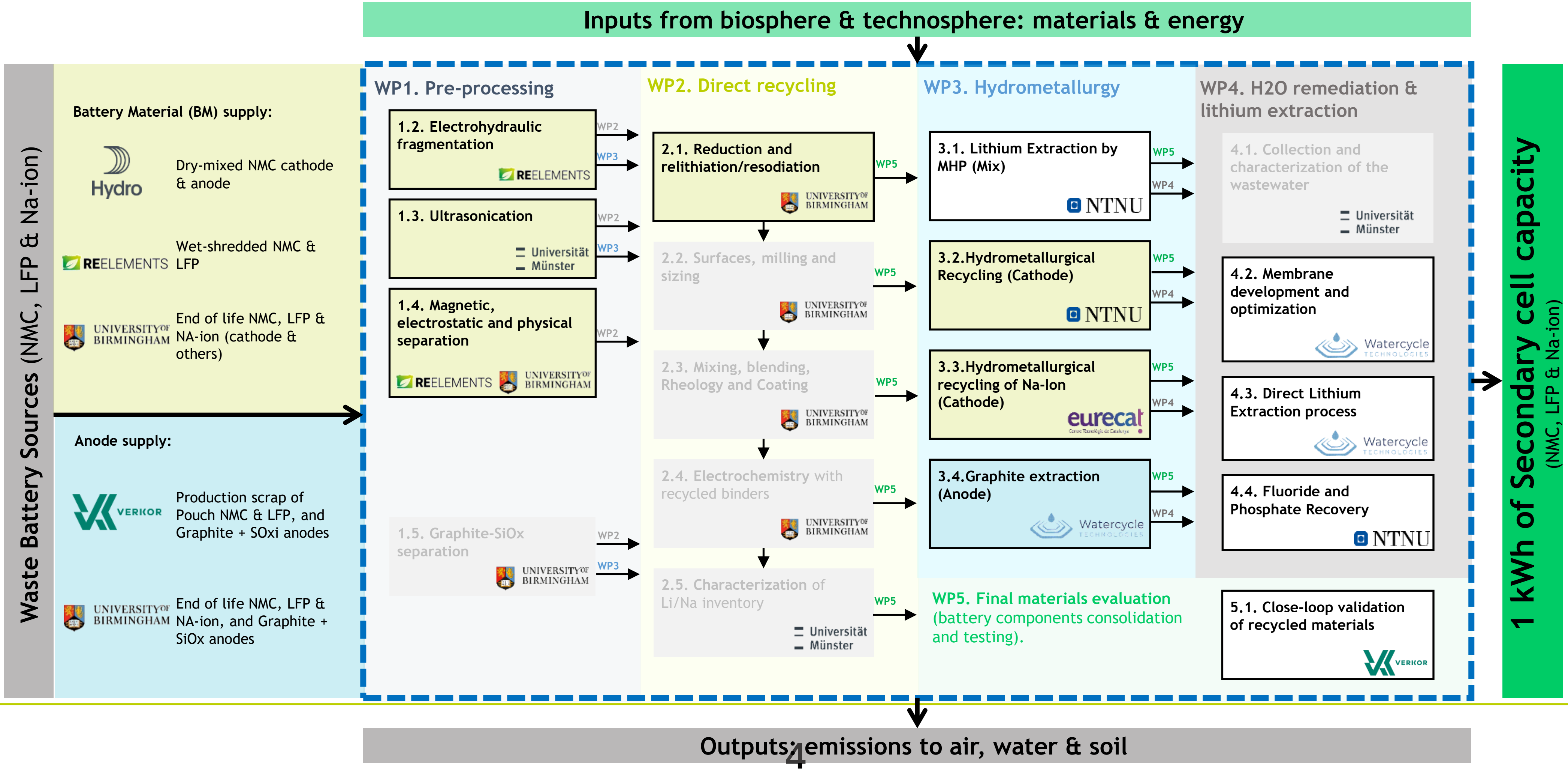
≥91%

Recycling rate target from post-production scrap and black mass across LIB and Na-ion chemistries.

REVITALISE integrated method

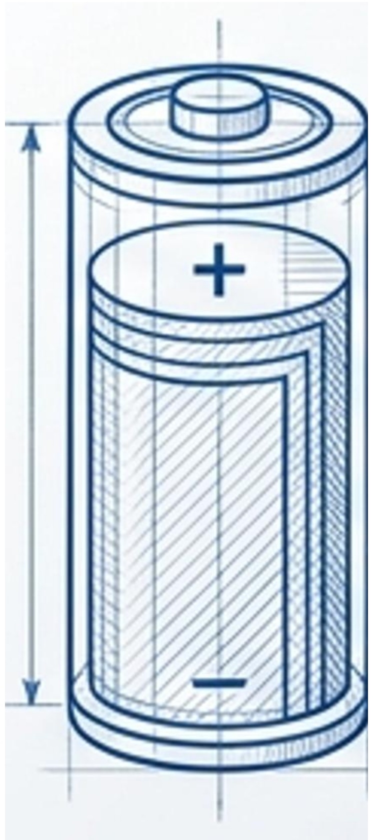
- ✓ High-purity pre-treatment
- ✓ 40% direct recycling
- ✓ Green hydrometallurgy
- ✓ H_2O remediation + lithium extraction

LCA Goal and Scope



LCA Goal and Scope

and the reality of implementation



Functional unit

Why 1 kWh?

- **Aligns strictly with the EU Battery Regulation and draft delegated acts**
- **Allows for true functional comparison across varying chemistries**

Also, requires more detailed information like material quality, cell performance, recovery yield...

LCA Goal and Scope

and the reality of implementation

Functional unit:

- Chosen:

1 kWh of the secondary cell's capacity

- However:
  - So far, assessments have been done in terms of **different FU/DUs for each task**:

Task	Functional Unit
Recycling of Hydrometallurgical Na-Ion (Cathode)	1 kg of waste Cathode from Na-ion battery
Ultrasonication	1kg of Active Material
Lithium Extraction by MHP (Mix)	1kg of waste NMC622 received
Hydrometallurgical Recycling (Cathode)	1kg of waste NMC111 Black Mass
Magnetic, electrostatic and physical separation	1kg of battery cell material
Reduction and relithiation/resodiation	1kg of waste cathodic material
Membrane development and optimization	1 kg of Membrane
Direct lithium extraction and crystallization	1L of wastewater

Integrated Sustainability Framework

Revitalise

LCA

- ISO 14040/14044
- SimaPro 9.5
- Ecoinvent 3.11
- Environmental Footprint 3.1

Connected by a single set of data

LCC

- ISO 15686-5
- Total Cost of Ownership
- Net Present Value
- Payback Period

CAPEX + OPEX over lifetime

Sustainability in Focus: Batt-Bridge Projects - Assessing recycling processes for a circular battery value chain

Alok Prasad, CyVi Group, University of Bordeaux

Online Webinar

Date: 09.07.2026

Co-funded by the European Union

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

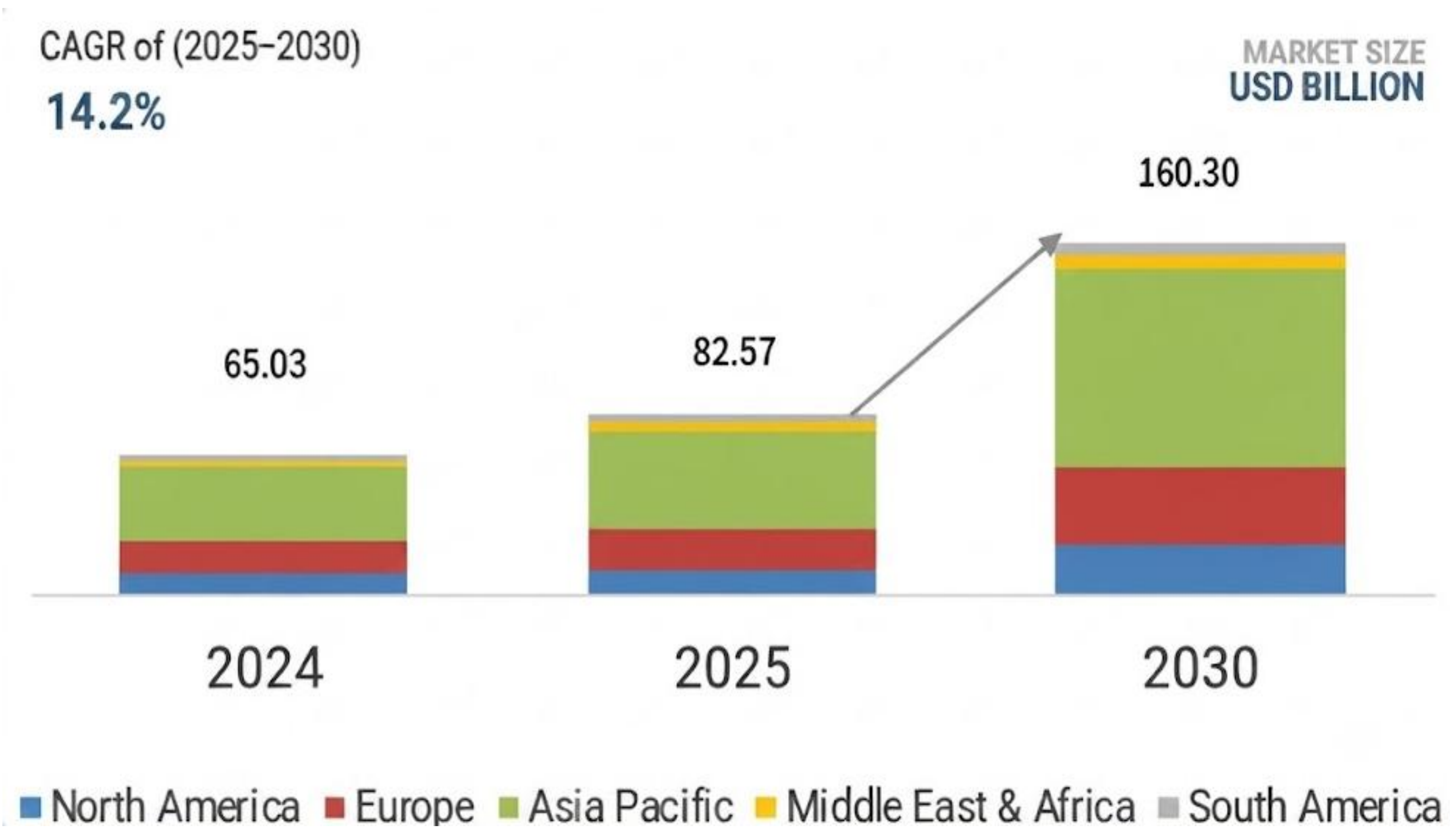
Session 1

Sustainability assessment approaches for innovative battery recycling

Growth of LFP Batteries and Recycling Challenges

Context

Lithium Iron Phosphate Batteries Market



Chemistry/ Criterion	Pyrometallurgy	Hydrometallurgy	Direct Recycling
LFP	**Low-**Lacks high-value metals (Ni, Co)	**Moderate**-Low economic return (no Ni, Co)	**High potential**-Recovers cathode/anode materials
	- Lithium often lost in slag	- High chemical use	- Preserves lithium
Economic Viability	**Poor** for LFP due to low-value metals	**Challenging** due to low-value metals	**Promising** if regenerated CAM/graphite meet quality
Environmental Impact	High energy use, GHG emissions, slag waste	High chemical use, wastewater generation	**Depends on** energy/chemical use, minimal waste
Material Recovery	Limited (Li loss, focus on Ni/Co)	High (Li, Ni, Co recoverable)	**Preserves active materials**, Li recovery)

Co-funded by the European Union

LFP Market: MarketsandMarkets, Lithium Iron Phosphate Batteries Market, 2025–2030
Adapted from : H. Rostami, J. Valio, P. Tynjälä, U. Lassi, P. Suominen, ChemPhysChem2024, 25, e202400459. https://doi.org/10.1002/cphc.202400459

ReUse case: sustainability assessment for direct recycling of LFP

The ReUse Project

The project ReUse will investigate and develop **novel processes for the direct recycling of lithium iron phosphate (LFP)-based lithium-ion batteries (LiBs) and their production waste.** The recycling concept will be widely applicable to upcoming and future low-cost battery technologies.

- Introduction of new disruptive technologies for the direct recycling of all components of LFP EoL batteries.
- ReUse applies automated sorting, deactivation, and cell disassembly to recover pure materials.

Early-Stage Sustainability

To carry out the Sustainability assessment integrating the **environmental, economic, social, circularity, and raw materials criticality** of the new recycling processes

The contribution of the project ReUse in the battery value chain is shown with green arrows.

LC³SA for ReUse: One Recycling System, Five Lenses

Assessment Framework

LC³SA GOAL & SCOPE

Evaluate ReUse direct recycling routes for LFP end-of-life cells and production waste across environmental, economic, social, circularity, and raw-material criticality dimensions and compare with waste management practices

LC³SA

LCA: Environmental	EF 3.1 Method	Climate change, energy use, water scarcity, mineral resource use, particulate matter, acidification. Functional Unit: Direct recycling of 1 kg battery cells/ recovered CAM
LCC: Economic	eLCC Approach	Solvent input, energy, labor, equipment, waste treatment, recovered product credit. Aligned with LCA functional unit; tracks scale-up economic drivers
S-LCA: Social	IP S-LCA Screening	Worker safety, chemical exposure, community wastewater risk, value chain actor screening. Reference-scale indicators focused on early-stage hotspots
Circularity: Material	Inventory-based	CAM/Graphite recovery yield (%), quality index (re-usability), loop closure rate. Material Circularity Indicator (MCI)
Criticality: Risk	GeoPolRisk Method	Supply risk exposure for Li and Natural Graphite (EU CRM 2023), Fe, P, Al, Cu. Outside-in lens: Does secondary recovery reduce geopolitical risk?

MIDPOINT INDICATORS ONLY — NO AGGREGATION INTO A SINGLE SCORE

AREAS OF PROTECTION

- Natural Environment→ LCA
- Human Health→ LCA + S-LCA
- Human Well-being→ S-LCA
- Prosperity→ LCC + Criticality
- Resources→ LCA + Circularity + Criticality

GeoPolRisk Method: Koyamparambath et al., 2022 ; LC³SA: Hackenhaar et al., 2024

Circularity and Raw-Material Criticality: Beyond LCSA

Assessment Framework

CIRCULARITY

HOW MUCH IS RECOVERED? CAM Yield (%) and Graphite Yield (%) mass recovery tracking.

AT WHAT QUALITY? Electrochemical re-usability: capacity retention, impedance, stability.

DOES THE LOOP CLOSE? Verification of cell-grade re-entry vs. low-value downcycling.

Inventory-based CE indicators (Type 1 & 2 per Moraga et al. 2019)

EoL LFP Cell > **Direct Recycling** > Recovered CAM > Cell Mfg.

CRITICALITY

GEOPOLRISK METHOD Integrates trade-weighted political stability with import dependency and market concentration (HHI).

STRATEGIC FOCUS (*2023 CRMA*) LFP avoids Co/Ni risk, but remains dependent on:

Lithium (Li) · Natural Graphite · Phosphorus (P) · Iron (Fe) · Copper (Cu) · Aluminum (Al)

KEY QUESTION Does secondary recovery from LFP meaningfully reduce the EU's geopolitical supply-risk exposure?

LCA → Inside-Out: Product System → Environment (Impacts)

Criticality → Outside-In: Geopolitics → Product System (Risks)

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LC³SA: Hackenhaar et al., 2024

How Assessment Supports Process Optimisation in ReUse

PROCESS DECISION POINT	LC³SA OPTIMISATION QUESTION
Solvent recovery	Lower fresh solvent burden vs. recovery energy and cost: what is the net benefit crossover?
CAM/graphite yield	Higher recovery rate vs. extra processing burden (energy, reagents): at what yield is the trade-off positive?
Material quality	Real loop closure (cell-grade) vs. downcycling? What quality threshold closes the loop?
Regeneration steps	Quality improvement vs. energy demand and reagent use: is there a sweet spot?
Waste treatment	Are environmental burdens shifted from air to water? Are social safety risks introduced?
Criticality gains	Can secondary recovery reduce supply-risk exposure under specific assumptions?

Assessment-feedback cycle

Process Data Collection

Assessment Model

Hotspot Identification

Process Adjustment

Updated System Model

CONTINUOUS FEEDBACK CYCLE

Ex-Ante Assessment, Upscaling and Fair Comparison

1. MEASURED (LAB/PILOT)

Mass balances, energy measurements, solvent consumption, residue composition.

2. ASSUMPTIONS (SCALE-UP)

Scale-up factors, electricity grid, solvent recovery rates, waste treatment.

3. SCENARIOS

Optimistic, reference, and conservative recovery yield and quality models.

Sensitivity Analysis

Identify parameters driving the results most significantly.

Uncertainty ranges / Monte Carlo if data distributions are available

Propagate uncertainty through range-based modeling.

Data Quality (DQI)

Scoring per inventory entry to flag data maturity levels.

Source Separation

Explicitly separate measured vs. assumed vs. modeled data.

FAIR COMPARISON CHECKLIST

- [x] Functional Unit (kg input / kWh)
- [x] System Boundary (Gate-to-Gate)
- [x] TRL Level (Lab vs. Industrial)
- [x] Data Source Reliability
- [x] Recovery Yield (Mass %)
- [x] Recovered Product Quality
- [x] Allocation / Credit Rules
- [x] Uncertainty Range Reported

! A single CO_2 number without this metadata is not comparable across different projects or technologies.

Co-funded by the European Union

Ex Ante: Cucurachi et al., 2018

STREAMS

SUSTAINABLE TECHNOLOGIES FOR REDUCING EUROPE'S BATTERY RAW MATERIALS DEPENDANCE

Session 1: Sustainability assessment approaches for innovative battery recycling

Location: Webinar

Date: 09/07/2026

Daniel Dias

Research Associate @ Imperial College London

Funded by the European Union

Funded by the European Union's Horizon Europe research and innovation programme under the Grant Agreement No 101137771. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.

Introduction

STREAMS: Introduction

Description

In STREAMS, a comprehensive portfolio of at least 12 scalable and flexible technologies and pilot scale solutions for the sustainable production of battery-grade precursors and their respective anode and cathode active materials will be developed, evaluated and successfully demonstrated.

These technological processes will be applied to materials from primary and secondary sources including recycled battery mass and photovoltaic waste.

STREAMS' technological solutions will meet EU requirements for environmentally responsible design, and scale up, and anticipate regulatory compliance by conducting techno-economic, environmental, social impact and integrated risks assessments combined with life cycle sustainability and circularity assessments.

The project aims to advance sustainable battery technologies, contributing to Europe's resilience and competitiveness. In its pursuit, STREAMS will focus on four key areas:

OBJECTIVES

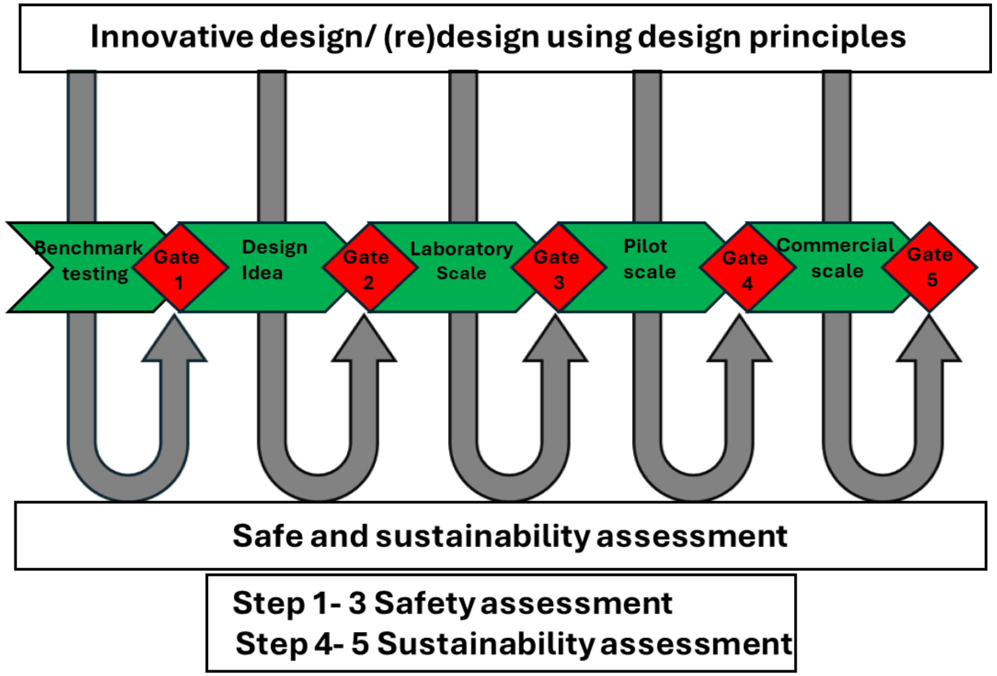
- Fortify Europe's battery materials **supply chain**;
- **Reduce dependency** on imports and improving resilience, competitiveness, and strategic autonomy;
- **Development and demonstration** of a versatile portfolio of sustainable technologies;
- Use of diverse **primary and secondary** sources;
- Implementing **circular models**;
- **Manufacturing** battery cells at a pilot scale

Strengthening the Domestic Supply Chain	Comprehensive Technological Solutions	Utilisation of Diverse Material Streams	Circular Models for Sustainability
Elevating Europe's battery materials supply chain, reducing dependency on imported raw materials, and enhancing resilience, competitiveness, and strategic autonomy.	Pioneering a portfolio of at least 12 flexible and scalable technologies for sustainable production of battery-grade precursors, anode, and cathode active materials.	Promoting the use of various primary and secondary sources, along with recycled battery mass, to decrease reliance on third countries.	Developing circular models, manufacturing battery cells at a pilot scale, and testing to identify optimal conditions for future project result exploitation.

Sustainability assessment approach

STREAMS: Sustainability assessment approaches for innovative battery recycling

Eco-design approach based on the SSbD



Stage 1: (re)design phase
Principles to be considered to maximise the possibilities of a successful safety and sustainability assessment outcome

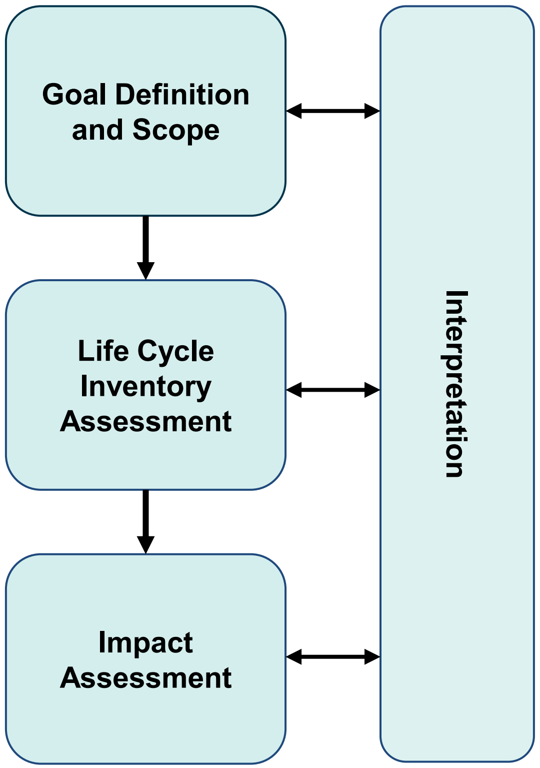
Stage 2: Safety and sustainability assessment
Step 1 - Hazard assessment of the chemical/material
Step 2 - Human health and safety aspects in the chemical/material production and processing phase
Step 3 - Human health and environmental aspects in the final application phase
Step 4 - Environmental sustainability assessment
Step 5- Socio-economic assessment

#	Phase	Design Principles
1	(re)design phase	Material efficiency
		Minimise the use of hazardous chemicals/materials
		Design for energy efficiency
		Use renewable sources
		Prevent and avoid hazardous emissions
		Reduce exposure to hazardous substances
		Design for end-of-life
		Consider the whole life cycle
		Design for circularity
		Design for supply chain resilience
		Design for electrochemical safety
		Design for thermal safety
		Design for mechanical integrity

Tailored to innovative battery development

STREAMS: Sustainability assessment approaches for innovative battery recycling (environmental)

Environmental sustainability (step 4) was assessed using life cycle assessment and the Environmental Footprint method

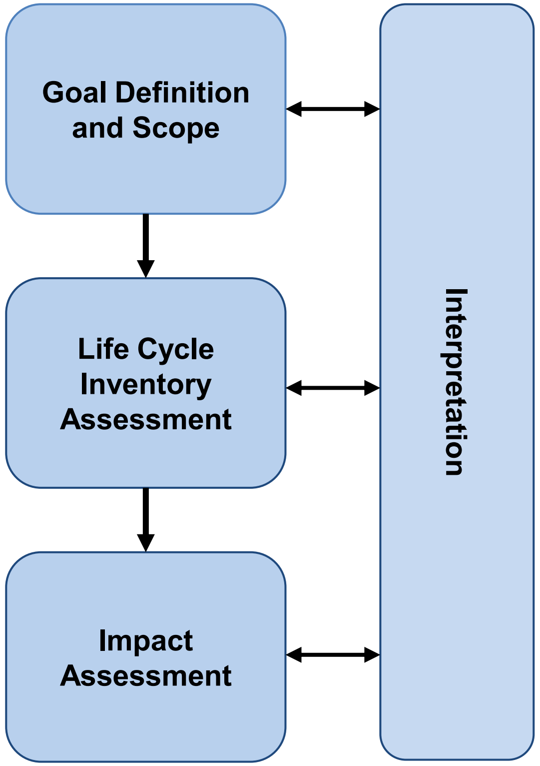


Life cycle assessment Components

S/N	Impact category	Abbreviation	Unit
1	Acidification	AF	mol H+-Eq
2	Climate Change	CC	kg CO_2-Eq
3	Ecotoxicity: freshwater	FET	CTUe
4	Energy resources: non-renewable	ER	MJ, net calorific value
5	Eutrophication: freshwater	FE	kg P-Eq
6	Eutrophication: marine	ME	kg N-Eq
7	Eutrophication: terrestrial	TE	mol N-Eq
8	Human toxicity: carcinogenic	HTc	CTUh
9	Human toxicity: non-carcinogenic	HTnc	CTUh
10	Ionising radiation: human health	IR	kBq U235-Eq
11	Land use	LU	dimensionless
12	Material resources: metals/minerals	MR	kg Sb-Eq
13	Ozone depletion	OD	kg CFC-11-Eq
14	Particulate matter formation	PMF	disease incidence
15	Photochemical oxidant formation: human health	POF	kg NMVOC-Eq
16	Water use	WU	m^3 world eq. deprived

Scoring
"0" when the alternative presents impacts 10% higher than the reference, **"1"** when results from the alternative are from 10% higher to 5% lower, **"2"** when results of the alternative are 5% lower to 10% lower, and **"3"** when results of the alternative are 20% lower or more

STREAMS: Sustainability assessment approaches for innovative battery recycling (social)



Social life cycle assessment components

S/N	Impact category
1	Association and bargaining rights
2	Violations of employment laws
3	Workers affected by natural disasters
4	Pollution
5	Trafficking in persons
6	Minerals consumption
7	Sanitation coverage
8	Embodied water footprints
9	DALYs due to indoor and outdoor air/water pollution
10	Indigenous rights

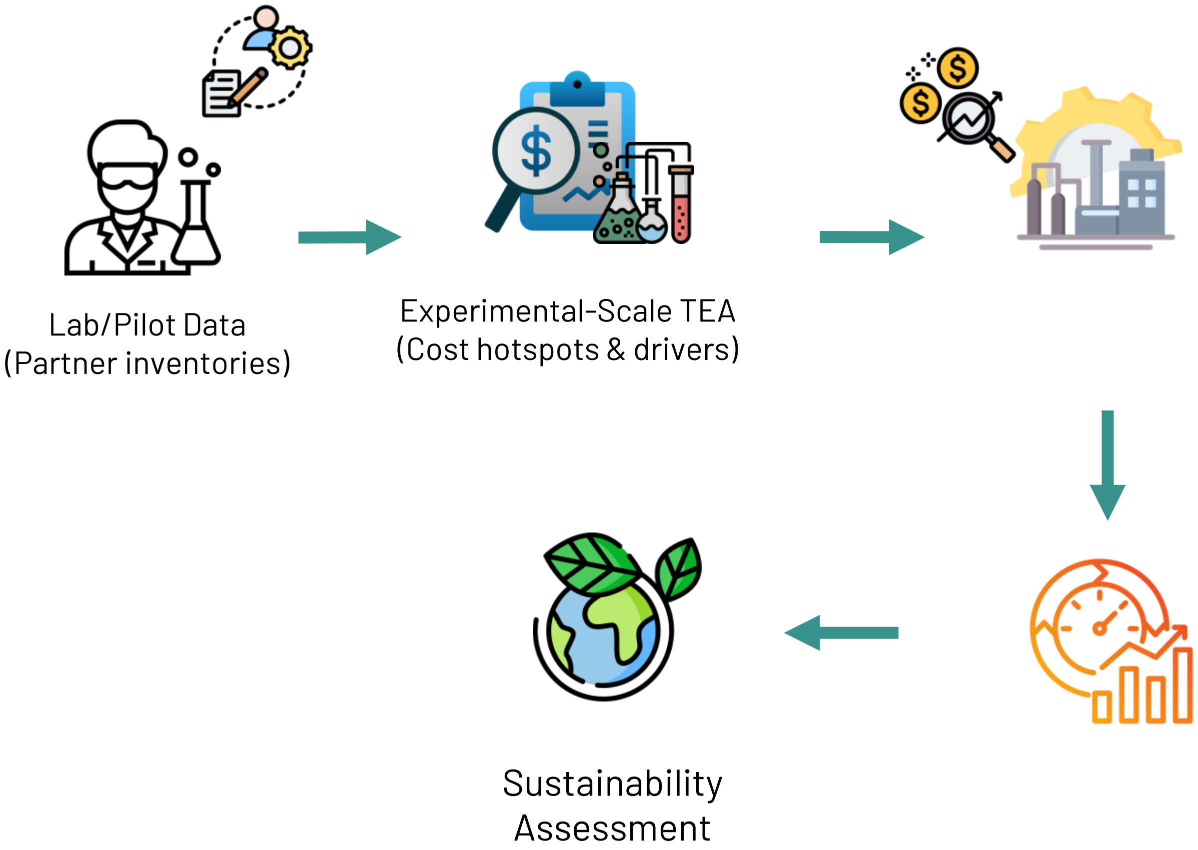
Scoring
"0" when the alternative presents impacts 10% higher than the reference, **"1"** when results from the alternative are from 10% higher to 5% lower, **"2"** when results of the alternative are 5% lower to 10% lower, and **"3"** when results of the alternative are 20% lower or more

STREAMS: Assessing Economic Sustainability of Battery Recycling (The STREAMS TEA Framework)

Why TEA?

- Europe depends heavily on imported critical raw materials for batteries
- Novel recycling technologies need economic validation before scale-up
- TEA bridges the gap between lab-scale experiments and industrial viability

Our Approach



+10 STREAMS process routes assessed | Li · Ni · Co · Mn · Graphite recovery | Hydrometallurgical · Electrochemical · Thermal · Membrane-based technologies

STREAMS: TEA as a Sustainability Tool — Beyond Profitability

STREAMS
SUSTAINABLE TECHNOLOGIES FOR REDUCING EUROPE'S BATTERY RAW MATERIALS DEPENDANCE

Experimental Scale

- Variable OPEX only
- Cost hotspot identification
- Material & energy intensity
- Based on lab data

Industrial Scale

- Full CAPEX + OPEX
- MSP vs market price
- NPV & payback period
- Engineering scale-up

Sustainability Link

- Feeds SSbD framework
- Identifies resource-intensive steps
- Guides process optimisation
- Supports circular economy goals

Methodology validated & published: Gkousis et al. (2026). Resources, Conservation and Recycling, 232, 108993

STREAMS: TEA as a Sustainability Tool — Beyond Profitability

STREAMS
SUSTAINABLE TECHNOLOGIES FOR REDUCING EUROPE'S BATTERY RAW MATERIALS DEPENDANCE

1. Scale-up transforms economics

Process	Lab Cost	Industrial MSP	Market price
Electrochemical Li recovery	€1,040/kg	**€10.95/kg**	€17.70/kg ✅
Spray drying NMC CAM	€175,000/kg	**€6.79/kg**	€10.31/kg ✅
Graphite from biochar	—	**€9.54/kg**	€15/kg ✅

2. TEA identified the decisive economic levers

Feedstock cost

zero-cost secondary streams are a major advantage

Co-product revenues

NaOH, graphite, scrap metals are often essential

Reagent consumption

extractants dominate OPEX in membrane processes

CAPEX intensity

51–64% of total costs in direct recycling

3. What this means for sustainable battery recycling

TEA results directly inform **where to focus optimisation efforts** — reducing extractant losses, improving electrode lifetime, maximising co-product valorisation

S T R E A M S

SUSTAINABLE TECHNOLOGIES
FOR REDUCING EUROPE'S BATTERY
RAW MATERIALS DEPENDANCE

Thank you

Daniel Dias

Research Associate @
Imperial College London
d.dias@imperial.ac.uk

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the European Union

Funded by the European Union's Horizon Europe research and innovation programme under the Grant Agreement No 101137771. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.

HighMag

High-energy, low-cost and scalable generation 5 magnesium-based batteries for mobility applications and beyond

Session 1: Sustainability assessment approaches for innovative battery recycling

COMPANY | REPRESENTATIVE

Daniel Dias

Research Associate @ Imperial College London

Funded by the European Union

Introduction

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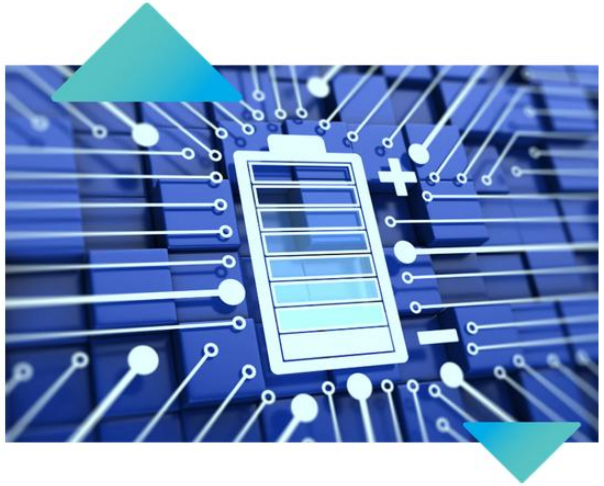
the European Union

HighMag: Introduction

DESCRIPTION

HighMag is a four-year European research project, funded by the EU's Horizon Europe programme and backed by CINEA. It brings together 13 academic and industrial partners from across Europe, Switzerland and Israel to tackle one of the most urgent challenges in energy storage: developing sustainable alternatives to lithium-ion technology.
At the core of HighMag is a focus on Rechargeable Magnesium Batteries (RMBs) – a Generation 5 battery technology that harnesses magnesium's natural abundance, lower cost, and enhanced safety. These attributes make RMBs a promising solution for next-generation mobility and other high-energy applications.



HighMag's objective is to advance RMBs from Technology Readiness Level (TRL) 2 to TRL 4, through:

Developing innovative cathode and anode materials	Optimising essential battery components	Applying advanced characterisation techniques
Embedding Safe and Sustainable by Design (SSbD) principles across all research phases	Ensuring compatibility with existing lithium-ion production infrastructure to enable future industrial scalability	Through this collaborative effort, HighMag is committed to delivering a sustainable, high-performance battery solution that supports Europe's transition to a greener and more resilient future.

OBJECTIVES

- Offer a **sustainable and low-cost** alternative to Li-ion batteries;
- Advance two Generation 5 **rechargeable magnesium** batteries;
- **Enhanced energies**: a magnesium-sulphur battery with a conversion cathode and a magnesium metal battery with an insertion cathode.

Expected Impacts

- ✓ Sustainable Materials
- ✓ Cleaner Chemistry
- ✓ Circular Economy
- ✓ Lower Battery costs
- ✓ Enhanced safety
- ✓ Strengthened EU Industry
- ✓ Strategic Autonomy
- ✓ Greener Mobility
- ✓ TRL Advancement
- ✓ High Performance
- ✓ Fast Charging
- ✓ Long Lifespan
- ✓ Fundamental Insight

Session 1: Sustainability assessment approach

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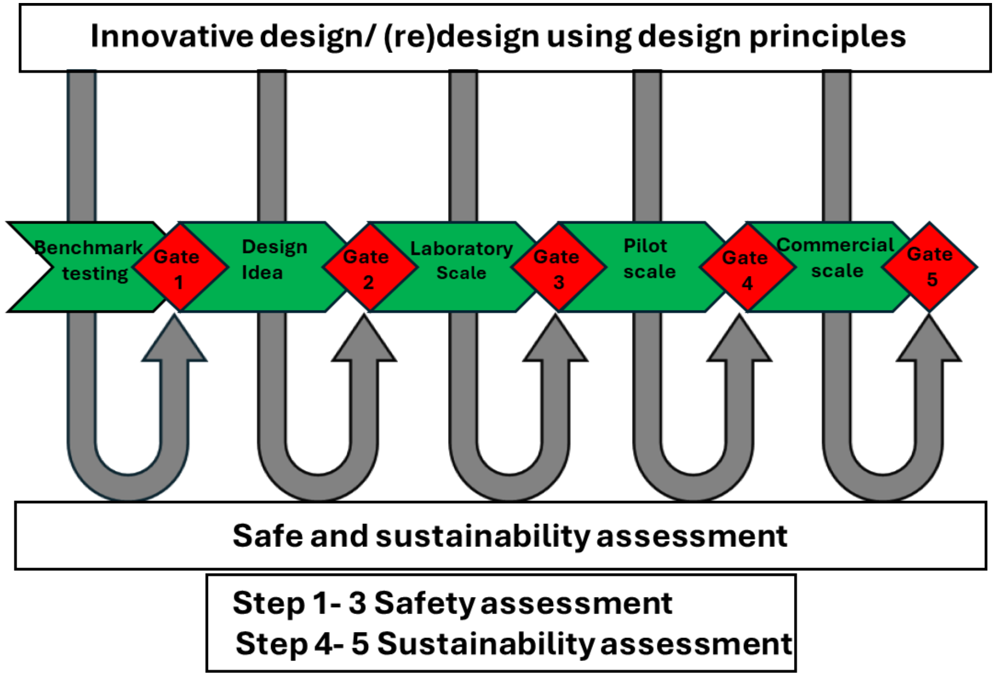
HighMag: Sustainability assessment approaches for innovative battery recycling



Stage 1: (re)design phase
Principles to be considered to maximise the possibilities of a successful safety and sustainability assessment outcome

Stage 2: Safety and sustainability assessment
Step 1 - Hazard assessment of the chemical/material
Step 2 - Human health and safety aspects in the chemical/material production and processing phase
Step 3 - Human health and environmental aspects in the final application phase
Step 4 - Environmental sustainability assessment
Step 5- Socio-economic assessment

#	Phase	Design Principles
1	(re)design phase	Material efficiency
		Minimise the use of hazardous chemicals/materials
		Design for energy efficiency
		Use renewable sources
		Prevent and avoid hazardous emissions
		Reduce exposure to hazardous substances
		Design for end-of-life
		Consider the whole life cycle
		Design for circularity
		Design for supply chain resilience
		Design for electrochemical safety
		Design for thermal safety
		Design for mechanical integrity

Tailored to innovative battery development

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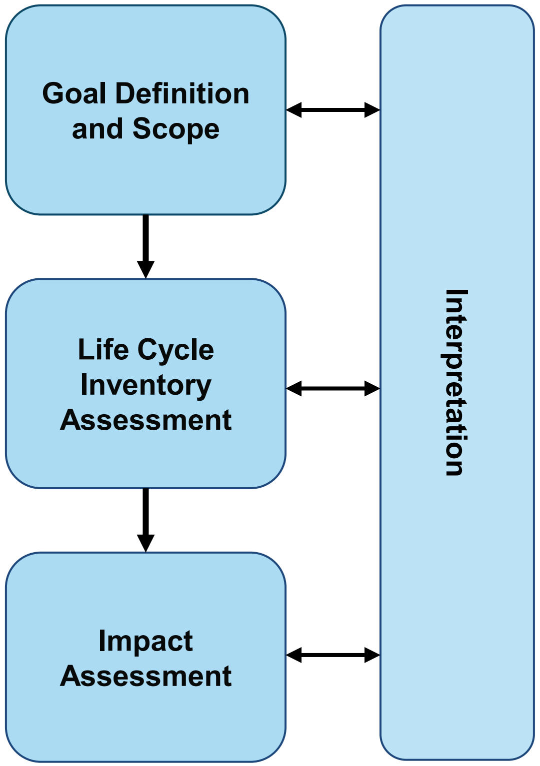
HighMag: Sustainability assessment approaches for innovative battery recycling (environmental)

HighMag

Environmental sustainability (step 4) was assessed using life cycle assessment and the Environmental Footprint method



Life cycle assessment Components

S/N	Impact category	Abbreviation	Unit
1	Acidification	AF	mol H+-Eq
2	Climate Change	CC	kg CO_2-Eq
3	Ecotoxicity: freshwater	FET	CTUe
4	Energy resources: non-renewable	ER	MJ, net calorific value
5	Eutrophication: freshwater	FE	kg P-Eq
6	Eutrophication: marine	ME	kg N-Eq
7	Eutrophication: terrestrial	TE	mol N-Eq
8	Human toxicity: carcinogenic	HTc	CTUh
9	Human toxicity: non-carcinogenic	HTnc	CTUh
10	Ionising radiation: human health	IR	kBq U235-Eq
11	Land use	LU	dimensionless
12	Material resources: metals/minerals	MR	kg Sb-Eq
13	Ozone depletion	OD	kg CFC-11-Eq
14	Particulate matter formation	PMF	disease incidence
15	Photochemical oxidant formation: human health	POF	kg NMVOC-Eq
16	Water use	WU	m^3 world eq. deprived

Scoring

"0" when the alternative presents impacts 10% higher than the reference, **"1"** when results from the alternative are from 10% higher to 5% lower, **"2"** when results of the alternative are 5% lower to 10% lower, and **"3"** when results of the alternative are 20% lower or more

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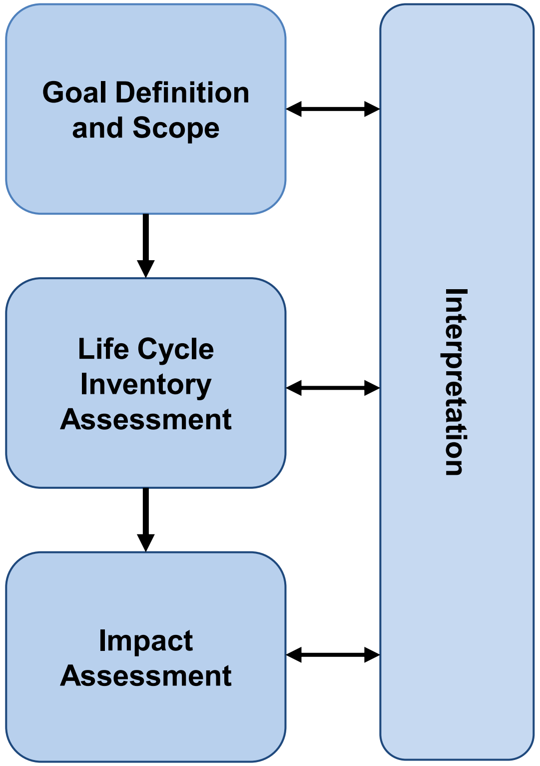
HighMag: Sustainability assessment approaches for innovative battery recycling (social)



Social life cycle assessment components

S/N	Impact category
1	Association and bargaining rights
2	Violations of employment laws
3	Workers affected by natural disasters
4	Pollution
5	Trafficking in persons
6	Minerals consumption
7	Sanitation coverage
8	Embodied water footprints
9	DALYs due to indoor and outdoor air/water pollution
10	Indigenous rights

Scoring
"0" when the alternative presents impacts 10% higher than the reference, **"1"** when results from the alternative are from 10% higher to 5% lower, **"2"** when results of the alternative are 5% lower to 10% lower, and **"3"** when results of the alternative are 20% lower or more

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HighMag: Assessing Economic Sustainability of Battery Recycling (The HighMag TEA Framework)

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Q & A

SESSION 2 Validating sustainability approaches

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Michael Hess
Battronics

James Duong
University of Greenwich

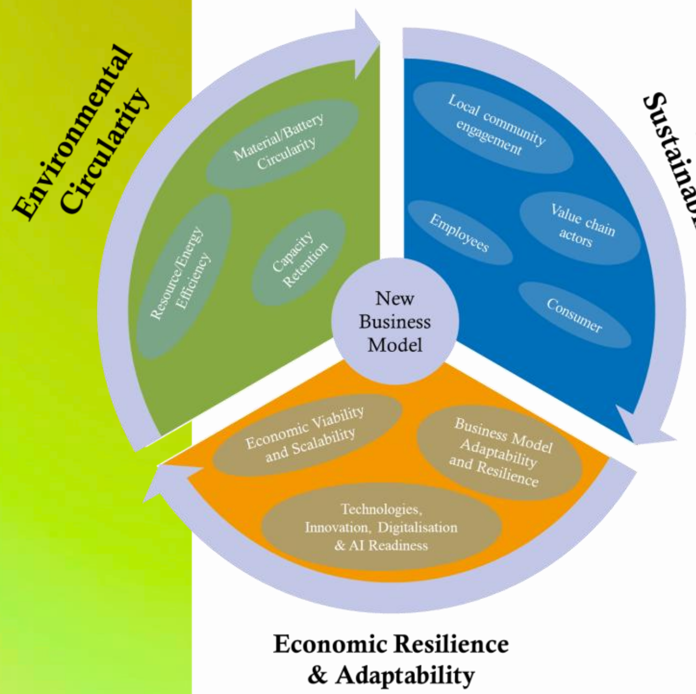
Pushpendra Chabrawal
KIT-HIU

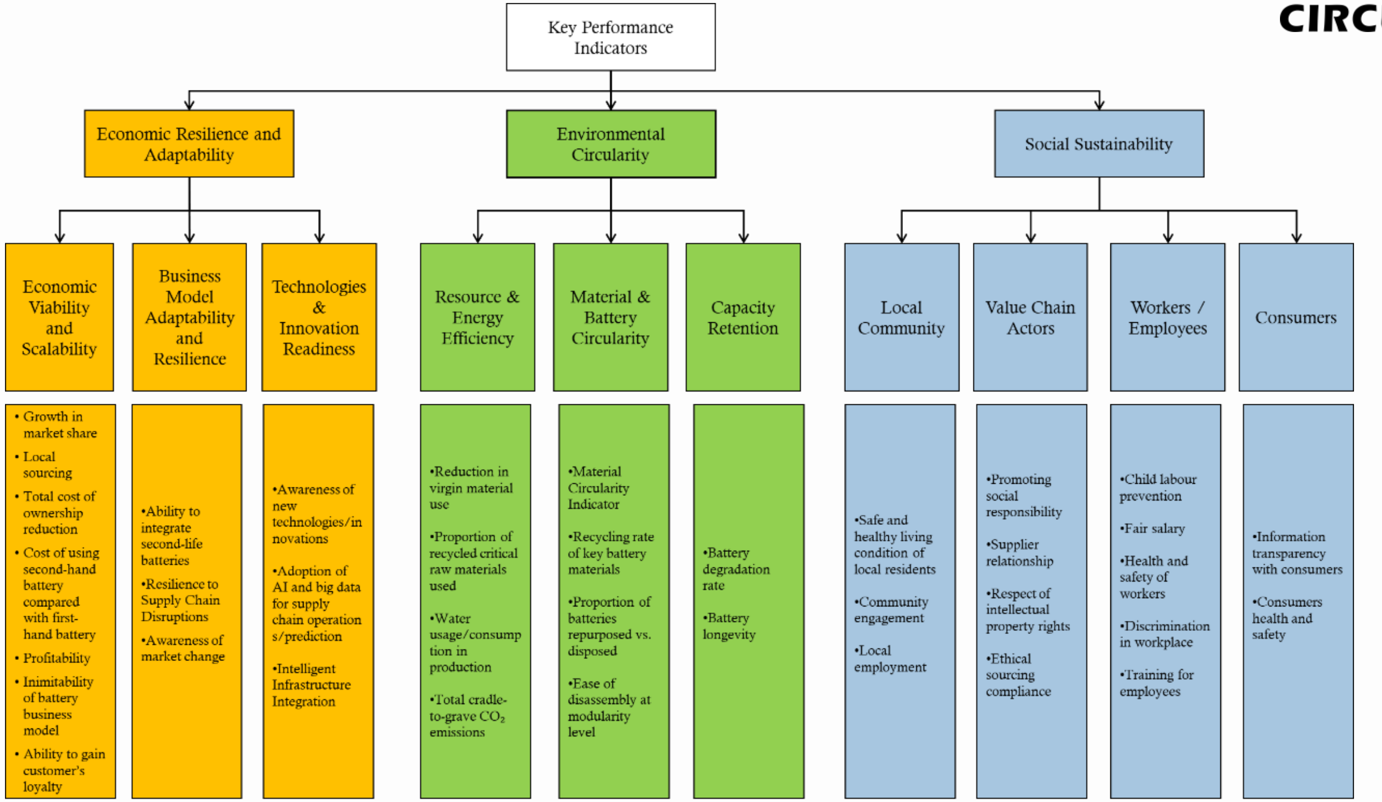
Violeta Vargas
Eurecat

Alok Prasad
University of Bordeaux

Daniel Dias
Imperal College London

Battery Business Model Methodology Assessment Framework: Multi-Criteria Decision Analysis Approach





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)
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)
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)

- 13 KPIs in Economic Resilience and Adaptability
- 10 KPIs in Environmental Circularity
- 14 KPIs in Social Sustainability

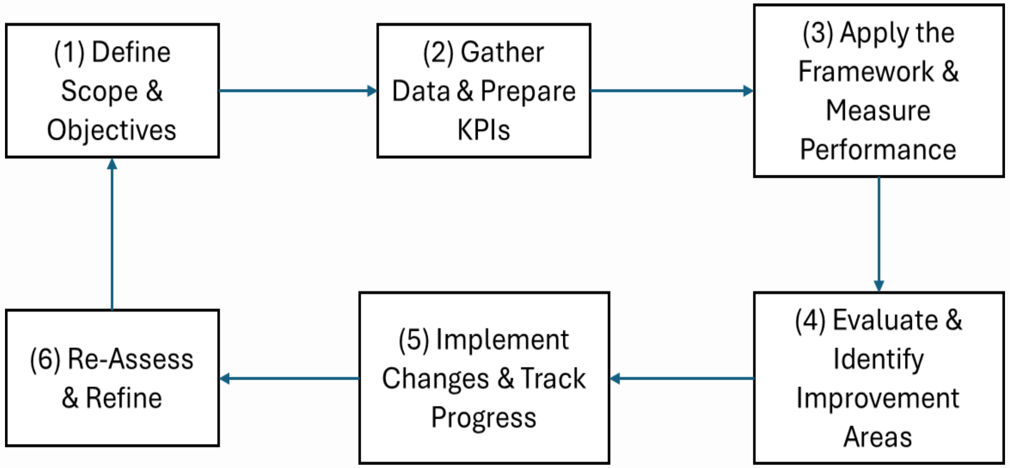
=> The KPIs were validated by **41 EVB experts and 4 semi-structured interviews.**

UNIVERSITY OF GREENWICH

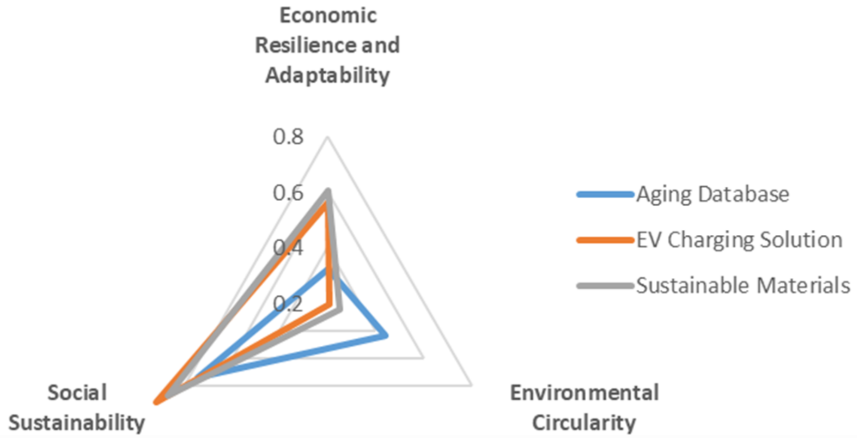
Battery Business Model Methodology Assessment Framework: Multi-Criteria Decision Analysis Approach

CIRCUBATT

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

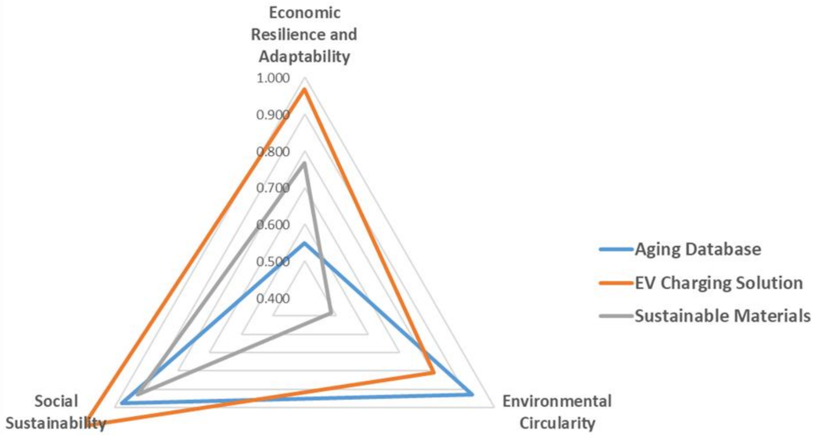


Six Implementation Steps



The Full Framework Score

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



Model-Specific Score

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

Contact Us

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BATT-BRIDGE Webinar
Sustainability in Focus: Batt-Bridge Projects – Assessing recycling processes for a circular battery value chain

Session 2:
Validating sustainability approaches

RENOVATE

A circular and chemistry-neutral approach for recycling and recovery of battery waste feeds

Karlsruhe Institute of Technology

HELMHOLTZ INSTITUTE ULM
Electrochemical Energy Storage

9 July 2026 (Online)

By: Pushpendra, Marcel Weil

Helmholtz Institute Ulm (HIU)/Karlsruhe Institute of Technology (KIT), Germany

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Learnings/Challenges at lab-scale LCAs

✓ **Different** ways of energy data collection **lead** to different LCA numbers!

Estimation Vs Measurements

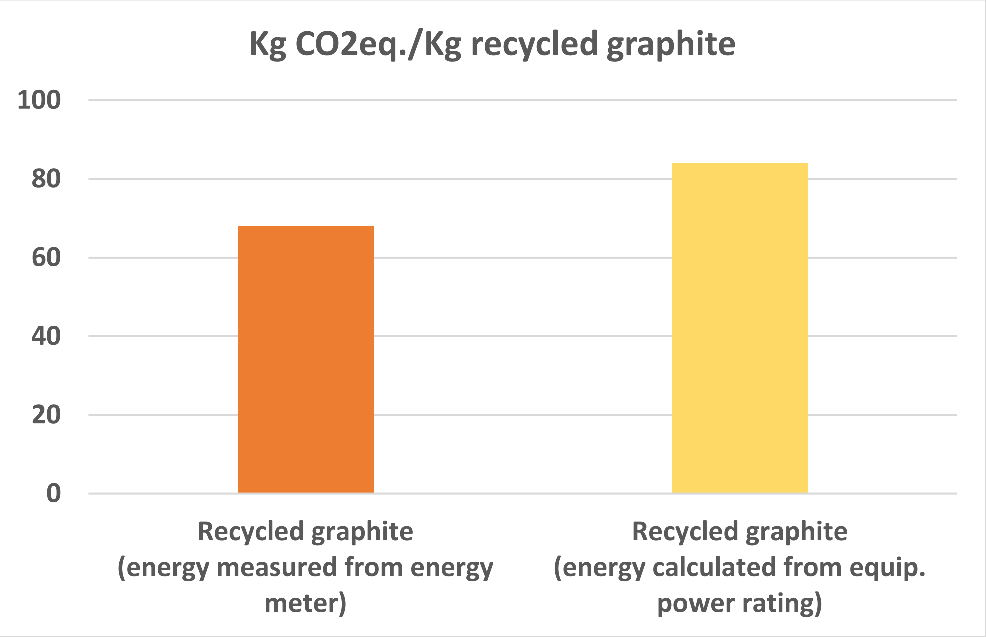


Fig: Comparison of (initial) GWP for recycled graphite at lab-scale with data collection methods for energy

✓ Role of **Utilization factor (UF)** of equipment in lab-scale LCA results

No utilization factor → **(may) lead** to wrong hotspot identification

Small size oven

With UF =

Big size oven

Challenges for upscaling

- ✓ Upscaling was the **most time consuming** stage
- ✓ **Require** good to expert level of knowledge of process engineering for a detailed upscaling
- ✓ Upscaling the process that are **not directly translated** to industrial-scale from lab-scale is very **difficult,** embed many assumptions, and **require expert knowledge** on specific processes
- ✓ Several assumption for internal heat and materials recovery streams

Fig: Single unit-operation for flotation at lab-scale

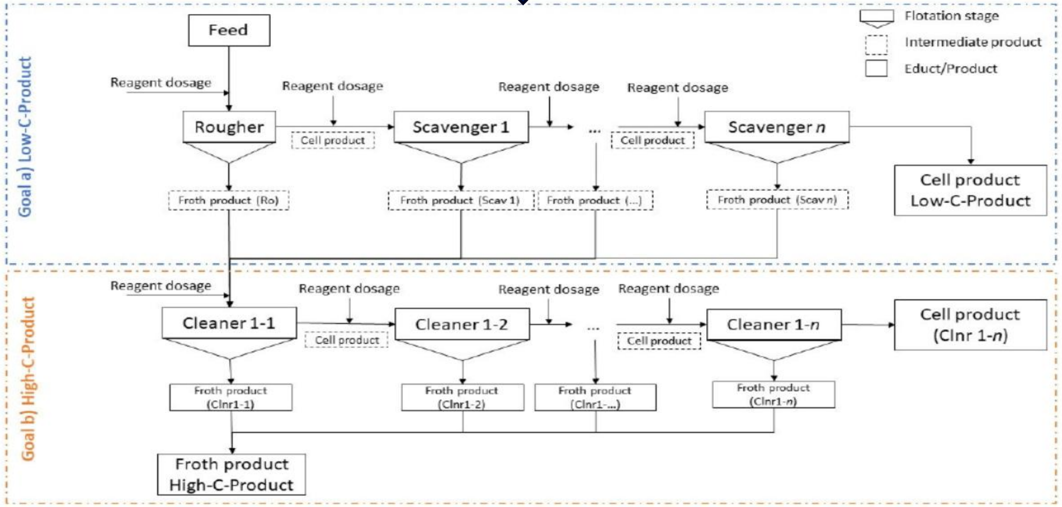


Fig: Multiple unit-operations at industrial-scale

Impacts of allocation type & substituted products on LCA results

- ✓ **Different** allocation leads to different LCA results for recovered products!

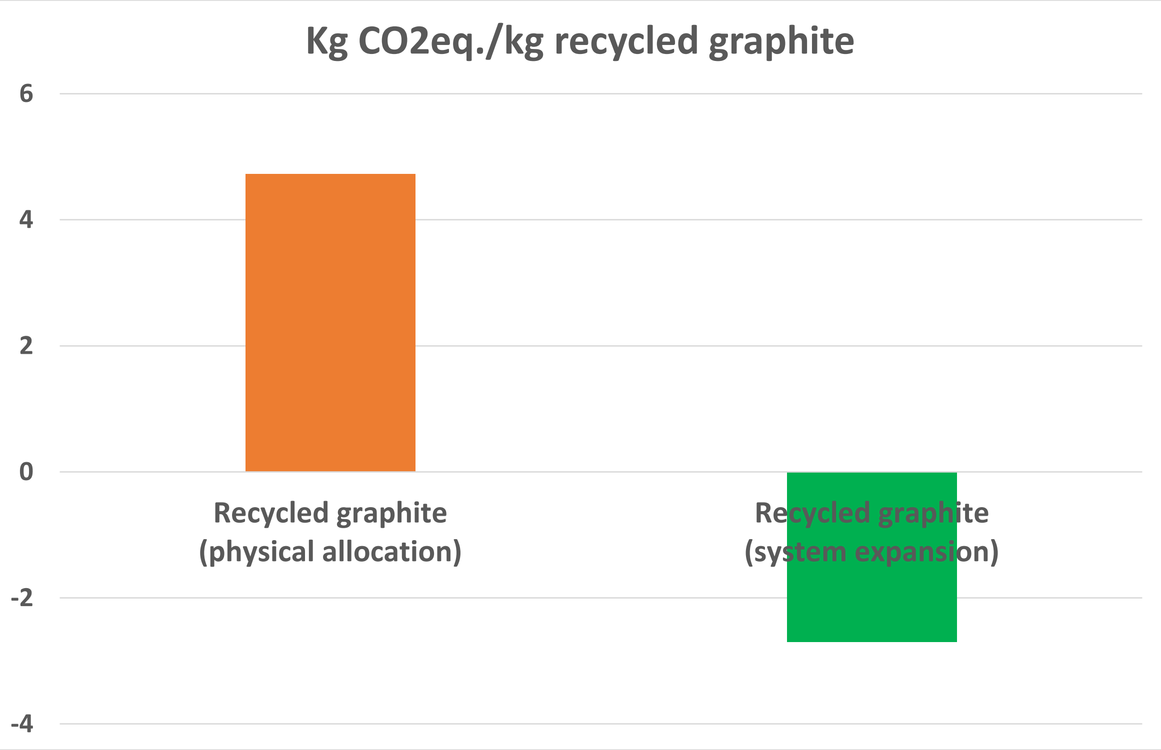


Fig: (initial) GWP for recycled graphite. Left bar: mass-based allocation for the co-product LFP; right bar: co-product LFP is further purified to achieve battery grade quality and substituted with primary LFP

- ✓ Results of recycled LFP **sensitive** to the **substitution** of recycled graphite (credits from NG or SG or blend) for system expansion approach.

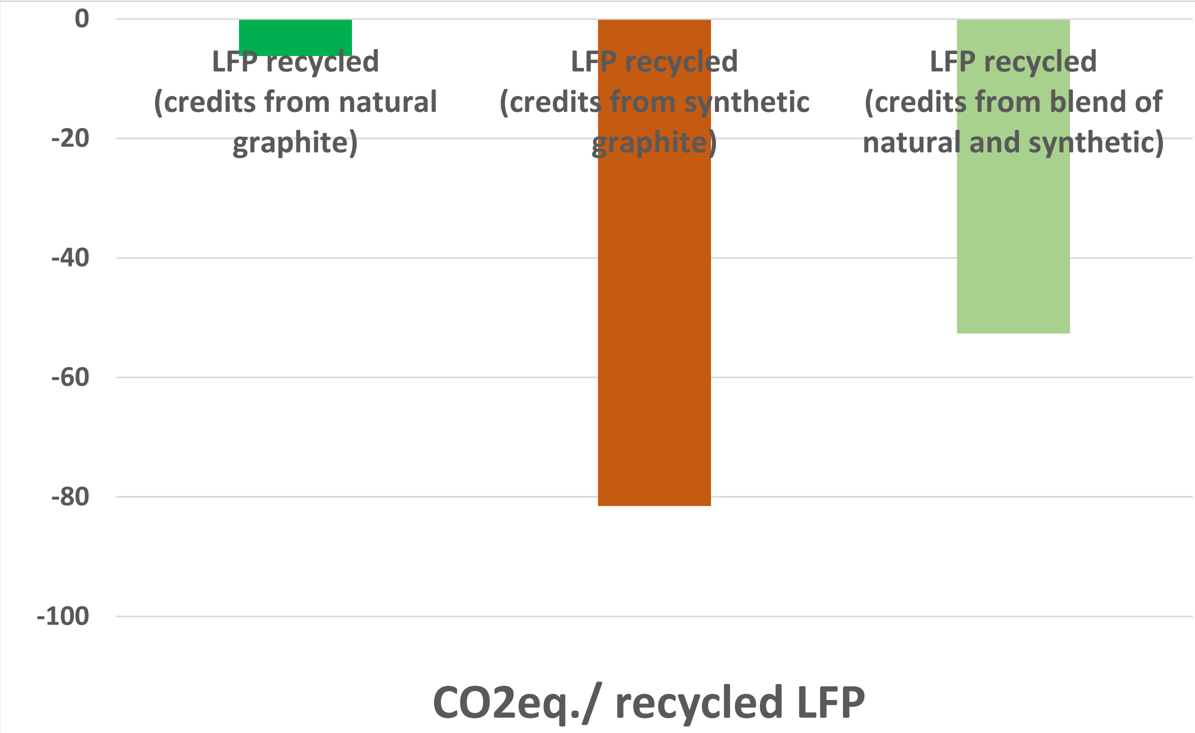


Fig: (initial) GWP for recycled LFP at industrial scale

Addressing the uncertainty & capturing full range of possible LCA outcomes of RENOVATE process

- ✓ Different scenarios to capture the full range of possible outcomes
- ✓ **SIMPL**[1] framework for plausible scenario generation for PLCAs
- ✓ **Sensitivity analysis** on scale-up parameters and assumptions

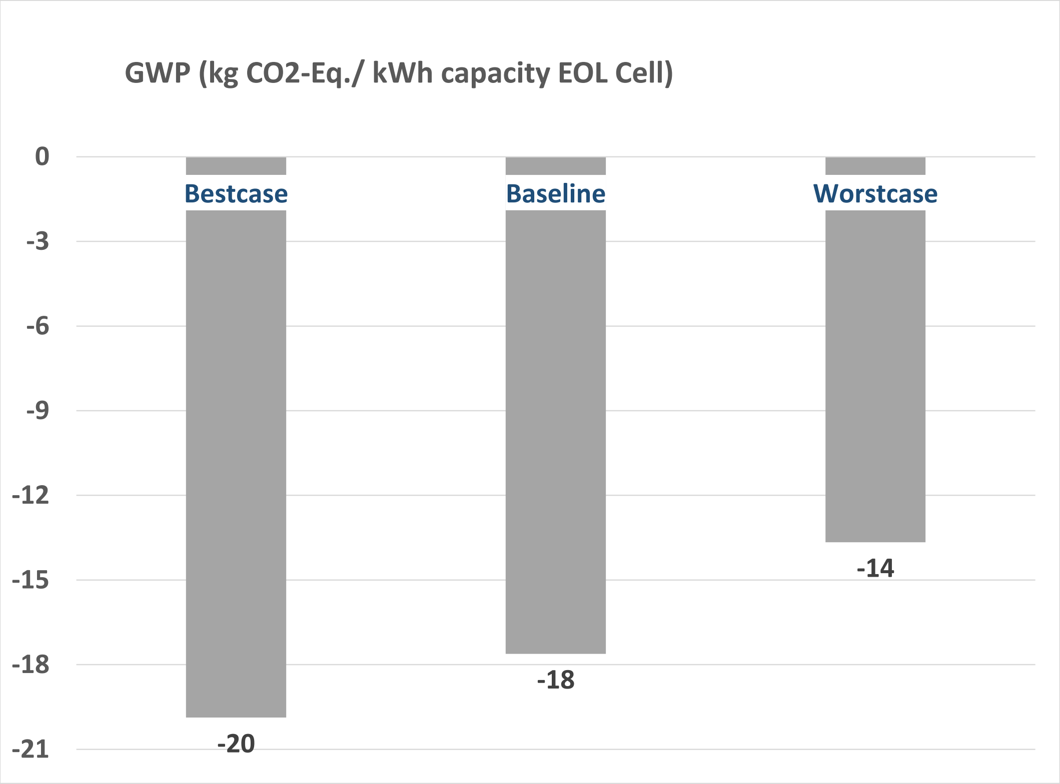


Fig: (initial) GWP for different scenarios for EOL-cell recycling

1 Langkau et al. 2023, A stepwise approach for Scenario-based Inventory Modelling for Prospective LCA (SIMPL)

Research for Sustainable Energy Technologies (RESET)

RESET Team Members

Group Leader
Dr. Marcel Weil

RESET

Thanks for your attention!

BATT-BRIDGE

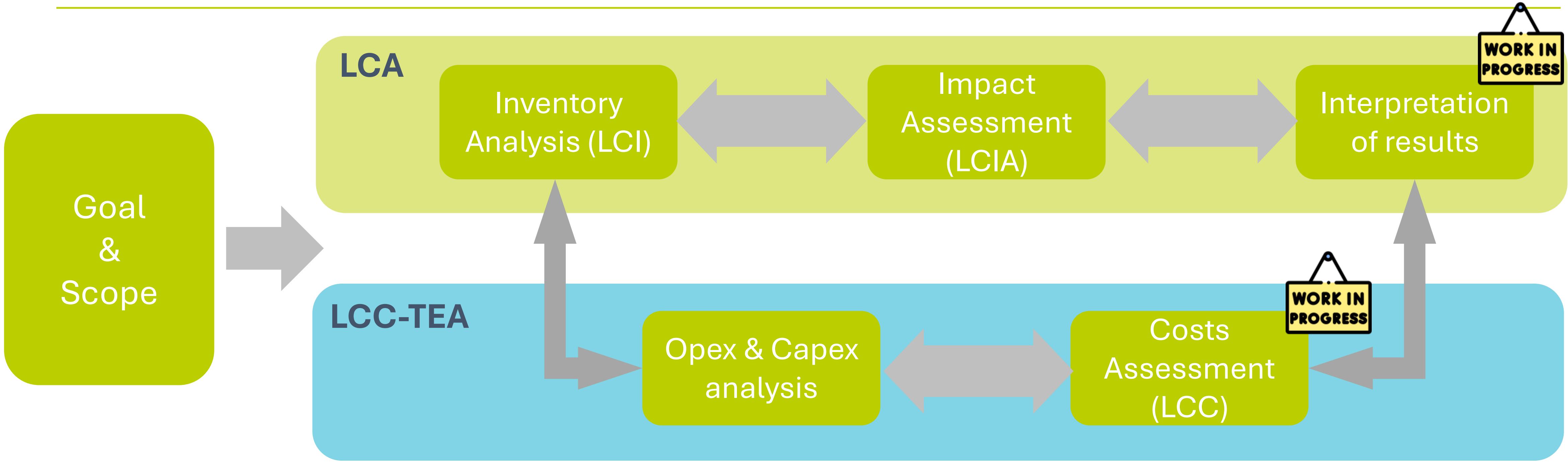
Revitalise

WEBINAR
Sustainability in Focus: Batt-Bridge Projects – Assessing recycling processes for a circular battery value chain

Session 2: Validating sustainability approaches

Violeta Vargas
Eurecat

Integrated Sustainability Framework



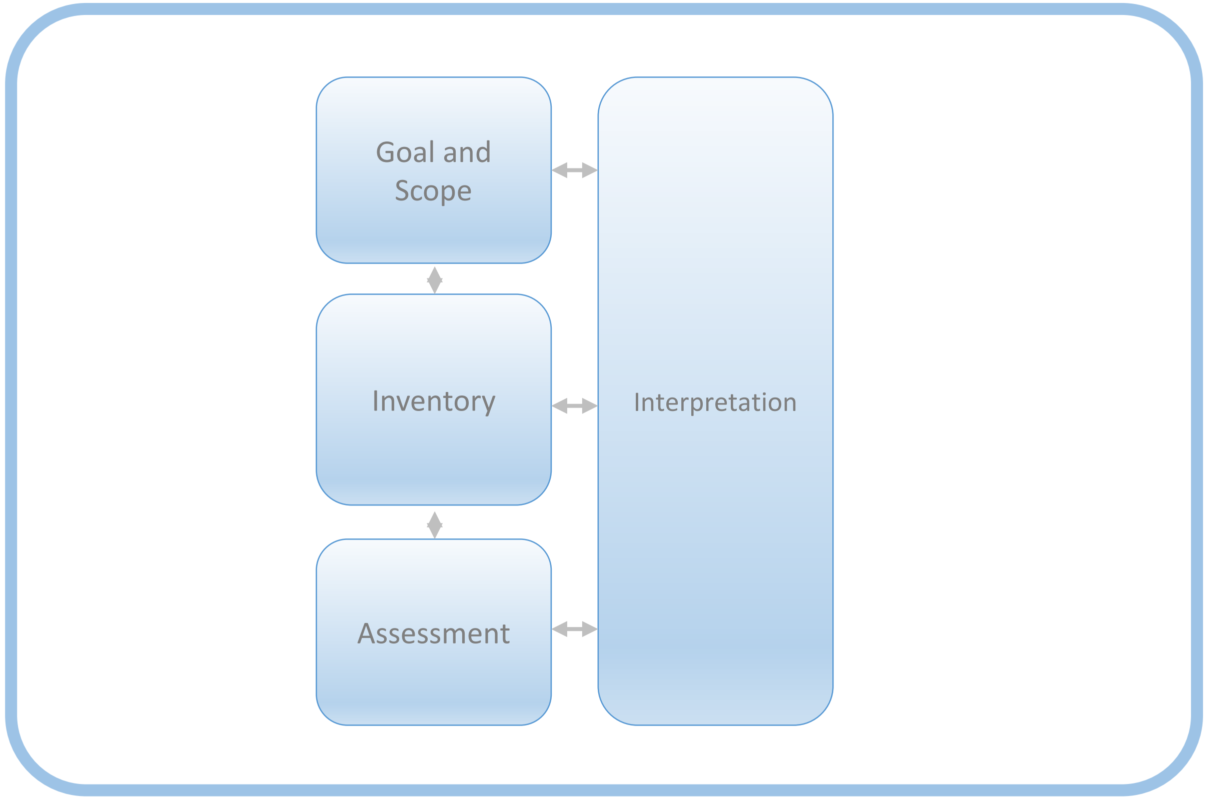
Functional unit:

1 kWh of the secondary cell's capacity

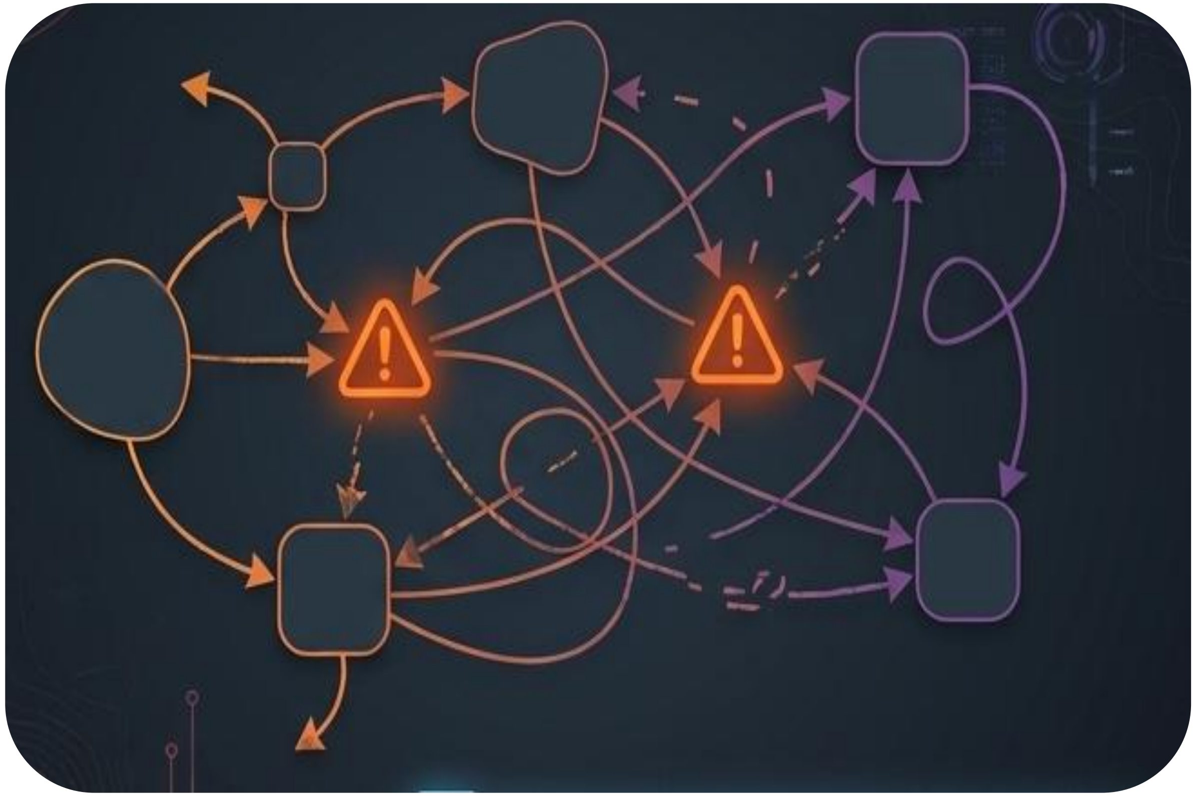
- However:
  - So far, assessments have been done in terms of **different FU/DUs for each task**:

Challenges

THE METHODOLOGY

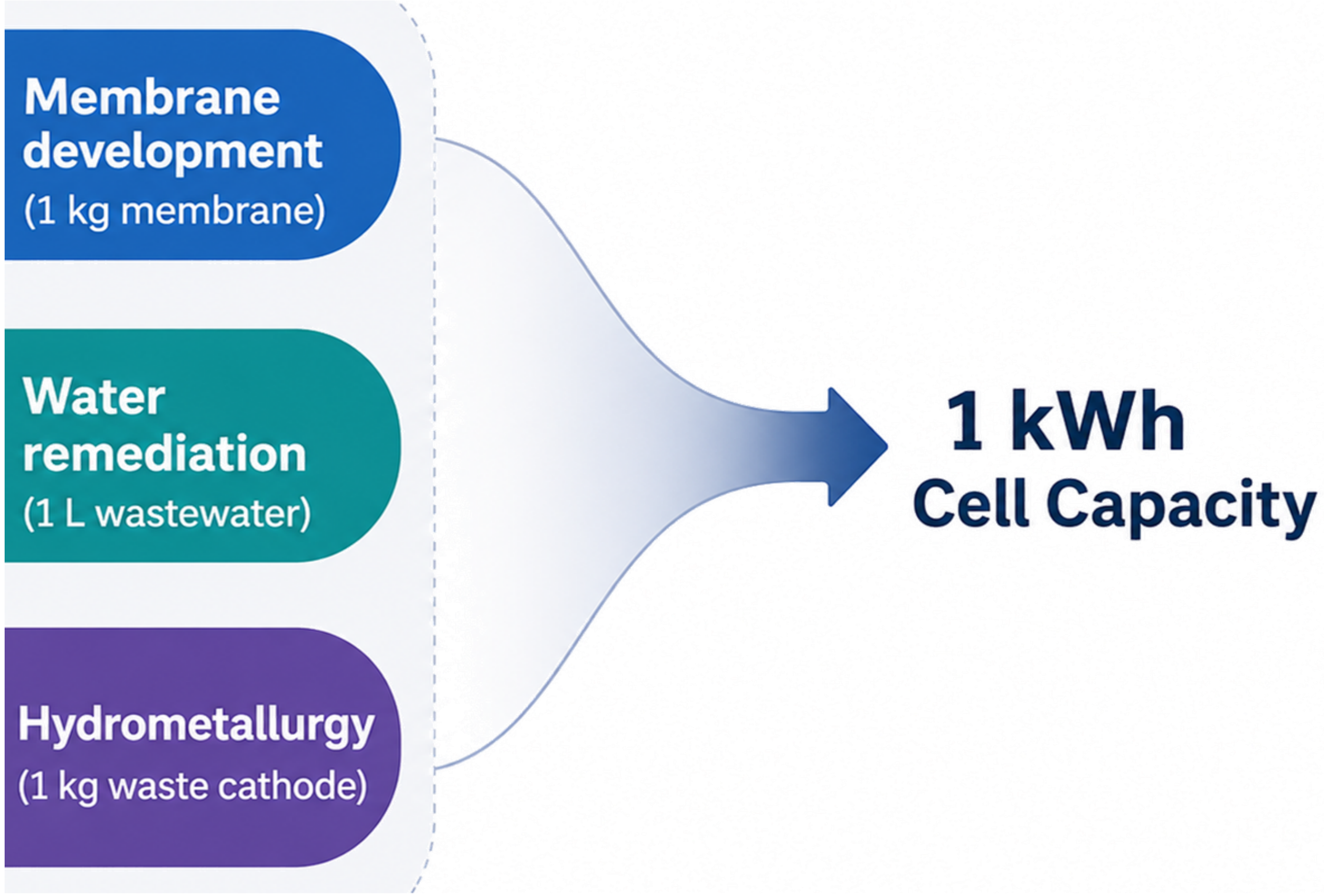


THE REALITY



Challenges

Functional Unit/Declared Unit



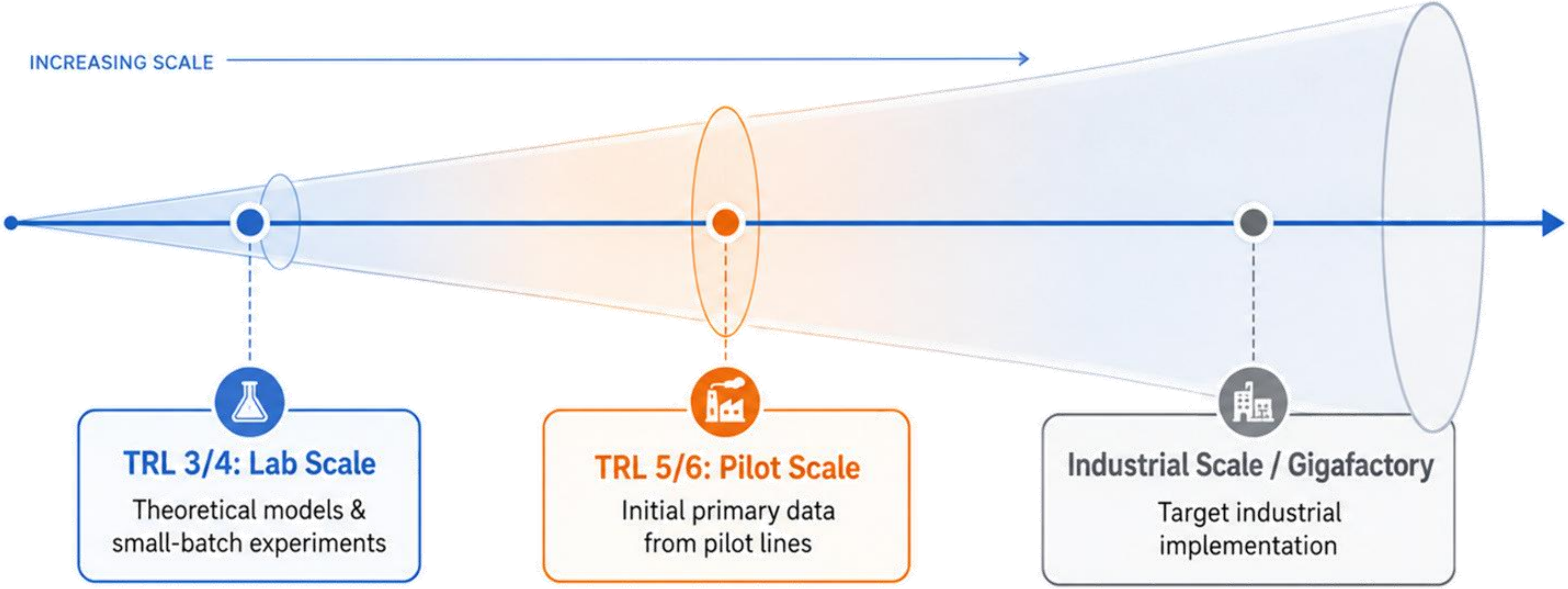
Challenges

Data availability in new developments

- **Mass balance**
- **Energy**
- **Cost**
- **Scale-up assumptions**

Challenges

LCA results scale-up



Lab-scale LCAs can mislead when non-optimized energy/chemicals used are projected directly to industrial scale.

Hydrometallurgy

Usually breaks the battery material down chemically and recovers metals or salts (lithium, nickel, cobalt, manganese, etc.)

These materials may still need additional processing before they can become battery-grade cathode material again.

Direct Recycling

Tries to preserve or restore the active material more directly, so the output may be closer to a usable cathode or anode material.

May require sorting, relithiation, purification, testing, or quality validation.

BATT-BRIDGE

Revitalise

WEBINAR

Sustainability in Focus: Batt-Bridge Projects – Assessing recycling processes for a circular battery value chain

Thank You!

Violeta Vargas
Eurecat

Session 2

Validating sustainability approaches

What Validation Means at Early TRL

"Validation asks: are assumptions traceable, physically consistent, transparent and decision-relevant?"

WHAT VALIDATION IS NOT

- Final proof that the process is **sustainable**
- A single **verified number** for CO_2 or cost
- Waiting until **industrial scale** to assess
- Reliance on **peer review alone**

WHAT VALIDATION IS

- **Mass balance** closure is checked, documented and reviewed
- Assumptions are **explicit and traceable**
- **Sensitive parameters** are identified and flagged
- Results change **predictably** with input changes

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Validation Workflow for ReUse

1 **Primary Data Harvesting** Data collection and inventory check

Consolidation of direct lab and pilot-scale measurements including mass balances, energy consumption, and reagent inputs across all process modules.

2 **Elemental Closure Verification** Physical Consistency

Tracking of critical battery elements (Li, Fe, P, C, Al, Cu) to ensure that output masses match inputs.

3 **Scientific Plausibility Check** Engineering plausibility check

Cross-referencing measured energy and solvent consumption against theoretical minimums to flag anomalies or measurement errors.

4 **LC³SA Inventory Mapping** Multi-Lens Alignment

Standardization of raw technical data into a unified inventory compatible with LCA, LCC, S-LCA, Circularity, and Criticality assessment methods.

5 **Process Partner Peer Review** Partner technical review

Iterative feedback loop with process engineers and material scientists to verify that model assumptions reflect actual operational reality.

6 **Transparent reporting** Decision Support

Final audit of the assessment model to ensure transparency and traceability before releasing results for process optimization decisions.

Assumptions to validate or test through sensitivity

To avoid biased ex-ante results, these 8 critical methodological risks require validation, partner confirmation or sensitivity testing:

Solvent Recovery Efficiency
Actual energy demand vs. recovery purity crossover; prevents underestimation of LCC/LCA impacts.

Reagent & Auxiliary Use
Tracking stoichiometric vs. actual consumption including process degradation and drag-out.

CAM & Graphite Recovery Yield
Discrepancy between lab theoretical mass balances and industrial-scale losses.

Wastewater Treatment Load
Burdens from complex electrolyte residues; ensuring impacts aren't shifted from air to water.

Substitution Credit Mapping
Is the credit based on displacing virgin LFP or lower-value industrial aggregates? (Avoids over-crediting).

Electrochemical Quality Gate
Threshold for true loop closure; if quality fails cell-grade specs, circularity benefits become limited or uncertain.

Upscaling Energy Intensity
Validation of non-linear scaling factors from batch lab reactors to continuous pilot lines.

Fair Comparison Across Recycling Routes and Projects

Essential Metadata Checklist

- ☑ **Functional Unit:** Per kg input, kWh recovered, or cell?
- ☑ **System Boundary:** Gate-to-Gate vs. Cradle-to-Grave?
- ☑ **TRL Maturity:** Lab (3-4), Pilot (5-6), or Industrial (7+)?
- ☑ **Data Quality:** Measured (primary) vs. Modeled (secondary)?
- ☑ **Recovery Yield:** Explicit mass-balance percentage?
- ☑ **Product Quality:** Cell-grade vs. Downcycling use?
- ☑ **Allocation Rule:** Substitution vs. System expansion?
- ☑ **Uncertainty:** Sensitivity range or Monte Carlo results?

Tiered Comparison Strategy

Benchmarking must happen between "peers." Comparing a Lab-scale (TRL 3) process directly with an Industrial (TRL 9) benchmark without upscaling modeling is methodologically weak or potentially misleading.

TIER 1: EXPLORATORY (TRL 3-4)
Focus on process potential and hotspot identification.

TIER 2: DEVELOPMENTAL (TRL 5-6)
Focus on pilot-validated mass balances and energy demand.

TIER 3: BENCHMARK (TRL 7-9)
Focus on industrial feasibility and market-ready LCA/LCC.

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Backup: Proposed Batt-Bridge Sustainability Reporting Template

System Definition

- **Functional Unit (FU)**
  Per kg of input material OR per kWh of recovered battery capacity.
- **System Boundary**
  Explicitly state Cradle-to-Gate vs Gate-to-Gate vs Cradle-to-Grave.
- **Technology Maturity**
  Reporting current TRL (3-9) and targeted industrial scale.
- **Geographic Scope**
  Electricity grid mix (EU-average vs specific nation) used for modeling.

Inventory & Data

- **Data Origin (DQI)**
  Share of measured lab data vs. literature vs. database proxies.
- **Recovery Yields**
  Mass balance of recovered CAM, graphite, Li, and other materials.
- **Product Quality**
  Electrochemical performance validation (cell-grade vs. downcycled).
- **Mass Balance Closure**
  Verification that input mass equals output mass + losses.

Modeling Choices

- **Allocation Strategy**
  Choice between system expansion (substitution) or partitioning.
- **Impact Categories**
  Adherence to EU EF 3.1 midpoint indicators (16 categories).
- **Uncertainty Reporting**
  Reporting of ranges/standard deviations rather than single values.
- **Circular Content**
  Explicit distinction between recycled content and recovery rate.

GOAL: Harmonized Cross-Project Benchmarking

Required for meaningful comparison between RENOVATE, CIRCUBATT, ReUse, and REVITALISE.

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Thank you!

Contact us if there are any questions.

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WEBSITE

www.reuse-batteries.eu

PRESENTER

Alok Prasad

EMAIL ADDRESS

alok.alok-prasad@u-bordeaux.fr

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Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

STREAMS

SUSTAINABLE TECHNOLOGIES FOR REDUCING EUROPE'S BATTERY RAW MATERIALS DEPENDANCE

Session 2: Validating sustainability approaches

Location: Webinar

Date: 09/07/2026

Daniel Dias

Research Associate @ Imperial College London

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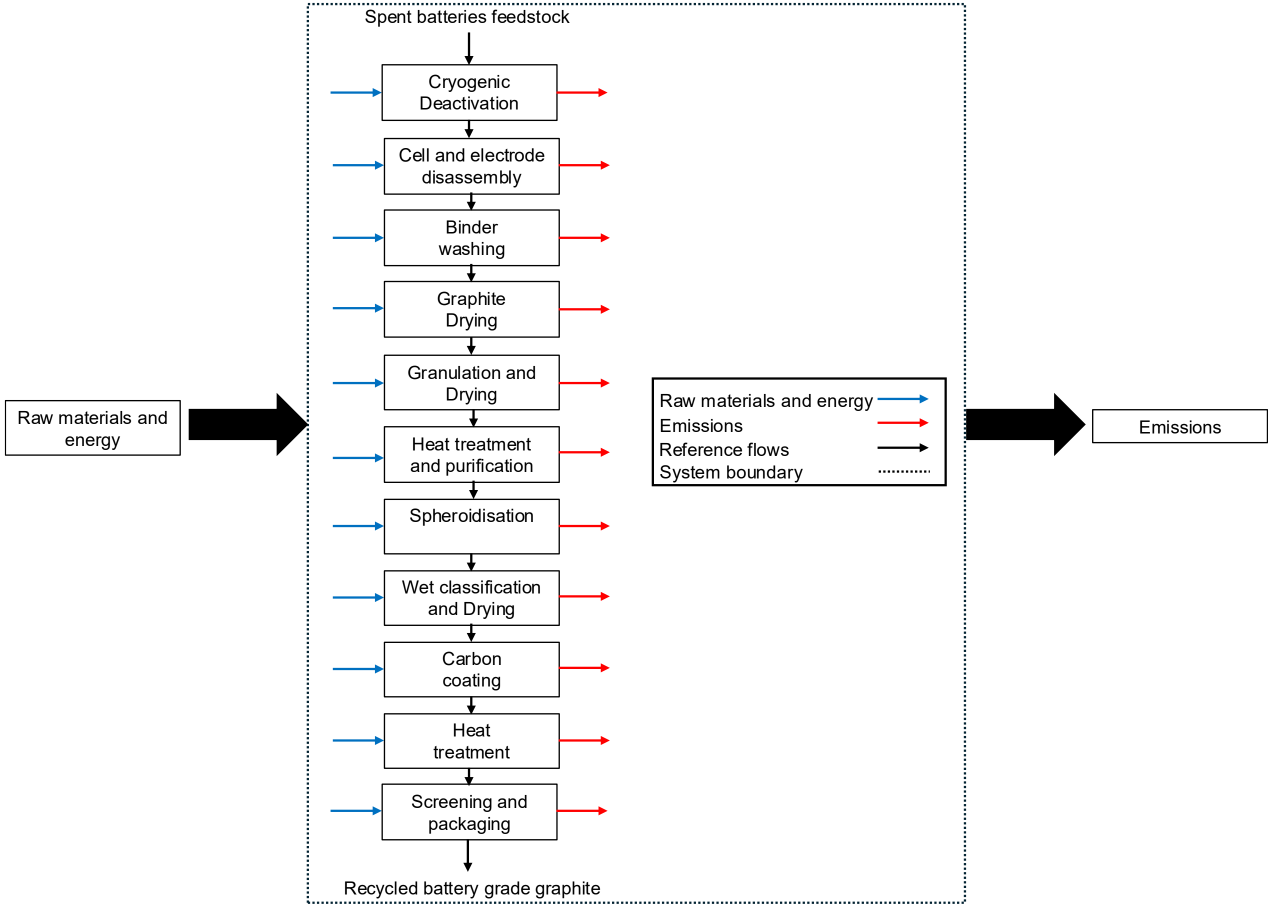
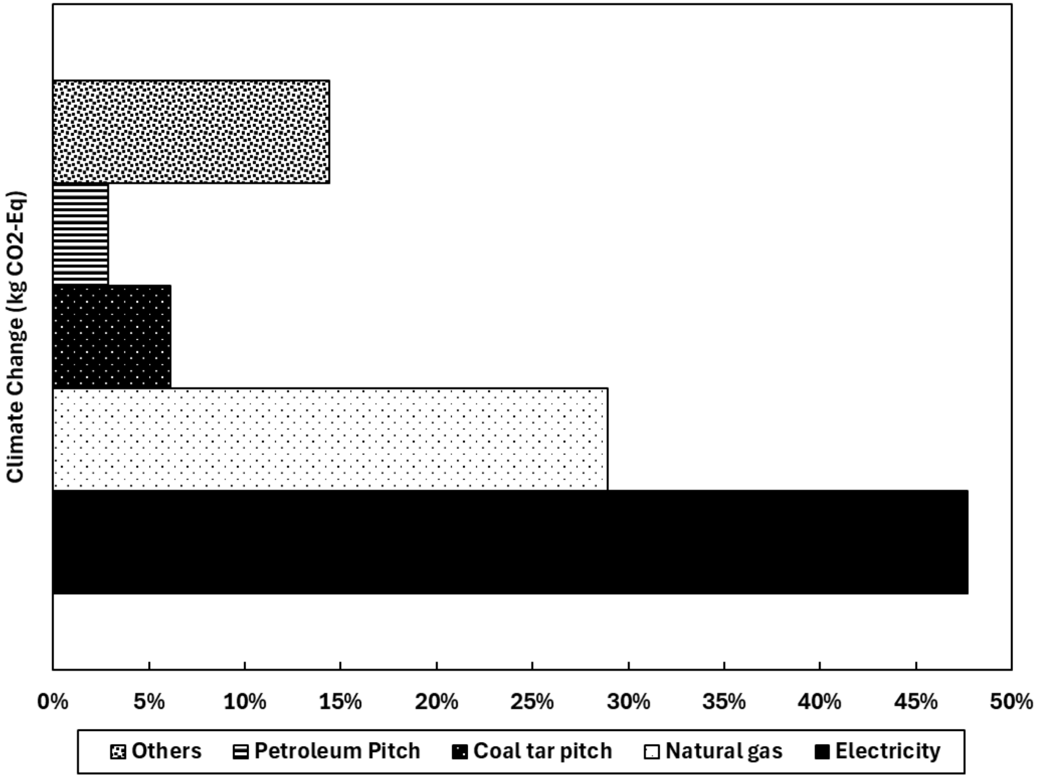
STREAMS: Validating sustainability approaches

Our sustainability approach facilitated the identification of key impact contributing inputs



Case study validation: Process flow sheet



Case study validation: Climate change impact

STREAMS: Validating sustainability approaches

Our sustainability approach helped identify areas for improvement against the selected benchmark

Example of an aggregated score from the STREAMS project (Reference: Development in China)

#	Steps in the safe and sustainability assessment stage	Assessment tool	Impact category group	Aggregated Scoring
1	Environmental sustainability assessment	LCA	Toxicity	2.00
			Climate change	0.00
			Pollution	2.63
			Resource	0.75
2	Social and economic sustainability assessment	SLCA	Social	2.78

Requires further improvement

Strong Average Weak

STREAMS: Validating TEA for Battery Recycling – Gaps & Next Steps

Limitations

- Linear scale-up
- Market uncertainty
- Early TRL gaps

How to improve

- Pilot-scale validation
- Integrated supply chain modelling
- TEA + LCA integration

S T R E A M S

SUSTAINABLE TECHNOLOGIES
FOR REDUCING EUROPE'S BATTERY
RAW MATERIALS DEPENDANCE

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Session 2: Validating sustainability approaches

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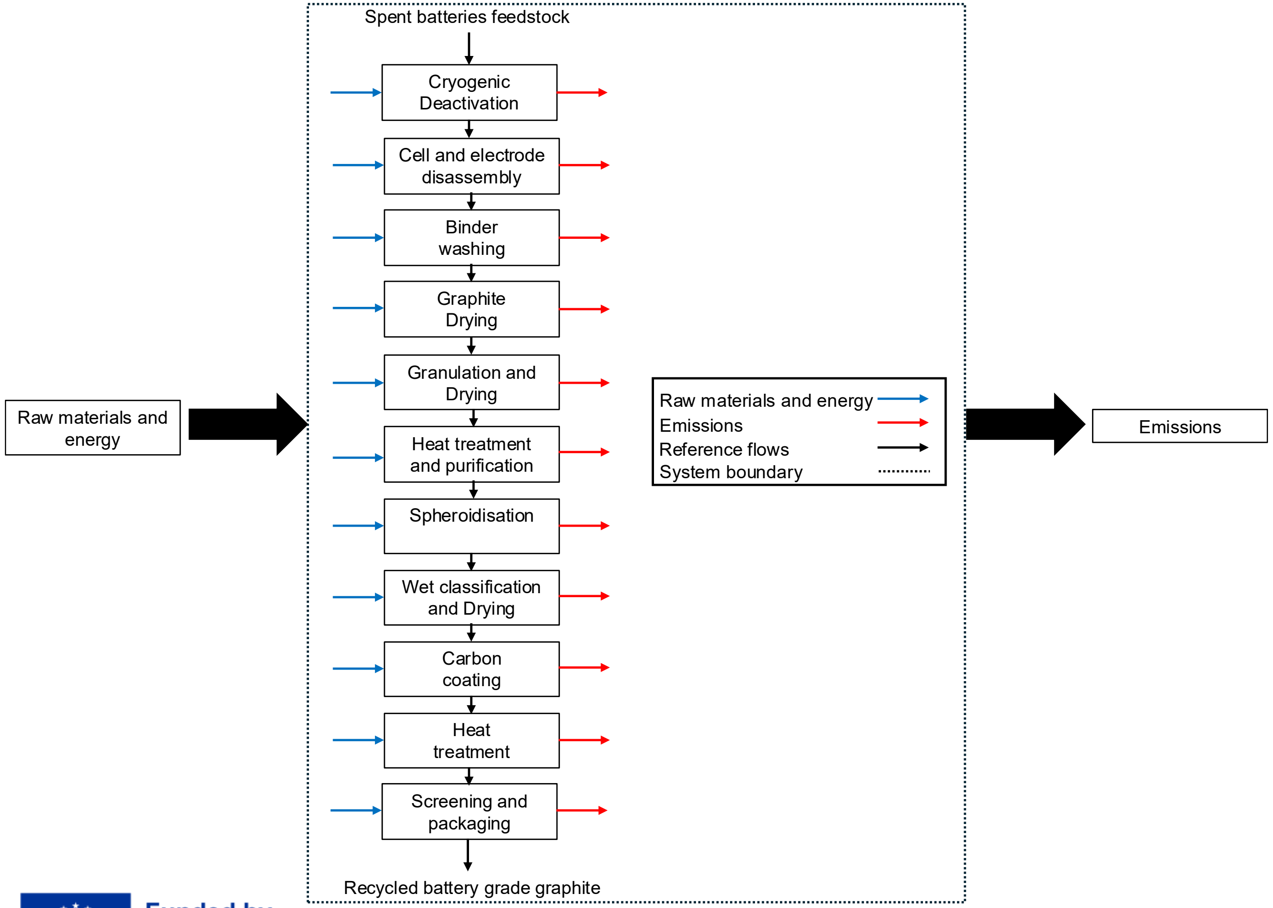
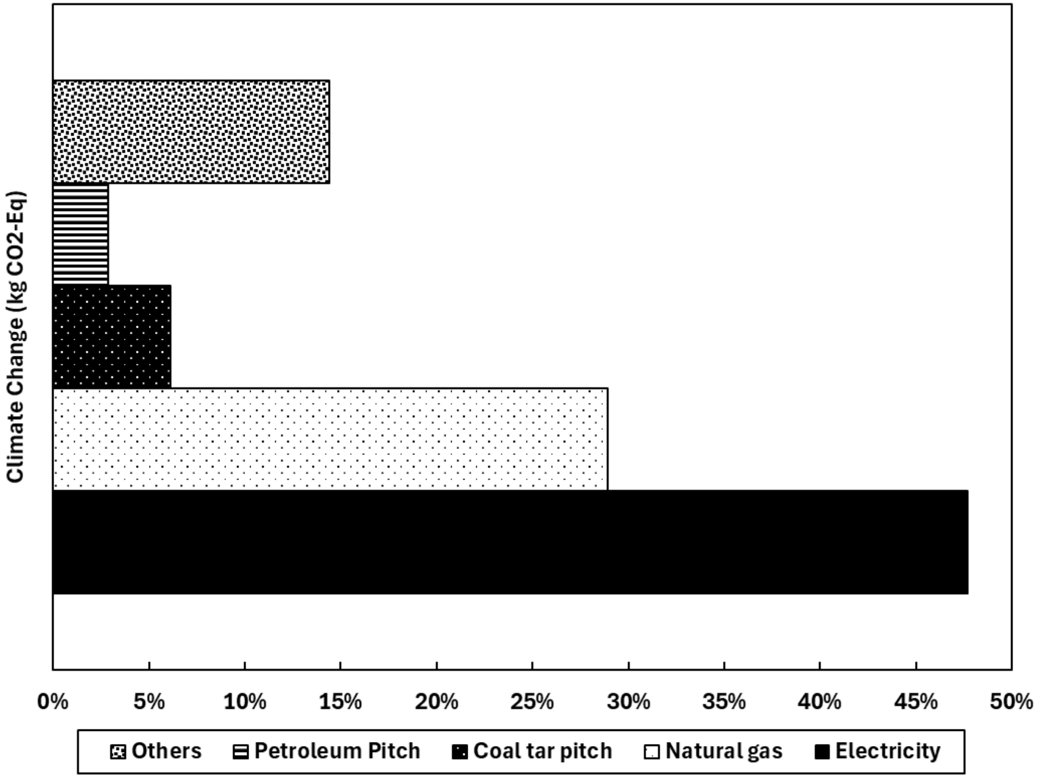
HighMag: Validating sustainability approaches

Our sustainability approach facilitated the identification of key impact contributing inputs



Case study validation: Process flow sheet



Case study validation: Climate change impact

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HighMag: Validating sustainability approaches

HighMag

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Strong Average Weak

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HighMag

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Thank you

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Q & A

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CONCLUSIONS & WRAP UP

UPCOMING ORGANISED EVENTS

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3 DECEMBER 2026

CIRCUBATT

CLUSTERING EVENT
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