BATTERIE E MATERIE PRIME CRITICHE
Sfide e opportunità dell'**economia circolare**

Valutazione prospettica del ciclo di vita di un processo innovativo di riciclo delle batterie agli ioni di litio sviluppato nell'ambito del progetto Tech4Lib

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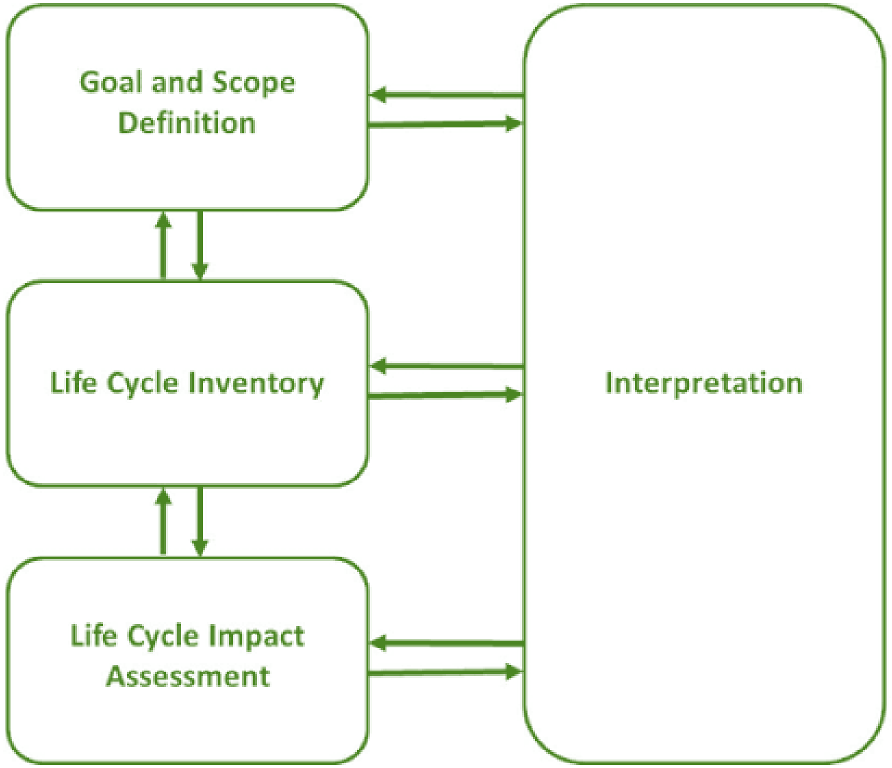
9 LUGLIO 2026 | 10:00 - 12:30

Life Cycle Assessment

What is Life Cycle Assessment (LCA)?

- **LCA** is a methodology for assessing the **environmental impacts** of products and services, covering their entire **life cycle** from raw material extraction to waste treatment.
- It allows quantification of **potential environmental impacts** and evaluation of options to reduce them.
- It is covered by norms: ISO 14040:2006 and ISO 14044:2021 and accordingly structured in **4 steps**.
- **Prospective LCA** is a scenario-based approach that evaluates the future environmental impacts of technologies by incorporating expected developments in technological, economic, and societal conditions (Thonemann et al., 2020).



International Organization for Standardization (2022) ISO 14044:2006 - Environmental management, Life cycle assessment, Requirements and guidelines. https://www.iso.org/standard/38498.html. Accessed 11 Apr 2024

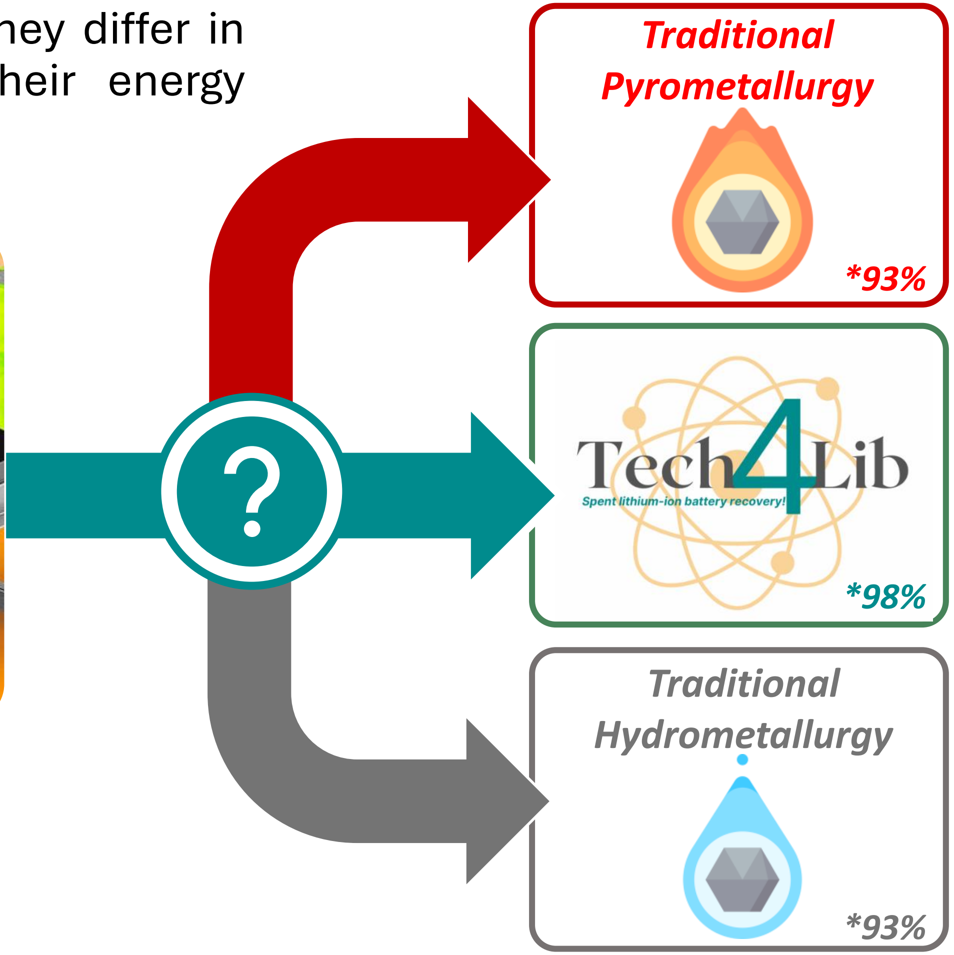
International Organization for Standardization (2022) ISO 14040:2006 - Environmental management, Life cycle assessment, Principles and framework. https://www.iso.org/standard/37456.html. Accessed 11 Apr 2024

Thonemann, N., Schulte, A., & Maga, D. (2020). How to conduct prospective life cycle assessment for emerging technologies? A systematic review and methodological guidance. In Sustainability (Switzerland) (Vol. 12, Number 3). MDPI. https://doi.org/10.3390/su12031192

Introduction - Batteries recycling routes

Battery chemistries are rapidly evolving. They differ in the materials they are composed of, their energy density, and their level of maturity.

Manufacturing



Industrial scale
(Mohr et al., 2020)

Laboratory scale

Industrial scale
(Mohr et al., 2020)

Lithium-ion batteries (**LIBs**) considered in **Tech4LIB**:

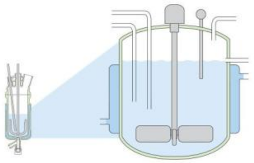
- ❖ Nickel Manganese Cobalt (**NMC**).
- ❖ Nickel Cobalt Aluminium (**NCA**).

Mohr, M., Peters, J. F., Baumann, M., & Weil, M. (2020). Toward a cell-chemistry specific life cycle assessment of lithium-ion battery recycling processes. Journal of Industrial Ecology, 24(6), 1310–1322. https://doi.org/10.1111/jiec.13021

Potential improvements of the process

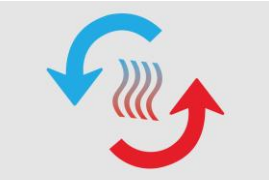
Upscaling

Larger production volumes are considered, as well as optimized resource efficiency.



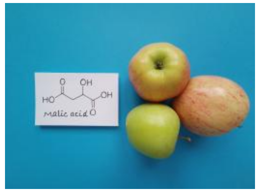
Heat recovery

Water is heated up to 80 °C during leaching. Heat recovery is possible.



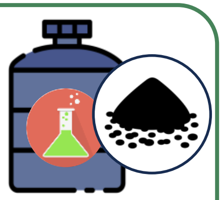
Secondary malic acid

Malic acid is recovered from organic waste.



Evolution of the leaching process

The solid–liquid ratio, the concentration of leaching agents, and the amount of black mass which can be treated with microwaves in a single batch are optimised.



Methodology - Prospective LCA

Goal and scope definition

- **Goal**: Assessing the environmental competitiveness of the emerging technology developed in Tech4Lib compared to traditional pyrometallurgy and hydrometallurgy.
- **Functional unit**: 1 kWh capacity of batteries.
- **System boundaries**: Cradle to Grave, with substitution approach. Use phase is excluded.

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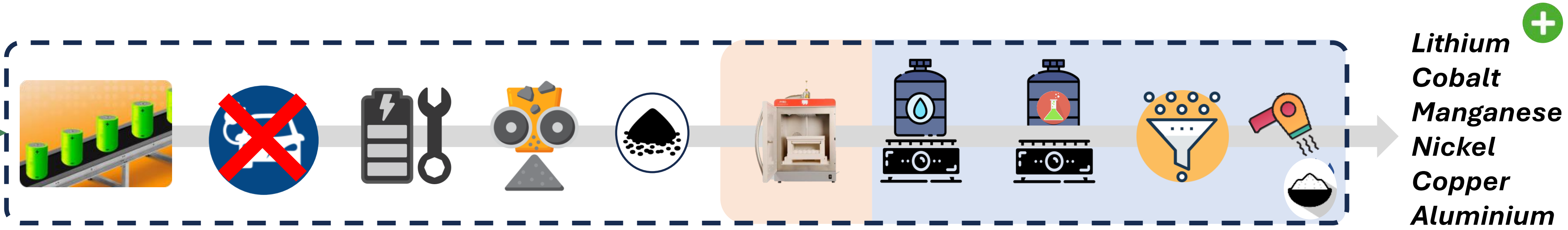
Life Cycle Inventory - LCI

Ecoinvent 3.10.1, cut-off version (Background LCI) + **Primary data** from the partners' laboratories (Foreground LCI).

Life Cycle Impact Assessment - LCIA

LCIA method: Environmental Footprint 3.1, with a focus on ***Climate Change*** *and* ***Resource use, metals/minerals***.



Methodology - Scenario development

Background scenario

REMIND (Regionalized Model of Investment and Development) SSP2-PkBudg1150.

- *Shared Socio-Economic Pathway-2 (SSP-2)*: Middle of the Road, extrapolation from historical developments.
- *Representative Concentration Pathway 2.6 (RCP2.6)*: in line with Paris Agreement Climate Policy (temperatures increase of 1.6-1.8 °C by 2100, atmospheric radiative forcing 2.6 W/m^2).

Foreground scenarios

Based on Scenario-based Inventory Modelling for Prospective LCA (SIMPL) methodology (Langkau et al. 2023):

- *Scenario field identification*: Explorative scenarios for 2030, 2040, and 2050 (European Climate Policies).
- *Key factor identification*: 1) **Upscaling**, 2) **Heat recovery**, 3) **Secondary Malic Acid**, 4) **Evolution of the leaching process**, 5) **Battery chemistries.**
- *Key factor analysis*: 1-2) **Upscaling** and **Heat recovery** modelling is based on Piccinno et al. 2016, 3) **Secondary malic acid** modelling is based on Moussa et al. 2016 , 4) **Evolution of the leaching process** is explored with the advice of technology experts, 5) **Battery chemistries** models are based on Mohr et al. 2020 as well as traditional hydrometallurgy and pyrometallurgy.

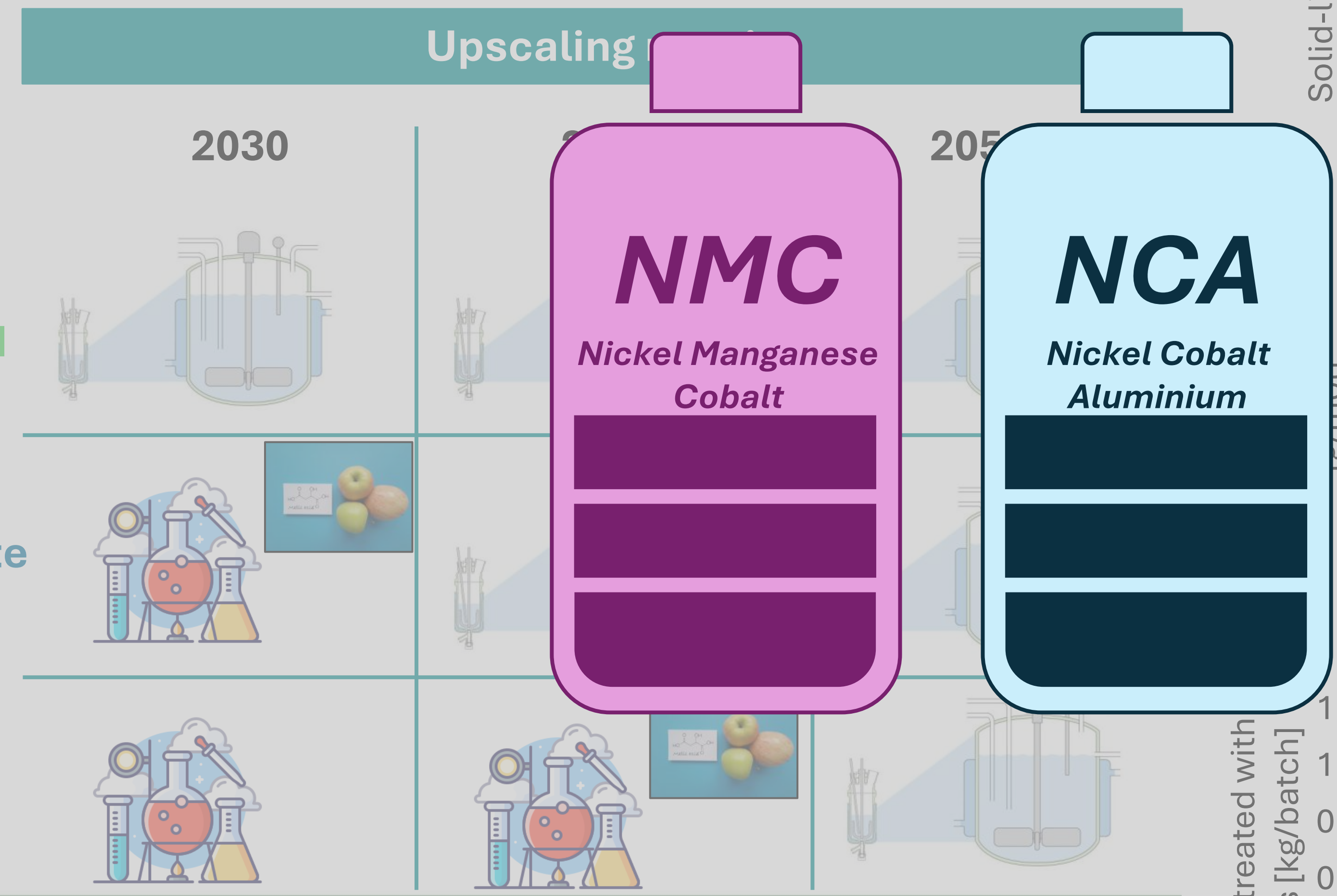
Moussa, H. I., Elkamel, A., & Young, S. B. (2016). Assessing energy performance of bio-based succinic acid production using LCA. Journal of Cleaner Production, 139, 761–769. https://doi.org/10.1016/j.jclepro.2016.08.104

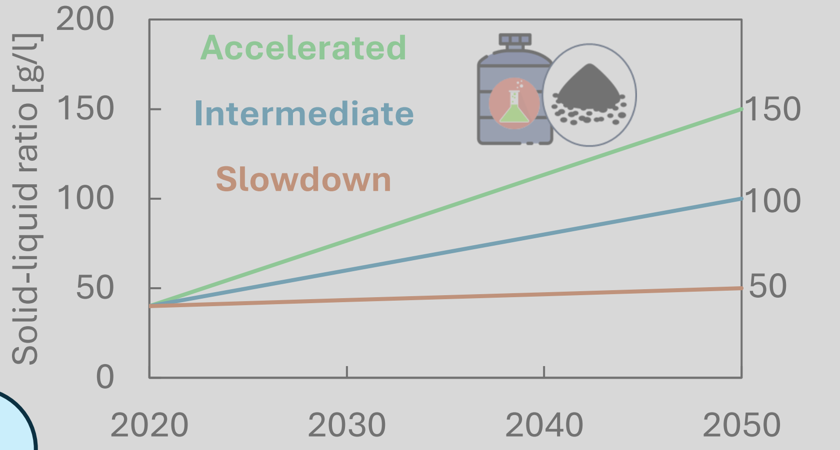
Piccinno, F., Hischier, R., Seeger, S., & Som, C. (2016). From laboratory to industrial scale: a scale-up framework for chemical processes in life cycle assessment studies. Journal of Cleaner Production, 135, 1085–1097. https://doi.org/10.1016/j.jclepro.2016.06.164

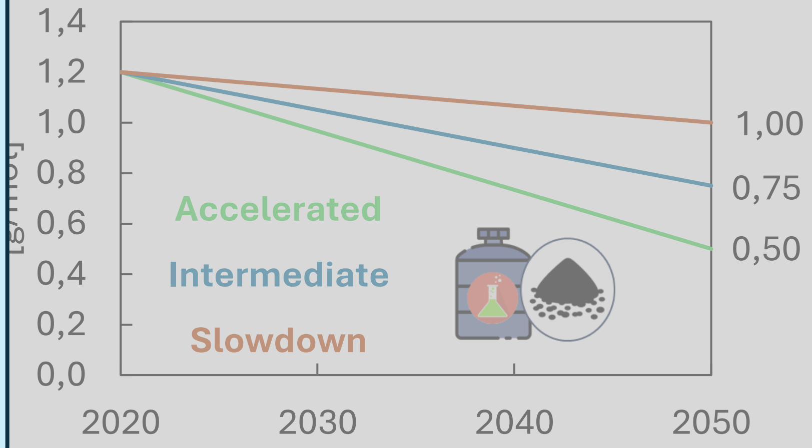
Langkau, S., Steubing, B., Mutel, C., Ajie, M. P., Erdmann, L., Voglhuber-Slavinsky, A., & Janssen, M. (2023). A stepwise approach for Scenario-based Inventory Modelling for Prospective LCA (SIMPL). International Journal of Life Cycle Assessment, 28(9), 1169–1193. https://doi.org/10.1007/s11367-023-02175-9

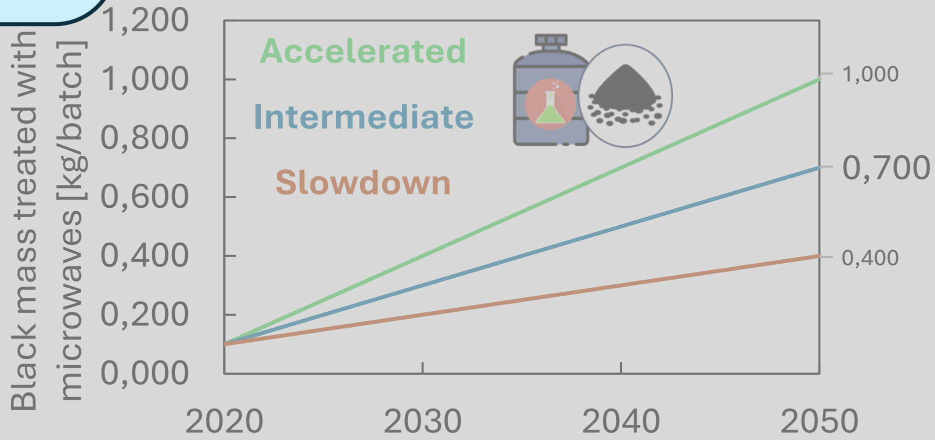
Scenario development

- *Scenario generation:*

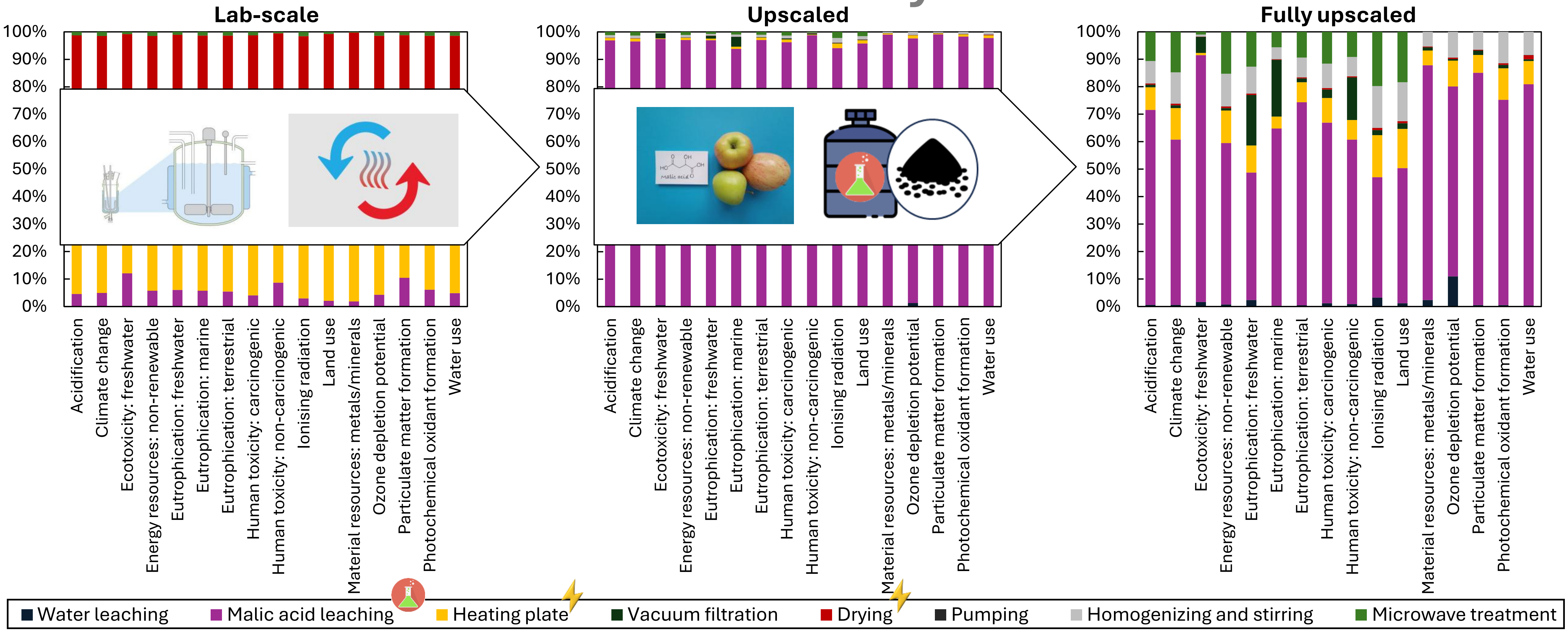




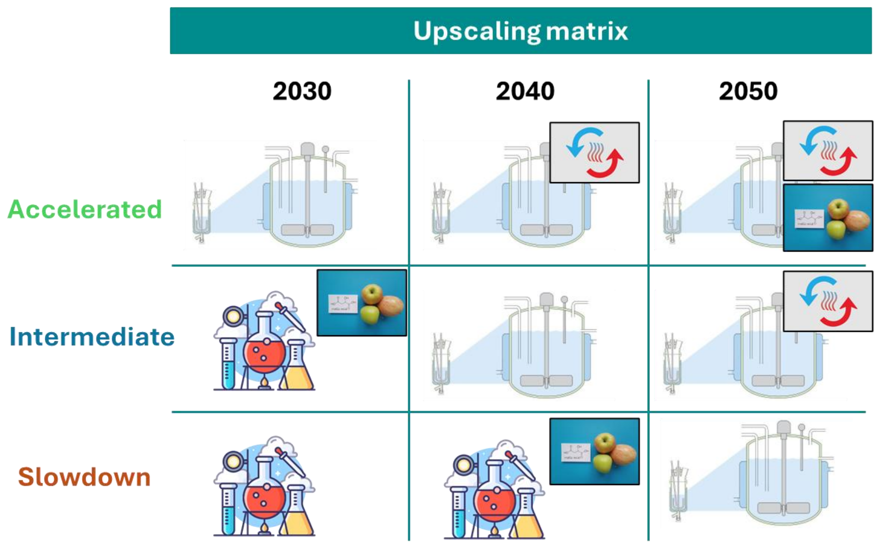




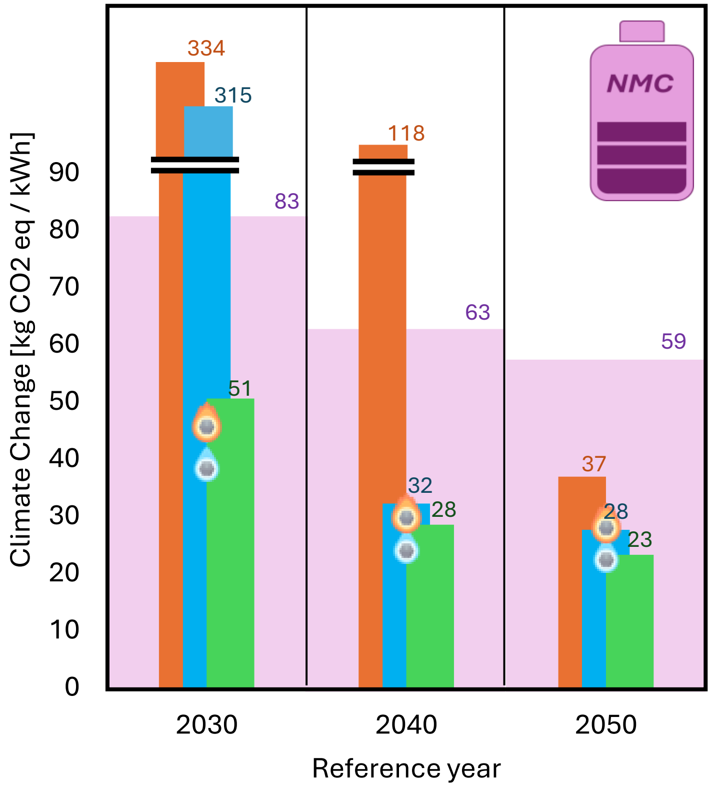
Results – Contribution analysis

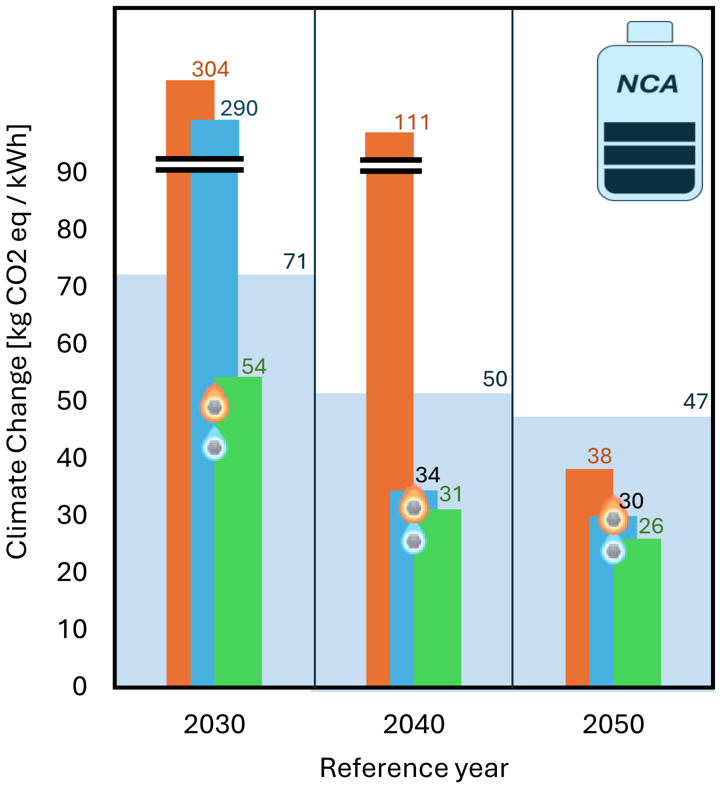


Results – Climate change



Lithium-ion batteries (**LIBs**): Nickel Manganese Cobalt (**NMC**), Nickel Cobalt Aluminium (**NCA**).





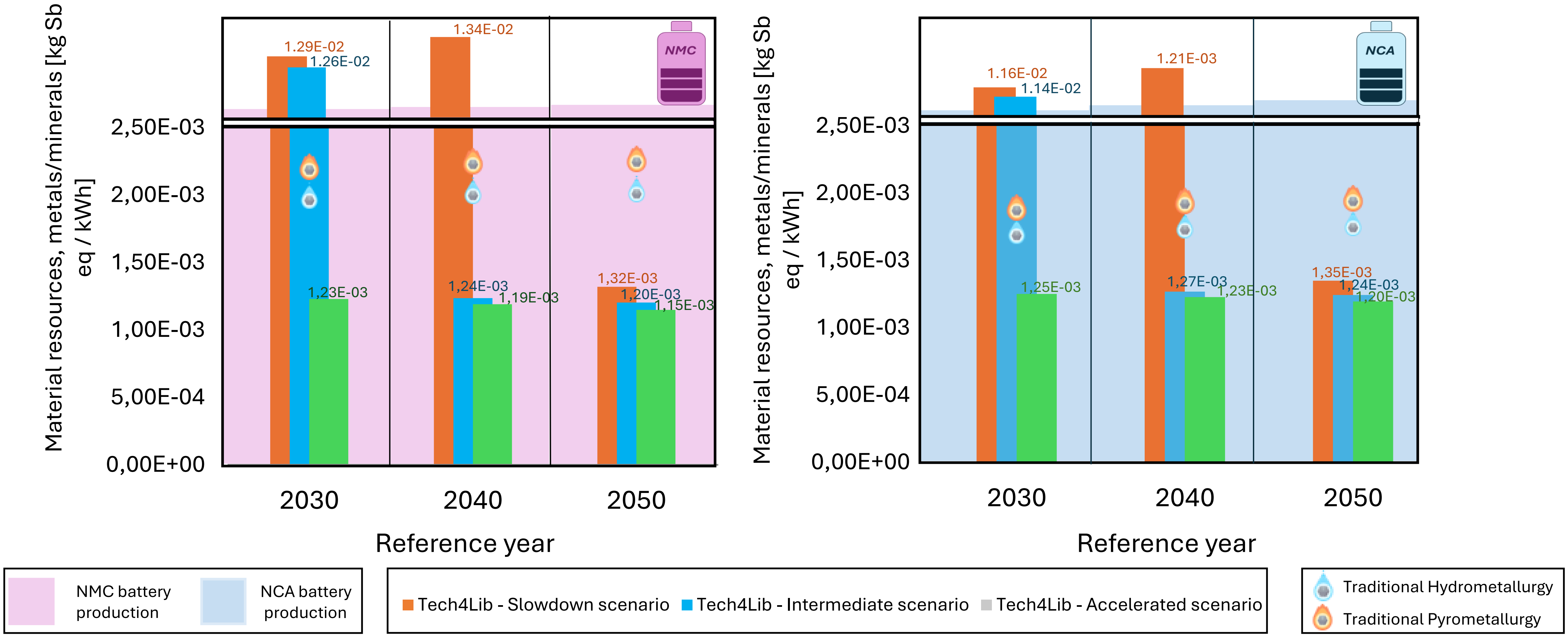
NMC battery production | NCA battery production

Tech4Lib - Slowdown scenario | Tech4Lib - Intermediate scenario | Tech4Lib - Accelerated scenario

Traditional Hydrometallurgy

Traditional Pyrometallurgy

Results – Material resources, metals/minerals



Take Home Messages

- At the current stage, the **Tech4Lib** recycling technology is at **lab-scale** and has a **significantly higher impact** than traditional **pyrometallurgy** and **hydrometallurgy**. **Upscaling** the technology is expected to drastically **reduce** its environmental footprint.
- At **lab-scale,** the **heating plate** and **drying** steps represent the main environmental **hotspots**, while in the upscaled process, **malic acid** is identified as the main contributor to environmental impact.
- For the **Climate change** impact category, the Tech4Lib process is expected to achieve adequate environmental competitiveness by **2040** in the **Accelerated** scenario, and by **2050** in the **Intermediate** scenario.
- For the **Material resources, metals/minerals** impact category, the Tech4Lib process is expected to achieve better environmental performance compared to conventional hydrometallurgy and pyrometallurgy by **2030** in the **Accelerated** scenario, by **2040** in the **Intermediate** scenario, and by **2050** in the **Slowdown** scenario.

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Thank You for your attention

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Tech4Lib
Spent lithium-ion battery recovery!

Fondazione CARIPLO

Introduction - The Tech4Lib technology

Tech4Lib project develops a novel recycling technology for recovering materials from waste batteries black mass (Cornelio et al., 2024; Fahimi et al., 2023).

Deactivation and disassembly — *Trituration* — *Black mass*

Carbothermic reaction — *Water Leaching* — *Malic acid Leaching* — *Vacuum filtration* — *Drying*

Tech4Lib
Spent lithium-ion battery recovery!

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Lithium
Cobalt
Manganese
Nickel
Copper
Aluminium

Pyrometallurgical treatment

Hydrometallurgical treatment