Research Summary

How Ready is Europe to Recycle it's EV Batteries? Findings from a CLSC Study

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THE PROBLEM

Electric vehicle (EV) batteries in Europe are nearing end-of-life more rapidly than the infrastructure required to manage them is being developed. It is estimated that, by 2030, 420,000 tonnes of lithium-ion battery packs will require end-of-life processing annually - reaching almost 500,000 tonnes by 2035 (Fraunhofer ISI, 2023; IEA, 2021). These batteries are made up of critical materials such as lithium, cobalt, nickel, and manganese that are both commercially useful when recovered, and environmentally harmful if improperly disposed of.

The EU Battery Regulation 2023/1542 mandates obligatory collection targets, material recovery ranges, and extended producer responsibility requirements across all member states. However, the physical infrastructure necessary to meet these targets does not actually exist at the required scale or geographic distribution. Collection rates vary significantly across member states, recycling capacity is mostly concentrated in Western and Northern Europe, and no cross-border reverse logistics network exists at the moment (Fraunhofer ISI, 2024).

Three specific research gaps motivated this study: the lack of a comprehensive quantitative Closed-Loop Supply Chain model for EU-wide EV battery reverse logistics; the absence of scenario-based analysis quantifying the trade-offs between infrastructure and policy; and the inclination towards treating second-life reuse and recycling as distinct rather than interrelated systems.

METHODOLOGY

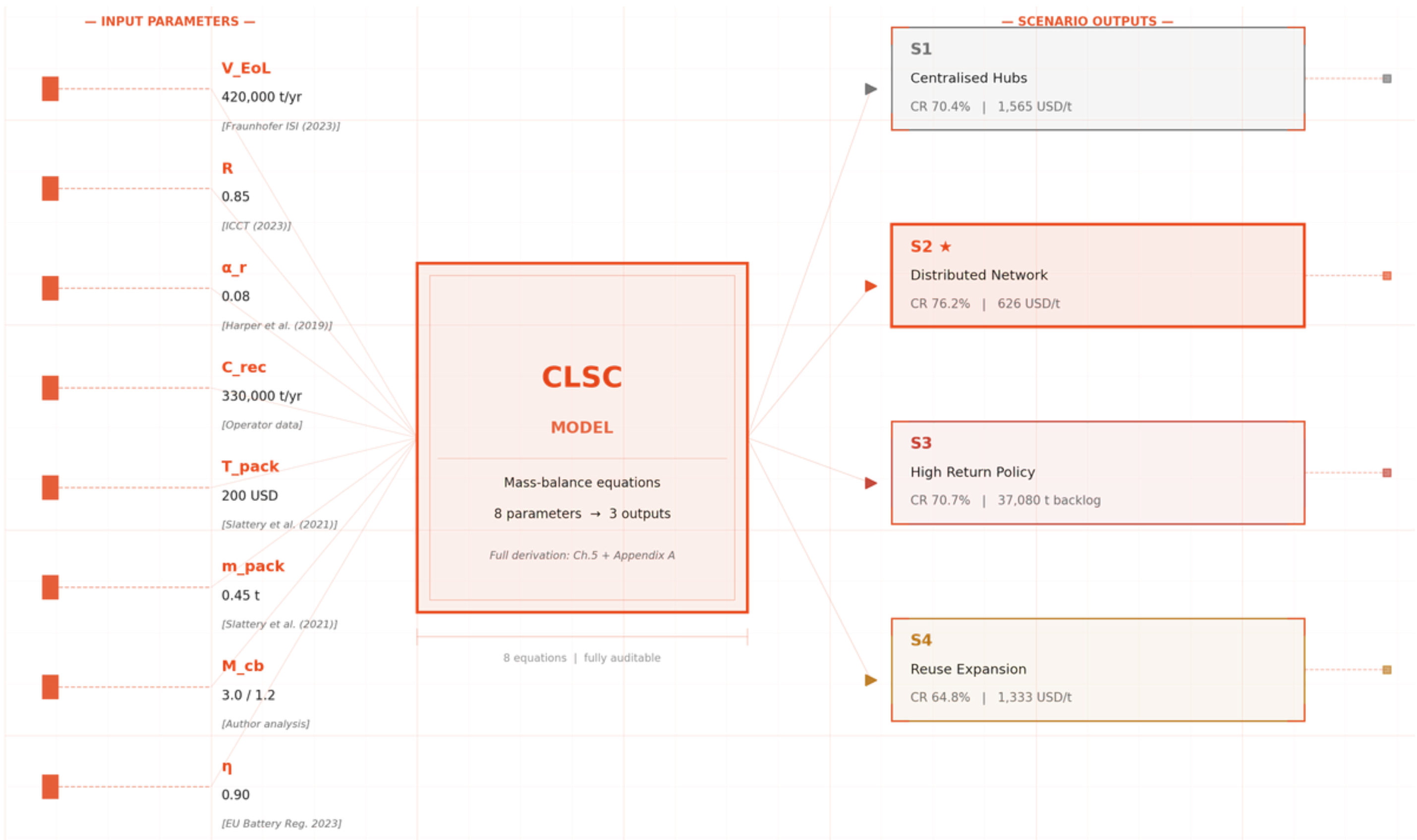
This study employed a descriptive-exploratory research approach using secondary data sources, including EU policy documents, peer-reviewed literature, industry reports (Fraunhofer ISI, ICCT, IEA, ACEA), and operator capacity data (Northvolt, BASF, Umicore, Cylib). A quantitative mass-balance closed-loop supply chain model was developed, incorporating all equations and calculations.

The model consists of eight sourced parameters - listed in Table 1 below, and generates three output variables: Circularity Rate (CR = recovered volume ÷ total EoL volume), Transport Cost (USD per processed tonne), and Backlog (volume surpassing available recycling capacity). Four infrastructure and policy scenarios were then assessed against these outputs.

Table 1: Model Input Parameters

Symbol	Value	Description	Source
V_eol	420,000 t/year	Annual EOL battery volume by 2030 in EU	Fraunhofer ISI (2023)
R	0.85	Return rate - conservative near-term estimate	ICCT (2023)
α_r	0.08	Reuse share - 5-8% of EOL volume at current scale	Harper et al. (2019)
C_rec	330,000 t/year	Total estimated EU recycling capacity (operator aggregation)	Aggregation of operator announced capacities
T_pack	200 USD	Per pack ADR freight rate - central estimate	Slattery et al. (2021)
m_pack	0.45 t	EU average car battery pack mass	Slattery et al. (2021)
M_cb	3.0 / 1.2	Cross-border transport multiplier - centralised vs distributed	Consistent with Slattery et al. (2021) and Rallo (2022)
η	0.90	Recovery efficiency - 90% Co/Ni target	EU Battery Regulation 2023

RESEARCH DESIGN



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THE FOUR SCENARIOS

Each scenario evaluates a specific hypothesis on the impact of infrastructure design and policy configuration on system performance. Parameters not specified for a particular scenario maintain baseline values as indicated in the table above.

- **Scenario 1 - Centralised Hubs (Baseline):** Evaluates the status quo; recycling concentrated in large Western European facilities. M_cb = 3.0 (high cross-border routing burden).
- **Scenario 2 - Distributed Regional Network:** Evaluates if distributing infrastructure geograhically near EOL volume sources is more effective than centralisation. M_cb decreases to 1.2; C_rec increases to 396,000 t/year; R rises to 0.90.
- **Scenario 3 - High Return Policy:** Evaluates the consequences of regulatory collection ambition (R=0.95) not being aligned with capacity development. C_rec remains at 330,000 t/year.
- **Scenario 4 - Reuse Market Expansion:** Tests whether increasing second-life reuse (α_r from 0.08 to 0.20) enhances system circularity or delays material loop closure.

RESULTS

This section describes what each of the four scenarios actually delivers, as measured in three terms: how much material is recovered for reuse in manufacturing (circularity rate), what it costs to transfer and process the batteries (transportation cost), and whether the system is capable of handling the volume received (backlog).
Table 2 outlines the total material flow and performance outputs for all four scenarios; the three findings that follow clarify what those figures imply in reality.

Table 2: Scenario results - Material Flow and Performance

Scenario	Effective Inflow	Backlog	Recovered Volume	Circularity Rate CR (%)	Cost (USD/t)
S1 Centralised Hubs	357,000 t	0	295,596 t	**70.38%**	**1,565**
★**S2** Distributed Network	378,000 t	0	319,939 t	**76.18%**	**626**
S3 High Return Policy	399,000 t	37,080 t	297,000 t	**70.71%**	**1,161**
S4 Reuse Expansion	378,000 t	0	272,160 t	**64.80%**	**1,333**

Source: Chapter 6 Tables 14-15 (research). CR=Circularity Rate. ★=best performing scenario.

Three findings emerge from the results:

- **Distributed infrastructure outperforms on both metrics simultaneously.** S2 attains the highest circularity rate (76.18%) at the lowest expense (626 USD/t). It is the only scenario in which both performance measures improve simultaneously, without necessitating a trade-off. The decrease in M_cb from 3.0 to 1.2 is the primary cost driver, whereas the increased return rate and expanded capacity collectively contribute to the improvement in circularity rate.
- **Policy ambition without capacity expansion leads to operational backlogs.** S3 increases the return rate to 0.95, resulting in an effective inflow of 399,000 tonnes; 69,000 tonnes more than the available recycling capacity. The resulting backlog of 37,080 tonnes cannot be processed and must be stored separately or disposed of. This shows that regulatory ambition without matching infrastructure investment does not enhance circularity but creates system-level coordination failure.
- **Second-life reuse scaling reduces near-term circularity rate.** S4 produces the lowest circularity rate of any scenario (64.80%), with recovered material dropping to 272,160 tonnes. This does not suggest that reuse is undesirable, but rather illustrates a definitional trade-off: reuse increases lifespan extension and decreases short-term recycling demand, while temporarily reducing near-term recovered secondary material flow to manufacturing.

IMPLICATIONS AND CONTRIBUTION

This research develops a transparent, parameterised decision-support framework for policymakers, original equipment manufacturers (OEMs), recyclers, and logistics service providers evaluating end-of-life battery infrastructure and policy scenarios. Three primary implications arise from the findings:

- **Distributed infrastructure is structurally superior.** Developing additional centralised capacity in Western Europe will not address the regional disparity, it will only worsen it. Regional pre-treatment facilities near EOL volume sources reduce transportation burdens while enhancing collection, accessibility, and circularity results.
- **Policy and capacity must be deployed in harmony.** The High Return Policy scenario illustrates that increasing collection targets without expanding recycling capacity does not improve circularity; it results in backlogs. Regulatory timelines and infrastructure investment plans must be synchronised.
- **Second-life reuse requires proactive management of material flow.** Repurposing used EV batteries for second-life, for example, stationary energy storage, represent one of the most promising strategies in circular economy, and demand for exactly this kind of application is growing. The issue is not whether to pursue reuse, but when and how. The model shows that when more batteries go into second-life use, fewer materials return to recycling in the near term, which temporarily lowers the circularity rate (S4: 64.80%).This is not a problem if anticipated; the solution is to design second-life projects with a clear end-of-second-life recycling pathway built in from the start, so that material eventually closes the loop rather than disappearing into an unmanaged state.

The study recognises several limitations: the model uses a static single-period framework; parameters rely on secondary data without primary operator interviews; and a uniform recovery efficiency (η=0.90) is used across all battery chemistries. Future research directions identified include multi-year dynamic modelling with phased capacity investment, geographical optimisation for EU-wide facility location, integration of real State of Health data for reuse allocation, and process-specific yield models categorised by battery chemistry.

KEY REFERENCES

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