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Bridging the gap: Environmental and policy challenges in lithium-ion battery disposal in New Zealand

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Abstract

This paper examines New Zealand's approach to lithium-ion battery (LIB) disposal, comparing it with best practices in China, South Korea, and Germany. As electric vehicle adoption and renewable energy use grow, effective LIB end-of-life management has become an urgent environmental and policy priority. Drawing on literature, international case studies, and an interview with Phoenix Metal Recyclers (Phoenix), New Zealand's largest battery recycling operator, was conducted to understand local industry perspectives on operational challenges and policy gaps. The study identifies key weaknesses in New Zealand's system, including the lack of a mandatory stewardship scheme, limited domestic processing capacity, and poor traceability. In contrast, leading countries operate integrated systems with producer responsibility, digital tracking, and advanced recycling technologies. The findings reveal clear opportunities for New Zealand to enhance battery lifecycle management through targeted policy reform, infrastructure investment, and stakeholder collaboration. Key recommendations include implementing a national stewardship scheme for all battery types, expanding public drop-off points, and establishing a digital traceability system. These actions are critical for advancing a circular battery economy and aligning with global sustainability goals.

1 Introduction

Lithium-ion batteries (LIBs) are essential to modern energy systems, powering devices from electronics to electric vehicles and supporting renewable energy storage. The global shift toward clean energy has intensified demand for LIBs, with electric vehicles projected to make up nearly 50% of global light duty vehicle sales by 2050 (Rahman, Afroz and Safrin, 2017). While LIBs reduce emissions during use, their production and disposal pose significant environmental and social challenges.

Battery manufacturing is highly resource and carbon-intensive, with battery production alone accounting for up to 60% of the greenhouse gas emissions generated during the manufacturing phase of electric vehicles. This substantial contribution is primarily due to the extraction and processing of materials such as lithium and cobalt (Vieira *et al.*, 2025). Supply chains are also geographically concentrated, 73% of lithium comes from Chile, Australia, and China, and 77% of cobalt from the Democratic Republic of the Congo, Australia, and Cuba, creating vulnerability for countries without local processing capabilities (Yu *et al.*, 2022). At end-of-life, LIBs present hazards such as groundwater contamination, fire risks, and material loss.

Globally, more than 20 countries have announced plans to phase out internal combustion engines in favour of electrified transport(Ma, Azhari and Wang, 2021). This rapid shift has intensified pressures on material supply chains and exposed the environmental costs of resource extraction, such as ecosystem degradation and human toxicity (Kang, Chen and Ogunseitan, 2013; Zhou *et al.*, 2024). Although recycling initiatives led by organisations like the Rechargeable Battery Recycling Corporation have gained traction in developed regions,

many developing countries still lack adequate regulation, resulting in large volumes of LIBs ending up in landfills (Zhou *et al.*, 2024).

Life cycle studies show that circular supply chains, where spent batteries are repurposed or recycled, can drastically reduce environmental burdens. For example, upstream impacts account for only 5% in circular systems compared to 31% in conventional ones (Machala *et al.*, 2023). Safe, structured recycling not only mitigates fire and contamination risks but also supports the recovery of valuable materials and reinforces a circular economy (Ma, Azhari and Wang, 2021; Wrålsen and O'Born, 2023)

New Zealand's EV adoption is accelerating, with projections estimating that EVs will make up 40% of the national light vehicle fleet by 2040, or approximately 1.34 million vehicles (Williams *et al.*, 2023). This trend increases the urgency for scalable and sustainable battery disposal systems. However, New Zealand has yet to formalise a cohesive end-of-life strategy for LIBs. While countries like Japan and South Korea have established integrated domestic recycling systems, New Zealand remains reliant on voluntary schemes, offshore processing, and fragmented local council initiatives.

Growing stakeholder concern and rising demand for transparency and environmental accountability underscore the need for a structured national approach (de Villiers and van Staden, 2012). In response, this study assesses the current landscape of LIB disposal in New Zealand, exploring environmental risks, regulatory frameworks, and operational practices. Drawing on international case studies (China, South Korea, Germany), literature analysis, and a semi-structured interview with a leading national recycler, the research identifies key gaps and offers actionable strategies for developing a more resilient, circular, and sustainable battery management system.

To address these challenges, this study aims to evaluate New Zealand's current approach to lithium-ion battery disposal and identify actions to support a more sustainable, circular waste management system. Through a qualitative methodology, the research combines a literature review, a semi-structured interview with a national industry leader, and comparative analysis of international case studies (China, South Korea, and Germany). The findings inform practical policy and infrastructure recommendations tailored to New Zealand's regulatory and geographic context.

2 Methodology

This research adopts a qualitative and comparative approach to examine LIB disposal practices in New Zealand and assess their environmental impacts. This methodology supports a deeper understanding of local systems, policy implementation gaps, and international best practices, which are often not captured through quantitative methods (Bazen et al., 2021).

The study began with a literature review to establish a global perspective on LIB disposal, including methods, environmental impacts, and emerging recycling technologies. It then focused on New Zealand's national legislation, council initiatives, and industry roles. To contextualise these findings, three international case studies were selected: China, South Korea, and Germany. These countries were chosen based on the maturity of their LIB management systems and their geographical relevance to New Zealand's regulatory and economic context.

Primary data collection included a semi-structured interview with Jasmine Faulkner, Product Stewardship Manager at Phoenix Metal Recyclers, New Zealand's largest battery recycler. Conducted on 2 December 2024, the interview provided in-depth insights into operational, financial, and regulatory challenges, including export processes and the proposed stewardship scheme. The interview was transcribed and analysed thematically, with emergent codes aligned to five key policy and operational domains: infrastructure, regulation, traceability, public access, and producer responsibility.

Finally, the study employed a comparative policy benchmarking framework to integrate findings from the literature, case studies, and interview. This approach enabled the

identification of structural gaps in New Zealand's current LIB management practices and highlighted transferable strategies from more advanced systems abroad.

However, this research has some limitations. The reliance on a single industry interview may not fully capture the diversity of perspectives within the LIB sector. Additionally, while the selected case studies offer robust international comparisons, they may not fully reflect the challenges faced by smaller or emerging economies. Further research involving multiple stakeholders and broader geographic coverage would improve the relevance of the findings to other contexts.

3 Literature review

3.1 Environmental impact of lithium battery disposal

Lithium-ion batteries (LIBs) are commonly discarded through four pathways: landfilling, recycling, illegal disposal, and informal processing. Due to limited infrastructure and weak regulatory enforcement, particularly in developing countries, landfilling remains the dominant method (Santos, Alves and Ferreira, 2025). This poses serious environmental risks, as LIBs contain hazardous substances that can leach into surrounding ecosystems.

Toxic elements such as cadmium, lead, lithium, nickel, carbon-based nanomaterials, and ionic liquids can contaminate soil and groundwater, disrupt ecological balance, and cause health issues including kidney damage, neurological disorders, and cancer (Melchor-Martínez *et al.*, 2021). While incineration is sometimes used to reduce landfill volumes, it produces fly ash and bottom ash containing heavy metals, which may return to landfills if not managed properly, contributing to long term contamination (Winslow, Laux and Townsend, 2018).

LIBs also increase the risk of landfill fires, often triggered by residual charge or interaction with methane from organic waste. The 2019 Dunbar landfill fire, which involved over 300 tonnes of waste, illustrates this danger. Such fires release hazardous emissions including hydrogen fluoride, carbon monoxide, volatile organic compounds, and fine particulates. These pollutants can spread widely, impacting air quality far from the landfill site (Santos, Alves and Ferreira, 2025).

Leachate from LIBs, formed when water percolates through landfill waste, contains metals such as lithium, cobalt, mercury, and thallium, as well as acids like hydrofluoric acid and sulphur dioxide. These contaminants acidify soil, mobilise toxic elements, and can travel several kilometres, entering groundwater and surface water systems. Once released, pollutants can be absorbed by plants or aquatic organisms, leading to bioaccumulation in the food chain and posing long term ecological and human health risks (Santos, Alves and Ferreira, 2025).

Informal and illegal disposal further exacerbates these risks. Without regulatory oversight, LIBs are frequently handled in unsafe conditions, exposing workers and nearby communities to toxic substances and environmental contamination. Globally, an estimated two thirds of electronic waste is exported illegally to countries lacking treatment facilities, resulting in environmental degradation and increased public health burdens (Santos, Alves and Ferreira, 2025).

Even regulated methods such as hydrometallurgical recycling carry environmental trade-offs. Although these processes recover 70 to 91% of critical metals like cobalt and lithium, they emit around 1,320 kilograms of carbon dioxide equivalent per tonne of battery processed, mainly due to high energy use and waste disposal (Boyden, Soo and Doolan, 2016). Additional emissions arise from exporting batteries to offshore facilities, with studies indicating that international shipping can further increase the carbon footprint depending on distance and destination. Nonetheless, life cycle assessments (LCAs) confirm that recycling remains environmentally preferable to disposal. Compared to scenarios where batteries are simply disposed of in landfills at the end of their life, recycling reduces air pollution and conserves finite resources, supporting the case for investment in recycling infrastructure and sustainable waste management systems (Winslow, Laux and Townsend, 2018).

In summary, improper disposal of LIBs presents severe environmental and health risks, including soil and water contamination, air pollution, and ecosystem disruption. Incineration, though meant to reduce landfill waste, often causes other environmental problems. In addition, poor global oversight has allowed illegal and informal disposal to spread widely, with greater harm falling on vulnerable communities. Effective battery management must therefore go beyond technological solutions and include strong regulatory frameworks, investment in infrastructure, and coordinated global action. Without systemic change, the growth of battery-reliant technologies may undermine their environmental benefits in terms of reduced tailpipe emissions. For New Zealand, understanding these global risks is essential for designing effective local policies that protect public health and support circular economy goals.

3.2 Recycling technologies and material recovery pathway

Recycling of lithium-ion batteries (LIBs) involves a combination of mechanical, thermal, and chemical processes to recover valuable metals such as lithium, cobalt, and nickel. These methods support resource conservation and reduce the environmental impacts associated with raw material extraction (Zanoletti *et al.*, 2024). Although the cost of recycled lithium can be several times higher than lithium extracted from brine sources, the environmental benefits are substantial. Studies show that producing high purity materials from used batteries can reduce environmental impact by over 50% compared to conventional production routes(Rahman, Afroz and Safrin, 2017; Machala *et al.*, 2023).

Mechanical pre-treatment is generally the first step, involving battery discharge and physical separation of components. Hydrometallurgical processing, the most widely used technique, employs chemical leaching to extract metals from the active material, or "black mass." This method achieves high recovery rates under controlled conditions and is considered more environmentally favourable than incineration or landfilling (Bae and Kim, 2021).

Other methods, such as pyrometallurgy and electrochemical recovery, are also employed depending on material types and desired outputs. Pyrometallurgy involves high-temperature treatment to extract metal alloys, while electrolysis allows high-purity recovery of selected metals (Bae and Kim, 2021; Toro *et al.*, 2023). However, these processes often require significant energy inputs and can result in the loss of lighter metals such as lithium unless paired with further refining.

While each method has strengths and limitations in terms of efficiency, cost, and environmental performance, the literature highlights the benefits of integrated approaches. Nonetheless, major challenges remain in scaling these technologies, particularly in regions with limited infrastructure or fragmented regulatory support. Most advanced recycling efforts are currently concentrated in countries with established industrial capacity. In the case of New Zealand, where LIB consumption is rising due to increasing electric vehicle uptake and portable electronics use, there is limited infrastructure and policy support for large-scale battery recycling. This presents a critical opportunity to evaluate how global best practices in recycling can be translated into locally appropriate solutions. Bridging this gap will require not only technological adaptation but also targeted investment, clear regulatory frameworks, and a national strategy for end-of-life battery management that aligns with circular economy goals.

3.3 Challenges in recycling

Recycling lithium-ion batteries (LIBs) presents a range of challenges across technical, economic, and regulatory domains. As global demand for LIBs continues to grow, especially in electric vehicles and portable electronics, addressing these challenges is essential for promoting sustainability and responsible resource use.

A major technical challenge lies in the diversity of battery designs. LIBs vary in shape, size, and configuration as manufacturers strive to optimise energy density and performance (Thompson *et al.*, 2020; Rehman *et al.*, 2025). While these innovations benefit end users, they complicate disassembly and material recovery. Recycling requires careful identification of battery types, disconnection of electrical and mechanical systems, and extraction of cells (Rehman *et al.*, 2025). These tasks demand trained personnel and strict safety protocols. Due

to limited design standardisation, automated dismantling remains underdeveloped, making manual disassembly the default. This slows processing, increases costs, and limits scalability (Rehman *et al.*, 2025; Santos, Alves and Ferreira, 2025).

Another barrier is the lack of standardised labelling and traceability. Most LIBs do not indicate internal components such as electrode types or electrolyte formulations. Recyclers must therefore rely on generalised methods, which reduces efficiency and heightens the risk of contamination (Thompson *et al.*, 2020). Inaccurate identification can also compromise safety during storage and transport, increasing the risk of thermal runaway and chemical leakage (Toro *et al.*, 2023; Rehman *et al.*, 2025). Moreover, different battery chemistries require specific discharge procedures, further complicating safe deactivation (Rehman *et al.*, 2025).

Scaling up recycling technologies remains a significant industrial challenge. Although many promising techniques have been demonstrated at laboratory scale, commercial implementation has been limited. This is due in part to the difficulty of bridging the gap between research and industry adoption, especially under strict environmental and social regulations (Santos, Alves and Ferreira, 2025). Greater collaboration across sectors and the development of flexible, scalable technologies are essential.

Regulatory inconsistency also constrains progress. While regions such as the European Union have introduced frameworks like Regulation 2023/1542 and China enforces strong national policies, many countries still lack clear legal standards for battery recycling and reuse. This uncertainty discourages investment in infrastructure and hinders international alignment (Santos, Alves and Ferreira, 2025).

Finally, the financial viability of LIB recycling remains a significant concern. In many regions, recycling is not profitable and often requires consumers to pay disposal fees, discouraging participation. There are also concerns about the performance and safety of recycled materials, which has limited their acceptance by manufacturers. Ensuring the reliability of recovered materials requires extensive testing at scale, adding to operational costs and delaying wider adoption (Santos, Alves and Ferreira, 2025).

Despite global progress in LIB recycling, significant challenges persist, particularly in technological scalability, regulatory consistency, and financial viability. These are further compounded by evolving battery chemistries, lack of design standardisation, and inadequate traceability, which collectively constrain the efficiency and safety of recycling systems. While industrialised nations invest in infrastructure and regulatory reform, countries like New Zealand remain in the early stages of formulating a cohesive national strategy for end-of-life battery management. This highlights a critical research gap: how can global best practices be effectively adapted to smaller markets with limited processing capacity, fragmented policies, and rising e-waste volumes? Addressing this requires not only assessing the relevance of international models, but also developing context-specific solutions aligned with New Zealand's environmental objectives, circular economy goals, and regulatory framework.

3.4 Future technological innovations in LIB disposal and recycling

The recycling of lithium-ion batteries (LIBs) faces several persistent challenges, including limited processing capacity, high operational costs, and notable environmental impacts. In response, researchers and industry experts are developing innovative technologies to support more efficient, sustainable, and circular approaches to battery waste management.

At the core of material recovery efforts, biological and chemical methods are being refined to reduce environmental burdens. Bioleaching, for example, uses microorganisms such as Acidithiobacillus ferrooxidans to extract valuable metals like lithium, cobalt, and nickel from spent batteries (Gu et al., 2018; Gomes, Funari and Ferrari, 2020). Compared to traditional acid leaching, bioleaching is less energy-intensive and avoids harsh chemicals, though its adoption is limited by slow reaction rates and microbial sensitivity(Gomes, Funari and Ferrari, 2020; Zhang *et al.*, 2023) .

In parallel, green solvents such as supercritical carbon dioxide (SC CO_2) and deep eutectic solvents (DESs) are being developed as safer, low-impact alternatives to traditional leaching

agents. SC CO_2 is chemically stable, non-toxic, and operates at moderate temperatures and pressures, making it effective for removing binders and electrolytes without producing hazardous residues (Cattaneo *et al.*, 2024). DESs, created by combining hydrogen bond donors and acceptors, can selectively extract metals like cobalt and lithium while offering low toxicity and biodegradability. However, challenges such as high viscosity, chemical instability, and difficult recovery processes limit their current use to laboratory-scale trials (Meles Neguse *et al.*, 2024; Svärd *et al.*, 2024).

To streamline recovery and reduce manual labour, automation and artificial intelligence (AI) are increasingly integrated into recycling workflows. Robotic disassembly systems equipped with sensors improve the precision of material separation, while AI enhances sorting accuracy, contamination detection, and smart bin monitoring, achieving up to 99.95% classification accuracy (Fang *et al.*, 2023; Antony Jose *et al.*, 2024). In parallel, design for recycling (DfR) is emerging as a proactive strategy. Modular battery designs have been shown to boost recovery efficiency by up to 20% (Xiaodong and Ishchenko, 2024). Supporting this trend, the European Union will require all portable electronic devices to have user-removable batteries by 2030, encouraging end-of-life recoverability (European Parliament, 2025).

To ensure accountability across the entire battery lifecycle, blockchain technology offers secure, end-to-end traceability, from raw material extraction to second-life use and recycling. It enables reliable tracking of performance, ownership, and recovery outcomes, enhancing transparency and trust (Shahjalal *et al.*, 2022; Faria, de Oliveira and Rüther, 2025). This is particularly valuable in second-life markets, where accurate data supports safety assessments and valuation. Initiatives like the Battery Digital Passport consolidate technical specifications and recycling instructions into verifiable records. However, high implementation costs, lack of standardised data protocols, and limited engagement remain barriers (Antônio Rufino Júnior *et al.*, 2022). Despite these barriers, blockchain presents a promising tool for advancing transparent and circular battery management.

Collectively, innovations such as bioleaching, green solvents, automation, AI, and blockchain hold strong potential to improve LIB recycling. While many are still emerging, they offer opportunities for countries like New Zealand to adopt more sustainable and efficient practices. Realising this potential will require coordinated investment, supportive regulation, and public–private collaboration.

4 Case studies

6.1 China

China holds 13.21% of global lithium reserves, making it a major player in the lithium sector (Guo et al., 2021). Its limited crude oil reserves have driven the rapid development of the electric vehicle (EV) industry, positioning China as a global leader in LIB production and recycling (Guo, Zhang and Tian, 2021; Yu *et al.*, 2022). With spent LIBs in China expected to exceed 800,000 tonnes by 2025, recycling has become a strategic response to resource scarcity and energy security (Sun *et al.*, 2021).

China has developed advanced recycling technologies, involving pretreatment (deactivation, dismantling, crushing, and separation) and recovery through pyrometallurgical and hydrometallurgical methods. Regeneration processes that directly restore cathode materials are also gaining traction due to their lower cost and energy demands (Yu *et al.*, 2022). However, while recycling efforts have primarily focused on recovering higher-value metals such as cobalt and nickel, less than 1% of lithium is currently being recycled, showing room for improvement (Guo, Zhang and Tian, 2021).

In response to the growing LIB waste, the Chinese Ministry of Industry and Information Technology introduced the Interim Measures for the Management of Power Battery Recovery and Utilization of New Energy Vehicles. This regulation emphasizes the accountability of automobile manufacturers for battery recovery and the need for complete lifecycle management of spent batteries. Cascade utilization is encouraged, where batteries are

repurposed for secondary use before being recycled. Following this, the Interim Provisions on the Traceability Management of Power Battery Recovery and Utilization of New Energy Vehicles was issued in 2018 to establish a national platform for monitoring and ensuring traceability throughout the battery lifecycle (Cheng *et al.*, 2021; Sun *et al.*, 2021).

Local initiatives complement these national policies. For instance, Shenzhen Municipal Finance Commission introduced a subsidy policy for battery recycling to incentivize participation (Shenzhen, 2018). Additionally, the government released the Industry Standard Conditions for the Comprehensive Utilization of Waste Power Batteries for New Energy Vehicles, a non-mandatory regulation aimed at identifying qualified recycling companies and promoting sustainable recycling strategies. In 2019, this framework was expanded to include cascade utilization and recovery approaches (Yu *et al.*, 2022).

Despite these efforts, informal recycling channels remain widespread due to their convenience, undermining formal sector growth. Poor coordination among producers, recyclers, and reuse operators, along with data and technical gaps, continues to hinder efficiency (Cheng *et al.*, 2021). China's model showcases how national regulation, industrial innovation, and traceability systems can scale sustainable LIB recycling. While it leads in infrastructure and policy, persistent challenges such as informal channels and low lithium recovery rates highlight the need for stronger enforcement and stakeholder integration. These experiences offer valuable lessons for other countries navigating similar battery lifecycle challenges.

6.2 South Korea

The rapid expansion of Korea's EV market, driven by government incentives such as tax exemptions, subsidies, charging infrastructure development, and discounted parking fees, has resulted in an anticipated increase in end-of-life EV batteries (Choi and Rhee, 2020). To address this surge, the Korean Ministry of Environment established the 'Future Waste Collection Center,' focusing on the collection of LED lamps, solar panels, and end-of-life EV batteries. Additionally, government bodies like the Ministry of Trade, Industry and Energy (MOTIE) and the Ministry of Environment (MoE) actively promote the reuse of these batteries as Energy Storage Systems (ESS). ESS reuse initiatives aim to extend battery life while supporting renewable energy integration. To facilitate this, ESS reuse centers have been set up in Jeju and provinces such as Gyeongbuk, where testing methods are developed to determine the suitability of end-of-life EV batteries for repurposing (Choi and Rhee, 2020). Simultaneously, the government, in collaboration with research institutes, is advancing pretreatment and recycling technologies to secure valuable raw materials and enhance the sustainability of battery management practices(Choi and Rhee, 2020).

Korea employs three distinct systems to manage EV components and their batteries: the Extended Producer Responsibility (EPR) system for lithium-ion batteries, the Eco-Assurance System (ECOAS) for EV bodies and hazardous materials, and the Allbaro System, a national digital waste tracking platform (Choi and Rhee, 2020). Under Korea's Extended Producer Responsibility (EPR) system, end-of-life EV batteries are managed through a structured cycle of production, consumption, collection, and recycling. Batteries are distributed via retail outlets or producer-affiliated branches, and when they reach the end of their life they are handled by designated repair shops. These batteries are then categorised by subsidy status: government-subsidised units are sent to state-operated recycling centres, while unsubsidised batteries are processed at approved private facilities using hydrometallurgical methods to recover valuable materials such as lithium and cobalt. All producers, including manufacturers and importers, are required to contribute financially to the system based on their market share, ensuring shared responsibility for collection and recycling costs (Kim *et al.*, 2018). The Eco-Assurance System (ECOAS) complements EPR by regulating the full lifecycle of EV components. It enforces restrictions on hazardous substances, promotes recycling-oriented design, and ensures compliance with end-of-life recycling obligations. ECOAS aims to improve resource efficiency by integrating environmental considerations into the design and disposal phases of electronic and automotive products. Meanwhile, the Allbaro System strengthens Korea's

waste governance by digitally tracking industrial and hazardous waste from generation through disposal. It ensures compliance with domestic regulations and international agreements such as the Basel Convention, helping to prevent illegal dumping and improve transparency in waste handling.

Together, these three systems create an integrated framework that demonstrates Korea's leadership in circular economy practices and sustainable battery management. Ongoing monitoring and infrastructure investment support environmental protection and operational efficiency, reflecting Korea's strong commitment to long-term sustainability.

6.3 Germany

Germany stands at the forefront of LIB recycling, with a well-structured framework that balances environmental sustainability and economic potential. Between 2013 and 2025, approximately 590,000 spent LIBs, weighing around 123,000 metric tons, are expected to accumulate in the country. If all these batteries were recovered and their materials sold, they could generate an estimated $467 million, underscoring the significant value of effective recycling systems (Hoyer, Kieckhäfer and Spengler, 2013)

Germany's efforts are guided by the EU Batteries Directive (2006/66/EC), which mandates a minimum collection rate of 45% for waste LIBs and a recycling efficiency of at least 50% by weight (Sun *et al.*, 2021). This directive has been instrumental in fostering sustainable practices, requiring producers to take responsibility for the recovery and recycling of spent batteries. Through its Producer Responsibility System, Germany has effectively implemented these guidelines, ensuring the seamless management of end-of-life batteries.

At the heart of Germany's recycling strategy is the LithoRec Project, a pioneering initiative that offers a holistic approach to LIB recycling, particularly for electric vehicles (EVs). The process begins with the collection of batteries from vehicle service stations and end-of-life treatment facilities, where they are assessed for reuse or recycling. Viable batteries are then sorted and stored before undergoing recycling. The LithoRec process unfolds in three key stages: Disassembly, Mechanical Conditioning and Hydrometallurgical Conditioning. A distinguishing feature of the LithoRec initiative is its foundation in life cycle assessment (LCA), in accordance with ISO 14040 standards, which validates its environmental performance compared to primary raw material extraction (Hoyer, Kieckhäfer and Spengler, 2013).

Germany's approach to LIB recycling illustrates the impact of strong regulatory alignment, producer responsibility, and lifecycle-based innovation. The implementation of EU directives has provided a robust legal foundation, while initiatives like the LithoRec Project demonstrate Germany's commitment to integrating environmental assessment and closed-loop recovery systems. By combining economic foresight with ISO-compliant sustainability practices, Germany offers a mature and replicable model for LIB recycling. However, as battery technologies and waste volumes evolve, continued adaptation will be necessary to maintain efficiency and meet future circular economy targets. These lessons from Germany contribute valuable insights into the role of policy integration and process optimization in shaping effective national recycling systems.

6.4 Case studies conclusions

Together, these case studies highlight the diversity of national approaches to LIB recycling, from China's centralized policies and industrial capacity to Korea's digitally integrated systems, and Germany's EU-aligned lifecycle focus. While each country demonstrates unique strengths, common challenges persist, including low lithium recovery rates, informal recycling channels, and the need for ongoing adaptation to evolving battery technologies. These international experiences provide valuable context for evaluating and improving emerging frameworks in other countries, including New Zealand

7 New Zealand practice

New Zealand currently manages end-of-life lithium-ion batteries (LIBs) primarily through export to certified facilities in Japan and South Korea. Batteries are sorted by chemistry at local sites in Christchurch and Auckland, packaged under IMDG regulations, and shipped with permits compliant with the Basel Convention. While this ensures regulatory alignment and environmental oversight through standards like ISO 14001, the system depends on long-distance transport and offshore processing, factors that significantly elevate the carbon footprint. Although viable in the short term, this export-based model exposes New Zealand's reliance on external infrastructure and underscores the environmental and strategic limitations of outsourcing recycling. These challenges highlight the need for domestic solutions that reduce emissions and strengthen system resilience.

Compounding the issue, not all batteries can be exported. Damaged or compromised units that are deemed unsafe for transport are typically sent to domestic landfills. This poses serious environmental and safety risks, including the leaching of hazardous metals such as lithium, cobalt, and nickel, and potential fire hazards due to residual charge. These risks align with global concerns surrounding landfill disposal of LIBs.

Recognising these limitations, Phoenix is exploring the development of a domestic pre-treatment facility to produce black mass from spent LIBs. Such a facility could reduce transport emissions, improve environmental oversight, and create a more resilient and self-contained recycling pathway, particularly if powered by renewable energy and integrated with downstream recovery partners. However, its financial feasibility depends on a stable feedstock supply, which is currently uncertain due to the absence of a national product stewardship scheme to support infrastructure investment. In the absence of formal regulation, private initiatives such as Phoenix Recycling have filled gaps, offering nationwide collection and processing services. Local councils further support battery recycling by partnering with community groups. For instance, Nelson City Council, in collaboration with tangata whenua, offers free drop-off points at the Nelson Waste Recovery Centre and Environment Centre, guided by the city's Solid Waste Activity Management Plan.

New Zealand's regulatory environment lacks a dedicated framework for LIB disposal. The current system is fragmented, reliant on voluntary industry initiatives, and anchored in general hazardous waste regulations under the Basel Convention and the Waste Minimisation Act. The Waste Minimisation Act 2008 provides the legislative foundation, promoting waste reduction through product stewardship. In 2020, the Ministry for the Environment classified large-format LIBs, commonly found in electric vehicles and energy storage systems, as priority products, mandating regulated stewardship schemes. While these schemes are still in development, the Ministry supports local and regional efforts through the Waste Minimisation Fund, including initiatives like Buller District Council's free household battery collection program. Phoenix, as one of the few licensed exporters, operates under strict international protocols. This regulatory gap allows some operators to export batteries under generic e-waste categories instead of hazardous waste, undermining traceability and weakening environmental safeguards. New Zealand's reliance on voluntary participation limits accountability, as producers and importers are not legally required to fund or manage end-of-life disposal. In contrast, countries like South Korea and Germany enforce extended producer responsibility (EPR) by law, ensuring consistent funding, national coverage, and stakeholder participation. Without such mandates, New Zealand's system remains fragmented, underfunded, and heavily dependent on voluntary efforts by industry and councils.

The most prominent policy shortfall is the absence of a mandatory product stewardship scheme. Although the Battery Industry Group proposed a national scheme covering LIBs over five kilograms, including producer registration and cost-sharing mechanisms, its implementation has stalled due to political changes following a change in government, a lack of fully costed end-of-life financial modelling, and reluctance from stakeholders to bear disposal costs. As a result, the financial burden of recycling is currently borne by consumers, councils, and private recyclers, limiting participation and increasing the risk of improper

disposal.Current customs protocols undermine strategic planning, as battery imports are recorded by unit or cell count rather than chemistry or weight, preventing accurate forecasting and infrastructure development.

Local councils, required under the Waste Minimisation Act to produce Waste Management and Minimisation Plans (WMMPs), often do not treat LIBs as a distinct category. Most WMMPs group LIBs with general batteries or e-waste, overlooking their specific environmental hazards and recovery potential. This has led to inconsistencies across councils, resulting in service gaps and uncoordinated infrastructure planning. A nationally consistent framework, supported by stronger enforcement mechanisms, is needed to improve oversight and align local strategies with national priorities.

Stakeholder collaboration remains limited but is gaining traction. Phoenix plays a key role in shaping the LIB recycling landscape by participating in the Battery Industry Group and WasteMINZ's Lithium Ion Working Group. These efforts have contributed to the design of stewardship proposals and development of national guidelines for handling LIBs. However, the voluntary nature of participation means many producers, importers, and retailers are not yet accountable for the end-of-life management of their products. This results in uneven service provision and inconsistent recycling practices. WasteMINZ supports public education, policy advocacy, and maintains a national recycling map, but the absence of formal regulation leaves participation voluntary and fragmented.

Public awareness and access also remain major barriers. Many consumers are unaware of LIB disposal pathways or lack access to convenient drop-off points. Consequently, batteries from vapes, power tools, and electronics are often discarded with household waste, exacerbating fire risks and chemical contamination in landfills. Unlike lead acid batteries, which are widely recycled at no cost, LIB disposal often incurs a fee, further discouraging responsible behaviour. To address this, expanding collection infrastructure into high-traffic retail environments (e.g., supermarkets and hardware stores) and launching targeted public education campaigns are essential steps.

Technological innovation presents long-term opportunities for improving LIB management. In addition to the proposed black mass facility, industry stakeholders are adopting enhanced safety protocols, including fire-resistant liners and specialised storage systems. Future strategies may focus on optimising battery disassembly, automating sorting processes, and developing protocols for handling unstable or non-exportable units. Digital traceability systems that record battery origin, chemistry, and usage conditions can support regulatory compliance and lifecycle monitoring, reinforcing accountability across the supply chain.

Taken together, these findings illustrate the structural and operational constraints facing New Zealand's LIB disposal system. Export-based recycling remains the dominant but environmentally costly method. Domestic infrastructure development is hindered by inconsistent policy, weak regulatory enforcement, and the absence of producer accountability. Public engagement and access are limited, and private actors bear a disproportionate share of the financial and logistical burden. To move toward a circular battery economy, New Zealand must implement coordinated reforms, including a comprehensive stewardship scheme, digital traceability systems, public-private partnerships, and investment in onshore processing. These actions are critical for building a LIB management system that is environmentally responsible, financially sustainable, and resilient to future demand.

7.1 Comparison between New Zealand with the global standards

New Zealand's LIB disposal framework is based on the Waste Minimisation Act 2008 and the Basel Convention. While these provide a general structure for managing hazardous waste, they do not specifically identify LIBs as a distinct category or mandate producer responsibility. By contrast, China enforces producer accountability through its Interim Measures for Battery Recovery and a national traceability platform. South Korea applies Extended Producer Responsibility (EPR), requiring manufacturers and importers to contribute to recycling costs, while Germany follows the EU Batteries Directive, which mandates collection targets and

producer-funded recovery schemes. In comparison, New Zealand's proposed stewardship scheme is still under development and currently limited to large-format batteries, reducing its overall impact.

New Zealand lacks a domestic LIB recycling facility and instead relies on partners to export batteries to certified processors in Japan and South Korea. In contrast, China, South Korea, and Germany have established extensive domestic recycling infrastructure. China integrates traceability with full-cycle recovery. South Korea operates centralised reuse and hydrometallurgical plants. Germany's LithoRec project exemplifies a closed-loop system supported by life cycle assessment. While New Zealand plans to build a black mass facility, this depends on securing consistent feedstock volumes.

The current financial model is another challenge. Although some councils receive support via the Waste Minimisation Fund (WMF), there is no national funding mechanism dedicated to LIB disposal. Infrastructure, insurance, and transport costs fall to recyclers and industry partners, making operations costly. In contrast, China and South Korea use public funding and shared cost models, while Germany's system is self-sustaining through material recovery and producer contributions. New Zealand's small market and lack of a coordinated funding structure limit its ability to replicate these systems, leaving recycling efforts largely voluntary.

In addition, New Zealand falls short in traceability, accessibility, and public engagement. Unlike China's national battery tracking platform or South Korea's Allbaro digital waste system, New Zealand's customs data records battery imports by unit rather than weight or chemistry, limiting effective forecasting and oversight. Public collection infrastructure remains sparse, and awareness of disposal options is low. In comparison, Germany and South Korea combine broad consumer access with national education campaigns and mandatory industry participation. These gaps highlight the need for integrated data systems, stronger regulatory enforcement, and expanded public outreach to align with international best practices.

Table 1: Comparison of LIB disposal systems: New Zealand vs. international best practice

Category	New Zealand	International Best Practice (China, Korea, Germany)
Product Stewardship	Still in proposal stage, limited to large batteries only	Legally enforced schemes with funding models for all battery sizes
Traceability and Data	Customs data tracks battery imports by cell, not weight; poor for forecasting	National digital platforms ensure traceability across the battery lifecycle (e.g. China's national system)
Infrastructure	No domestic LIB recycling facility; fully reliant on export	Domestic, high-capacity recycling and regeneration plants in operation
Convenience for Public	Limited access to drop-off points, with collection units not yet deployed in high-traffic locations like supermarkets and petrol stations	Easily accessible drop-off points in retail stores and service centers nationwide
Industry Participation	Voluntary participation; financial burden on recyclers	Mandatory producer responsibility with financial contributions from manufacturers and importers
Policy Enforcement	No formal enforcement framework in place; stewardship scheme for large batteries remains in proposal stage	Strong legal frameworks and enforcement mechanisms to ensure compliance

Consumer Awareness	Low engagement due to lack of incentives and visibility	National education campaigns and economic incentives promote public participation

Closing these gaps is crucial for New Zealand to build a self-reliant and sustainable lith LIB disposal system. Despite ongoing progress, current efforts remain limited by infrastructure constraints, fragmented policies, and heavy reliance on the private sector. In contrast, international leaders succeed through integrated approaches combining regulation, funding, and advanced processing. To align with these benchmarks, New Zealand must formalise a national stewardship scheme covering all battery types with secured funding, invest in onshore black mass processing, establish a national traceability system, and foster public-private partnerships to expand collection networks. These steps are vital for advancing a circular battery economy and improving national resource recovery.

8 Conclusion and recommendations

This research assessed New Zealand's LIB disposal practices, comparing them with global leaders: China, South Korea, and Germany. Through a combination of literature review, international case studies, and an interview with Phoenix, the study identifies key gaps in New Zealand's system, including reliance on offshore recycling, lack of a mandatory stewardship scheme, limited traceability, and no domestic processing infrastructure. In contrast, leading countries have adopted legally enforced frameworks combining extended producer responsibility (EPR), material recovery technologies, digital tracking systems, and coordinated funding.

While New Zealand is still developing a nationally consistent and circular approach, local stakeholders demonstrate strong potential to support progress. To build a more sustainable and self-reliant system, the following actions are recommended:

1. **Implement a mandatory national product stewardship scheme** covering all LIB types, with clear producer responsibilities and dedicated funding for collection, education, and infrastructure.
2. **Establish a national digital traceability system** and update customs classifications to track battery imports by chemistry and weight for accurate forecasting and oversight.
3. **Invest in domestic pre-treatment facilities** for black mass production to reduce emissions, support system resilience, and enable onshore material recovery.
4. **Expand drop-off infrastructure and launch national public awareness campaigns** to improve consumer participation and reduce improper disposal.
5. **Support pilot projects for emerging recycling technologie**s, such as bioleaching, green solvents, AI-assisted sorting, and blockchain traceability, through targeted funding and regulatory sandboxes.

Aligning national regulation with international best practices, including enforceable targets and producer accountability, will require a central advisory body to coordinate data sharing and policy alignment. These actions are essential for transitioning toward a circular battery economy that meets both national and global sustainability goals.

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