FINANCIAL FEASIBILITY ANALYSIS OF LITHIUM-ION BATTERY RECYCLING FACILITIES: A COMPARATIVE STUDY OF THE NETHERLANDS, JAPAN, AND INDONESIA

BACHELOR THESIS

To complete Bachelor Program at the Undergraduate Program (S1) of the Faculty of Economics and Business, Diponegoro University

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ABSTRACT

The rapid growth of electric vehicle (EV) adoption has substantially increased global demand for lithium-ion batteries (LIBs), generating a growing volume of end-of-life batteries and raising urgent concerns about sustainable critical mineral supply chains. Battery recycling has emerged as a strategically important solution for recovering valuable materials including lithium, nickel, cobalt, manganese, and copper while supporting circular economy objectives. However, the financial feasibility of LIB recycling facilities varies considerably across countries due to differences in industrial maturity, cost structures, financing conditions, and market dynamics.

This study compares the financial feasibility of hypothetical LIB recycling facilities each with an annual processing capacity of 5,000 tonnes in the Netherlands, Japan, and Indonesia. Benchmark financial and operational data are drawn from Umicore (Netherlands) and DOWA Holdings (Japan), while assumptions for Indonesia are calibrated using percentage proxies derived from Huayou to reflect regional industrial conditions. Investment appraisal methods Net Present Value (NPV), Internal Rate of Return (IRR), and Weighted Average Cost of Capital (WACC) are applied across conservative, base case, and optimistic scenarios. Sensitivity analysis is conducted to identify the variables with the greatest impact on project feasibility.

Keywords: *Lithium-ion battery recycling, financial feasibility analysis, Net present value (NPV), Circular economy*

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ABSTRAK

Pesatnya adopsi kendaraan listrik (EV) telah meningkatkan permintaan global terhadap baterai lithium-ion (LIB) secara signifikan, menghasilkan volume baterai yang habis masa pakainya dalam jumlah yang terus bertambah, sekaligus menimbulkan kekhawatiran mendesak mengenai keberlanjutan rantai pasok mineral kritis. Daur ulang baterai telah muncul sebagai solusi yang strategis untuk memulihkan material bernilai tinggi termasuk litium, nikel, kobalt, mangan, dan tembaga sekaligus mendukung tujuan ekonomi sirkular. Namun, kelayakan finansial fasilitas daur ulang LIB sangat bervariasi antar negara, dipengaruhi oleh perbedaan kematangan industri struktur biaya, kondisi pembiavaan, dan dinamika pasar.

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Kata kunci: *Daur ulang baterai lithium-ion, Analisis kelayakan finansial, Nilai bersih (NPV), Ekonomi sirkular*

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CHAPTER 1
INTRODUCTION

1.1 Background of study

The global transition toward cleaner and more sustainable transportation has accelerated the adoption of electric vehicles (EVs), resulting in a significant increase in demand for lithium-ion batteries (LIBs). As governments and industries intensify efforts to reduce carbon emissions, EVs have become an important solution for achieving climate targets. According to the International Energy Agency, global electric vehicle sales surpassed 17 million units in 2024, reflecting the rapid growth of the EV market worldwide. While this growth creates opportunities for sustainable mobility, it also raises concerns regarding the future management of end-of-life batteries, which are expected to increase substantially in the coming years. IEA Global EV Outlook 2025

Lithium-ion batteries contain valuable critical materials such as lithium, nickel, cobalt, manganese, and copper, which are essential for battery production. However, when batteries reach the end of their useful life, improper disposal can create environmental problems and lead to the loss of valuable resources. As a result, battery recycling has emerged as an important strategy to support a circular economy, where materials can be recovered and reused instead of discarded. In addition to reducing waste, recycling helps decrease dependence on virgin mining activities and supports a more sustainable battery supply chain. Previous studies have shown that battery recycling can reduce environmental impacts while also creating economic value through the recovery of metals contained in spent batteries (Harper et al., 2019).

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From a business perspective, battery recycling has increasingly gained attention because it offers multiple revenue opportunities. Recycling companies can generate income not only from recovered metals but also from gate fees paid for processing battery waste. However, the profitability of battery recycling facilities depends on several important factors, including metal prices, operating costs, plant efficiency, and the amount of battery waste available for processing. Since these factors vary between countries, financial feasibility may differ significantly depending on local market conditions and industrial infrastructure.

Several countries have already established advanced battery recycling industries that can be used as benchmarks for future projects. In Europe, Umicore has developed one of the leading battery recycling systems supported by strong environmental regulations and circular economy policies. Similarly, in Japan, DOWA Holdings has extensive experience in urban mining and metal recovery, making it an important reference for battery recycling operations. These companies provide useful insights into financial performance, operational structures, and investment requirements for recycling facilities. However, directly applying European or Japanese business models to Indonesia may not be appropriate due to differences in labor costs, energy prices, industrial maturity, and waste management systems.

Indonesia has strong potential to develop a battery recycling industry because of its large nickel reserves and growing ambition to become a major player in the global EV battery supply chain. In recent years, the Indonesian government has actively encouraged investments in battery manufacturing and downstream mineral industries. Despite this development, research on the financial feasibility of battery recycling facilities in Indonesia remains limited. Most existing studies focus on technical processes or environmental impacts rather than evaluating whether such projects are financially attractive for investors.

Therefore, this study aims to assess the financial feasibility of establishing a lithium-ion battery recycling facility with a processing capacity of 5,000 tonnes per year in Indonesia. To achieve this, the study applies investment evaluation methods, including Net Present Value (NPV), Internal Rate of Return (IRR), and Weighted Average Cost of Capital (WACC). Benchmark data from Umicore in the Netherlands and DOWA Holdings in Japan are used as key references, while selected operational assumptions are adjusted using percentage proxies from Huayou to better reflect Indonesian market conditions. By conducting scenario and sensitivity analyses, this research seeks to evaluate whether battery recycling can become a financially viable investment opportunity in Indonesia.

1.2 Research Problem

The rapid growth of the electric vehicle (EV) industry has significantly increased global demand for lithium-ion batteries (LIBs), creating a growing need for effective end-of-life battery management. As the number of electric vehicles continues to increase, battery waste generation is expected to rise substantially in the coming years. Improper disposal of lithium-ion batteries may result in environmental pollution and resource loss, particularly because batteries contain valuable critical minerals such as lithium, nickel, cobalt, manganese, and copper (Harper et al., 2019). Consequently, battery recycling has become increasingly

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important as a strategy to support resource efficiency, reduce environmental impacts, and strengthen circular economy practices.

Despite growing interest in battery recycling, establishing a lithium-ion battery recycling facility requires substantial capital investment, operational efficiency, and stable revenue streams. Financial performance is influenced by multiple factors, including gate fees, metal recovery values, operating expenditures, energy costs, labour expenses, and policy environments. Since these factors differ significantly between countries, the financial feasibility of battery recycling projects may vary considerably across regions. Therefore, understanding how country-specific conditions affect investment outcomes has become increasingly important for both researchers and industry stakeholders.

Countries such as the Netherlands, Japan, and Indonesia present different industrial and economic environments for battery recycling development. The Netherlands represents a mature European market with advanced circular economy policies and established recycling infrastructure, supported by companies such as Umicore. Japan, through companies such as DOWA Holdings, has extensive experience in urban mining and metal recovery systems. Meanwhile, Indonesia is emerging as an important player in the battery supply chain due to its abundant nickel resources and increasing investments in EV battery industries. However, differences in cost structures, infrastructure, industrial maturity, and regulatory support create uncertainty regarding the comparative attractiveness of battery recycling investments among these countries.

Although previous studies have explored technical processes and environmental benefits of battery recycling, limited research has compared the financial feasibility of battery recycling facilities across different national contexts using a standardized investment evaluation approach. As a result, there remains a gap in understanding how financial viability differs between developed and emerging markets. Therefore, this study seeks to compare the financial feasibility of lithium-ion battery recycling facilities in the Netherlands, Japan, and Indonesia by applying investment evaluation methods such as Net Present Value (NPV), Internal Rate of Return (IRR), and Weighted Average Cost of Capital (WACC).

1.3 Research Objective

The main objective of this study is to compare the financial feasibility of lithium-ion battery recycling facilities in the Netherlands, Japan, and Indonesia.

To achieve this objective, the study aims to:

1. Analyse the financial and operational characteristics of battery recycling benchmark companies in the Netherlands, Japan, and Indonesia.
2. Estimate project-level revenue, operating expenditure, and capital expenditure for lithium-ion battery recycling facilities in each country.
3. Evaluate the financial feasibility of battery recycling facilities using Net Present Value (NPV), Internal Rate of Return (IRR), and Weighted Average Cost of Capital (WACC).
4. Compare financial feasibility outcomes under conservative, base case, and optimistic scenarios across the three countries.

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5. Identify the key factors influencing investment feasibility through sensitivity analysis.

1.4 Research Question

Based on the research problem and objectives, this study seeks to answer the following research questions:

1. What are the financial and operational characteristics of battery recycling benchmark companies in the Netherlands, Japan, and Indonesia?
2. How do revenue structures, operating expenditures, and capital requirements differ among lithium-ion battery recycling facilities across the three countries?
3. How financially feasible are lithium-ion battery recycling facilities in the Netherlands, Japan, and Indonesia based on NPV, IRR, and WACC analysis?
4. How do conservative, base case, and optimistic scenarios influence project feasibility in each country?
5. Which variables have the greatest impact on project feasibility in the Netherlands, Japan, and Indonesia based on sensitivity analysis?

1.5 Country Justification

This study selects the Netherlands, Japan, and Indonesia because each country represents a different stage of development and industrial structure within the lithium-ion battery recycling ecosystem, enabling meaningful cross-country comparison.

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The Netherlands is selected because it represents a mature European market with advanced circular economy implementation, strict environmental regulations, and established recycling infrastructure. Companies such as Umicore provide valuable benchmark data due to their experience in battery material recovery and industrial-scale recycling operations. As a result, the Netherlands serves as an important reference for understanding battery recycling feasibility in a highly developed market environment.

Japan is selected due to its strong expertise in urban mining and metal recovery, supported by long-established industrial capabilities. Through companies such as DOWA Holdings, Japan has developed advanced resource recovery systems and recycling technologies that contribute to efficient battery material processing. Japan therefore provides a relevant benchmark for evaluating battery recycling feasibility in an advanced Asian industrial economy.

Indonesia is included because of its growing strategic importance in the global EV battery supply chain, particularly due to its abundant nickel reserves and increasing investment in battery manufacturing industries. While Indonesia's recycling ecosystem remains less mature compared to the Netherlands and Japan, the country presents strong long-term potential for battery recycling development. To better reflect Indonesian operational conditions, selected percentage assumptions from Huayou are incorporated as cost proxies due to similarities in regional industrial structures and battery supply chain dynamics. However, Huayou is not treated as a primary benchmark company but rather as an adjustment reference for specific operational assumptions.

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By comparing these three countries, this study aims to identify how differences in industrial maturity, cost structures, and market conditions influence the financial feasibility of lithium-ion battery recycling facilities.

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CHAPTER 2
THEORETICAL FRAMEWORK

2.1 Literature

2.1.1 Overview of Lithium-Ion Battery Recycling

The increasing adoption of electric vehicles (EVs) has accelerated the global demand for lithium-ion batteries (LIBs), making them one of the most important technologies supporting the transition toward sustainable transportation. Lithium-ion batteries are widely used in EVs due to their high energy density, long lifespan, and charging efficiency compared to conventional battery technologies. However, the rapid expansion of the EV market has also created concerns regarding the management of end-of-life batteries. According to the International Energy Agency, global EV sales have continued to increase significantly, implying that substantial volumes of spent batteries are expected to emerge over the coming decades. Without proper waste management systems, these batteries may pose environmental risks due to hazardous chemical contents and improper disposal practices. IEA Global EV Outlook 2025

Battery recycling has emerged as a critical solution for addressing these environmental and economic concerns. Rather than treating used batteries as waste, recycling enables the recovery of valuable materials that can be reintegrated into battery manufacturing processes. Lithium-ion batteries contain critical raw materials, including lithium, nickel, cobalt, manganese, and copper, which are essential for battery production and often subject to price volatility and supply chain disruptions. Recovering these materials can reduce dependency on virgin mining activities while supporting a more circular and sustainable supply chain (Harper et al., 2019).

The concept of battery recycling is closely linked to the circular economy, which emphasizes minimizing waste generation and maximizing resource utilization through reuse and material recovery. In the context of lithium-ion batteries, recycling contributes to material circularity by returning valuable metals into production systems, reducing environmental burdens associated with extraction and refining activities. Previous studies have suggested that battery recycling can significantly lower greenhouse gas emissions compared to primary raw material extraction, particularly for metals such as nickel and cobalt (Gaines, 2018). This has increased global interest in battery recycling not only from an environmental perspective but also from an economic and strategic viewpoint.

From an economic perspective, battery recycling facilities generate revenue through multiple channels. One important source of revenue comes from gate fees, which refer to payments received for accepting and processing battery waste. In addition, recycling facilities generate income through the sale of recovered metals and black mass, which contains concentrated valuable materials extracted during the recycling process. The profitability of battery recycling therefore depends heavily on commodity market prices, recovery efficiency, and the volume of battery waste processed. Since metal prices are highly volatile, financial performance may vary substantially over time and across different market conditions.

In relation to this study, understanding the role and economic characteristics of lithium-ion battery recycling is essential because the financial feasibility of battery recycling facilities depends largely on material recovery value, processing costs, and market conditions. Since this research compares battery recycling feasibility across the Netherlands, Japan, and Indonesia, differences in industrial maturity, market structure, and recycling ecosystems are expected to influence investment performance in each country.

2.1.2 Battery Recycling Technologies

Several recycling technologies have been developed to recover valuable materials from lithium-ion batteries, with pyrometallurgical and hydrometallurgical methods being the most widely adopted at industrial scale. The selection of recycling technology is an important determinant of operational efficiency, environmental performance, and overall project feasibility because different technologies require different levels of investment and operating costs.

Pyrometallurgical recycling is a high-temperature treatment process in which batteries are smelted to recover valuable metals, particularly cobalt, nickel, and copper. This process is widely used because it can efficiently process mixed battery chemistries and requires relatively simple sorting procedures. Companies such as Umicore have adopted pyrometallurgical approaches in their recycling operations due to their ability to process complex battery waste streams efficiently. However, pyrometallurgical recycling also presents limitations, including high energy consumption and relatively lower lithium recovery rates, which may reduce material recovery efficiency (Harper et al., 2019).

In contrast, hydrometallurgical recycling uses chemical leaching techniques to extract valuable metals from battery materials. This process generally offers higher recovery rates for lithium, cobalt, nickel, and manganese while consuming lower amounts of energy compared to pyrometallurgical systems. However, hydrometallurgical processes often require more complex chemical handling and wastewater treatment systems, potentially increasing operational complexity and costs (Gaines, 2018). Despite these challenges, hydrometallurgical technology has gained increasing attention because of its higher recovery efficiency and lower environmental footprint.

A more recent development in battery recycling is direct recycling, which aims to recover battery materials while preserving their chemical structure for direct reuse in battery production. Compared to conventional recycling methods, direct recycling has the potential to reduce energy use and processing costs. However, this technology remains relatively underdeveloped and has not yet achieved large-scale commercial adoption due to technical limitations and feedstock inconsistency.

Technology selection is particularly relevant to this study because recycling methods directly influence both capital expenditure (CAPEX) and operating expenditure (OPEX), which are central variables in financial feasibility analysis. Facilities using more advanced recovery systems may require higher upfront investments but potentially benefit from higher recovery rates and increased revenues. Consequently, technological differences may partially explain variations in financial performance among battery recycling facilities in the Netherlands, Japan, and Indonesia.

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2.2 Cost Structure of Battery Recycling Facilities

2.2.1 Operating Expenditure (OPEX)

Operating expenditure (OPEX) represents the recurring costs required to operate a battery recycling facility on a daily basis. In industrial recycling projects, OPEX is considered one of the most important determinants of financial feasibility because it directly influences profitability and cash flow generation. Previous studies indicate that operating costs in lithium-ion battery recycling are primarily influenced by energy consumption, labor requirements, chemical reagents, transportation costs, maintenance expenses, and waste treatment activities (Mayyas et al., 2019).

Energy cost represents one of the largest operating expenses in battery recycling, particularly for pyrometallurgical processes due to high-temperature treatment requirements. Electricity prices vary significantly across countries, potentially affecting the competitiveness of recycling facilities. For example, industrial electricity costs in European countries are generally higher than those in developing economies, which may influence overall operating costs in the Netherlands compared to Indonesia.

Labor costs also play an important role in determining operational efficiency and project profitability. Countries with higher wage structures generally experience greater labor expenses, potentially increasing total OPEX. At the same time, logistics and transportation costs influence the economic viability of recycling projects because end-of-life batteries must be collected, transported, and processed safely under hazardous material regulations.

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In battery recycling projects, operating expenditure can be estimated on a per-tonne basis to improve comparability across facilities of different scales. This study applies an operating cost estimation approach by dividing total operating expenditure by annual processing capacity.

Formula used in this study:

$$OPEX\ per\ tonne = \frac{Total\ Operating\ Cost}{Processing\ Capacity}$$

This formula enables comparison of operational efficiency between recycling facilities in different countries. Since industrial conditions vary significantly across the Netherlands, Japan, and Indonesia, differences in labor cost, electricity prices, industrial infrastructure, and supply chain maturity are expected to influence OPEX assumptions used in this study.

2.2.2 Capital Expenditure (CAPEX)

Capital expenditure (CAPEX) refers to the upfront investment required to establish a battery recycling facility before operations begin. Unlike OPEX, which consists of recurring costs, CAPEX is incurred primarily during the project development stage and represents a major determinant of long-term investment feasibility. High initial investment requirements are one of the primary barriers to entry in battery recycling industries, particularly for facilities utilizing advanced processing technologies.

Battery recycling CAPEX typically includes land acquisition, construction of industrial buildings, recycling process lines, utilities infrastructure, safety systems, environmental protection systems, and engineering expenses. Additional costs such as permitting, contingency allowances, and pre-operational preparation

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may also significantly affect total investment requirements. Previous techno-economic studies have highlighted that capital intensity in battery recycling varies substantially depending on technology type, plant capacity, and regional regulatory requirements (Mayyas et al., 2019).

To incorporate capital costs into investment analysis, annual depreciation is often estimated using the straight-line depreciation method. This approach distributes the total investment cost evenly across the project lifetime.

The depreciation formula applied in this study is:

$$Annual\ Depreciation = \frac{CAPEX}{Project\ Lifetime}$$

In this study, CAPEX is treated as an initial investment variable affecting future cash flows and profitability calculations. Since construction costs, labor costs, land values, and industrial infrastructure differ across countries, variations in CAPEX are expected among battery recycling facilities in the Netherlands, Japan, and Indonesia.

2.3 Financial Feasibility Theory

2.3.1 Net Present Value (NPV)

Investment feasibility studies are commonly used to evaluate whether a project is capable of generating financial value over its operational lifetime. One of the most widely applied methods in capital budgeting and industrial project evaluation is Net Present Value (NPV). NPV measures the difference between the present value of future cash inflows and the initial investment required for project implementation. Since future revenues and expenses occur over time, NPV incorporates the time value of money by discounting future cash flows into present value terms (Brealey et al., 2020).

The main purpose of NPV analysis is to determine whether a project generates value beyond its investment cost. A positive NPV indicates that expected project returns exceed the cost of capital, suggesting that the investment is financially attractive. Conversely, a negative NPV implies that the project may not sufficiently compensate investors for the associated risks and costs. Due to its ability to account for project timing, cash flow magnitude, and financing costs, NPV is frequently applied in infrastructure, manufacturing, and industrial investment decisions.

In battery recycling projects, NPV is particularly relevant because recycling facilities require substantial upfront investments while generating revenues gradually over long operational periods. Factors such as fluctuating metal prices, gate fees, operating expenditures, and plant utilization rates can significantly influence long-term project returns. Therefore, evaluating the present value of expected future cash flows becomes essential in determining project viability.

The NPV formula applied in this study is:

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} - C_0$$

Where:

CF_t represents annual cash flow,

r represents the discount rate or weighted average cost of capital (WACC), and

C_0 represents the initial investment cost.

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In this study, NPV is used to compare the financial attractiveness of lithium-ion battery recycling facilities across the Netherlands, Japan, and Indonesia. By applying a consistent evaluation method, differences in country-specific costs, revenues, and financing conditions can be assessed systematically.

2.3.2 Internal Rate of Return (IRR)

In addition to NPV, Internal Rate of Return (IRR) is another widely used method for evaluating investment feasibility. IRR refers to the discount rate at which the present value of future cash inflows equals the initial investment cost, resulting in an NPV of zero (Ross et al., 2022). In other words, IRR reflects the expected annual return generated by a project throughout its operational lifetime.

Compared to NPV, IRR provides a more intuitive measure because it expresses investment performance as a percentage return. Investors and financial analysts frequently compare IRR with the company's required rate of return or cost of capital to determine whether a project should be accepted. When the IRR exceeds the cost of capital, the investment is generally considered financially feasible. However, when the IRR is lower than the required return, the investment may not sufficiently compensate for project risks.

Battery recycling projects often involve substantial uncertainty due to fluctuations in commodity prices and operational costs. As a result, IRR becomes useful in assessing how resilient project returns remain under different market conditions. Since this study compares battery recycling feasibility across multiple countries, IRR enables comparison of relative investment attractiveness beyond absolute monetary values.

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The theoretical condition for IRR is expressed as:

$$NPV = 0$$

In this study, IRR is used alongside NPV to evaluate whether recycling investments in the Netherlands, Japan, and Indonesia are financially attractive relative to their financing costs.

2.3.3 Weighted Average Cost of Capital (WACC)

The Weighted Average Cost of Capital (WACC) is an important financial indicator used to determine the discount rate applied in investment appraisal. WACC reflects the average cost of financing from both debt and equity sources, weighted according to their proportion within the overall capital structure (Damodaran, 2015). Since investors and lenders expect compensation for the risks associated with providing capital, WACC represents the minimum return required for a project to create value.

The cost of equity generally reflects the return expected by shareholders, while the cost of debt represents borrowing costs associated with loans or external financing. Tax considerations are also included because interest payments on debt may reduce taxable income, effectively lowering financing costs. Consequently, the composition of debt and equity financing can significantly affect project feasibility outcomes.

For battery recycling projects, WACC plays a crucial role because the industry requires substantial upfront investments and long payback periods. Differences in financial environments, interest rates, and country risks may result in variations in WACC across the Netherlands, Japan, and Indonesia. Therefore,

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incorporating country-specific financing assumptions is necessary to ensure realistic investment evaluation.

The WACC formula used in this study is:

$$WACC = \frac{E}{V}K_e + \frac{D}{V}K_d(1 - T)$$

Where:

E/V represents the proportion of equity financing,

D/V represents the proportion of debt financing,

K_e represents cost of equity,

K_d represents cost of debt, and

T represents the tax rate.

In this study, WACC serves as the discount rate used in NPV calculations and acts as a benchmark against IRR to evaluate investment attractiveness.

2.3.4 Operating Cash Flow (OCF)

Operating Cash Flow (OCF) represents the annual net cash generated from operational activities after accounting for taxes and depreciation adjustments. OCF is an important component of financial feasibility analysis because it reflects the actual yearly cash available to support investment returns and long-term sustainability. Unlike accounting profits, cash flow measures the real liquidity generated by project operations, making it more suitable for investment evaluation.

In battery recycling facilities, annual cash flow is influenced by revenues from gate fees and recovered materials, as well as operating expenses such as labor, energy, chemicals, and transportation costs. Since battery recycling profitability may fluctuate depending on market conditions, estimating operating cash flow becomes necessary to assess long-term project performance.

The formula applied in this study is:

$$OCF = (EBITDA - D)(1 - T) + D$$

Where:

$EBITDA$ refers to earnings before interest, tax, depreciation, and amortization,

Drepresents depreciation, and

Trepresents the applicable tax rate.

This study uses OCF to estimate annual project returns before calculating NPV and IRR under different country scenarios.

2.4 Sensitivity Analysis

Sensitivity analysis is commonly used in investment appraisal to evaluate the extent to which changes in key assumptions influence project outcomes. Since investment decisions are often exposed to uncertainty, sensitivity analysis helps identify which variables have the greatest impact on project feasibility while holding other assumptions constant.

Battery recycling projects are exposed to several uncertainties, including volatility in metal prices, variations in gate fees, differences in operational costs, and changes in financing conditions. Because revenues in battery recycling are closely linked to recovered metal values and treatment fees, changes in commodity markets may significantly influence profitability. Similarly, operating expenditure (OPEX), capital expenditure (CAPEX), and plant utilization rates can substantially affect overall financial performance. As a result, relying solely on a single base-case scenario may not fully capture the financial risks associated with battery recycling investments.

Sensitivity analysis enables researchers and investors to evaluate how variations in a single input variable affect financial outputs such as Net Present Value (NPV) and Internal Rate of Return (IRR). By adjusting one assumption at a time while keeping all other variables constant, the analysis identifies which factors have the strongest influence on project feasibility. This approach provides greater transparency regarding investment risks and improves decision-making under uncertain market conditions (Brealey et al., 2020).

The sensitivity index applied in this study is expressed as:

$$Sensitivity\ ndex = \frac{\%\ change\ in\ utput}{\%\ change\ in\ nput}$$

Additionally, the impact of variable changes on investment value can be measured through changes in NPV:

$$\Delta NPV = NPV_{new} - NPV_{base}$$

In this study, sensitivity analysis is conducted by testing several variables that are expected to significantly influence battery recycling feasibility, including metal prices, gate fees, OPEX, CAPEX, plant utilization rates, project lifetime, tax rates, and WACC. These variables are adjusted individually to determine their relative impact on project profitability in the Netherlands, Japan, and Indonesia.

To improve the clarity of results, sensitivity analysis findings are presented using a tornado diagram. A tornado diagram visually ranks variables based on their impact on project feasibility, with the most influential variables appearing at the top. This method helps identify the key drivers of financial performance and provides practical insights into which assumptions require the most careful consideration in battery recycling investments.

2.5 Benchmark Company Review

2.5.1 Umicore (Netherlands)

The Netherlands is represented in this study through Umicore, a global materials technology and recycling company with established battery recycling operations. Umicore is selected as a benchmark because it operates within a mature European market characterized by advanced recycling infrastructure, strict environmental regulations, and strong circular economy implementation. The company provides relevant financial and operational references for estimating revenue structures, operating costs, and investment requirements related to lithium-ion battery recycling. Therefore, Umicore serves as a suitable benchmark for evaluating battery recycling feasibility under developed market conditions.

2.5.2 DOWA Holdings (Japan)

Japan is represented through DOWA Holdings, a company specializing in metal recovery and urban mining activities. DOWA Holdings is selected due to its extensive experience in resource recovery and recycling operations within an advanced industrial economy. The company provides relevant insights into operational efficiency and cost structures in battery-related recycling activities. Including DOWA Holdings allows this study to compare battery recycling feasibility within an Asian industrial context.

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2.5.3 Huayou Proxy for Indonesia

Due to the limited availability of industrial-scale battery recycling benchmarks in Indonesia, this study incorporates selected operational assumptions from Huayou Cobalt as a proxy reference. Huayou is not used as a primary benchmark company but rather as an adjustment tool for operational assumptions relevant to Indonesian conditions. This approach is considered appropriate because similarities in regional industrial structures and battery supply chain development may provide more realistic cost assumptions for Indonesia.

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CHAPTER 3
METHODOLOGY

3.1 Literature Review Methodology

This study applies a literature review methodology to establish the theoretical foundation and conceptual understanding of lithium-ion battery recycling feasibility. A literature review is appropriate because it allows researchers to critically evaluate existing knowledge and identify research gaps relevant to the study topic (Saunders et al., 2019).

The literature review process in this study follows a systematic approach to ensure the relevance, reliability, and comparability of sources, which is important for improving research quality and reducing bias in data selection (Creswell & Creswell, 2023).The literature search focuses on several key themes, including lithium-ion battery recycling technologies, recycling economics, revenue structures, operating costs, investment feasibility methods, and sensitivity analysis.

Academic sources were primarily identified through databases such as Google Scholar, ScienceDirect, and SpringerLink. Search keywords included “lithium-ion battery recycling”, “battery recycling feasibility”, “EV battery recycling economics”, “battery recycling cost structure”, “NPV battery recycling”, and “battery recycling techno-economic analysis”. Preference was given to peer-reviewed journal articles published between 2018 and 2025 to ensure relevance to recent developments in EV markets and battery technologies.

In addition to academic sources, institutional and industry reports were included to provide updated market information regarding electric vehicle adoption, battery waste growth, and recycling trends. Publications from organizations such as the International Energy Agency and company annual reports were used to complement academic findings and provide practical industry context.

To ensure data quality, this study follows the principles of data integrity discussed in Research Skills courses, including accuracy, consistency, completeness, and comparability. Accuracy refers to selecting information from reliable and credible sources. Consistency is ensured by comparing financial figures using similar units and reporting periods. Completeness is addressed by combining multiple sources when information is missing, while comparability is maintained by applying consistent financial assumptions across countries.

The literature review findings are used to support the theoretical framework in Chapter 2 and to justify the selection of financial variables used in the feasibility analysis, including revenue assumptions, operating expenditure, capital expenditure, discount rates, and sensitivity variables.

3.2 Data Research Methodology

3.2.1 Research Design

This study applies a comparative financial feasibility research design to evaluate lithium-ion battery recycling projects across the Netherlands, Japan, and Indonesia. Comparative research is appropriate when analyzing differences between multiple environments under a standardized framework (Yin, 2018). A comparative approach is selected because financial feasibility may vary substantially across countries due to differences in industrial maturity, labor costs, energy prices, recycling infrastructure, and policy environments.

The study evaluates a hypothetical lithium-ion battery recycling facility with an annual processing capacity of 5,000 tonnes in each country. A standardized project size is used to ensure comparability and reduce distortions caused by differences in company scale. The financial feasibility of each country is assessed using investment appraisal techniques, including Net Present Value (NPV), Internal Rate of Return (IRR), and Weighted Average Cost of Capital (WACC).

This research adopts a quantitative approach because financial feasibility evaluation relies on numerical estimations and financial modelling. Quantitative research is suitable for studies involving measurable financial variables and numerical analysis (Creswell & Creswell, 2023).

3.2.2 Benchmark Company Selection

This study uses benchmark companies to estimate financial and operational assumptions relevant to battery recycling activities in each country. Benchmarking is necessary because detailed project-level financial data for battery recycling facilities are often unavailable.

For the Netherlands, Umicore is selected due to its established position in battery recycling and material recovery. The company provides relevant information regarding operational structure, revenue generation, and recycling economics in a mature European market.

For Japan, DOWA Holdings is selected because of its expertise in urban mining and non-ferrous metal recovery. The company offers insights into battery-related recycling economics within an advanced Asian industrial environment.

For Indonesia, selected assumptions are adjusted using percentage proxies derived from Huayou. Since Indonesia currently lacks sufficient industrial-scale battery recycling benchmarks, Huayou is used to improve the realism of operational assumptions rather than functioning as a direct benchmark company.

This benchmarking approach allows the study to compare battery recycling feasibility while accounting for country-specific industrial conditions.

3.2.3 Data Collection Method

This study relies on secondary data collected from academic literature, company annual reports, institutional reports, and financial databases. Secondary data collection is appropriate when researchers analyze existing industrial and financial information that is publicly available and verifiable (Saunders et al., 2019). Secondary data is considered appropriate because battery recycling projects involve industrial and financial information that is publicly available through official reporting channels.

The primary data source for financial benchmarking consists of annual reports from Umicore, DOWA Holdings, and Huayou. Relevant financial variables extracted include total revenue, operating expenses, EBITDA, depreciation, net income, and, where available, processing capacity. These figures are used to estimate revenue per tonne and operational cost per tonne.

Additional market data, including metal prices, gate fees, country risk premiums, risk-free rates, and debt financing assumptions, are collected from institutional and financial sources. Metal prices are obtained through commodity market references, while country risk and financing variables are derived from Damodaran datasets and central bank publications.

To improve consistency, all financial figures are standardized into comparable units and adjusted where necessary to reflect annual project assumptions.

3.2.4 Financial Modelling Procedure

Investment feasibility is assessed using Net Present Value (NPV) and Internal Rate of Return (IRR), which are commonly applied methods in capital budgeting and investment appraisal studies (Brealey et al., 2020).

Step 1: Revenue Estimation

Revenue is estimated based on gate fees and recovered metal values. Revenue per tonne is calculated using benchmark company information and multiplied by annual plant capacity.

Step 2: OPEX Estimation

Operating expenditure is estimated based on benchmark company cost structures, including labor, energy, transportation, chemicals, and waste treatment costs.

Step 3: CAPEX Estimation

Capital expenditure is estimated using benchmark investments from battery recycling facilities and adjusted according to country-specific industrial assumptions.

Step 4: Operating Cash Flow Calculation

Annual operating cash flow is calculated by incorporating EBITDA, depreciation, and tax assumptions.

Step 5: WACC Calculation

WACC is estimated using country-specific financing assumptions, including cost of equity, cost of debt, risk-free rates, market risk premiums, and capital structure assumptions.

Step 6: NPV and IRR Analysis

Investment feasibility is assessed using NPV and IRR under a project lifetime assumption.

Step 7: Sensitivity Analysis

This approach uses to examine the possibilities of the calculation on certain scenarios.

3.2.5 Scenario Analysis

To account for uncertainty, this study applies three scenarios: conservative, base case, and optimistic. Scenario analysis is necessary because battery recycling profitability is highly sensitive to fluctuations in metal prices, gate fees, and operating costs.

The conservative scenario assumes lower revenue and higher operational costs, while the optimistic scenario assumes higher revenue and improved operational efficiency. The base case represents expected market conditions.

3.2.6 Sensitivity Analysis

Sensitivity analysis is conducted to identify variables with the greatest influence on project feasibility. According to Brealey et al. (2020), sensitivity analysis is useful for evaluating uncertainty and determining how changes in assumptions affect investment performance.

Variables tested include:

- Metal prices
- Gate fees
- OPEX
- CAPEX
- Plant utilization rate

- WACC
- Tax rate
- Project lifetime

The results are presented through tornado diagrams to visualize the variables with the strongest impact on project feasibility outcomes.

3.2.7 Reliability and Validity

To improve reliability and validity, this study applies triangulation by combining academic literature, company reports, and institutional data sources. Triangulation improves research credibility by reducing dependence on a single source of information (Yin, 2018). Cross-country comparisons are conducted using standardized assumptions and consistent project scales to ensure comparability.

Additionally, assumptions used in financial modelling are documented transparently to improve reproducibility and reduce potential bias in feasibility estimations.

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CHAPTER 4
DATA RESEARCH & ANALYSIS

4.1 The Netherlands

4.1.1 Capital and Operational Cost Structure

1. Capital Cost Structure

The CAPEX estimation for the Netherlands is benchmarked using publicly available battery recycling investment data and annual reports from Umicore, supported by industrial battery recycling feasibility studies. Since Umicore does not disclose detailed project-level investment costs for a standalone 5,000 tonnes-per-year facility, the capital cost estimation is adjusted using industrial benchmarks from comparable recycling facilities and scaled to the project capacity applied in this study. European location premiums and stricter environmental compliance costs are also considered, resulting in relatively higher investment requirements compared to emerging economies.

Table 4.1
Capital Expenditure in The Netherlands

Capex	Percentage	Amount
Total CAPEX	100%	€99,600,000.00
Land	7%	€6,972,000.00
Building	18%	€17,928,000.00
Process Lines	45%	€44,820,000.00
Utilities	10%	€9,960,000.00
Safety & Environment	9%	€8,964,000.00
Engineering	8%	€7,968,000.00
Permitting	3%	€2,988,000.00
Project lifetime		15
Annual Depreciation		€6,175,200.00
CAPEX per tonne capacity		€19,920.00

Source: Author's calculation based on Umicore Annual Report (2024), GS Engineering benchmark, and Thompson et al. (2021).

The table above shows the estimated capital expenditure (CAPEX) structure of a lithium-ion battery recycling facility in the Netherlands. The total estimated investment amounts to approximately €99.6 million, with process lines representing the largest component at 45% of total CAPEX. This suggests that battery recycling facilities in the Netherlands are highly capital intensive and rely heavily on advanced recycling technologies and equipment. Additionally, land and environmental compliance costs remain relatively high, reflecting strict environmental regulations and industrial standards in the Dutch market.

2. Operational Cost Structure

The operational cost structure in the Netherlands is estimated based on Umicore's reported financial performance and adjusted through scenario analysis to account for market uncertainty. The conservative scenario applies actual benchmark performance, while the base and optimistic scenarios include upward adjustments of 20% and 30%, respectively, to reflect potential improvements in operational efficiency and market conditions. Scenario analysis is commonly applied in feasibility studies to assess project performance under different assumptions and uncertainty levels (Bresters, 2021).

Table 4.2
Revenue, OPEX, and EBITDA per Tonne under Different Scenarios in the Netherlands

Indicator	*Conservative*	*Base*	*Optimistic*
Revenue per tonne	*€55,142.86*	*€66,171.43*	*€71,685.71*
OPEX per tonne	*€68,000.00*	*€61,200.00*	*€57,800.00*
EBITDA per tonne	*-€12,857.14*	*€4,971.43*	*€13,885.71*
Annual EBITDA	*-€64,285,714.29*	*€24,857,142.86*	*€69,428,571.43*

The conservative scenario in this study applies the actual financial performance reported by Umicore as the benchmark company. This approach is intended to represent a downside or less favorable market condition, reflecting real operational performance under existing industrial and market circumstances. Since reported EBITDA per tonne remains negative under actual benchmark conditions, the conservative scenario serves as a realistic reference for evaluating project resilience under unfavorable profitability conditions.

The base and optimistic scenarios are developed by applying upward adjustments of 20% and 30%, respectively, to reflect potential improvements in market conditions and operational performance. Scenario analysis is commonly used in feasibility studies to capture uncertainty and evaluate how alternative assumptions may influence financial outcomes. Rather than relying solely on a single benchmark condition, alternative scenarios allow researchers to assess a range of possible outcomes under moderate and favorable circumstances (Bresters, 2021). Scenario analysis literature further suggests that financial modelling should incorporate variations in key assumptions to better represent uncertainty in project evaluation and improve investment decision-making under volatile conditions.

The selected adjustment percentages are considered appropriate given the high volatility of lithium-ion battery recycling economics, particularly due to fluctuations in metal prices, gate fees, and recovery efficiency. The base case (+20%) represents moderate improvements in operational and market conditions, while the optimistic scenario (+30%) reflects stronger profitability potential resulting from more favorable commodity prices and operational efficiency. Since battery recycling profitability is highly sensitive to external market conditions, applying percentage-based scenario adjustments is considered a reasonable approach for feasibility assessment

4.1.2 Key Financial Metrics and Performance Indicators

The Weighted Average Cost of Capital (WACC) is estimated to determine the discount rate used in evaluating project feasibility. WACC reflects the average financing cost from debt and equity sources and serves as an important benchmark for assessing investment attractiveness. Previous financial studies indicate that WACC plays a significant role in evaluating industrial investment projects due to its ability to account for financing risk and opportunity cost (Brealey et al., 2020).

Table 4.3
Weighted Average Cost of Capital (WACC) Components for the Netherlands

WACC Components	
Risk-free rate (RF)	2.90%
Market risk premium	4.33%
Beta	1.2
Cost of Equity	8.10%
Cost of debt	5.00%
Tax rate	25.80%
Weight Equity	40.00%
Weight debt	60.00%
WACC	5.46%

Source: Writer's calculation based on Damodaran (2025), ECB data, and financial modelling.

Table 4.3 presents the WACC components applied in the Netherlands. A relatively higher WACC may indicate increased financing costs and investment risk, reducing the present value of future cash flows. Consequently, WACC significantly influences overall project feasibility and investment attractiveness.

Following the estimation of operational performance and financing costs, financial feasibility is evaluated using key investment indicators under conservative, base, and optimistic scenarios. The assessment incorporates Operating Cash Flow (OCF), Net Present Value (NPV), Internal Rate of Return (IRR), and the comparison between IRR and WACC to determine project viability. These indicators are commonly applied in investment appraisal to assess whether projected returns sufficiently compensate for investment costs and associated risks (Ross et al., 2022).

Table 4.4
Financial Feasibility Indicators under Different Scenarios in the Netherlands

Indicator	Conservative	Base	Optimistic
ANNUAL OCF	-€46,106,798.40	€20,037,201.60	€53,109,201.60
PVIFA	10.06	10.06	10.06
PVCF	-€463,897,604.07	€201,601,718.99	€534,351,380.52
CAPEX	€99,600,000.00	€99,600,000.00	€99,600,000.00
NPV	-€563,497,604.07	€102,001,718.99	€434,751,380.52
IRR	-	18.55%	53%
WACC	5.46%	5.46%	5.46%
IRR VS WACC	IRR < WACC	IRR > WACC	IRR > WACC
Verdict	NO GO	GO	GO

Source: Author's calculation based on financial modelling results.

Table 4.4 presents the financial feasibility outcomes for the Netherlands under different market conditions. Under the conservative scenario, the project generates a negative NPV of approximately €563.5 million and a negative operating cash flow, indicating that project revenues are insufficient to recover investment costs. Consequently, the project is categorized as a *No-Go* investment under unfavorable market conditions. However, the base and optimistic scenarios generate positive NPVs of approximately €102.0 million and €434.8 million, respectively. Additionally, the IRR exceeds the WACC in both scenarios, suggesting that expected returns are sufficient to justify investment risk. These findings indicate that battery recycling feasibility in the Netherlands is highly dependent on improved operational performance and favorable market conditions.

4.1.3 Sensitivity Analysis

Sensitivity analysis is conducted to evaluate how changes in selected variables influence the financial feasibility of the lithium-ion battery recycling facility in the Netherlands. Since battery recycling profitability is highly dependent on fluctuating market conditions, variables including metal prices, gate fees, operational expenditure (OPEX), capital expenditure (CAPEX), plant utilization, WACC, tax rate, and project lifetime are tested to assess their influence on project outcomes. Sensitivity analysis is commonly used in investment appraisal to identify variables with the greatest influence on project performance and financial risk (Brealey et al., 2020).

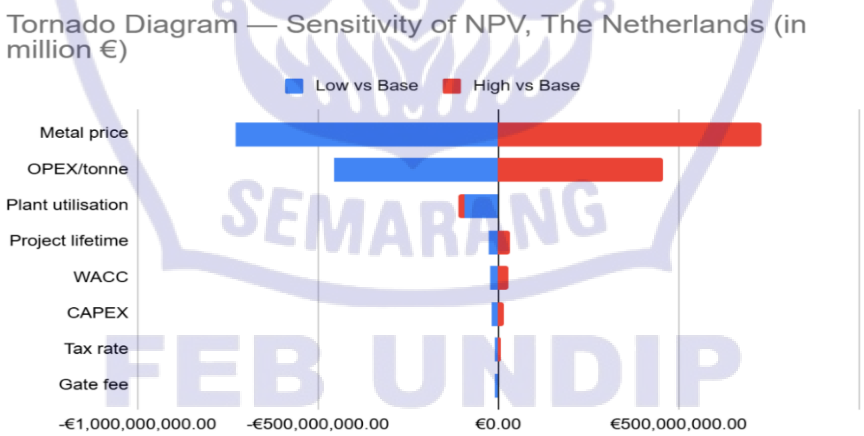

Figure 4.1
Tornado Diagram of Sensitivity Analysis for the Netherlands

Figure 4.1 illustrates the relative impact of key variables on the Net Present Value (NPV) of the project. The results indicate that metal prices have the greatest influence on project feasibility, followed by gate fees and operational expenditure (OPEX). This finding suggests that profitability in the Netherlands is highly dependent on favorable commodity prices and incoming battery processing revenues, both of which are highly exposed to market volatility (Harper et al., 2019). Meanwhile, variables such as CAPEX, WACC, tax rate, and project lifetime demonstrate comparatively smaller impacts on NPV outcomes, indicating lower sensitivity to changes in these assumptions. Overall, the results imply that market-related variables play a more significant role than financing or project duration in determining the financial feasibility of lithium-ion battery recycling facilities in the Netherlands (Brealey et al., 2020).

4.2 Japan

4.2.1 Capital and Operational Cost Structure

1. Capital Cost Expenditure

The capital expenditure (CAPEX) of the lithium-ion battery recycling facility in Japan is estimated using DOWA Holdings as the benchmark company and adjusted to a hypothetical facility with a processing capacity of 5,000 tonnes per year. Since detailed project-level investment costs for battery recycling facilities are not fully disclosed, the estimation is supported through benchmark scaling and financial modelling based on industrial recycling investment characteristics. The CAPEX estimation includes land acquisition, industrial buildings, process lines, utilities, environmental systems, engineering, and permitting costs. Previous studies indicate that battery recycling facilities require substantial upfront investment due to their technologically intensive operations and environmental compliance requirements (Thompson et al., 2021).

Table 4.5
Capital Expenditure in Japan

Capex	Percentage	Amount
Total CAPEX	100.00%	€29,842,615.00
Land	4.80%	€1,432,445.52
Building	13.70%	€4,088,438.26
Process lines	44.60%	€13,309,806.29
Utilities	13.40%	€3,998,910.41
Safety & Environment	8.30%	€2,476,937.05
Engineering	10.10%	€3,014,104.12
Permitting	5.10%	€1,521,973.37
Project lifetime		15
Annual Depreciation		€1,989,507.67
CAPEX per tonne capacity		€5,968.52

Source: Author's calculation based on DOWA Holdings Integrated Report (2024) and financial modelling

Table 4.5 presents the estimated CAPEX structure of the battery recycling facility in Japan. The results indicate that process lines account for the largest proportion of total investment, reflecting the technology-intensive nature of lithium-ion battery recycling operations. Additional investment in environmental systems and utilities also contributes significantly to total project costs, emphasizing the importance of industrial safety and operational efficiency in the Japanese market. Overall, the findings suggest that battery recycling in Japan remains capital intensive despite potential advantages in industrial efficiency.

2. Operational Cost Expenditure

The operational expenditure (OPEX) of the battery recycling facility in Japan is estimated using DOWA Holdings as the benchmark company and adjusted through scenario analysis to account for market uncertainty. The conservative scenario applies actual benchmark performance, while the base and optimistic scenarios assume improvements in revenue and operational efficiency. Specifically, revenue per tonne is increased by 15% and 20%, while OPEX per tonne is reduced by 15% and 10%, respectively, to represent moderate and favorable market conditions. Scenario analysis is commonly applied in feasibility studies to assess investment resilience under uncertain market assumptions (Bresters, 2021).

Table 4.6
Revenue, OPEX, and EBITDA per Tonne under Different Scenarios in Japan

Indicator	Conservative	Base	Optimistic
Revenue per tonne	€7,000.23	€8,050.27	€8,400.28
OPEX per tonne	€7,590.40	€6,451.84	€5,806.66
EBITDA per tonne	-€590.17	€1,598.43	€2,593.62
Annual EBITDA	-€2,950,842.46	€7,992,131.28	€12,968,109.20

Source: Author's calculation based on DOWA Holdings Integrated Report (2024) and scenario adjustments adapted from feasibility study methodology (Bresters, 2021).

Table 4.6 presents the operational performance of the battery recycling facility in Japan under different scenarios. Under the conservative scenario, EBITDA remains negative, indicating that operational costs exceed revenues under current benchmark conditions. However, the base and optimistic scenarios generate positive EBITDA outcomes due to higher revenue assumptions and lower operational expenditures. These findings suggest that profitability in Japan is highly dependent on operational efficiency and favorable market conditions, particularly improvements in metal recovery value and cost management (Harper et al., 2019).

4.2.2 Key Financial Metrics and Performance Indicators

The Weighted Average Cost of Capital (WACC) is estimated to determine the discount rate applied in evaluating project feasibility. WACC represents the average financing cost derived from equity and debt financing and is commonly used to assess investment attractiveness and risk exposure (Brealey et al., 2020). In this study, the Japanese WACC is calculated using country-specific assumptions including the risk-free rate, market risk premium, beta, cost of debt, tax rate, and capital structure.

Table 4.7
Weighted Average Cost of Capital (WACC) Components for Japan

WACC Components	
Risk-Free Rate	1.50%
Market Risk Premium	5.14%
Beta	1.05
Cost of Equity	6.897%
Cost of Debt	2.10%
Tax Rate	27.40%
Weight of Equity	60.00%
Weight of Debt	40.00%
WACC	4.75%

Source: Writer's calculation based on Damodaran (2025), Bank of Japan interest rate data, DOWA Holdings Integrated Report (2024), and financial modelling.

Table 4.7 presents the Weighted Average Cost of Capital (WACC) estimation for the Japanese battery recycling project. The results indicate a WACC of 4.75%, reflecting a relatively moderate financing cost for investment in Japan. The relatively low cost of debt and stable financial environment contribute to a lower discount rate compared to markets with higher investment risk. A lower WACC generally improves project feasibility by increasing the present value of future cash flows, thereby strengthening investment attractiveness (Ross et al., 2022). Consequently, Japan may benefit from relatively favorable financing conditions for long-term industrial investments.

Financial feasibility is further evaluated using key investment indicators, including Operating Cash Flow (OCF), Net Present Value (NPV), Internal Rate of Return (IRR), and the comparison between IRR and WACC. These indicators are commonly used in capital budgeting to determine whether projected returns are sufficient to recover initial investment costs and compensate for financing risks (Brealey et al., 2020). The feasibility assessment is conducted under conservative, base, and optimistic scenarios to evaluate project resilience under different market conditions.

Table 4.8
Financial Feasibility Indicators under Different Scenarios in Japan

Indicator	Conservative	Base	Optimistic
Annual OCF	-€1,863,965.43	€6,671,554.08	€10,552,816.87
CAPEX	€29,842,615.00	€29,842,615.00	€29,842,615.00
NPV	-€49,523,697.94	€40,600,434.57	€81,581,588.75
IRR	-	21.00%	35.00%
WACC	4.75%	4.75%	4.75%
IRR vs WACC	IRR < WACC	IRR > WACC	IRR > WACC
Verdict	NO GO	GO	GO

Source: Author's calculation based on financial modelling results using projected operating cash flow, CAPEX, and WACC assumptions.

Table 4.8 presents the financial feasibility outcomes for the lithium-ion battery recycling project in Japan under different market conditions. Under the conservative scenario, the project produces a negative NPV of approximately €49.5 million, indicating that projected cash flows are insufficient to recover investment costs. As a result, the project is categorized as a *No Go* investment under unfavorable conditions. However, under the base and optimistic scenarios, the project generates positive NPVs of approximately €40.6 million and €81.6 million, respectively. In both scenarios, IRR exceeds WACC, indicating that expected project returns are sufficient to compensate for financing costs and investment risks. These findings suggest that battery recycling investment in Japan becomes financially attractive when supported by improved operational performance and more favorable market conditions (Brealey et al., 2020).

4.2.3 Sensitivity Analysis

Sensitivity analysis is conducted to evaluate how changes in selected variables influence the financial feasibility of the lithium-ion battery recycling project in Japan. Since battery recycling profitability is highly dependent on both market conditions and financing assumptions, variables including metal prices, WACC, plant utilization, OPEX, tax rate, project lifetime, CAPEX, and gate fees are tested to determine their impact on Net Present Value (NPV). Sensitivity analysis is commonly applied in investment appraisal to identify the variables with the greatest influence on project outcomes and financial risks (Brealey et al., 2020).

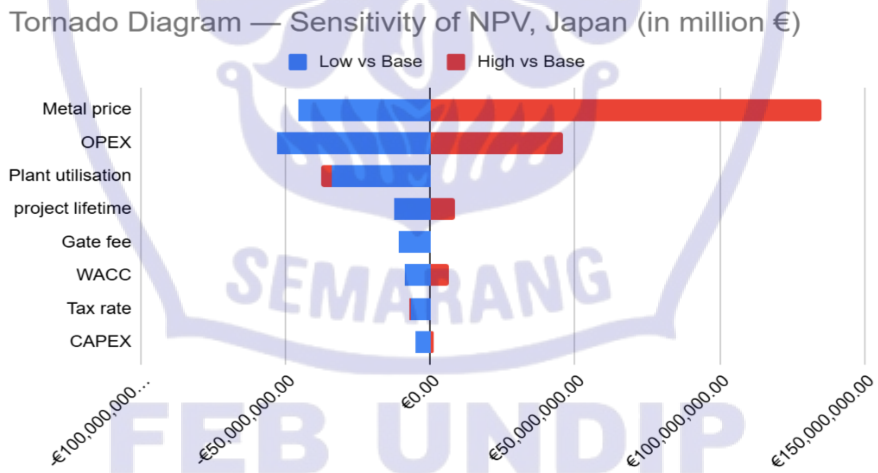

Figure 4.2
Tornado Diagram of Sensitivity Analysis for Japan

Figure 4.2 illustrates the relative sensitivity of NPV to changes in selected variables for the battery recycling project in Japan. The results indicate that metal price has the strongest influence on project feasibility, suggesting that profitability is highly dependent on fluctuations in recovered metal values and commodity market conditions (Harper et al., 2019). In addition, WACC and plant utilization also demonstrate substantial impacts on NPV outcomes, indicating that financing conditions and operational efficiency play important roles in determining project feasibility. Meanwhile, variables such as OPEX, tax rate, project lifetime, and CAPEX show moderate influence on financial performance, while gate fee demonstrates the smallest impact on project outcomes. Overall, the findings suggest that market-driven variables and financing conditions contribute more significantly to investment risk than structural cost assumptions in the Japanese battery recycling market (Brealey et al., 2020).

4.3 Indonesia

4.3.1 Capital and Operational Cost Structure

1. Capital Cost Structure

The capital expenditure (CAPEX) of the lithium-ion battery recycling facility in Indonesia is estimated using adjusted industrial assumptions based on Huayou proxy percentages and regional battery material industry conditions. Since Indonesia currently has limited publicly available financial data for industrial-scale lithium-ion battery recycling facilities, cost assumptions are adjusted to reflect local industrial conditions while maintaining comparability with the Netherlands and Japan. The CAPEX estimation includes land acquisition, industrial buildings, process lines, utilities, environmental systems, engineering, and permitting costs. Previous studies suggest that battery recycling facilities remain capital intensive due to technological requirements, although emerging markets may benefit from relatively lower construction and labor costs (Thompson et al., 2021).

Table 4.9
Capital Expenditure Structure of Lithium-Ion Battery Recycling Facility in Indonesia

CAPEX Component	Percentage	Amount
Total CAPEX	100.00%	€12,684,392.00
Land	5.00%	€646,903.99
Building	14.00%	€1,826,552.45
Process lines	45.00%	€5,746,029.58
Utilities	13.00%	€1,674,339.74
Safety & Environment	8.00%	€1,014,751.36
Engineering	10.00%	€1,268,439.20
Permitting	4.00%	€507,375.68
Project lifetime		15
Annual Depreciation		€802,499.20
CAPEX per tonne capacity		€2,536.88

Source: Author's calculation based on Huayou proxy adjustments, industrial recycling benchmarks, and financial modelling.

Table 4.8 presents the estimated CAPEX structure of the battery recycling facility in Indonesia. The results indicate that process lines account for the largest share of total investment (45%), reflecting the technology-intensive nature of battery recycling operations. However, the total estimated investment of approximately €12.7 million remains significantly lower than in developed markets, mainly due to lower construction, labor, and industrial costs in Indonesia. This finding suggests that Indonesia may offer cost advantages for battery recycling investment, although infrastructure readiness and operational capability remain important considerations.

2. Operational Cost Expenditure

The operational expenditure (OPEX) of the battery recycling facility in Indonesia is estimated using baseline assumptions adjusted through scenario analysis to account for uncertainty in market and operational performance. The conservative scenario reflects baseline operating conditions, while the base and optimistic scenarios assume improvements in market performance and cost efficiency. Specifically, revenue per tonne is increased by 10% and 15%, while OPEX per tonne is reduced by 10% and 15%, respectively, to represent moderate and favorable operating conditions. Scenario analysis is commonly applied in feasibility studies to evaluate project performance under uncertain assumptions and changing market conditions (Bresters, 2021). Given the volatility of battery recycling economics, these assumptions are considered appropriate for evaluating investment feasibility (Harper et al., 2019).

Table 4.10
Capital Expenditure Structure of Lithium-Ion Battery Recycling Facility in Indonesia

Indicator	Conservative	Base	Optimistic
Revenue per tonne	€4,188.00	€4,606.80	€5,297.82
OPEX per tonne	€4,327.00	€3,894.30	€3,310.16
EBITDA per tonne	-€139.00	€712.50	€1,987.67
Annual EBITDA	-€695,000.00	€3,562,500.00	€9,938,325.00

Source: Author's calculation based on Huayou proxy adjustments and scenario assumptions adapted from feasibility study methodology (Bresters, 2021).

Table 4.10 presents the operational performance of the battery recycling facility in Indonesia under different scenarios. Under the conservative scenario, EBITDA remains negative, indicating that revenues are insufficient to cover operating expenses under baseline conditions. However, the base and optimistic scenarios produce positive EBITDA outcomes due to higher revenue assumptions and lower operational expenditures. These findings suggest that profitability in Indonesia is highly dependent on operational efficiency and favorable market conditions, particularly improvements in recovered metal value and cost optimization (Harper et al., 2019).

4.3.2 Key Financial Metrics and Performance Indicators

The Weighted Average Cost of Capital (WACC) is estimated to determine the discount rate used in evaluating the financial feasibility of the battery recycling project in Indonesia. WACC reflects the average financing cost derived from debt and equity financing and serves as an important benchmark in investment decision-making (Brealey et al., 2020). In this study, the Indonesian WACC is estimated using country-specific assumptions including the risk-free rate, market risk premium, beta, cost of debt, tax rate, and financing structure. Since Indonesia is considered an emerging market with relatively higher financing costs and country risk, the estimated WACC is expected to be higher compared to developed economies such as the Netherlands and Japan (Damodaran, 2025).

Table 4.11
Weighted Average Cost of Capital (WACC) in Indonesia

WACC Components	
Risk-free rate (RF)	3.42%
Market risk premium	5.80%
Beta	1.12
Cost of Equity	9.916%
Cost of debt	8.15%
Tax Rate	22.00%
Weight equity	60.00%
Weight debt	40.00%
WACC	8.49%

Source: Author's calculation based on Damodaran (2025), Indonesian financial market assumptions, and financial modelling.

Table 4.11 presents the estimated Weighted Average Cost of Capital (WACC) for Indonesia at 8.49%, which is higher than the estimated WACC in Japan and the Netherlands. This result reflects Indonesia's relatively higher financing costs, country risk premium, and borrowing conditions as an emerging market economy. A higher WACC reduces the present value of future cash flows, making investment feasibility more difficult to achieve. Therefore, achieving strong operational performance becomes increasingly important in supporting project viability (Ross et al., 2022).

Financial feasibility is further evaluated through Operating Cash Flow (OCF), Net Present Value (NPV), Internal Rate of Return (IRR), and the comparison between IRR and WACC. These indicators are commonly used in capital budgeting to determine whether projected returns are sufficient to recover initial investment costs and compensate for financing risks (Brealey et al., 2020). The feasibility assessment is conducted under conservative, base, and optimistic scenarios to evaluate project resilience under different market conditions.

Table 4.12
Financial Feasibility Indicators in Indonesia

Indicator	Conservative	Base	Optimistic
Annual OCF	-€365,550.18	€2,955,299.82	€7,928,443.32
CAPEX	€12,684,392.00	€12,684,392.00	€12,684,392.00
NPV	-€15,721,392.73	€11,868,318.75	€53,185,329.25
IRR	-	22%	62%
WACC	8.49%	8.49%	8.49%
IRR vs WACC	IRR < WACC	IRR > WACC	IRR > WACC
Verdict	NO GO	GO	GO

Source: Author's calculation based on projected operating cash flow, CAPEX, and WACC assumptions.

The financial feasibility outcomes of the battery recycling project in Indonesia under different market conditions. Under the conservative scenario, the project generates a negative NPV of approximately €15.7 million, indicating that projected returns are insufficient to recover investment costs under baseline assumptions. Consequently, the project is categorized as a *No-Go* investment.

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However, under the base and optimistic scenarios, the project generates positive NPVs of approximately €11.9 million and €53.2 million, respectively. In both scenarios, IRR exceeds WACC, indicating that projected returns are sufficient to justify financing costs and investment risks. These findings suggest that battery recycling investment in Indonesia becomes financially attractive when supported by improved operational efficiency and favorable market conditions, particularly through increased revenue generation and cost optimization (Harper et al., 2019).

4.3.3 Sensitivity Analysis Indonesia

Sensitivity analysis is conducted to evaluate how changes in selected variables influence the financial feasibility of the battery recycling project in Indonesia. Since battery recycling profitability is highly dependent on market conditions, operational performance, and financing assumptions, variables including metal prices, OPEX, plant utilization, tax rate, WACC, project lifetime, CAPEX, and gate fees are tested to determine their influence on Net Present Value (NPV). Sensitivity analysis is commonly applied in investment appraisal to identify variables with the greatest influence on project outcomes and financial risks, thereby improving investment decision-making under uncertainty (Brealey et al., 2020).

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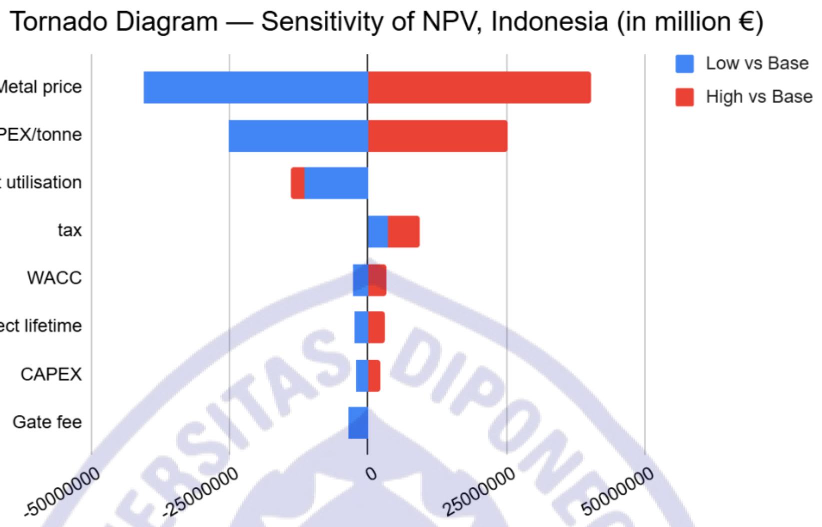

Figure 4.3
Tornado Diagram of Sensitivity Analysis for Indonesia
Source: Author's sensitivity analysis based on financial modelling results.

Figure 4.3 illustrates the relative sensitivity of NPV to changes in selected variables for the battery recycling project in Indonesia. The results indicate that metal price has the strongest influence on project feasibility, suggesting that profitability is highly dependent on fluctuations in recovered metal values and global commodity market conditions (Harper et al., 2019). In addition, OPEX per tonne and plant utilization also demonstrate substantial impacts on NPV outcomes, indicating that operational efficiency and facility utilization rates play important roles in determining project performance. Meanwhile, variables such as tax rate, WACC, project lifetime, and CAPEX show comparatively smaller effects on project feasibility, while gate fee demonstrates the lowest sensitivity among all tested variables. Overall, these findings suggest that market-related and operational variables contribute more significantly to investment risk than financing or structural cost assumptions in the Indonesian battery recycling market (Brealey et al., 2020).

CHAPTER 5
CONCLUSION

5.1 Summary of Findings

This study set out to compare the financial feasibility of lithium-ion battery recycling facilities across three distinctly different national contexts: the Netherlands, Japan, and Indonesia. By applying a standardised investment appraisal framework encompassing Net Present Value (NPV), Internal Rate of Return (IRR), and Weighted Average Cost of Capital (WACC) the analysis evaluated hypothetical facilities with a uniform processing capacity of 5,000 tonnes per year. Three scenario variants (conservative, base case, and optimistic) were developed for each country to capture the inherent uncertainty surrounding metal prices, gate fees, operational costs, and recovery efficiency. The findings reveal that financial feasibility is not a fixed property of battery recycling as a technology but is instead a highly context-dependent outcome shaped by industrial maturity, cost structures, financing conditions, and market dynamics.

Across all three countries, the conservative scenario produced negative NPVs and irrecoverable cash positions, underscoring the fragility of battery recycling economics when market conditions are unfavourable. This outcome is consistent with the broader literature, which emphasises that battery recycling profitability depends on a delicate balance between volatile commodity revenues and substantial fixed operational costs (Harper et al., 2019). In each country, however, the base case and optimistic scenarios reversed this trajectory, generating positive NPVs and IRR values comfortably exceeding country-specific WACC benchmarks. The transition from a no-go verdict under the conservative scenario to a go verdict under the base case reflects how sensitive these projects are to even moderate improvements in metal prices, operational efficiency, or gate fee structures.

In the Netherlands, the total estimated capital expenditure reached approximately €99.6 million, reflecting the high cost of establishing advanced recycling infrastructure in a mature European regulatory environment. Despite this capital intensity, the base case and optimistic scenarios produced NPVs of roughly €102 million and €434.8 million respectively, with IRR values of 18.55% and 53% both well above the estimated WACC of 5.46%. Sensitivity analysis further revealed that metal prices exert the greatest single influence on NPV in the Netherlands, followed by gate fees and OPEX. These findings confirm that the Dutch recycling market, while financially viable under improved conditions, remains highly exposed to commodity market fluctuations and is supported by a strong policy infrastructure that incentivises circular economy investment (Gaines, 2018).

In Japan, the capital expenditure was estimated at approximately €29.8 million considerably lower than the Netherlands reflecting differences in land costs, construction economics, and industrial structure. The base case NPV reached €40.6 million with an IRR of 21%, and the optimistic scenario produced an NPV of €81.6 million with an IRR of 35%, both exceeding Japan's WACC of 4.75%. The sensitivity analysis highlighted that metal prices, WACC, and plant utilisation are the most influential drivers of project feasibility in the Japanese context. Japan's comparatively lower financing costs and established urban mining capabilities contribute meaningfully to the country's investment attractiveness, suggesting that the recycling industry can build upon well-developed industrial foundations (Brealey et al., 2020).

Indonesia offered the most cost-competitive entry point among the three countries, with an estimated total CAPEX of approximately €12.7 million reflecting lower land, labour, and construction costs in an emerging market environment. The base case NPV was approximately €11.9 million with an IRR of 22%, while the optimistic scenario yielded an NPV of €53.2 million and an IRR of 62%, both exceeding Indonesia's WACC of 8.49%. Although Indonesia demonstrated strong return potential under favourable conditions, the higher WACC compared to the Netherlands and Japan reflects the elevated financing costs and country risk associated with emerging market investment. Sensitivity analysis confirmed that metal prices, OPEX per tonne, and plant utilisation have the most significant impacts on project feasibility in Indonesia (Damodaran, 2025).

5.2 Cross-Country Comparison

Taken together, the results of this study illustrate a clear trade-off between capital accessibility and operational risk across the three countries. The Netherlands offers a financially robust environment underpinned by strong regulatory support and circular economy policy but requires the highest upfront investment. Japan provides a well-balanced middle ground with moderate capital requirements, low financing costs, and advanced industrial capabilities. Indonesia, by contrast, offers the lowest capital requirements and potentially the highest IRR under optimistic conditions but carries the greatest financing risk due to a higher WACC and a less developed recycling ecosystem.

A consistent finding across all three countries is the dominant influence of metal prices on project feasibility. Whether in a developed market such as the Netherlands or an emerging market such as Indonesia, fluctuations in the value of recovered lithium, nickel, cobalt, manganese, and copper fundamentally determine whether a recycling project generates value. This finding aligns with established literature suggesting that revenue volatility in battery recycling is primarily driven by commodity market dynamics rather than operational inefficiency alone (Harper et al., 2019; Mayyas et al., 2019).

Beyond metal prices, operational expenditure emerged as a consistently influential variable across all three countries. Managing OPEX effectively through energy efficiency, labour optimisation, and chemical cost control is essential for improving project margins, particularly under conservative market assumptions. Plant utilisation rates were also identified as a meaningful driver of feasibility, reflecting the importance of sufficient feedstock supply and reliable collection infrastructure in sustaining economically viable recycling operations.

5.3 Implications for Investors and Industry Stakeholders

For investors considering battery recycling infrastructure, the results of this study highlight several important considerations. First, no single country can be considered universally superior across all investment dimensions. The Netherlands offers policy certainty and advanced infrastructure but at a high capital cost. Japan offers cost efficiency and industrial sophistication with lower financing risk. Indonesia offers low entry costs and strong return potential but with higher financing risk and greater operational uncertainty. Investment decisions should therefore be guided by the specific risk appetite, capital availability, and strategic objectives of each investor.

Second, the consistent sensitivity of all three country scenarios to metal price movements suggests that investors should consider commodity hedging strategies or offtake agreements to manage revenue volatility over the long investment horizon. Without such mechanisms, the financial viability of battery recycling projects may be undermined by short-term market corrections in metal prices. Third, achieving base case or better operational performance is critical to project success, as all conservative scenarios produced negative NPVs regardless of country. This implies that operational excellence including maximising recovery efficiency, minimising energy consumption, and ensuring adequate feedstock supply must be treated as a core investment priority rather than an aspirational outcome.

5.4 Limitations and Directions for Future Research

This study is subject to several limitations that should be acknowledged. First, the financial assumptions applied in the analysis are derived from benchmark company data, which may not fully capture the nuances of standalone project-level economics. Because Umicore, DOWA Holdings, and the Huayou proxy operate at different scales and with different product portfolios, the translation of company-level financials into project-level assumptions introduces a degree of estimation uncertainty. Future research could benefit from primary data collection through industry interviews, detailed engineering studies, or pilot facility assessments.

Second, the study applies a standardised processing capacity of 5,000 tonnes per year across all three countries to ensure comparability. In practice, optimal facility size may vary depending on feedstock availability, regulatory requirements, and market demand. Economies of scale are not fully explored in this study, and future work could investigate how varying capacity assumptions affect feasibility outcomes. Third, while sensitivity analysis identifies the most influential variables, it does not capture the simultaneous interaction between multiple variables. Monte Carlo simulation or stochastic modelling approaches could provide a more comprehensive assessment of risk under conditions where multiple variables change simultaneously.

Finally, the rapidly evolving nature of both the electric vehicle market and battery recycling technologies means that financial assumptions may shift substantially over time. The growing adoption of solid-state batteries, shifting battery chemistries, and improvements in hydrometallurgical recovery processes could alter the cost and revenue structures underlying this study. Future research should therefore seek to update financial models as the industry matures and as new data become available from operational recycling facilities.

5.5 Concluding Remarks

Battery recycling stands at the intersection of environmental necessity and economic opportunity. As the global fleet of electric vehicles expands and end-of-life batteries accumulate, the ability to recover critical minerals efficiently and cost-effectively will become increasingly important for both industrial sustainability and supply chain resilience. This study demonstrates that lithium-ion battery recycling facilities can be financially viable across different national contexts but that viability is conditional on market conditions, operational performance, and an enabling policy environment.

The Netherlands, Japan, and Indonesia each offer distinct pathways toward a sustainable battery recycling industry. By understanding the financial dynamics and country-specific conditions that shape investment feasibility, policymakers, investors, and industry stakeholders can make better-informed decisions about where and how to develop recycling infrastructure. Ultimately, realising the full potential of battery recycling will require not only favourable economics but also coherent policy frameworks, robust collection systems, and sustained investment in processing technology themes that are explored in the policy recommendations presented in the following chapter.

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CHAPTER 6
POLICY RECOMMENDATIONS

6.1 Introduction

The financial feasibility analysis conducted in this study makes clear that lithium-ion battery recycling projects are commercially viable under moderate to favourable market conditions, but that achieving and sustaining those conditions requires active policy intervention. Market forces alone are unlikely to deliver the scale of battery recycling infrastructure needed to manage growing volumes of end-of-life batteries or to secure domestic supplies of critical minerals. Instead, coordinated policy action across regulatory, fiscal, and industrial domains is essential to accelerate investment, reduce financial risk, and ensure that recycling facilities can operate profitably and sustainably over the long term.

The following policy recommendations are directed at three distinct but complementary levels: recommendations applicable across all three countries studied (the Netherlands, Japan, and Indonesia), followed by country-specific measures that reflect each nation's particular stage of industrial development, regulatory context, and strategic priorities. The recommendations draw on the financial modelling results, sensitivity analysis findings, and theoretical framework presented in previous chapters, and are further informed by the existing policy literature on circular economy strategy and sustainable industrial development (Gaines, 2018; Harper et al., 2019; Mayyas et al., 2019).

6.2 Cross-Country Policy Recommendations

6.2.1 Establish Mandatory Battery Collection and Take-Back Systems

One of the most fundamental prerequisites for viable battery recycling is a reliable and sufficient supply of end-of-life batteries. Without adequate feedstock, recycling facilities cannot achieve the plant utilisation rates necessary to generate positive cash flows, as demonstrated by the sensitivity analysis results across all three countries. Governments should therefore implement mandatory battery collection and take-back schemes that require EV manufacturers, battery producers, and retailers to accept spent batteries for proper processing.

Such systems are well-established in European regulatory frameworks, including the European Union Battery Regulation (2023), which sets collection targets and requires battery producers to fund end-of-life management (European Commission, 2023). Expanding and enforcing similar frameworks in Japan and Indonesia would help ensure that recycling facilities have access to stable feedstock volumes, directly improving plant utilisation and project feasibility. In emerging markets like Indonesia, where informal waste collection networks are prevalent, formalising collection systems through licensed aggregators and digital tracking platforms could help bridge the gap between informal and formal recycling sectors.

6.2.2 Introduce Investment Tax Incentives for Battery Recycling Infrastructure

Capital expenditure represents one of the most significant barriers to entry in battery recycling, particularly for facilities utilising advanced processing technologies. The findings of this study indicate that CAPEX in the Netherlands reaches approximately €99.6 million for a 5,000 tonne-per-year facility, placing a substantial financial burden on prospective investors. While CAPEX is lower in

Japan and Indonesia, it still represents a material investment requiring strong return expectations over a 15-year project lifetime.

Governments can reduce this barrier by introducing targeted tax incentives for battery recycling infrastructure, including accelerated depreciation allowances, investment tax credits, and reduced corporate tax rates for qualifying recycling operations. Accelerated depreciation in particular allows investors to recover capital costs more quickly, improving early-period cash flows and reducing the risk of project abandonment during the initial operational phase. Such incentives have been shown to significantly improve investment attractiveness in capital-intensive industrial sectors and can be structured to target facilities that meet specific environmental or recovery efficiency standards (Brealey et al., 2020).

6.2.3 Support Research, Development, and Technology Adoption

Battery recycling economics are heavily influenced by recovery efficiency and processing technology choices. Hydrometallurgical processes offer higher recovery rates for lithium and other valuable metals compared to pyrometallurgical alternatives but require greater chemical handling expertise and more complex wastewater treatment infrastructure (Harper et al., 2019). Emerging direct recycling technologies hold the promise of even lower processing costs and higher material quality but have not yet achieved commercial scale.

Governments and supranational bodies should actively fund research and development programmes aimed at improving battery recycling efficiency, reducing chemical consumption, and accelerating the commercial readiness of next-generation recycling technologies. Public-private partnerships, university-industry collaboration platforms, and government-backed technology grants can all play a role in advancing the technological frontier. Additionally, governments should facilitate knowledge transfer between countries by supporting international research networks and technology licensing agreements, enabling emerging markets such as Indonesia to adopt best practices from more advanced recycling ecosystems.

6.2.4 Develop Transparent Metal Price Risk-Sharing Mechanisms

The sensitivity analysis conducted in this study consistently identified metal prices as the single most influential driver of project feasibility across all three countries. This finding reflects the structural challenge facing battery recycling projects: revenues are largely determined by commodity markets over which individual facilities have no control. Sudden price collapses in lithium, cobalt, or nickel can rapidly erode project margins and push financially viable projects into loss-making positions.

To address this risk, policymakers should explore mechanisms to reduce metal price exposure for recycling facilities. These could include government-backed offtake agreements that guarantee minimum prices for recovered materials over defined contract periods, creating revenue certainty for investors. Alternatively, strategic reserve programmes similar to those operated by some governments for critical minerals could stabilise domestic recovered metal markets by absorbing excess supply during periods of low commodity prices. Such mechanisms would reduce the variance of financial outcomes for battery recycling projects, making investment more attractive and reducing the risk premium embedded in WACC calculations.

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6.3 Country-Specific Policy Recommendations

6.3.1 The Netherlands: Deepening the Circular Economy Policy Framework

The Netherlands already benefits from one of the most advanced circular economy policy environments in the world, underpinned by the EU Battery Regulation, national circular economy action plans, and strong enforcement of environmental standards. However, the financial analysis revealed that even in this favourable environment, the conservative scenario yields a deeply negative NPV of approximately €563.5 million, indicating that the existing policy landscape is not sufficient to guarantee financial viability under all market conditions.

To strengthen investment conditions further, the Dutch government should consider expanding the scope of existing environmental subsidies to explicitly cover advanced battery material recovery technologies, including hydrometallurgical processing lines that currently may not qualify under existing industrial scheme criteria. Additionally, the government should develop a national battery waste registry that tracks battery volumes entering the market and forecasts end-of-life flows, providing investors with improved visibility into future feedstock availability. This would directly address one of the key uncertainties that investors face when evaluating long-horizon recycling projects.

The Netherlands should also leverage its position as a founding member of the European Battery Alliance to attract further EU funding for domestic recycling infrastructure through the Innovation Fund and the European Fund for Strategic Investments. These mechanisms could provide grant financing that lowers effective CAPEX for qualifying projects, improving NPV outcomes and reducing IRR thresholds required for investment decisions (European Commission, 2023).

6.3.2 Japan: Strengthening Urban Mining Incentives and Feedstock Infrastructure

Japan has a well-established tradition of urban mining and resource recovery, supported by companies such as DOWA Holdings and an advanced industrial infrastructure. The financial results confirm that Japan presents strong investment prospects, with base case IRR of 21% and an optimistic IRR of 35% both comfortably exceeding the estimated WACC of 4.75%. However, sustaining and expanding these returns will require continued policy support to manage feedstock supply and technological evolution.

The Japanese government should strengthen the existing Small Home Appliance Recycling Law and related frameworks to explicitly include EV battery waste, ensuring that collection and processing obligations extend to the growing volume of end-of-life EV batteries expected in coming decades. Additionally, Japan's strategic resource policy should be updated to classify recovered battery materials as domestically produced critical minerals, qualifying recycling operations for the same strategic subsidies and preferential procurement arrangements as primary mining activities. This would directly improve the revenue certainty of recycling facilities and strengthen their long-term business cases.

Given the sensitivity analysis finding that plant utilisation rate is a significant driver of NPV in Japan, the government should also invest in developing a national battery logistics network including standardised collection points, battery condition assessment centres, and pre-treatment facilities to maximise the effective feedstock supply available to processing facilities. Improving feedstock logistics would raise utilisation rates and reduce per-unit processing costs, improving overall project economics.

6.3.3 Indonesia: Building Enabling Infrastructure and Reducing Investment Risk

Indonesia presents the most complex policy challenge among the three countries studied. While the financial analysis confirms that battery recycling can generate strong returns under optimistic conditions with a base case NPV of €11.9 million and an optimistic IRR of 62% the country's higher WACC of 8.49% and relatively underdeveloped recycling ecosystem mean that the policy environment must do considerably more work to attract private investment.

The most urgent policy priority for Indonesia is to reduce the cost of capital for battery recycling investments. This can be achieved through a combination of mechanisms: first, establishing a government-backed green financing facility specifically targeted at battery recycling and critical mineral recovery, offering concessional loans at below-market interest rates; second, partnering with multilateral development banks such as the Asian Development Bank and the International Finance Corporation to provide blended finance structures that share risk with private investors; and third, offering political risk insurance through state-owned institutions to mitigate investor concerns about regulatory instability and currency risk.

Indonesia should also prioritise the development of a comprehensive battery waste management regulatory framework. Currently, the absence of enforceable take-back obligations for EV batteries creates uncertainty about feedstock availability and may deter long-term investment commitments. Drawing on the European Battery Regulation as a legislative model and adapting it to Indonesian market conditions would provide a clear regulatory foundation for battery collection, transportation, and processing, reducing uncertainty for prospective investors (European Commission, 2023).

Furthermore, given that OPEX per tonne was identified as one of the most sensitive variables for Indonesia's project feasibility, targeted industrial skills development programmes should be introduced to build a domestic workforce capable of operating advanced battery processing facilities. Collaborations between Indonesian polytechnic institutions and international recycling companies could establish training pipelines that reduce labour-related operational risks and improve facility efficiency over time. Industrial zones with shared utility infrastructure including reliable electricity supply and wastewater treatment capacity would also help reduce per-facility fixed costs and make Indonesian recycling operations more cost-competitive.

6.4 Recommendations for International Coordination

Battery recycling is not purely a domestic concern. The critical minerals recovered from spent batteries lithium, cobalt, nickel, manganese, and copper are globally traded commodities with supply chains that cross multiple international borders. As a result, the effectiveness of national battery recycling policies is partly determined by the coherence of the international regulatory environment and trade frameworks governing these materials.

International bodies, including the United Nations Environment Programme, the International Energy Agency, and the World Trade Organization, should work collaboratively to develop harmonised standards for battery material traceability, recycled content certification, and cross-border battery waste trade.

Harmonised standards would reduce compliance costs for multinational recycling companies operating across multiple jurisdictions and would create a level playing field that prevents regulatory arbitrage the practice of routing battery waste to countries with lower environmental standards to reduce processing costs.

The three countries studied in this research the Netherlands, Japan, and Indonesia could themselves serve as constructive partners in developing such international frameworks, given their complementary positions in the global battery supply chain. A formalised trilateral cooperation agreement on battery material recovery, knowledge sharing, and investment facilitation could accelerate progress in all three countries while demonstrating a practical model for international battery recycling governance.

6.5 Summary of Policy Recommendations

In summary, the policy recommendations presented in this chapter address the financial, regulatory, and infrastructural challenges identified through the feasibility analysis. Across all three countries, the priority actions include establishing mandatory battery collection systems, introducing investment tax incentives, supporting technology development, and creating metal price risk-sharing mechanisms. At the country level, the Netherlands should deepen its circular economy funding architecture; Japan should expand its urban mining policy framework and invest in feedstock logistics; and Indonesia should reduce its cost of capital, establish a comprehensive regulatory framework, and develop industrial capacity. At the international level, harmonised standards and cooperative governance frameworks are essential to creating a well-functioning global battery recycling ecosystem.

Together, these recommendations aim to bridge the gap between the financial viability demonstrated under favourable scenarios in this study and the practical conditions needed to consistently attract and sustain investment in battery recycling infrastructure. Effective policy implementation will not only support the financial performance of individual recycling projects but will also contribute to broader goals of sustainable resource management, circular economy development, and critical mineral supply chain resilience.

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APPENDIX

The Netherland Calculation

THE NETHERLANDS — Benchmark: Umicore (2024)

Step 1 — Benchmark Company Overview

Item	Value
Total Income	€386.00M
Total Expenses	€476.00M
EBITDA	(€5.00M)
D&A	€85.00M
EBIT	(€90.00M)
Net Income	(€90.00M)
Effective Tax Rate	25.80%
Processing Capacity (t/yr)	7,000
Revenue per Tonne	€55.143

Step 2 — Revenue, OPEX & EBITDA by Scenario (per tonne)

Indicator	Conservative	Base Case	Optimistic
Revenue per Tonne	€55.143	€66.171	€71.686
OPEX per Tonne	€68.000	€61.200	€57.800
EBITDA per Tonne	**(€12.857)**	**€4.971**	**€13.886**
Annual EBITDA	**(€64.29M)**	**€24.86M**	**€69.43M**

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Step 3 — Capital Expenditure (CAPEX) Structure

CAPEX Component	Proportion	Amount
Total CAPEX	**100%**	**€99.600.000**
Land	7%	€6.972.000
Building	18%	€17.928.000
Process Lines	45%	€44.820.000
Utilities	10%	€9.960.000
Safety & Environment	9%	€8.964.000
Engineering	8%	€7.968.000
Permitting	3%	€2.988.000
Project Lifetime	—	15 years
Annual Depreciation	—	€6.175.200
CAPEX per Tonne	—	€19.920

Step 4 — Operating Cash Flow (OCF) Calculation

Component	Conservative	Base Case	Optimistic
EBITDA	(€64.29M)	€24.86M	€69.43M
Depreciation	€6.175.200	€6.175.200	€6.175.200
EBIT	(€70.46M)	€18.68M	€63.25M
Tax	(€18.18M)	€4.819.941	€16.32M
Operating Cash Flow (OCF)	**(€46.11M)**	**€20.04M**	**€53.11M**

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Step 5 — Weighted Average Cost of Capital (WACC)

Item	Value
Risk-Free Rate (Rf)	2.90%
Market Risk Premium	4.33%
Beta (β)	1.20
Cost of Equity (Ke)	8.10%
Cost of Debt (Kd)	5.00%
Tax Rate	25.80%
Weight of Equity	40.00%
Weight of Debt	60.00%
WACC	5.46%

Step 6 — Investment Feasibility Summary (NPV / IRR)

Indicator	Conservative	Base Case	Optimistic
Annual OCF	(€46.11M)	€20.04M	€53.11M
PVIFA	10.0614	10.0614	10.0614
PV of Cash Flows	(€463.90M)	€201.60M	€534.35M
CAPEX	€99.600.000	€99.600.000	€99.600.000
NPV	**(€563.50M)**	**€102.00M**	**€434.75M**
IRR	—	18.55%	53.23%
WACC	5.46%	5.46%	5.46%
IRR vs WACC	IRR < WACC	IRR > WACC	IRR > WACC
Verdict	**NO GO**	**GO**	**GO**

Tornado Diagram Data — Sensitivity Analysis (Base Case NPV Impact)

Note: Sorted by total NPV impact (highest to lowest). Variables shifted individually; all others held at base case.

Variable	Low NPV	High NPV	Base NPV	Total Impact
Metal Price	(€627.81M)	€831.81M	€102.00M	**€1459.62M**
OPEX / Tonne	(€354.89M)	€558.89M	€102.00M	**€913.78M**
Plant Utilisation	€9.22M	€83.44M	€102.00M	**€111.34M**
Project Lifetime	€76.87M	€135.79M	€102.00M	**€58.91M**
WACC	€77.66M	€131.76M	€102.00M	**€54.10M**
CAPEX	€85.29M	€118.72M	€102.00M	**€33.43M**
Tax Rate	€92.57M	€107.88M	€102.00M	**€15.30M**
Gate Fee	€92.67M	€102.05M	€102.00M	**€9.38M**

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Japan Calculation

JAPAN — Benchmark: DOWA Holdings (2024)

Step 1 — Benchmark Company Overview

Item	Value
Total Income	€99.09M
Total Expenses	€107.44M
EBITDA	(€3.22M)
D&A	€5.45M
EBIT	(€8.70M)
Net Income	(€6.32M)
Effective Tax Rate	27.40%
Processing Capacity (t/yr)	14,155
Revenue per Tonne	€7.000

Step 2 — Revenue, OPEX & EBITDA by Scenario (per tonne)

Indicator	Conservative	Base Case	Optimistic
Revenue per Tonne	€7.000	€8.050	€8.400
OPEX per Tonne	€7.590	€6.452	€5.807
EBITDA per Tonne	**(€590)**	**€1.598**	**€2.594**
Annual EBITDA	**(€2.95M)**	**€7.99M**	**€12.97M**

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Step 3 — Capital Expenditure (CAPEX) Structure

CAPEX Component	Proportion	Amount
Total CAPEX	**100%**	**€29.842.615**
Land	4.8%	€1.432.446
Building	13.7%	€4.088.438
Process Lines	44.6%	€13.309.806
Utilities	13.4%	€3.998.910
Safety & Environment	8.3%	€2.476.937
Engineering	10.1%	€3.014.104
Permitting	5.1%	€1.521.973
Project Lifetime	—	15 years
Annual Depreciation	—	€1.894.011
CAPEX per Tonne	—	€5.969

Step 4 — Operating Cash Flow (OCF) Calculation

Component	Conservative	Base Case	Optimistic
EBITDA	(€2.95M)	€7.99M	€12.97M
Depreciation	€1.894.011	€1.894.011	€1.894.011
EBIT	(€4.94M)	€6.00M	€10.98M
Tax	(€1.09M)	€1.320.577	€2.415.292
Operating Cash Flow (OCF)	**(€1.88M)**	**€6.65M**	**€10.53M**

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Step 5 — Weighted Average Cost of Capital (WACC)

Item	Value
Risk-Free Rate (Rf)	1.50%
Market Risk Premium	5.14%
Beta (β)	1.05
Cost of Equity (Ke)	6.90%
Cost of Debt (Kd)	2.10%
Tax Rate	27.40%
Weight of Equity	60.00%
Weight of Debt	40.00%
WACC	4.75%

Step 6 — Investment Feasibility Summary (NPV / IRR)

Indicator	Conservative	Base Case	Optimistic
Annual OCF	(€1.88M)	€6.65M	€10.53M
PVIFA	10.56	10.56	10.56
PV of Cash Flows	(€19.90M)	€70.22M	€111.20M
CAPEX	€29.842.615	€29.842.615	€29.842.615
NPV	**(€49.75M)**	**€40.38M**	**€81.36M**
IRR	—	21%	35%
WACC	4.75%	4.75%	4.75%
IRR vs WACC	IRR < WACC	IRR > WACC	IRR > WACC
Verdict	**NO GO**	**GO**	**GO**

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Tornado Diagram Data — Sensitivity Analysis (Base Case NPV Impact)

Note: Sorted by total NPV impact (highest to lowest). Variables shifted individually; all others held at base case.

Variable	Low NPV	High NPV	Base NPV	Total Impact
Metal Price	(€5.05M)	€175.68M	€40.37M	**€180.73M**
OPEX / Tonne	(-€12.73M)	€86.17M	€40.37M	**€98.91M**
Plant Utilisation	€6.27M	€36.9M	€40.37M	**€37.58M**
Project Lifetime	€27.95	€48.82M	€40.37M	**€20.86M**
Gate fee	€29.71M	€40.43M	€40.37M	**€10.61M**
WACC	€31.70M	€47.01M	€40.37M	**€15.30M**
Tax rate	€33.73M	€39.77M	€40.37M	**€7.2M**
CAPEX	€35.11M	€41.62M	€40.37M	**€6.51M**

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Indonesia calculation

INDONESIA — Benchmark: Huayou Proxy (2024)

Step 1 — Benchmark Company Overview

Item	Value
Total Income	€83.76M
Total Expenses	€86.54M
EBITDA	(€2.78M)
D&A	€845.626,00
EBIT	(€3.63M)
Net Income	(€4.39M)
Effective Tax Rate	22.00%
Processing Capacity (t/yr)	20,000
Revenue per Tonne	€4.188

Step 2 — Revenue, OPEX & EBITDA by Scenario (per tonne)

Indicator	Conservative	Base Case	Optimistic
Revenue per Tonne	€4.188	€4.607	€5.298
OPEX per Tonne	€4.327	€3.894	€3.310
EBITDA per Tonne	**(€139)**	**€713**	**€1.988**
Annual EBITDA	**(€695.000,00)**	**€3.56M**	**€9.94M**

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Step 3 — Capital Expenditure (CAPEX) Structure

CAPEX Component	Proportion	Amount
Total CAPEX	**100%**	**€12.684.392**
Land	5.1%	€646.904
Building	14.4%	€1.826.552
Process Lines	45.3%	€5.746.030
Utilities	13.2%	€1.674.340
Safety & Environment	8.0%	€1.014.751
Engineering	10.0%	€1.268.439
Permitting	4.0%	€507.376
Project Lifetime	—	15 years
Annual Depreciation	—	€802.499
CAPEX per Tonne	—	€2.537

Step 4 — Operating Cash Flow (OCF) Calculation

Component	Conservative	Base Case	Optimistic
EBITDA	(€695.000,00)	€3.56M	€9.94M
Depreciation	€802.499	€802.499	€802.499
EBIT	(€1.50M)	€2.76M	€9.14M
Tax	(€329.450,00)	€607.200	€2.01M
Operating Cash Flow (OCF)	**(€365.550,00)**	**€2.96M**	**€7.93M**

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Step 5 — Weighted Average Cost of Capital (WACC)

Item	Value
Risk-Free Rate (Rf)	3.42%
Market Risk Premium	5.80%
Beta (β)	1.12
Cost of Equity (Ke)	9.92%
Cost of Debt (Kd)	8.15%
Tax Rate	22.00%
Weight of Equity	60.00%
Weight of Debt	40.00%
WACC	8.49%

Step 6 — Investment Feasibility Summary (NPV / IRR)

Indicator	Conservative	Base Case	Optimistic
Annual OCF	(€365.550,00)	€2.96M	€7.93M
PVIFA	8.3080	8.3080	8.3080
PV of Cash Flows	(€3.04M)	€24.55M	€65.87M
CAPEX	€12.684.392	€12.684.392	€12.684.392
NPV	**(€15.72M)**	**€11.87M**	**€53.19M**
IRR	—	22.14%	62.46%
WACC	8.49%	8.49%	8.49%
IRR vs WACC	IRR < WACC	IRR > WACC	IRR > WACC
Verdict	**NO GO**	**GO**	**GO**

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Tornado Diagram Data — Sensitivity Analysis (Base Case NPV Impact)

Note: Sorted by total NPV impact (highest to lowest). Variables shifted individually; all others held at base case.

Variable	Low NPV	High NPV	Base NPV	Total Impact
Metal Price	(€28.54M)	€52.27M	€11.87M	**€80.81M**
OPEX / Tonne	(€13.37M)	€37.10M	€11.87M	**€50.47M**
Plant Utilisation	€325.354,00	€9.56M	€11.87M	**€13.85M**
Tax Rate	€15.48M	€17.73M	€11.87M	**€9.47M**
WACC	€9.18M	€15.12M	€11.87M	**€5.94M**
Project Lifetime	€9.32M	€14.86M	€11.87M	**€5.53M**
CAPEX	€9.59M	€14.09M	€11.87M	**€4.50M**
Gate Fee	€8.22M	€11.91M	€11.87M	**€3.69M**

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