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Sustainable Li-Ion EV Battery Recycling in Nepal: A Techno-Economic and Forecast-Based Approach

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Abstract
The swift uptake of electric vehicles in Nepal brings about both benefits and difficulties in terms of managing waste from lithium-ion batteries This study conducts a thorough evaluation of the practicality of setting up a Li- Ion Battery recycling facility in Nepal, encompassing predictive models, forecasting techniques, and a technical-economic analysis. This research predicts the widespread acceptance of electric vehicles by employing Compound Annual Growth Rate (CAGR) models with growth rates of 10% and 20%, examines the creation of battery waste, and performs a techno-economic assessment for a proposed lithium-ion battery recycling facility. Assessing financial viability involves determining capital expenditures (CAPEX), operational expenses (OPEX), and revenue generated from recycling materials. The selection of the best recycling technology is determined using the Analytic Hierarchy Process (AHP). The objective of the study is to provide guidance to policymakers and investors in regards to sustainable battery recycling options. Our research offers a systematic framework for policymakers and business leaders to implement environmentally friendly recycling practices that will aid Nepal's shift towards renewable energy.

Keywords*—Electric Vehicles, Lithium-ion Battery Recycling, Forecasting, Techno-Economic Analysis, Analytical Hierarchy Process*

1. INTRODUCTION

1.1 Background

In many developing nations, including Nepal, a scarcity of recycling facilities is a significant concern, as reported by the [1]. As of mid-July 2024, Nepal has seen a significant increase in the import of electric vehicles (EVs), particularly passenger four-wheelers. In the first 11 months of the fiscal year 2023-24, Nepal imported 11,466 EVs worth NPR 29 billion, marking a 158.23% increase compared to the same period in the previous fiscal year. Of these imports, 69% (7,931 units) were from China, followed by India, which supplied 3,277 units [2] [3].

- **Fiscal Year 2022-23**:11,466 electric four-wheelers imported.
- **Fiscal Year 2022-23**: 4,050 electric four-wheelers imported.
- **Fiscal Year 2021-22**: 1,805 electric four-wheelers imported.

Surge in EV imports is attributed to Nepal's efforts to reduce dependence on petroleum imports and leverage its surplus hydropower. The government has set an ambitious target for EVs to constitute 25% of all private passenger vehicle sales by 2025.

The shift towards electric vehicles on a global scale is gaining momentum, primarily driven by objectives focused on sustainability and policies aimed at achieving carbon neutrality [4]. Nepal has witnessed a rise in electric vehicle adoption driven by government encouragement, decreased reliance on fuel, and a growing awareness among consumers. The disposal of LIBs remains a significant challenge primarily due to the risks associated with hazardous waste and a lack of adequate local recycling facilities [5].

1.2 Problem statement

Forecasted electric vehicle sales are expected to reach 28,531 units by 2029, resulting in a substantial increase in LIB waste generation. Nepal's environment and economy are at risk if the country lacks a functional recycling system, with potential consequences including leakage of hazardous materials and the loss of precious raw materials. Nepal is exposed to environmental and economic hazards unless it establishes a functional recycling system, which will be vulnerable to toxic waste spills and valuable resource depletion. The research presents a sustainable design for a lithium-ion battery recycling plant and an economic-technical evaluation to assess the viability of recycling facilities in local areas The research suggests a sustainable design for a LIB recycling plant along with an economic evaluation to assess the viability of local recycling options.

1.3 Research objective

The primary goal is to assess the viability of a sustainable lithium-ion battery recycling facility in Nepal, taking into account projected growth in electric vehicle sales and the potential for recovering valuable materials. Some of the other Specific Objectives are as follows:

- Predict EV sales and battery waste creation for the years 2024 through 2029.
- Choose the most suitable recycling technology through the Analytical Hierarchy Process (AHP).
- Assess the capital expenditures, operational expenditures, and revenue generated from recovered materials.

2. METHODOLOGY

2.1 Predicting the Expansion of Electric Vehicle Adoption and the Consequences of Battery Disposal.

Using the baseline import of 11,466 EVs in 2024 and applying CAGR rates of 10% and 20%, the forecasted EV imports for Nepal are Studies on literature suggest that compound annual growth rate (CAGR) can be employed for forecasting electric vehicle adoption, a method also utilized in previous studies conducted in China and India [4]

$\text{EV Units}_n = \text{EV Units}_{\text{Base Year}} * (1+\text{CAGR})^n$

- Total Battery Weight (kg):
  $W = S \times B \times W_{\text{per kWh}}$
  Where:
  W =Total battery weight (kg)
  S = Number of EVs sold in a given year (units)
  B = Battery size per EV (kWh)
  $W_{\text{per kWh}}$ = Battery weight per kWh (kg/kWh)
- Cumulative Weight = Sum of total battery weights from the starting year to the current year

Sources of data comprise import statistics, policy trends, and market analysis.

2.2 Selection of Recycling Technology Using the Analytic Hierarchy Process (AHP) Approach.

The AHP method, utilizing survey inputs from industry specialists, ranks recycling techniques based on their priority. The Analytical Hierarchy Process (AHP) is selected because it methodically assesses a variety of criteria, encompassing economic viability, environmental impact, and operational feasibility. The Analytical Hierarchy Process is an established technique for resolving decisions when several conflicting factors are involved. Research from studies in China and Europe [6] [7] demonstrates the effectiveness of AHP in technology choice for recycling plants.

- Hydrometallurgical recycling is a process offering high purity at a moderate cost. [8]
- Pyrometallurgical recycling processes are highly energy-intensive and yield high material recovery rates. [9]
- Direct recycling involves environmentally friendly processes and complex sorting methods. [10]

The method with the highest ranking from AHP analysis is the recommended approach.

2.3 A techno-economic analysis is conducted on a recycling plant.

The capital expenditures, operational expenditures, and revenue are calculated using

- Net Present Value (NPV), Internal Rate Of return (IRR) & Payback Period Analysis for battery recycling investments.
  - $NPV = \sum (Revenue - OPEX) / (1 + r)^{t} - CAPEX$
- Policy Impact Assessment
  Determining the effects of different policy initiatives on the levels of recycling.

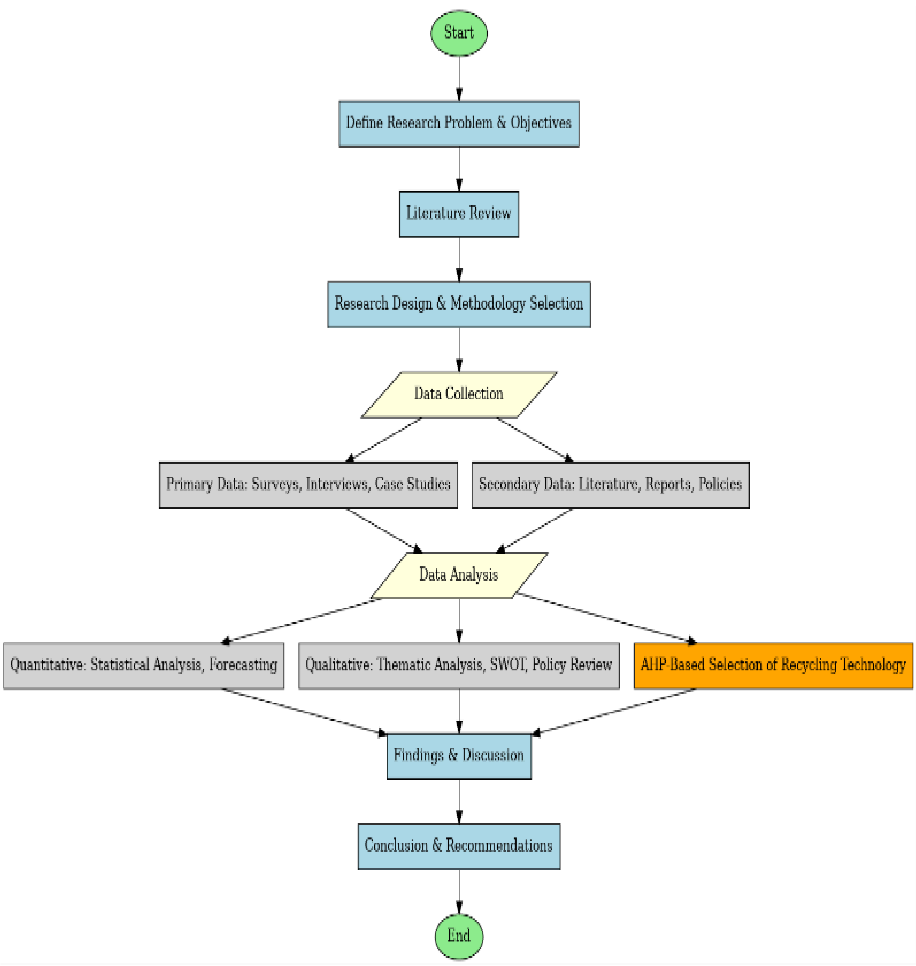

Figure 1: Research Frame work

3. RESULTS AND DISCUSSION

3.1 EV forecast in next 5 years trend:

- **CAGR Method**
  Using the baseline import of 11,466 EVs [3] [2]in 2024 and applying CAGR rates of 10% and 20%, the forecasted EV imports for Nepal are:

Table 1: Forecasting Using CAGR method

Year	Forecast (10% CAGR)	Forecast (20% CAGR)
2025	12,613	13,759
2026	13,874	16,511
2027	15,261	19,813
2028	16,787	23,776
2029	18,466	28,531

- **Declining Growth Model**
  Assumes an initial high growth rate of 100% for the first year, declining by 10% every two years, stabilizing at 20% growth by 2035.

Table 2: Forecasting using declining growth method

Year	Growth Rate (%)	Imports Forecast
2025	100%	23,402
2026	90%	44,464
2027	80%	80,035
2028	70%	136,060
2029	60%	217,696

- **Result** showing the more factual and practical forecast of EV for next 5 year to be CAGR method using 10% growth rate.

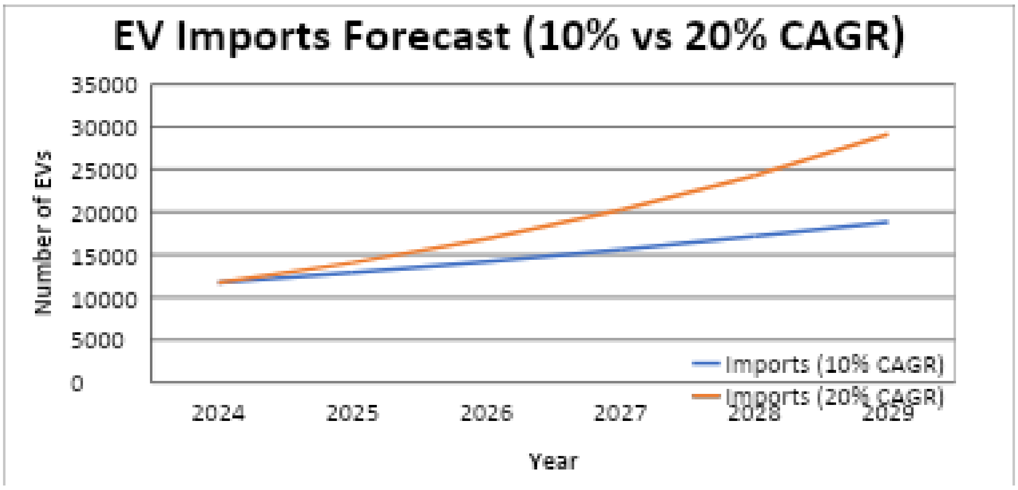

Figure 2: Graphical representation on forecast using 10% and 20% growth

3.2 Forecast of Sales and Weight of Electric Vehicle Batteries

- Short-Range: Maximum energy capacity of 30kWh
- Medium-Range: Energy capacity of approximately 30–50 kWh.
- Long-Range: Energy capacity above 50 kWh.

An examination of current market trends and import statistics indicates that the typical battery capacity per electric vehicle in Nepal is roughly 40 kilowatt hours, with the majority attributed to supplies coming from China and India. This categorization improves the accuracy of battery waste estimation and capacity forecasting

Table 3: Approximate EV sales and cumulative battery weights

Year	EV Sales (units)	Battery Size (kWh)	Battery Weight per kWh (kg/kWh)	Total Battery Weight (kg)	Cumulative Battery Weight (kg)	Total Battery Weight (tons)	Cumulative Battery Weight (tons)
2024	11,466	40	10	4586400	4586400	4586.4	4586.4
2025	12,613	42	9.8	5191511	9777911	5191.511	9777.9
2026	13,874	45	9.6	5993568	15771479	5993.568	15771.5
2027	15,261	47	9.4	6742310	22513789	6742.310	22513.8
2028	16,787	50	9.2	7722020	30235809	7722.020	30235.8
2029	18,466	52	8.8	8450042	38685851	8450.042	38685.9

3.3 Analysis of Hybrid Approach (AHP) for Recycling Technology Selection

- The AHP comparison ranked direct recycling as the most favorable technology primarily due to:

- Reducing energy usage.
- Enhanced material recycling effectiveness.
- Low environmental footprint.
- Economic Feasibility
  -Cost of setup and operation,
  -Return of Investment (ROI)

- Technological Efficiency
  -Recovery rate of materials
  -Scalability

- Social Impact
  -Job creation
  -Worker safety
  -Community benefits

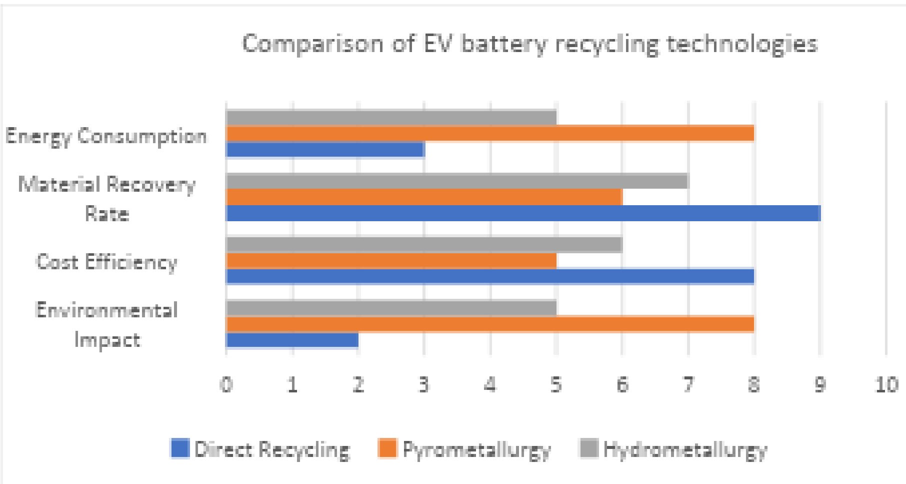

Figure 3: Clustered Bar Chart with reference to Harper et al. (2019), Gaines & Dunn (2015), and Wang et al. (2021)

Figure 3. compares three major recycling technologies Direct Recycling, Pyrometallurgy, and Hydro metallurgy—across several key aspects. The comparison is essential to justify the selection of the most sustainable and cost-effective method for EV battery recycling in Nepal [11] [6].

3.4 Techno-Economic Analysis of proposed recycling plant

3.4.1 Technology Layout for Nepal

To establish a recycling plant in Nepal, the following technology layout is proposed, considering the country's unique geographic, economic, and energy landscape:

- Collection and Transportation System
    - o Decentralized collection hubs in major cities such as Kathmandu, Pokhara, and Biratnagar to minimize transportation costs.
    - o Efficient reverse logistics using existing EV service networks to transport EOL batteries to the plant.
- Plant Layout
  Location: A feasible site is Hetauda Industrial Area, which offers the following advantages:
    - o Proximity to key urban centers like Kathmandu and Chitwan for battery collection.
    - o Access to the East-West Highway for nationwide transportation.
    - o Availability of renewable energy sources (hydropower plants nearby Super Lower Bagmati Hydropower).
    - o Logistics infrastructure (road connectivity, suppliers)

3.4.2 Resource Requirements

- **Energy**: 1.5 MWh/day (renewable energy preferred). Battery recycling facilities consume around 1-2 MWh per day [6], depending on automation Battery recycling facilities consume around 1-2 MWh per day, depending on automation.
- **Water**: Water is essential for battery cooling, washing, and leaching, estimated at 45,000 liters per day for processing 15 tons [5]. An additional 5,000 liters per day is required for cooling systems and maintenance, totaling 50,000 liters/day. Medium-scale plants typically consume 40,000 to50,000 liters/day. Recycling systems integrated to minimize water wastage.
- Labor: 50 skilled workers and 30 unskilled workers.
- Land Area: 10,000 square meters (2 bigha 9.3 katha). The layout is divided into processing zones, storage areas, administrative offices, and safety management spaces. Chinese case studies show a similar land utilization pattern, demonstrating the practical feasibility of the proposed layout. [13] Medium-scale recycling plants typically require 8,000 to 12,000 m² for efficient processing and storage. – Includes storage and processing zones

3.4.3 Economic analysis

- Estimates for setting up direct recycling facilities indicate a CAPEX between $4 million and $8 million, with land and machinery as the most significant costs
- Typical construction and setup costs in Asian contexts (including China) range from $2 million to $5 million [5].
- Annual OPEX for battery recycling plants ranges from $800,000 to $1.2 million, depending on labor intensity and energy costs. [10]
- Energy cost estimation: Approx. $200,000 per year for medium-sized facilities with moderate automation. [12]
- Waste management costs are around $50,000 per year, including hazardous waste disposal and wastewater treatment. [13]

- Capital Expenditure (CAPEX)

As per [14](Rs.13650000/katha) of Hetauda released by Hetauda Sub Metropolitan city

Table 4: Capital Expenditure

Expense	Cost (USD)
Land Acquisition	3,000,000 (rs.13650000/katha)
Plant Construction	2,000,000
Machinery and Equipment	3,000,000
Installation and Setup	500,000
Contingency (10%)	600,000
Total CAPEX	6,600,000

- Operational Expenditure (OPEX)

Table 5: Annual Operational Expenditure

Expense	Annual Cost (USD)
Labor	400,000
Energy Costs	200,000
Maintenance and Repairs	150,000
Raw Material Inputs	100,000
Waste Management	50,000
Administration and Overheads	100,000
Total OPEX	1,000,000

- Revenue Streams

  The revenue streams for a sustainable LIB recycling plant in Nepal are based on the recovery rates provided by Farasis Energy. The key sources of revenue include:
  - Recovered Materials: Sale of high-value recovered materials such as lithium, cobalt, nickel, and manganese.
  - Refurbished Battery Sales: Repurposing second-life batteries for renewable energy storage applications.
  - Government Incentives: Potential subsidies and incentives for recycling initiatives.
  - Processing Fees: Revenue from disposal fees charged to EV manufacturers and consumers for end-of-life battery management

    As per the rate of recover from Farasis Energy.

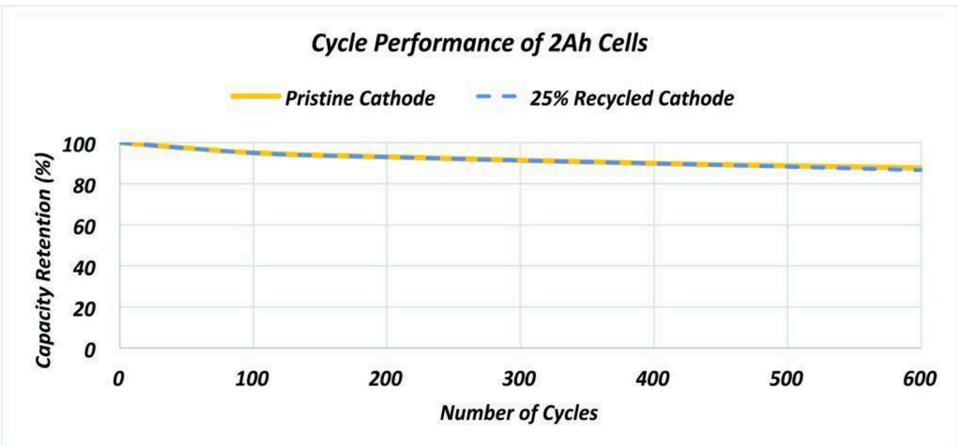

Figure 5: Recovery rate of direct recycling Source: Idaho National Laboratory

Table 6: Annual Revenue Stream [15]

Recovered Material	Recovery Rate (%)	Price (USD/tonne)	Revenue (USD)
Lithium	25	10,414.34	911,255
Cobalt	10	24,300	850,500
Nickel	15	15,930	477,900
Graphite	10	5,000	400,000
Copper and Aluminum	15	4,000	300,000
Total Annual Revenue			2,669,655

3.5 Economic Metrics:

- Net Present Value (NPV):
  - o Assume a project lifetime of 10 years and a discount rate of 10%.
  - o $NPV = \sum_{0}^{10} \frac{(Revenue-OPEX)}{(1+r)^{t}-CAPEX}$
  - o Annual net cash Cashflows =2,669,655-1,000,000 = \$1,669,655/year.
  - o NPV = \$3,326,642.90
- Internal Rate of Return (IRR): ~22%.
- Payback Period: ~2.95years.

The direct recycling plant with a capacity of 5000 tons/year is technically feasible and economically viable, with a profit margin and significant environmental benefits. However, reducing labor costs and securing stable material prices are critical for improving profitability. This pilot-scale study provides a foundation for scaling up the technology in the future.

Table 7: Economic metric calculation

Years	Cashflows	Cumulative cash flows
0	-6600000	-4930345
1	1669655	-3260690
2	1669655	-1591035
3	1669655	78620
4	1669655	1748275
5	1669655	3417930
6	1669655	5087585
7	1669655	6757240
8	1669655	8426895
9	1669655	10096550
10	1669655	11766205
IRR	22%	
Payback period	2.952912428	
NPV	$3,326,642.90	

3.6 Emission Reduction

- CO_2 Savings=Battery Recycled (tons)×Emission Reduction per Ton (kg CO_2)
- Assumed emission reduction: 15 tons CO_2 per ton of LIB recycled (based on industry studies).
    - o Plant capacity: 5,000 tons/year 5,000×15=75,000tons of CO_2 /year
- Recycling prevents mining for virgin materials, saving approximately 15 tons of CO2 emissions per ton of Lithium Ion Batter recycled. [16]
- Estimated reduction in CO2 emissions: 75,000 tons of CO2annually (at 5,000 tons capacity)

4. CONCLUSION

- By Fiscal year 29/30, Nepal is projected to generate over 600-1000 tons of Li-ion battery (LIB) waste assuming the condition of life span of EV High voltage battery be 8 years in context of Nepal assuming electricity supplement grid quality and nature of loading due to topography and charging discharging phenomena of user., necessitating local recycling solution
- $6.6 million USD recycling plant is financially viable, with a 3-year payback period.
- It is advisable to use direct recycling due to its high recovery rate and cost-effectiveness.
- Widespread support for policy is essential for achieving widespread adoption.

- Estimated reduction in CO2 emission 75,000tonnes of CO2 annually (at 5,000 tones capacity)

The research study shows that it is possible to set up a direct recycling facility for electric vehicle batteries in Nepal. Results of trend forecasting suggest a growing need for battery recycling, and techno-economic analysis verifies the financial viability of the proposed plant. According to AHP results, direct recycling is identified as the most environmentally sustainable and cost-efficient method. Suggestions for policy include offering government incentives for recycling and investing in infrastructure development.

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