Proceedings of the 2022 Winter Simulation Conference
B. Feng, G. Pedrielli, Y. Peng, S. Shashaani, E. Song, C.G. Corlu, L.H. Lee, E.P. Chew, T. Roeder, and P. Lendermann, eds.

EXPLORING THE COMPLEXITY IN MANAGING END-OF-LIFE LITHIUM-ION BATTERY: A SYSTEM DYNAMICS PERSPECTIVE

Bhanu Pratap
R K Amit

Department of Management Studies
Indian Institute of Technology Madras
Chennai, 600036, INDIA

Krishna Mohan T V

University of Exeter Business School
Exeter, EX4 4PU, UK

Shankar Venugopal

Mahindra Research Valley
Mahindra & Mahindra
Chennai, 603004, INDIA

ABSTRACT

The growing share of electric vehicles (EVs) in the transportation sector presents a challenge in handling end-of-life (EOL) lithium-ion batteries (LIB) that serve as the primary power source of EVs. EOL LIB can be recycled to obtain strategic raw material by using different recycling methods, or it can be used as second-use LIB. This research presents a systematic approach for analyzing the trade-off between LIB recycling and LIB second-use by applying system dynamics modelling. Our study shows that collection rate increment will reduce the landfill and increases the quantity of recovered strategic raw materials. Model results indicate that cascading use of LIB for stationary storage applications will limit their availability for recycling. Cascade's use of EOL LIB eases the demand for new LIB by using the repurposed LIB for stationary energy storage applications.

1 INTRODUCTION

Rapid growth in the mobility sector's share of electric vehicles (EVs) is imperative to meet the global targets for reducing greenhouse emissions set by the Paris agreement. However, the growing share of EVs in the transportation sector increases the demand for lithium-ion batteries (LIB) that serve as the primary power source of EVs. According to Bibra et al. 2022, automotive LIB demand reached 340 gigawatt-hours (GWh) in 2021 which is expected to reach 2.2-3.5 terawatt-hour (TWh) per year in 2030. LIB reaches end-of-life (EOL) when its nominal capacity reaches 80% of the original capacity, and it varies from 8-10 years. Richa et al. 2014 forecasts that about 0.83-2.87 million LIB pack reaches EOL in the United States in 2040, whereas Abergel et al. 2020 forecast that 100-120 GWh of LIB reaches EOL in 2030 based on the difference in scenarios taken by the International Energy Agency (IEA). Vlachos et al. 2007 states that EOL LIBs need to be collected before further processing. The collection rate depends on the efficiency of collection processes Vlachos et al. 2007. But, due to a lack of clarity in government policies on extended producer responsibility, the collection rate of EOL LIB is low. Poor collection rate impacts the strategic decision taken for managing EOL LIB.

The literature considers that EOL LIB can be either recycled to obtain critical raw materials like lithium, cobalt, and nickel, or it can be second use for other applications like stationary storage systems, frequency regulation, renewable integration, etc., based on the quality of collected LIB, Chen et al. 2019. Recycling efficiency of material and recycling process, the collection rate of EOL life, and recycling profitability play a crucial role in raw material recovery, whereas the quality of collected raw material, maturity of the repurposing process, and demand for repurposed LIB impact the repurposing process, Georgiadis and Athanasiou 2010.

This work emphasizes understanding the trade-off for battery manufacturers between battery recycling and repurposing. Our study states that the recovery of raw materials from EOL LIB improves by enhancing the collection rate of EOL LIB and improving LIB recycling process efficiency. Our analysis says that improving the repurposing of LIB reduces the demand for new LIB for stationary energy storage. Both recycling and repurposing of EOL LIB reduce the raw material demand, easing the pressure on exploring new raw material mines to fulfil the increasing demand for the booming electrical mobility market.

2 MODEL

Battery manufacturers are always in a dilemma in resource allocation for recycling or LIB second-use when LIB reaches EOL. Interdependence and interconnections among variables like battery collection rate, battery quality, recycling process efficiency, repurposing efficiency, etc. make the system dynamic. System dynamics models are a widely used methodology for exploring a complex system involving strategic recycling and repurposing decisions, Georgiadis and Athanasiou 2010. Hence, we develop a system dynamics model to study the trade-offs between EOL LIB recycling and second-use and its impact on raw material recovery and the LIB market. In our model, government regulations, EOL LIB collection capacity, and product quality impact the quantity allotted to the recycling process and second use. Collected EOL undergoes quality tests that decide the quantity allotment for recycling and second use. The leftover EOL LIB send to the landfill. The quantity allotment to recycling and second use affects the raw material recovery from EOL LIB, raw materials market price and process profitability.

3 RESULTS and DISCUSSION

Model results indicate that while cascading use of LIB for stationary storage applications reduces the battery material demand, the extended life of LIB limits their availability for recycling and material availability in the long term. While poor collection rates and battery quality limit repurposing scope, process efficiency limitations hamper recycling profitability. Recycling process efficiency impacts the quantity of recovered raw material from EOL LIB. We aim to provide recommendations for LIB manufacturers to identify effective end-of-life management practices and for regulators to identify suitable instruments for effective policy decisions.

REFERENCES

Abergel, T., T. Bunsen, M. Gorner, P. Leduc, and S. Pal. 2020. “Global EV Outlook 2020 Entering the Decade of Electric Drive?”. Technical report, International Energy Agency.

Bibra, E. M., E. Connelly, S. Dhir, M. Drtil, and L. Cozzi. 2022. “Global EV Outlook 2022 Securing Supplies for an Electric Future”. Technical report, International Energy Agency.

Chen, M., X. Ma, B. Chen, R. Arsenault, P. Karlson, N. Simon, and Y. Wang. 2019, 11. “Recycling End-of-Life Electric Vehicle Lithium-Ion Batteries”. *Joule* 3(11):2622–2646.

Georgiadis, P., and E. Athanasiou. 2010, 4. “The Impact of Two-product Joint Lifecycles on Capacity Planning of Remanufacturing Networks”. *European Journal of Operational Research* 202(2):420–433.

Richa, K., C. W. Babbitt, G. Gaustad, and X. Wang. 2014, 2. “A Future Perspective on Lithium-Ion Battery Waste Flows from Electric Vehicles”. *Resources, Conservation and Recycling* 83:63–76.

Vlachos, D., P. Georgiadis, and E. Iakovou. 2007, 2. “A System Dynamics Model for Dynamic Capacity Planning of Remanufacturing in Closed-loop Supply Chains”. *Computers & Operations Research* 34(2):367–394.