Modeling performance and cost dynamics of Lithium-ion Battery for Mobility

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1 Introduction

According to the European Environmental Agency (EEA), road transport contributes around 71% of overall transport emissions in 2018 in European nation countries. Therefore, the decarbonization of road transportation is the uttermost requirement to reduce the overall carbon emission. Electric vehicles (EVs) are considered as "zero tailpipe emission" vehicles and hence, it playing a crucial role in alleviating the level of the carbon emission generated through road transportation.

Lithium-Ion batteries (LIBs), lead-acid, and alkaline batteries are commonly available variants of batteries in the market that are used as power source for EVs. High energy density, high power density, long cycle life, high operating voltage, and low self-discharging makes LIBs as promising power source for electric vehicles. LIBs' demand evolves with the increase in market penetration of electric mobility. But high cost and range anxiety issues related to EVs limit the growth of the LIBs market.

The literature consider that LIB cost crates monetary barrier whereas range anxiety related to EVs creates physiological barrier that hindered LIB market. The cost of LIB depends upon battery capacity, energy density of battery pack, material composition of electrodes, cost of raw material, and learning effect that based on the demand of LIBs (Ahmed et al., 2017; Azevedo et al., 2018; Hsieh et al., 2019). Pevec et al. (2020) stated that "Range anxiety" is defined as the physiological barrier in the mind of drivers that forced them to think that battery size will limit their driving pattern. Li et al. (2020) stated that Battery electric vehicles (BEVs) sales will go up by around 0.075% for every 1% increase in subsidy.

This work analyses the variations in LIB demand. The model results show that battery capacity and battery life significantly impact LIB cost per kWh when there is a fixed subsidy. The LIB demand improves when there is a high subsidy on EVs' price and when LIB has low capacity and life, which can be considered while developing EV models for different customer segments.

2 Model

In this paper, we consider NMC-622 battery chemistry and develop a system dynamics model to evaluate the impact of battery capacity on the cost and demand of LIBs and range requirements for EVs. The model captures the performance and cost dynamics persistent in the LIB market that impact the LIBs demand. The model considers battery capacity, the subsidy given on EVs, EV sales, and LIB replacement based on LIB life as factors that impacts the LIB market.

3 Results and Discussion

Range anxiety is substantially reduced by increasing the battery capacity, but an increase in battery capacity will increase the LIB cost. An increase in LIB cost will increase the EV cost and reduces the EVs sales. An increase in EV cost is alleviated by giving subsidies on EVs. The result shows that in the case of fixed subsidy, LIB has lesser battery capacity and low battery life will dominate the LIB market. An increase in demand will increase the learning impact of the experience curve that will eventually reduce the LIB cost per kWh.

References

Ahmed, S., Nelson, P.A., Gallagher, K.G., Susarla, N., Dees, D.W., 2017. Cost and energy demand of producing nickel manganese cobalt cathode material for lithium ion batteries. Journal of Power Sources 342, 733–740. doi:10.1016/j.jpowsour.2016.12.069.

Amit, R.K., Venugopal, S., 2018. Is this time different for electric vehicle (EV) battery materials?, in: FISITA World Automotive Congress 2018.

Azevedo, M., Campagnol, N., Hagenbruch, T., Hoffman, K., Lala, A., Ramsbottom, O., 2018. Lithium and cobalt – a tale of two commodities. Technical Report.

Barlas, Y., 1996. Formal aspects of model validity and validation in system dynamics. System Dynamics Review 12, 183–210. doi:10.1002/(sici)1099-1727(199623)12:3<183::aid-sdr103>3.0.co;2-4.

Benveniste, G., Rallo, H., Canals Casals, L., Merino, A., Amante, B., 2018. Comparison of the state of Lithium-Sulphur and lithium-ion batteries applied to electromobility. Journal of Environmental Management 226, 1–12. doi:10.1016/j.jenvman.2018.08.008.

Curry, C., 2017. Lithium-ion Battery Costs and Market Squeezed margins seek technology improvements & new business models. Technical Report. Bloomberg New Energy Finance.

Hsieh, I.Y.L., Pan, M.S., Chiang, Y.M., Green, W.H., 2019. Learning only buys you so much: Practical limits on battery price reduction. Applied Energy 239, 218–224. doi:10.1016/j.apenergy.2019.01.138.

Kieckhäfer, K., Volling, T., Spengler, T.S., 2014. A hybrid simulation approach for estimating the market share evolution of electric vehicles. Transportation Science 48, 651–670. doi:10.1287/trsc.2014.0526.

Kittner, N., Lill, F., Kammen, D.M., 2017. Energy storage deployment and innovation for the clean energy transition. Nature Energy 2, 1–6. doi:10.1038/nenergy.2017.125.

Li, L., Guo, S., Cai, H., Wang, J., Zhang, J., Ni, Y., 2020. Can China's BEV market sustain without government subsidies?: An explanation using cues utilization theory. Journal of Cleaner Production 272, 122589. doi:10.1016/j.jclepro.2020.122589.

Nelson, P.A., Bloom, K.G., I Dees, D.W., 2011. Modeling the performance and cost of lithium-ion batteries for electric-drive vehicles. Argonne National Laboratory, doi:10.2172/1027714.

Nitta, N., Wu, F., Lee, J.T., Yushin, G., 2015. Li-ion battery materials: Present and future. Materials Today 18, 252–264. doi:10.1016/j.mattod.2014.10.040.

Nykvist, B., Sprei, F., Nilsson, M., 2019. Assessing the progress toward lower priced long range battery electric vehicles. Energy Policy 124, 144–155. doi:10.1016/J.ENPOL.2018.09.035.

Olivetti, E.A., Ceder, G., Gaustad, G.G., Fu, X., 2017. Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals. doi:10.1016/j.joule.2017.08.019.

Pevec, D., Babic, J., Carvalho, A., Ghiassi-Farrokhfal, Y., Ketter, W., Podobnik, V., 2020. A survey-based assessment of how existing and potential electric vehicle owners perceive range anxiety. Journal of Cleaner Production 276, 122779. doi:10.1016/j.jclepro.2020.122779.

Pratap, B., Mohan T V, K., Amit, R.K., Venugopal, S., 2020. Visualizing the complex demand and supply dynamics of critical battery materials—a key enabler for realizing the Electric Mobility Vision 2030, in: IEEE Transportation Electrification Conference (ITEC-India).