Second-Life Applications of Electric Vehicle Batteries in Energy Storage

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Abstract. This paper reviews the work in the areas of energy and climate implications, grid support, and economic viability associated with the second-life applications of electric vehicle (EV) batteries. The increasing adoption of EVs has raised concerns about the end-of-life management of their batteries. The potential of repurposing these batteries for energy storage offers them a renewed purpose. The research underscores the energy and climate benefits anticipated in the coming decades, the role of these batteries in stabilizing energy grids, and the economic aspects of battery repurposing in energy storage. Together, these areas highlight the multifaceted advantages of giving EV batteries a second life, from environmental benefits to grid stability and economic feasibility.

1 Introduction

The surge in electric vehicle (EV) adoption represents a transformative shift in the transportation sector. This transition is not only reshaping how we perceive mobility but also introducing a plethora of opportunities and challenges. One of the most pressing concerns is the end-of-life management of EV batteries. As vehicles age and their batteries no longer meet the stringent requirements for automotive use, they are often left with a significant residual capacity. This residual capacity, although insufficient for vehicular demands, is still substantial and presents a potential resource waiting to be tapped.

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In light of the rapid advancements in renewable energy and the global push towards sustainable solutions, these used EV batteries have garnered attention as potential energy storage solutions. Their ability to store and release energy can be harnessed to stabilize power grids, especially in regions with high renewable energy integration. This not only aids in addressing the intermittency issues associated with renewable sources like solar and wind but also provides a cost-effective storage solution, reducing the need for new battery production.

The concept of giving batteries a "second life" has thus emerged as a promising research area. By repurposing these batteries, we can extend their utility, reduce waste, and contribute to a more circular economy. Researchers are now exploring various domains where these batteries can be integrated, from grid support and backup power systems to off-grid applications in remote areas. The potential of these second-life applications is vast, and as research progresses, it is anticipated that new and innovative uses will continue to emerge, further solidifying the role of repurposed EV batteries in our sustainable future.

2 Literature survey

In the rapidly evolving landscape of sustainable energy and transportation, the potential of repurposed electric vehicle (EV) batteries has emerged as a focal point of interest. Recognizing the significance of this area, our intention is to review the pioneering works of various studies that have delved deep into the second-life applications of EV batteries. By synthesizing the findings of these studies, we aim to provide a comprehensive overview of the current state of research, its implications, and the future trajectory of this domain.

Sathre et al. (2015) embarked on a comprehensive study focusing on the energy and climate implications of reusing EV batteries. Their research, set against the backdrop of California's energy landscape, delved into the prospective benefits of such repurposing endeavors up to 2050. By analyzing the potential reductions in greenhouse gas emissions and the enhancement of renewable energy integration, their work provides invaluable insights into the environmental advantages of second-life battery applications, making it directly relevant to our review topic.

Lacey et al. (2013) took a different approach, concentrating on the technical feasibility and benefits of using second-life EV batteries for grid support. Their research underscores the batteries' capability to stabilize energy grids, especially in scenarios with high renewable energy penetration. This aspect of their work aligns with our review's focus on understanding the broader applications and benefits of repurposed batteries. On the other hand, Wu et al. (2020) posed an essential question about the economic side of the equation. Their study delves deep into the profitability of repurposing EV batteries for energy storage, shedding light on the economic viability and potential return on investment. Such an economic perspective is crucial for our review, as it offers a balanced view, combining environmental benefits with economic considerations.

Together, these studies provide a holistic view of the second-life applications of EV batteries, encompassing environmental, technical, and economic dimensions, setting the stage for our comprehensive review on the topic.

3 Review and discussion

3.1 Principal Insights from the Research by Sathre et al. (2015)

The increasing prominence of electric vehicles (EVs) in the transportation sector has led to a surge in research focusing on the potential applications of their batteries post their vehicular life. One such pivotal study by Sathre et al. (2015) provides a comprehensive analysis of the energy and climate implications of reusing EV batteries, particularly in the context of California's energy landscape. Their findings, set against the backdrop of projected PEV adoption and first-life duration, offer a deep dive into the prospective benefits of such repurposing endeavours up to 2050 [1].

1. Projections Concerning Battery Disposal: Looking ahead to 2050, under the foundational scenarios, it's projected that roughly 60,000 metric tonnes of batteries will be disposed of annually. This estimate spans a spectrum, with figures as low as 30,000 tonnes and as high as 90,000 tonnes in the more conservative and optimistic scenarios, respectively. This translates to an initial energy storage capacity of about 15,000 MWh, with potential variations between 8,000 MWh and 25,000 MWh.

2. Consumption of Energy and Greenhouse Gas Emissions: The energy consumed and the greenhouse gases emitted during the transportation of batteries for their subsequent use are comparatively negligible. Notably, the scenario that leans towards decentralised solar energy emerges as the most energy-consuming, demanding 1240 MJ for every tonne and releasing 92.6 kg of CO2 equivalent for the same quantity.

3. Equilibrium of Energy: By the time we reach 2050, it's estimated that second-life PEV batteries will deliver close to 15 TWh of electricity. To achieve this, roughly 18 TWh of sporadic renewable electricity would be needed for charging, keeping in mind an assumed efficiency of 80% for the round trip. Additionally, the cooling process for these repurposed batteries is expected to consume around 1 TWh of electricity.

4. Balance of Greenhouse Gas Emissions: The act of charging these repurposed batteries is predicted to release approximately 0.5 Mt of CO2 equivalent annually, a consequence of the life-cycle emissions stemming from sporadic PV electricity generation. In contrast, the subsequent discharge of this stored electricity, intended to supplant electricity generated by burning natural gas, is projected to prevent the emission of about 7.5 Mt of CO2 equivalent each year.

5. Sensitivity Analysis: The research also undertook a sensitivity analysis to discern the effects of diverse parameters on the performance metrics of the batteries. Two elements stood out as particularly influential: the rate at which PEVs are adopted and the point of inflection in battery degradation. Both these factors play a pivotal role in determining the efficacy of batteries in their second life.

The tabulated data provides a concise representation of the key findings from the study by Sathre et al. (2015). The data underscores the potential environmental benefits and challenges associated with the second-life use of EV batteries. The detailed breakdown of energy use, GHG emissions, and the sensitivity analysis offers a comprehensive understanding of the various factors influencing the performance of second-life batteries [1,4-9].

Table 1. Projected Second-Life Battery Performance Metrics (2050)

Parameter	Base-Case Value	Low-Performance Value	High-Performance Value
Battery Disposal (Metric Tons/Year)	60,000	30,000	90,000
Original Energy Storage Capacity (MWh)	15,000	8,000	25,000
Energy Use (MJ/Ton)	-	880 (Centralized Renewable)	1240 (Decentralized Solar)
GHG Emissions (kg CO2e/Ton)	-	65.5 (Centralized Renewable)	92.6 (Decentralized Solar)
Electricity Delivered by Second-Life Batteries (TWh)	15	-	-
Electricity Required for Charging (TWh)	18	-	-
Cooling Electricity Requirement (TWh)	1	-	-
GHG Emissions from Charging (Mt CO2e/Year)	0.5	-	-
GHG Emissions Avoided (Mt CO2e/Year)	7.5	-	-

In the context of our review, the findings from this study highlight the multifaceted implications of repurposing EV batteries. The potential reductions in greenhouse gas emissions, combined with the enhancement of renewable energy integration, emphasize the environmental advantages of second-life battery applications. The detailed analysis provided by Sathre et al. (2015) serves as a foundational reference, offering invaluable insights that are directly relevant to our review topic.

3.2 Principal Insights from the Research by Lacey et al. (2013)

Lacey et al. (2013) embarked on a meticulous investigation, centring their attention on the technical feasibility and advantages of utilising second-life EV batteries for grid support [2]. Their research was delineated around four distinct scenarios, each crafted to observe the intricacies of power demand and voltage variation within the network. These scenarios encompassed:

- A rudimentary model of the network devoid of any supplementary elements.
- The integration of the Battery Energy Storage System (BESS) with the primary objective of peak shaving.
- The introduction of Distributed Generators (DG), notably a 100kW PV array and a 100kW Wind Energy Conversion System (WECS) on the detailed Low Voltage (LV) feeder.
- A holistic approach, amalgamating both the BESS and DG into the network for a synergistic effect.

The outcomes from their simulations unveiled pronounced voltage fluctuations on Bus B1 and Bus B6. Particularly, Bus B6 occasionally breached the lower limit during peak demand periods. When the BESS was amalgamated into the original network, it adeptly achieved peak shaving. Consequently, the nocturnal trough witnessed an elevation due to the battery's charging dynamics. This rectification addressed the immediate conundrums faced by the network, such as the overburdening of transformers. However, the researchers astutely highlighted the evolving nature of networks, suggesting that today's solutions might be rendered obsolete given the rapid transformations in network conditions.

The study further accentuated the sporadic nature of DG and postulated the BESS as an efficacious solution for renewable energy storage. By coalescing DG & BESS, not only was peak shaving realised, but the voltage profile was also buttressed, which is paramount for the networks of the future. This integration mandates the BESS to be dimensioned aptly for renewable energy storage, capacitating it to charge utilising power generated from the DG. Such a configuration ensures that any voltage aberrations outside the permissible thresholds would instigate the storage system to either proffer or absorb power, thereby equilibrating the voltage.

In their culminating remarks, Lacey et al. (2013) underscored the multifarious benefits of harnessing BESS for grid support. They spotlighted the waning technical and market barriers to BESS deployment, though they acknowledged that achieving cost competitiveness with conventional technologies remains an elusive challenge. The potential panacea, as propounded by the researchers, resides in capitalising on afterlife EV batteries within the BESS framework. Their findings elucidated the positive ramifications of a BESS, harnessing afterlife EV batteries, on a detailed LV feeder. The study also magnified the significance of the BESS's locale, magnitude, and operational nuances, contingent upon its designated function.

In tandem with our review's thematic focus, the work of Lacey et al. (2013) furnishes a comprehensive comprehension of the expansive applications and merits of repurposed batteries. Their research accentuates the batteries' prowess to stabilise energy grids, especially in scenarios characterised by a high penetration of renewable energy. This facet of their work is particularly salient as it proffers a detailed technical vantage point on the potential of second-life EV batteries in contemporary and prospective energy grids.

3.3 Principal Insights from the Research by Wu et al. (2020)

Wu et al. (2020) embarked on an intricate exploration, delving into the prospective merits of repurposing electric vehicle (EV) batteries for stationary energy storage systems [3]. Their research was meticulously structured around four distinct scenarios, each centred on the remaining capacity of EV batteries when they were transitioned from their primary use in vehicles to stationary storage systems. These capacities were pegged at 90%, 80%, 70%, and 65% of their original prowess. The overarching aim was to discern the multifaceted influences on the potential profitability of these second-life batteries in energy storage contexts [10-14].

Simulation Insights:
The team simulated the operations of a typical day within a second-life battery energy storage framework. This simulation illuminated the dynamic fluctuations in electricity storage, primarily driven by arbitrage activities. These activities were characterised by charging the batteries during periods of low electricity demand and subsequently discharging them during peak demand hours. The decision-making process for these charging and discharging cycles was intricately tied to the residual capacity of the second-life battery.

Value Proposition and Longevity of Second-Life Batteries:
One of the pivotal findings of the study was the direct correlation between the remaining capacity of the battery when repurposed and its subsequent value in stationary storage applications. The potential value derived from this secondary use was approximately a third of the cost of procuring a brand-new battery. The residual capacity at the point of retirement and eventual abandonment dictated the potential value and operational lifespan of the battery in its secondary role. Two critical determinants of potential profitability were identified: the rate of battery degradation and the prevailing discount rate.

Sensitivity Analysis:
A comprehensive sensitivity analysis was undertaken to gauge the ramifications of variations in the discount rate and the battery degradation rate on potential profits. The findings underscored the inverse relationship between the discount rate and the value proposition of second-life batteries. Furthermore, the degradation rate of the battery emerged as a paramount factor, with different degradation rates yielding disparate potential profit margins.

Market Valuation of Second-Life Batteries:
Wu et al. (2020) ventured into estimating the market prices for these repurposed batteries. They delineated two distinct price points: the market evaluation price, influenced by the battery's condition juxtaposed against the market price of new batteries, and the willing-to-sell price, which was the bare minimum a battery owner would be inclined to accept, factoring in the lifecycle costs associated with the EV [14].

Proposed Business Model and Broader Implications:
The authors put forth an innovative business model, advocating for the cascading utilisation of EV batteries. This model envisaged a scenario where EV manufacturers would not only provide batteries to consumers through sales or leases but would also play an active role in reclaiming these batteries upon their retirement. These reclaimed batteries would then be channelled to energy storage operators, who would, in turn, lease them to end-users. This model was crafted to mitigate the challenges posed by asymmetric information. Furthermore, the research accentuated the potential for recycling raw materials from batteries that had reached the end of their lifecycle [15,16].

In alignment with our review's overarching theme, the work of Wu et al. (2020) offers a profound understanding of the multifaceted benefits and challenges associated with repurposing EV batteries. Their research underscores the potential profitability and value of these batteries in stationary energy storage applications, while also shedding light on the myriad factors that influence this profitability. Their proposed business model, centred on the cascading utilisation of EV batteries, presents a compelling blueprint for maximising the value of these batteries throughout their lifecycle.

4 Future scope and knowledge gaps

- Battery Degradation and Lifespan: While the studies have touched upon the degradation rates of EV batteries, there's a need for more in-depth research on the factors influencing battery degradation over time, especially in their second-life applications.

- Economic Viability: While the potential profitability of second-life batteries has been explored, comprehensive economic analyses that factor in the costs of repurposing, maintenance, and eventual recycling are still required.

- Environmental Impact: The environmental benefits of repurposing EV batteries have been highlighted, but a detailed lifecycle analysis, from production to disposal, would provide a clearer picture of their overall environmental footprint.

- Technical Challenges: More research is needed on the technical challenges associated with repurposing EV batteries, especially concerning their integration into different types of energy grids and storage systems.

- Policy and Regulation: As the second-life battery market grows, there will be a need for clear policies and regulations to ensure safety, efficiency, and fairness in the market.

- Consumer Behaviour: Understanding consumer willingness to adopt second-life battery products, and the factors influencing their decisions, can provide insights for businesses and policymakers.

5 Conclusion

The burgeoning field of electric vehicles has brought to the fore the pressing question of battery end-of-life management. As the world grapples with the dual challenges of sustainable energy and environmental conservation, the potential of repurposing EV batteries for stationary energy storage emerges as a promising solution.

Key Findings from Our Review:

- Potential for Second-Life Applications: EV batteries, even after their primary use, retain a significant portion of their capacity, making them suitable for stationary energy storage applications, as highlighted by Sathre et al. (2015) and Wu et al. (2020).

- Grid Stabilisation: Lacey et al. (2013) underscored the potential of second-life EV batteries in stabilising energy grids, especially in scenarios with high renewable energy penetration.

- Economic Benefits: Wu et al. (2020) highlighted the potential profitability of second-life batteries, suggesting that they could generate about a third of the value of a new battery in energy storage applications.

- Environmental Impact: The repurposing of EV batteries can significantly reduce the environmental impact associated with battery disposal, as indicated by the projections for California by Sathre et al. (2015).

- Technical Challenges and Solutions: While there are technical challenges associated with repurposing EV batteries, solutions such as peak shaving and voltage stabilisation can be achieved through strategic battery management, as demonstrated by Lacey et al. (2013) and Wu et al. (2020).

- Business Models for Cascade Utilisation: Wu et al. (2020) proposed a business model that promotes the cascade utilisation of EV batteries, suggesting a structured approach to maximising the value of these batteries throughout their lifecycle.

The repurposing of EV batteries for stationary energy storage offers a promising avenue to address contemporary energy challenges. As the EV market expands, sustainable solutions for battery end-of-life management become paramount. The research we've reviewed illuminates the potential of second-life EV batteries in reshaping the energy landscape. This transition isn't solely about reducing transportation emissions but also about leveraging used batteries within a circular economy. Echoing our initial insights, it's evident that integrating these applications is crucial for a comprehensive sustainability strategy. The future beckons with opportunities for innovation, and our review sets the stage for further exploration in this domain.

References

1. Sathre, R., Scown, C. D., Kavvada, O., & Hendrickson, T. P. (2015). Energy and climate effects of second-life use of electric vehicle batteries in California through 2050. Journal of Power Sources, 288, 82-91.
2. Lacey, G., Putrus, G., & Salim, A. (2013, July). The use of second life electric vehicle batteries for grid support. In Eurocon 2013 (pp. 1255-1261). IEEE.
3. Wu, W., Lin, B., Xie, C., Elliott, R. J., & Radcliffe, J. (2020). Does energy storage provide a profitable second life for electric vehicle batteries?. Energy Economics, 92, 105010.
4. Smith, B. (2014). Personal Communication. Nissan North America, Houston, TX.
5. Yeh, A. G., & Chow, M. H. (1996). An integrated GIS and location-allocation approach to public facilities planning: An example of open space planning. Computers, Environment and Urban Systems, 20, 339-350.
6. Spiers, D. (2014). Personal Communication. ATC New Technologies, Oklahoma City, OK.
7. Vidovic, M., Dimitrijevic, B., Ratkovic, B., & Simic, V. (2011). A novel covering approach to positioning ELV collection points. Resources, Conservation and Recycling, 57, 1-9.
8. Greenblatt, J. B. (2015). Modelling California policy impacts on greenhouse gas emissions. Energy Policy, 78, 158-172.

9. Saxena, S., Le Floch, C., MacDonald, J., & Moura, S. (2015). Quantifying EV battery end-of-life through analysis of travel needs with vehicle powertrain models. Journal of Power Sources, 282, 265-276.
10. Neubauer, J., &Pesaran, A. (2011). The ability of battery second use strategies to impact plug-in electric vehicle prices and serve utility energy storage applications. Journal of Power Sources, 196(23), 10351-10358.
11. M L B., Sripriya T., Muthuraj B., Kumar D.S., Venkatesh V., Sridevi B.S., Krishna M.M.S., Rajan K. & Diriba A.(2022),"Deep Learning-Based Smart Hybrid Solar Water Heater Erection Model to Extract Maximum Energy",International Journal of Photoenergy.
12. Marra, F., Træholt, C., Larsen, E., & Wu, Q. (2010, October). Average behavior of battery-electric vehicles for distributed energy studies. In 2010 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT Europe) (pp. 1-7). IEEE.
13. NREL, http://www.nrel.gov/vehiclesandfuels/energystorage/ (accessed Aug 2012)
14. http://www.mathworks.co.uk/products/simulink/
15. Lih, W. C., Yen, J. H., Shieh, F. H., & Liao, Y. M. (2012, June). Second use of retired lithium-ion battery packs from electric vehicles: technological challenges, cost analysis and optimal business model. In 2012 International Symposium on Computer, Consumer and Control (pp. 381-384). IEEE.
16. Lin, B., Wu, W., Bai, M., Xie, C., & Radcliffe, J. (2019). Liquid air energy storage: Price arbitrage operations and sizing optimization in the GB real-time electricity market. Energy Economics, 78, 647-655.