Aalto University School of Arts, Design and Architecture

PLATE Product Lifetimes And The Environment

5th PLATE 2023 Conference
Espoo, Finland - 31 May - 2 June 2023

Sustainable Business Models for the Second Use of Electric Vehicles Lithium ion Batteries in an Ecosystem Context: A Review

Saad Ahmed [a], Elli Verhulst[a], Casper Boks[a]
a) Norwegian University of Science and Technology, Trondheim, Norway

Keywords: Sustainable business models; Ecosystems; Electric vehicles; Battery second use; Circular economy.

Abstract: Repurposing electric vehicle lithium-ion batteries (EV LiBs) for second use can potentially prolong the life of the batteries, partially close the value chain loop and contribute towards circularity. Rapid adoption of EVs has paved way for new business models incorporating sustainability for the EV LiB second use industry. This study is conducted through a literature review to provide a better understanding of current sustainable business models (SBMs) for second use EV LiBs and their position in the related ecosystem. The initial insights suggest that SBMs can play an important role in adaption for the EV LiB second use. However, the EV LiB ecosystem is complex consisting of multiple stakeholders and interconnected activities. These stakeholders include but are not limited to automotive original manufacturers, batteries collectors, system integrators, users, and repurposers etc. Their BMs can be interdependent, affecting one another positively, negatively, or symbiotically and influencing the overall value of LiB second use. This paper synthesizes three research fields: SBM, Ecosystems, and Second use EV LiBs and provides insights that support the need for considering SBMs in an ecosystem context for second use. It also presents SBM types for various stakeholders in existing second use ecosystems. Furthermore, it provides the basis for further research into SBM interactions and SBM innovations in the EV LiB ecosystem.

Introduction

The continuous increase in the sale of electric vehicles (EV) has increased the number of lithium ion batteries(LiBs) being produced (IEA, 2022; Winslow et al., 2018; Wrålsen et al., 2021). It is not ideal to use these batteries in the EVs once their capacity drops below 80% and hence should be either recycled or repurposed for second use. The materials present in LiBs are hazardous and if treated irresponsibly, can result in adverse environmental impacts at their end of life (EOL) ((Jiao & Evans, 2018a; Kim et al., 2021). According to estimates, by 2030 more than 200,000 metric tons of LiBs will have to be recycled in EU alone, which is expected to double by 2035 (*Building a Circular Battery Economy in Norway*, 2021). Moreover, the recycling processes are not yet efficient enough (Heelan et al., 2016) and it is therefore pertinent to prolong the use phase of these batteries.

Repurposing EV LiBs in less demanding energy storage systems (ESS) can potentially prolong the use phase and partially close the value chain loop while reducing the environmental impacts and increasing the economic benefits (Chen et al., 2019; Montes et al., 2022). However, there are numerous barriers that need to be addressed to make repurposing economically, environmentally, and socially viable. A potential way to achieve this is by innovating business models and integrating sustainability initiatives into the core business activities of the stakeholders. This can be a challenge as the EV LiB value chain is complex and consists of multiple stakeholders across different industries. Understanding the value chain in a circular context and mapping the ecosystem can contribute to understanding how these stakeholders and their business models interact and innovate (N. Bocken et al., 2016; Cheng et al., 2022; Wrålsen et al., 2021; Zulkarnain et al., 2014).

The business models having sustainability at their core, considering economic, environmental, and social aspects, are known as sustainable business models (SBM) while circular business models (CBM) are a type of SBMs that can close, slow, narrow, intensify, and dematerialize loops to promote sustainability (Geissdoerfer et al., 2018). Although CBMs do not address the social dimension (Murray et al., 2017) the literature of SBMs and CBMs is partially overlapping, and hence both are considered in this paper.

Initial investigation reveals an emerging field in the literature on SBM perspectives (Evans et al., 2017; Geissdoerfer et al., 2017; Lüdeke-Freund, 2020; Wrålsen et al., 2021). However, to date there is scarcity in the literature about the interrelation between SBM perspectives in an ecosystem context for the EV LiB second use market. Addressing this gap, this paper investigates the state of the art on SBMs for the second use of LiBs focusing on repurposing in an ecosystem context.

Methodology

The study applied a literature review covering three main themes: Sustainable business models, ecosystems, and second use EV lithium-ion batteries. The literature search consisted of journal articles, conference papers, research reports and to some extent grey literature like news, press releases and company websites. A database search through Scopus and Google Scholar was conducted followed by snowballing, while Google search was used to search for grey literature. A combination of keywords such as *sustainable business models, circular business models, EV lithium-ion batteries, second life or second use of EV lithium ion batteries, Value chain EV lithium-ion batteries, EV Lithium ion batteries ecosystems, circular ecosystems, reusing and repurposing* was used for the search. Purely techno-economic studies analyzing the technical efficiency of recycling or the life cycle cost effectiveness of the batteries while neglecting the value proposition, stakeholder perspectives, and environmental and social aspects of the business models were not considered. After screening, a total of 28 core articles were selected for review while additional articles were selected through snowballing.

Results

A funnel approach is used to present the interrelationship between the three selected research themes. At first, general concepts related to SBMs and second use EV LiBs are presented, and then these concepts are analyzed in the context of ecosystems.

Sustainable Business Models (SBMs)

The main purpose of a business model is to identify how value is created, delivered, and captured by a business (Johnson et al., 2008; Osterwalder et al., 2010). Until recent times, businesses mostly focused on the economic value, but now sustainability has become an important factor on how they deliver their services (Miller, 2020; Osterwalder & Pigneur, 2010). A BM where sustainability is integrated in the core business activities, and includes pro-active stakeholder engagement is called a sustainable business model (SBM) (Geissdoerfer et al., 2018). SBMs can be viewed from both systems and firm-level perspective while also considering environment and society as stakeholders (N. Bocken, 2021; Boons & Lüdeke-Freund, 2013; Stubbs & Cocklin, 2008). They offer tools that can deliver social and environmental sustainability (Lüdeke-Freund, 2010), and provide sustainable value to stakeholders that are affected by the business (Nosratabadi et al., 2019).

Some of the emerging topics within this field are related to tools and methods such as BM experimentation and SBM archetype strategies that businesses can use to transform their BMs. Other fields include assessment of the impacts of such BMs on the firms, their rebound effects, and extending product lives through BM innovations (N. Bocken et al., 2013; N. Bocken, 2023). For businesses, it is considered essential that new sources of sustainable value are created to attain competitive advantage (Jiao & Evans, 2016a).

Second use of the EV LiBs

An EV LiB consists of multiple modules comprising of battery cells. These modules consist of a specific chemistry, battery management system (BMS), and thermal management system catered to the kind of application they are used for (Saw et al., 2016). When the LiBs reach 70%-80% of their capacity, they are no longer used in EVs. However, multiple studies suggest that these batteries can still be repurposed in less demanding applications for second use (Reinhardt et al., 2019). Ideally, repurposing the batteries to be used in energy storage systems (ESS) is the most sustainable way to prolong the battery life and mitigate environmental negative effects (Bobba et al., 2018; Chirumalla et al., 2022; Islam & Iyer-Raniga, 2022; Jiao & Evans, 2016b; Schulz-Mönninghoff & Evans, 2023). This also delays the recycling phase which is considered inefficient and unsustainable (Golmohammadzadeh et al., 2022). These batteries are mostly used in grid stabilization, residential backup power, load levelling and backup storage systems for the electricity generation grids (Wrålsen & Faessler, 2022).

The spent EV LiBs have to go through disassembly, testing, necessary reparations, battery management system adjustments, reassembly of module and pack, and repackaging for second use application (Reinhardt et al., 2019). The kind of second use application they are used for depends on factors such as state of health (SOH), market conditions, chemistry etc, which are assessed by the battery handler (Ahmadi et al., 2017; Shahjalal et al., 2022; Wrålsen et al., 2021). Monitoring the battery condition and effective data traceability can potentially help in better control of the second use market (Antônio Rufino Júnior et al., 2022).

SBMs in the second use of EV LiBs

Extending product life can contribute towards circularity, and SBMs can play a fundamental role as an enabler (Boons & Lüdeke-Freund, 2013). With an ever increasing market for EVs, the second use LiB market is naturally growing and new business models are emerging (Jiao & Evans, 2016b). Several SBM archetypes have been proposed in the literature based on the environmental, social, and economic aspects (N. Bocken et al., 2014). These archetypes are further used in the context of second use of LiBs that provides an overview of how SBMs are developed in the second use industry (Reinhardt et al., 2020). Three fundamental actors for the EV LiB second use market are proposed in the literature: Automotive original equipment manufacturers (OEMS), intermediaries, and customers, where an intermediary collects, repurposes and sells the second use batteries (Klör et al., 2015), while Bräuer et al (2020) have explored how transactions take place in a second use complex system, as an EV LiB can be traded as it is, or disassembled into components, repurposed and integrated into another system, or its BMS can be reconfigured to be used in another application.

Relatedly, Jiao and Evans (2018b) and Rufino Júnior et al (2023) have proposed three types of SBMs related to EV LiBs: standard, collaborative, and integrated business models. The business model of selling used batteries by the OEMs directly to the battery repurposers is considered as a standard business model, while in a collaborative business model, the OEMs and the battery repurposers collaborate to reach a final solution. This collaboration could be 1) assistive collaboration where OEMs assist battery repurposers, 2) OEMs codevelop the final solution with repurposers, and 3) Repurposers provide solution to the OEMs. While in an integrated business model the ownership is retained by the OEM. Other studies have proposed two types of second use BMs: refurbishing, where the second use batteries are again used in an EV but in another market where short range and low capacity are not a concern and repackaging, where the spent batteries are used in another application (Albertsen et al., 2021; Wrålsen et al., 2021)

The current research points out to several barriers that exist for the EV LiB SBMs. These include but are not limited to financial, technological, market, social, and legislative barriers (Wrålsen et al., 2021). These barriers are further categorized in the table 1:

Category	Barriers	Source
Technological	1. Variable battery design, chemistry, and management system 2. High optimization for first life leads to mismatch for second life. 3. Limited data sharing between OEMs and Repurposers 4. Unclear state of health	(Balasingam et al., 2020; Börner et al., 2022; Montes et al., 2022; Reinhardt et al., 2019)
Market	1. Raw materials supply considerations 2. Price reduction of the new batteries 3. Battery availability (economies of scale) 4. Disassembly and repackaging costs. 5. Unclear value proposition 6. Transportation costs	(Albertsen et al., 2021; Hu et al., 2021; Kumar et al., 2021; Malinauskaite et al., 2021; Rajaeifar et al., 2022)
Social	1. Safety and reliability uncertainty 2. Lack of awareness and information 3. Unclear user incentives	(Börner et al., 2022; Sopha et al., 2022; Wrålsen et al., 2021)
Legislative	1. Policy incentives unclear 2. Lack of legislation	(Lee et al., 2021; Wrålsen et al., 2021; Yang et al., 2021)

Table 1. SBM barriers for second use EV Libs.

EV LiB SBMs in the context of eco-systems

Most of the BM literature is focused on a single firm view around the notion of value generation from a value chain perspective (Kanda et al., 2021). However, this perspective can be limiting as it only considers stakeholders that directly contribute to the production, use, reuse and recycling of the EV LiBs without necessarily taking into account other stakeholders that can directly or indirectly affect this value chain. An ecosystem perspective, on the other hand, provides a much broader systemic perspective considering actors beyond the value chain (Barquete et al., 2022; N. Bocken et al., 2013; Hellström & Wrålsen, 2020; Kapoor, 2018). It is defined as a diverse set of stakeholders interconnected in a complex structure in which both competition and cooperation may exist (Peltoniemi & Vuori, 2008), collectively generating a common output or value proposition (Adner, 2017).

An ecosystem can provide a systemic view of different stakeholders and their interlinked business models interacting with each other to create common value (Fobbe & Hilletofth, 2021; Schiavone et al., 2021; Tsujimoto et al., 2018; Zulkarnain et al., 2014). Mapping the ecosystem can illustrate these interactions and dependencies between the existing stakeholders and their BMs leading to development of new BM designs (N. Bocken et al., 2018; Weiller & Neely, 2013).

Similarly, in the EV LiB ecosystem, several other stakeholders are also considered which are otherwise neglected in a value chain perspective. Hellström and Wrålsen (2020) provide a list of actors in a typical EV LiB repurposing ecosystem. These are shown in the figure 1:

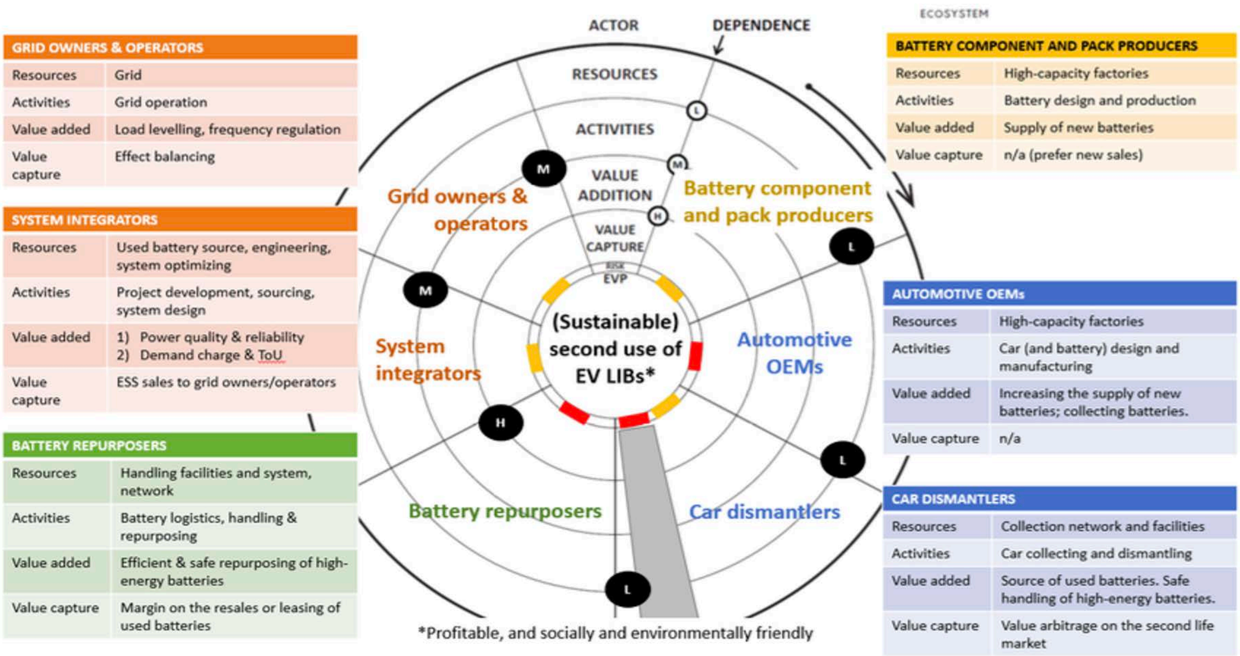

Figure 1. BATMAN IFE Report 2020 Hellström and Wrålsen (2020).

Examples of SBMs in the second use EV LiB ecosystem

A review of grey literature provides an overview of actors and their SBMs currently organized in existing ecosystems, with an emphasis on the European context. This is shown in table 2, and by no means represents all the actors within an ecosystem but only provides examples. These SBM types have been categorized based on the business activities, partnerships, and value being delivered by the actors and are based on the study conducted by Jiao and Evans (2018b). These types can be further categorized into different sub-types of SBMs but it is beyond the scope of this study. Furthermore, in an ecosystem, these SBMs can be interdependent on each other.

Name	Actor	Collaboration Examples	SBM Type	Region	Second Use	Source
Nissan	Automotive OEM	Ecostor + Agder energi + Morrow Batteries + NorskGjenvenning	Collaborative Business Model	Norway	Energy storage system	(*Ecostor*, 2021)
BMW	Automotive OEM	Offgrid Energy	Collaborative Business Model	UK	Mobile Power units / Fast charging	(*BMW Group UK Second-Life Battery Solution in Partnership with Off Grid Energy.*, 2020)
Volkswagen	Automotive OEM	Mostly internal but also some cooperative projects	Integrated Business Model	Germany /Global	Energy Storage System	(*Second life for used batteries*, 2019)
Renault	Automotive OEM	Connected Energy	Collaborative Business Model	UK	Energy Storage system	(*A Second Life for Batteries*, 2020)
Mercedes	Automotive OEM	Batteryloop	Collaborative Business Model	Sweden	Energy Storage System	(Randall, 2022)
4R Energy Corp	Automotive OEM	Joint venture by Nissan and Sumitomo corp	Integrated Business Model	Japan	Energy Storage / Fast Charging	(*Nissan Gives EV Batteries a Second Life*, 2021)
Grønvold's Bil Demontering AS	Car Dismantler	Partnership with insurance companies	Standard Business Model	Norway	Sell to Repurposers	("Gbd.No," n.d.)
Betteries	Repurposer	Example: Partnership with Mobilize	Collaborative /standard Business Model	Germany	Modular solutions for energy storage	(Hoenig, 2021)
Statnett	Grid Owner/ Operator	Norwegian State owned	Standard Business Model	Norway	-	(*statnett*, 2023)

Table 2. SBM types in 2nd use EV LiB ecosystem.

Discussion and Conclusions

Extending the lifetime of products is one of the fundamental requirements to build circularity (N. M. P. Bocken et al., 2016; *The Circularity Gap Report*, 2022). This is also considered an important step towards a more sustainable electrification of the transport sector. Extending life span of the LiBs after their life in the EVs has thus become an emerging research topic. Several studies suggest that repurposing EV LiBs into second use in less demanding energy storage applications can extract the residual value of the spent batteries and provide economic, environmental, and social benefits (Reinhardt et al., 2019; Wrålsen et al., 2021). SBMs and business model innovations are considered to play a pivotal role in making repurposing of EV LiBs viable. However, until now, the prospects of adaption of second use batteries have not been optimistic because of the various SBM barriers mentioned in the literature including technical, market, legislative, and social barriers.

SBM perspective in the second use of EV LiBs has only recently started to gain attention from the researchers and industry (Jiao & Evans, 2018b). Several authors have proposed different business model typologies and archetypes which can be used in the second use of EV LiBs (Jiao & Evans, 2016a) but the experimentation of these BMs in real life has been limited. An interesting point for discussion is whether the existing knowledge of SBMs and the associated use cases in the research can be applied to the second use EV LiB industry or if the second use EV LiB is fundamentally different from other cases.

Several circular economy studies indicate that companies cannot be seen as isolated entities, and there is a need to understand the value networks which they are a part of in larger ecosystems (Barquete et al., 2022). There has also been a growing interest in the BM literature to have a more systemic view (N. Bocken et al., 2013). However, the research so far has mostly focused on the value chain perspectives of the LiB second use, neglecting the broader ecosystem of which the EV LiB value chain is a part of. Mainly, the discussion about policy makers, competitors, users and indirect stakeholders (non-governmental organizations etc), and their influence on the stakeholders' BMs in an ecosystem context has been missing. These stakeholders can positively, negatively, or symbiotically affect business models in the value chain of the EV LiB. For example, the business model of a second-life batteries storage facility can be affected if the business model of an OEM changes. Moreover, both businesses may have to innovate their business models if there is a shift in the policy of the local government where they operate.

However, how can multiple stakeholders within this ecosystem innovate their BMs to become more sustainable is yet to be explored. Therefore, this study aims to contribute to an established field of circular economy research by synergizing SBM, Ecosystems, and Second use EV LiB literature. Further research in this area and a comprehensive analysis of the second use EV LiB ecosystem can contribute to understanding the BM innovations taking place because of the BM interactions between the stakeholders and pave way for adaption of second use EV LiBs.

References

Adner, R. (2017). Ecosystem as Structure: An Actionable Construct for Strategy. Journal of Management, 43(1), 39–58. https://doi.org/10.1177/0149206316678451

Ahmadi, L., Young, S. B., Fowler, M., Fraser, R. A., & Achachlouei, M. A. (2017). A cascaded life cycle: Reuse of electric vehicle lithium-ion battery packs in energy storage systems. International Journal of Life Cycle Assessment, 22(1), 111–124. Scopus. https://doi.org/10.1007/s11367-015-0959-7

Albertsen, L., Richter, J. L., Peck, P., Dalhammar, C., & Plepys, A. (2021). Circular business models for electric vehicle lithium-ion batteries: An analysis of current practices of vehicle manufacturers and policies in the EU. Resources, Conservation and Recycling, 172, 105658. https://doi.org/10.1016/j.resconrec.2021.105658

Antônio Rufino Júnior, C., Sanseverino, E. R., Gallo, P., Koch, D., Schweiger, H.-G., & Zanin, H. (2022). Blockchain review for battery supply chain monitoring and battery trading. Renewable and Sustainable Energy Reviews, 157, 112078. https://doi.org/10.1016/j.rser.2022.112078

Balasingam, B., Ahmed, M., & Pattipati, K. (2020). Battery Management Systems—Challenges and Some Solutions. Energies, 13(11), Article 11. https://doi.org/10.3390/en13112825

Barquete, S., Shimozono, A. H., Trevisan, A. H., Castro, C. G., Gomes, L. A. de V., & Mascarenhas, J. (2022). Exploring the Dynamic of a Circular Ecosystem: A Case Study about Drivers and Barriers. Sustainability, 14(13), Article 13. https://doi.org/10.3390/su14137875

BMW Group UK second-life battery solution in partnership with Off Grid Energy. (2020). https://www.press.bmwgroup.com/united-kingdom/article/detail/T0318650EN_GB/bmw-group-uk-second-life-battery-solution-in-partnership-with-off-grid-energy?language=en_GB

Bobba, S., Mathieux, F., Ardente, F., Blengini, G. A., Cusenza, M. A., Podias, A., & Pfrang, A. (2018). Life Cycle Assessment of repurposed electric vehicle batteries: An adapted method based on modelling energy flows. Journal of Energy Storage, 19, 213–225. https://doi.org/10.1016/j.est.2018.07.008

Bocken, N. (2021). Sustainable Business Models (pp. 963–975). https://doi.org/10.1007/978-3-319-95867-5_48

Bocken, N. (2023). Business models for Sustainability.

Bocken, N., Boons, F., & Baldassarre, B. (2018). Sustainable business model experimentation by understanding ecologies of business models. Journal of Cleaner Production, 208C, 1498–1512. https://doi.org/10.1016/j.jclepro.2018.10.159

Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. Journal of Industrial and Production Engineering, 33(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Bocken, N., Short, S., Rana, P., & Evans, S. (2013). A value mapping tool for sustainable business modelling. Corporate Governance International Journal of Business in Society, 13, 482–497. https://doi.org/10.1108/CG-06-2013-0078

Bocken, N., Short, S. W., Rana, P., & Evans, S. (2014). A literature and practice review to develop sustainable business model archetypes. Journal of Cleaner Production, 65, 42–56. https://doi.org/10.1016/j.jclepro.2013.11.039

Bocken, N., Weissbrod, I., & Tennant, M. (2016). Business Model Experimentation for Sustainability (pp. 297–306). https://doi.org/10.1007/978-3-319-32098-4_26

Boons, F., & Lüdeke-Freund, F. (2013). Business Models for Sustainable Innovation: State of the Art and Steps Towards a Research Agenda. Journal of Cleaner Production, 45, 9–19. https://doi.org/10.1016/j.jclepro.2012.07.007

Börner, M. F., Frieges, M. H., Späth, B., Spütz, K., Heimes, H. H., Sauer, D. U., & Li, W. (2022). Challenges of second-life concepts for retired electric vehicle batteries. Cell Reports Physical Science, 3(10), 101095. https://doi.org/10.1016/j.xcrp.2022.101095

Bräuer, S., Plenter, F., Klör, B., Monhof, M., Beverungen, D., & Becker, J. (2020). Transactions for trading used electric vehicle batteries: Theoretical underpinning and information systems design principles. Business Research, 13(1), 311–342. https://doi.org/10.1007/s40685-019-0091-9

Building a circular battery economy in Norway. (2021, February 22). https://www.theexplorer.no/stories/energy/building-a-circular-battery-economy-in-norway

Chen, M., Ma, X., Chen, B., Arsenault, R., Karlson, P., Simon, N., & Wang, Y. (2019). Recycling End-of-Life Electric Vehicle Lithium-Ion Batteries. Joule, 3(11), 2622–2646. https://doi.org/10.1016/j.joule.2019.09.014

Cheng, M., Sun, H., Wei, G., Zhou, G., & Zhang, X. (2022). A sustainable framework for the second-life battery ecosystem based on blockchain. ETransportation, 14, 100206. https://doi.org/10.1016/j.etran.2022.100206

Chirumalla, K., Reyes, L. G., & Toorajipour, R. (2022). Mapping a circular business opportunity in electric vehicle battery value chain: A multi-stakeholder framework to create a win–win–win situation. Journal of Business Research, 145, 569–582. https://doi.org/10.1016/j.jbusres.2022.02.070

Ecostor. (2021). https://www.eco-stor.com/news/nissan-eco-stor-norsk-gjenvinning-and-agder-energi-signs-mou-around-re-use-of-ev-batteries

Evans, S., Vladimirova, D., Holgado, M., Van Fossen, K., Yang, M., Silva, E. A., & Barlow, C. Y. (2017). Business Model Innovation for Sustainability: Towards a Unified Perspective for Creation of Sustainable Business Models. Business Strategy and the Environment, 26(5), 597–608. https://doi.org/10.1002/bse.1939

Fobbe, L., & Hilletofth, P. (2021). The role of stakeholder interaction in sustainable business models. A systematic literature review. Journal of Cleaner Production, 327, 129510. https://doi.org/10.1016/j.jclepro.2021.129510

Gbd.no. (n.d.). GBD. Retrieved March 21, 2023, from https://gbd.no/en/utvalgte-deler/batteripakke-elbil/

Geissdoerfer, M., Morioka, S., Carvalho, M., & Evans, S. (2018). Business models and supply chains for the circular economy. Journal of Cleaner Production, 190. https://doi.org/10.1016/j.jclepro.2018.04.159

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? Journal of Cleaner Production, 143, 757–768. Scopus. https://doi.org/10.1016/j.jclepro.2016.12.048

Golmohammadzadeh, R., Faraji, F., Jong, B., Pozo-Gonzalo, C., & Banerjee, P. C. (2022). Current challenges and future opportunities toward recycling of spent lithium-ion batteries. Renewable and Sustainable Energy Reviews, 159, 112202. https://doi.org/10.1016/j.rser.2022.112202

Heelan, J., Gratz, E., Zheng, Z., Wang, Q., Chen, M., Apelian, D., & Wang, Y. (2016). Current and Prospective Li-Ion Battery Recycling and Recovery Processes. JOM, 68(10), 2632–2638. Scopus. https://doi.org/10.1007/s11837-016-1994-y

Hellström, M., & Wrålsen, B. (2020). Modelling Business Ecosystems for spent Lithium ion batteries. https://ife.no/wp-content/uploads/2023/02/modeling-business-ecosystems-for-libs-batman-external-report-2020.pdf

Hoenig, R. (2021, June 16). Betteries secures industrial partnership with Mobilize. Betteries. https://betteries.com/partnership-with-mobilize/

Hu, X., Wang, C., Zhu, X., Yao, C., & Ghadimi, P. (2021). Trade structure and risk transmission in the international automotive Li-ion batteries trade. Resources, Conservation and Recycling, 170, 105591. https://doi.org/10.1016/j.resconrec.2021.105591

IEA. (2022). Global electric car sales have continued their strong growth in 2022 after breaking records last year—News. IEA. https://www.iea.org/news/global-electric-car-sales-have-continued-their-strong-growth-in-2022-after-breaking-records-last-year

Islam, M. T., & Iyer-Raniga, U. (2022). Lithium-Ion Battery Recycling in the Circular Economy: A Review. Recycling, 7(3), Article 3. https://doi.org/10.3390/recycling7030033

Jiao, N., & Evans, S. (2016a). Business Models for Sustainability: The Case of Second-life Electric Vehicle Batteries. Procedia CIRP, 40, 250–255. https://doi.org/10.1016/j.procir.2016.01.114

Jiao, N., & Evans, S. (2016b). Secondary use of Electric Vehicle Batteries and Potential Impacts on Business Models. Journal of Industrial and Production Engineering, 33(5), 348–354. https://doi.org/10.1080/21681015.2016.1172125

Jiao, N., & Evans, S. (2018a). Business Models for Repurposing a Second-Life for Retired Electric Vehicle Batteries. In G. Pistoia & B. Liaw (Eds.), Behaviour of Lithium-Ion Batteries in Electric Vehicles: Battery Health, Performance, Safety, and Cost (pp. 323–344). Springer International Publishing. https://doi.org/10.1007/978-3-319-69950-9_13

Jiao, N., & Evans, S. (2018b). Business Models for Repurposing a Second-Life for Retired Electric Vehicle Batteries. In G. Pistoia & B. Liaw (Eds.), Behaviour of Lithium-Ion Batteries in Electric Vehicles: Battery Health, Performance, Safety, and Cost (pp. 323–344). Springer International Publishing. https://doi.org/10.1007/978-3-319-69950-9_13

Johnson, M. W., Christensen, C. M., & Kagermann, H. (2008, December 1). Reinventing Your Business Model. Harvard Business Review. https://hbr.org/2008/12/reinventing-your-business-model

Kanda, W., Geissdoerfer, M., & Hjelm, O. (2021). From circular business models to circular business ecosystems. Business Strategy and the Environment, 30(6), 2814–2829. https://doi.org/10.1002/bse.2895

Kapoor, R. (2018). Ecosystems: Broadening the locus of value creation. Journal of Organization Design, 7(1), 12. https://doi.org/10.1186/s41469-018-0035-4

Kim, S., Bang, J., Yoo, J., Shin, Y., Bae, J., Jeong, J., Kim, K., Dong, P., & Kwon, K. (2021). A comprehensive review on the pretreatment process in lithium-ion battery recycling. Journal of Cleaner Production, 294, 126329. https://doi.org/10.1016/j.jclepro.2021.126329

Klör, B., Beverungen, D., Bräuer, S., Plenter, F., & Monhof, M. (2015). A Market for Trading Used Electric Vehicle Batteries—Theoretical Foundations and Information Systems.

Kumar, P., Singh, R. K., Paul, J., & Sinha, O. (2021). Analyzing challenges for sustainable supply chain of electric vehicle batteries using a hybrid approach of Delphi and Best-Worst Method. Resources, Conservation and Recycling, 175, 105879. https://doi.org/10.1016/j.resconrec.2021.105879

Lee, J. W., Haram, M. H. S. M., Ramasamy, G., Thiagarajah, S. P., Ngu, E. E., & Lee, Y. H. (2021). Technical feasibility and economics of repurposed electric vehicles batteries for power peak shaving. Journal of Energy Storage, 40, 102752. https://doi.org/10.1016/j.est.2021.102752

Lüdeke-Freund, F. (2010, September 19). Towards a Conceptual Framework of “Business Models for Sustainability.” https://doi.org/10.13140/RG.2.1.2565.0324

Lüdeke-Freund, F. (2020). Sustainable entrepreneurship, innovation, and business models: Integrative framework and propositions for future research. Business Strategy and the Environment, 29(2), 665–681. https://doi.org/10.1002/bse.2396

Malinauskaite, J., Anguilano, L., & Rivera, X. S. (2021). Circular waste management of electric vehicle batteries: Legal and technical perspectives from the EU and the UK post Brexit. International Journal of Thermofluids, 10, 100078. https://doi.org/10.1016/j.ijft.2021.100078

Miller, K. (2020, December 8). The Triple Bottom Line: What It Is & Why It’s Important. Business Insights Blog. https://online.hbs.edu/blog/post/what-is-the-triple-bottom-line

Montes, T., Etxandi-Santolaya, M., Eichman, J., Ferreira, V. J., Trilla, L., & Corchero, C. (2022). Procedure for Assessing the Suitability of Battery Second Life Applications after EV First Life. Batteries, 8(9), Article 9. https://doi.org/10.3390/batteries8090122

Murray, A., Skene, K., & Haynes, K. (2017). The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. Journal of Business Ethics, 140(3), 369–380. https://doi.org/10.1007/s10551-015-2693-2

Nissan gives EV batteries a second life. (2021, January 27). Nissan Gives EV Batteries a Second Life. https://global.nissanstories.com/en/releases/4r

Nosratabadi, S., Mosavi, A., Shamshirband, S., Kazimieras Zavadskas, E., Rakotonirainy, A., & Chau, K. W. (2019). Sustainable Business Models: A Review. Sustainability, 11(6), Article 6. https://doi.org/10.3390/su11061663

Osterwalder, A., & Pigneur, Y. (2010). Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers. OSF.

Osterwalder, A., Pigneur, Y., & Tucci, C. (2010). Clarifying Business Models: Origins, Present, and Future of the Concept. Communications of AIS, 16. https://doi.org/10.17705/1CAIS.01601

Peltoniemi, M., & Vuori, E. (2008). Business Ecosystem as the New Approach to Complex Adaptive Business Environments. Proceedings of EBusiness Research Forum.

Rajaeifar, M. A., Ghadimi, P., Raugei, M., Wu, Y., & Heidrich, O. (2022). Challenges and recent developments in supply and value chains of electric vehicle batteries: A sustainability perspective. Resources, Conservation and Recycling, 180, 106144. https://doi.org/10.1016/j.resconrec.2021.106144

Randall, C. (2022). Batteryloop to give Mercedes batteries a second life—Electrive.com. Https://Www.Electrive.Com/. https://www.electrive.com/2022/09/15/batteryloop-to-build-three-stationary-batteries-from-old-mercedes-batteries/

Reinhardt, R., Christodoulou, I., García, B. A., & Gassó-Domingo, S. (2020). Sustainable business model archetypes for the electric vehicle battery second use industry: Towards a conceptual framework. Journal of Cleaner Production, 254, 119994. https://doi.org/10.1016/j.jclepro.2020.119994

Reinhardt, R., Christodoulou, I., Gassó-Domingo, S., & Amante García, B. (2019). Towards sustainable business models for electric vehicle battery second use: A critical review. Journal of Environmental Management, 245, 432–446. Scopus. https://doi.org/10.1016/j.jenvman.2019.05.095

Rufino Júnior, C. A., Riva Sanseverino, E., Gallo, P., Koch, D., Kotak, Y., Schweiger, H.-G., & Zanin, H. (2023). Towards a business model for second-life batteries – barriers, opportunities, uncertainties, and technologies. Journal of Energy Chemistry, 78, 507–525. https://doi.org/10.1016/j.jechem.2022.12.019

Saw, L. H., Ye, Y., & Tay, A. A. O. (2016). Integration issues of lithium-ion battery into electric vehicles battery pack. Journal of Cleaner Production, 113, 1032–1045. https://doi.org/10.1016/j.jclepro.2015.11.011

Schiavone, F., Mancini, D., Leone, D., & Lavorato, D. (2021). Digital business models and ridesharing for value co-creation in healthcare: A **multi**-stakeholder ecosystem analysis. Technological Forecasting and Social Change, 166, 120647. https://doi.org/10.1016/j.techfore.2021.120647

Schulz-Mönninghoff, M., & Evans, S. (2023). Key tasks for ensuring economic viability of circular projects: Learnings from a real-world project on repurposing electric vehicle batteries. Sustainable Production and Consumption, 35, 559–575. Scopus. https://doi.org/10.1016/j.spc.2022.11.025

Second life for used batteries. (2019). https://www.volkswagen.is/is/um-volkswagen/timarit/second-life-for-used-batteries.html

Shahjalal, M., Roy, P. K., Shams, T., Fly, A., Chowdhury, J. I., Ahmed, Md. R., & Liu, K. (2022). A review on second-life of Li-ion batteries: Prospects, challenges, and issues. Energy, 241, 122881. https://doi.org/10.1016/j.energy.2021.122881

Sopha, B. M., Purnamasari, D. M., & Ma'mun, S. (2022). Barriers and Enablers of Circular Economy Implementation for Electric-Vehicle Batteries: From Systematic Literature Review to Conceptual Framework. Sustainability, 14(10), Article 10. https://doi.org/10.3390/su14106359

Statnett. (2023, March 23). Statnett. https://www.statnett.no/

Stubbs, W., & Cocklin, C. (2008). Conceptualizing a "Sustainability Business Model." Organization & Environment, 21(2), 103–127. https://doi.org/10.1177/1086026608318042

The Circularity Gap Report (pp. 16–17). (2022). Circle Economy.

Tsujimoto, M., Kajikawa, Y., Tomita, J., & Matsumoto, Y. (2018). A review of the ecosystem concept—Towards coherent ecosystem design. Technological Forecasting and Social Change, 136, 49–58. https://doi.org/10.1016/j.techfore.2017.06.032

Weiller, C., & Neely, A. (2013). Business Model Design in an Ecosystem Context. University of Cambridge, 22.

Winslow, K. M., Laux, S. J., & Townsend, T. G. (2018). A review on the growing concern and potential management strategies of waste lithium-ion batteries. Resources, Conservation and Recycling, 129, 263–277. https://doi.org/10.1016/j.resconrec.2017.11.001

Wrålsen, B., & Faessler, B. (2022). Multiple Scenario Analysis of Battery Energy Storage System Investment: Measuring Economic and Circular Viability. Batteries, 8(2), Article 2. https://doi.org/10.3390/batteries8020007

Wrålsen, B., Prieto-Sandoval, V., Mejia-Villa, A., O'Born, R., Hellström, M., & Faessler, B. (2021). Circular business models for lithium-ion batteries—Stakeholders, barriers, and drivers. Journal of Cleaner Production, 317, 128393. https://doi.org/10.1016/j.jclepro.2021.128393

Yang, Y., Okonkwo, E. G., Huang, G., Xu, S., Sun, W., & He, Y. (2021). On the sustainability of lithium ion battery industry – A review and perspective. Energy Storage Materials, 36, 186–212. https://doi.org/10.1016/j.ensm.2020.12.019

Zulkarnain, Z., Leviäkangas, P., Kinnunen, T., & Kess, P. (2014). The Electric Vehicles Ecosystem Model—Construct, Analysis and Identification of Key Challenges. Managing Global Transitions, 12, 253–277.

5th PLATE 2023 Conference
Espoo, Finland - 31 May - 2 June 2023

Deducing environmental implication of clothing rental from consumer voices and behaviors: a social experiment in Japan

Eri Amasawa[(a,b)] and Koji Kimita[(c)]
a) Department of Chemical System Engineering, The University of Tokyo, Tokyo, Japan
b) Research Center for Advanced Science and Technology, The University of Tokyo, Tokyo, Japan
c) Department of Technology Management for Innovation, The University of Tokyo, Tokyo, Japan

Keywords: Sustainable fashion; Consumer behavior experiment; Subscription service; Access-based economy; Consumer perception.

Abstract: Fashion rentals of casual to office wears present a particularly interesting business model for sustainability through mitigating personal clothing consumption. While environmental impact mitigation is theoretically possible, past studies have shown that several consumer behavior conditions exist to capture the environmental benefit. Among the conditions, changes in consumer behavior and perception using fashion rental services are found to be the critical factors. To examine the changes in consumer behavior brought by the fashion rental services and deduce their environmental implication, we performed a consumer behavior experiment where 22 participants used a fashion rental subscription service for three months in Japan. The experiment data were analyzed qualitatively and quantitatively for the changes in absolute volume of consumptions (i.e., clothing purchases) and garment wear intensity (i.e., weartime per garment). The results suggested that absolute reduction of garment consumption was limited quantitatively, but we found garments may be purchased more selectively through interviews. The intensifying use was observed for skirts and dresses, implying rentals may be effective for a specific category of garments.

Introduction

Today, fashion has become an infamous example of a global environmental problem, where mass production, mass consumption, and mass disposal continue to persist. One estimates that clothing production volume has doubled in the past twenty years while the lifetime wears have halved (Ellen MacArthur Foundation, 2017).

To reduce the environmental impact led by the current consumption patterns of garments, fashion rental services have been attracting attention. Rental services offer a consumption pattern alternative to purchasing of goods, which could reduce the material demand in the society while meeting consumer needs. Among them, fashion rentals of casual to office wears present a particularly interesting business model for sustainability (Amasawa et al., 2023; Piontek et al., 2020; Zamani et al., 2017). Unlike occasion wear rentals that are rented for a short-term, most casual wear fashion rentals adopt a subscription model, where customers access a specific number of garments in a month. Additionally, while the garment rented in occasion wear rentals are generally worn only once during its rental period, the nature of casual wears provides an extended opportunity to wear the rented clothing, which could increase the lifetime wear and reduce clothing purchases. As a result, fashion rental services of casual wears could reduce the environmental impact through mitigating personal clothing consumptions.

While the environmental impact mitigation is theoretically possible, past studies have shown that several consumer behavior conditions exist to capture the environmental benefit. For example, Piontek et al. (2020) stated that clothing rentals need to avoid consumption of new infrequently worn garments through their life cycle assessment study on fashion rental services in Germany and Japan. Johnson and Plepys (2021) also showed a resembling conclusion that rentals need to increase the wear time and consumers need to use rentals to substitute their purchasing. In other words, the environmental implication of fashion rental services is decisively influenced by the consumer behavior in fashion rentals. Consumers of fashion rental services have been investigated for their motivations for the service use (Camacho-Otero et al., 2019) but the changes in consumer behavior and perception using fashion rental services are yet to be understood.

To examine the changes in consumer behavior brought by the fashion rental services and deduce their environmental implication, we conducted a consumer behavior experiment. The experiment asked participants to use a fashion rental subscription service for three months in Japan. This paper presents the overview of the experiment and the results obtained up to today.

Method

This research collected qualitative and quantitative data on clothing consumptions through an experimental use of clothing rentals. The collected data were analyzed for consumer behavior conditions that directly relate to the environmental impact.

Social experiment overview

The consumer behavior experiment recruited 22 female participants in Japan by word-of-mouth method. The participants were asked to use a fashion rental subscription service that rents casual to office attires for three months. The fashion rental service allows subscribers to borrow three garment pieces selected by stylists each month. The garments were always rented out as a set of three types: tops, bottoms (skirts or pants), and dresses. The subscribers must return the set of three pieces to exchange for the new garments. We used a subscription membership with unlimited exchanges, which allows participants to freely exchange garments. The experiment took place in October 2022 to mid-January 2023.

The experimental design applied One Group Pre-Test-Post-Test from Pre-Experimental method (Malhotra, 2007). The data collection process contains in-depth interviews performed before and after the experiment, and a monthly survey. The in-depth interviews aimed to understand the consumer attitudes and perceptions on their clothing consumption. The monthly survey asks for the number of garments they rented, the number of wears for each garment, the level of satisfaction on the rented garment, and garment purchases during the experiment period.

Analysis method

The environmental impact from clothing consumptions were implicitly analyzed by examining the following two aspects:

a) *Absolute reduction of consumption*: whether the clothing rental replaced purchasing to reduce the overall clothing purchases.
b) *Intensifying use*: whether the clothing rental increased the lifetime wear of the garment relative to when owning the garment

The survey data was first analyzed quantitatively for the two aspects. The qualitative data was then used to understand the consumer motivations and factors influencing the quantitative results.

Results and Discussions

Participants' basic information

The participants' age ranged between 20s to 50s, where 60% of them were 20s and 30s. All participants except one were all employed. Among them, 30% have considered using a fashion rental service, and half of them were unaware of their existence. Table 1 shows the consumer characteristics of the participants based on a categorization from a literature (Johnson & Plepys, 2021). From the study by Johnson and Plepys (2021), consumers categorized in *Stand-out* and *Eco-friendly* were likely to replace dress rentals with a purchase, which would satisfy the aspect a) absolute reduction. Our participants largely fell into *Influencer* or *Avoid* category, which suggested that environmental benefit from using clothing rentals may be limited.

Consumer type (Johnson & Plepys, 2021)	**Characteristics**	**Number of participants**
Stand-out	Buys unique clothing	2
Bargain	Buys cheaper alternatives	4
Influencer	Buys latest styles	7
Avoid	Buys only when needed	9
Eco-friendly	Buys sustainable alternatives	0
Fitting-in	Buys similar styles to friends	0

Table 1 Consumer type of the participants.

Clothing consumption trends

We found that 80% of the rentals were returned within 14 days, and 25% of the rentals were returned within less than 4 days, which indicates that some rentals had a short rental cycle with a limited opportunity to be worn. When we analyzed the number of garment pieces rented by each participant, the average was 6 pieces per month, which equates to 2 rentals. We also found that only 60% of the rented garments were actually worn; thus, whether the rented garments match the user's style preference decisively influence the environmental impact on personal clothing consumption.

When the garment purchase behavior was analyzed, participating in the rental service appeared to have limited influence. The total number of garment purchases by the participants ranged between 20 to 33 pieces whereas the monthly average prior to the experiment was around 37 pieces. One reason for the consistent garment purchasing behavior is the seasonality. January has new year sales, which stimulates purchase motivation. Another interesting find was some participants purchased the rented garments. Several participants also noted that they wanted to buy the rented garment, but the price was considered expensive, so they purchased an alternative with a similar style. Thus, clothing rentals have encouraged users to purchase garments to certain extent.

Additionally, when the weartime of the rented garments was analyzed and compared against the average weartime for purchased garments from our past study (Amasawa et al., 2022), the weartime increase from purchased to rentals was only observed with skirts and dresses. In other words, skirts and dresses were able to intensify its use through rentals, but pants and tops were not. Because skirts and dresses are garment category which of its design is likely to be more influenced by trends, which may have led to increase in weartime when rented.

Consumer voices

Table 2 shows excerpts of the Post-experiment interview results categorized by the factors influencing the two aspects for environmental impact reduction. Based on the results, clothing rentals may be effective in reducing clothing purchases through satisfying the consumer wants for "a new piece." Another interesting consequence of clothing rentals was gaining a deeper understanding in the personal styles. Through the opportunity to try out diverse garment styles, many participants noted that they were able to define their personal styles better than before. As a result, the participants became more selective when purchasing garments, which consequentially would help to prolong the garment lifetime and increase weartime of the garments.

	Positive influence	Negative influence
a) Absolute reduction	- Less impulsive shopping - Better understanding in my personal style	- Encouraged shopping because rented garments were unsatisfactory
b) Intensi-fying use	- Learned the importance of trying out before the purchase - Began wearing clothes that were not worn frequently	- Short rental periods to try out many styles - Returned the rentals quickly because the rental garments were unsatisfactory

Table 2 Consumer voices related to clothing consumption.

Conclusions

Our social experiment on clothing rentals suggested that absolute reduction of garment consumption was limited quantitatively, but we found that participants may have become a more selective shopper through interviews. The intensifying use was observed for skirts and dresses, implying rentals may be effective for a specific category of garments. Further analysis, especially on qualitative data, is needed to understand the motivation of consumer behavior.

Acknowledgments

This research has been supported by JSPS KAKENHI Grant Number 18K18232 and 20K12082, as well as the Environment Research and Technology Development Fund (JPMEERF20223R04) of the Environmental Restoration and Conservation Agency of Japan.

References

Amasawa, E., Brydges, T., Henninger, C. E., & Kimita, K. (2023). Can rental platforms contribute to more sustainable fashion consumption? Evidence from a mixed-method study. Cleaner and Responsible Consumption, 100103. https://doi.org/10.1016/j.clrc.2023.100103

Amasawa, E., Yoshida, T., Kimita, K., & Hirao, M. (2022). Designing sustainable fashion rentals based on environmental benefit and consumer preference. Conference Proceeding of the 15th Biennial International Conference on EcoBalance (EcoBalance2022).

Camacho-Otero, J., Boks, C., & Pettersen, I. N. (2019). User acceptance and adoption of circular offerings in the fashion sector: Insights from user-generated online reviews. Journal of Cleaner Production, 231, 928–939. https://doi.org/10.1016/j.jclepro.2019.05.162

Ellen MacArthur Foundation. (2017). A New Textiles Economy: Redesigning fashion's future.

Johnson, E., & Plepys, A. (2021). Product-service systems and sustainability: Analysing the environmental impacts of rental clothing. Sustainability (Switzerland), 13(4), 1–30. https://doi.org/10.3390/su13042118

Malhotra, N. K. (2007). Marketing Research: An Applied Orientation (5th ed.). Pearson Education Inc.

Piontek, F. M., Amasawa, E., & Kimita, K. (2020). Environmental implication of casual wear rental services: Case of Japan and Germany. Procedia CIRP, 90, 724–729. https://doi.org/10.1016/j.procir.2020.01.076

Zamani, B., Sandin, G., & Peters, G. M. (2017). Life cycle assessment of clothing libraries: can collaborative consumption reduce the environmental impact of fast fashion? Journal of Cleaner Production, 162, 1368–1375. https://doi.org/10.1016/j.jclepro.2017.06.128