Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 109 (2022) 107–112

www.elsevier.com/locate/procedia

32nd CIRP Design Conference

Exploring the applicability of circular design criteria for electric vehicle batteries

Aitor Picatoste[a,*], Daniel Justel[a], Joan Manuel F. Mendoza[a,b,*]

[a]Mondragon Unibertsitatea, Faculty of Engineering, Mechanics and Industrial Production, Loramendi 4, Mondragon 20500 Gipuzkoa, Spain
[b]IKERBASQUE, Basque Foundation for Science, Plaza Euskadi 5, Bilbao 48009 Bizkaia, Spain

* Corresponding authors: apicatoste@mondragon.edu, jmfernandez@mondragon.edu

Abstract

Battery electric vehicles (BEVs) represent a promising solution to mitigate carbon emissions by road transportation. However, life cycle assessment (LCA) studies on BEVs have demonstrated that batteries are responsible for around 30% of the vehicle's environmental impacts. Therefore, the integration of circular economy (CE) criteria in battery design and life cycle management is key to improve resource efficiency and environmental sustainability. Nevertheless, literature analysing the implementation of CE design criteria in BEVs´ battery development is scarce. Focusing on Li-ion batteries (LIB) for BEVs, this paper examines the potential for implementation of life cycle-based CE design criteria. Accordingly, a CE design assessment tool, including a list of 53 relevant design criteria gathered from the literature, industrial practice and EU legislation, with application to BEVs´ batteries, was shared with industrial stakeholders from the H2020 LIBERTY project (LC-BAT-10-2020 No. 963522) to receive feedback. The industrial stakeholders were asked to evaluate the potential implementation of each CE design criteria based on the relationship between importance and viability by providing scores from 0% to 94%.The results indicate that the most important CE design criteria are related to the manufacturing stage of LIBs, including innovations oriented to increase the performance and quality of the final product by anticipating to new legislation requirements, including resource and environmental aspects, for BEVs. On the other hand, design criteria related to the end of life (EOL) management of LIBs show low implementation potential due to low viability scores. The benefits of considering CE design criteria in LIB development are discussed as well as the potential trade-offs in order to support well-informed decision-making. This includes an analysis of the causes for the low score for some CE design criteria and the opportunities to improve their implementation potential to increase the resource efficiency and environmental performance of BEVs´ LIBs.

Keywords: Circular economy; eco-design; design for sustainability; design for circularity; battery electric vehicle; electromobility

1. Introduction

Battery electric vehicles (BEVs) represent a cleaner alternative to petrol-fueled vehicles. However, BEVs are not exempt from environmental impacts when they are analyzed from a life cycle perspective [1]. Battery manufacturing and vehicle operation highly determine up to 80% of the environmental impacts of BEVs [2].Likewise, batteries determine 20% of the total weight of BEVs [3]. Moreover, with the widespread use of lithium-ion batteries (LIBs) in BEVs, the importance of resource consumption is growing as key materials used in batteries, such as Manganese or Cobalt are critical for the EU [4]. Therefore, much of the resource decoupling and potential environmental improvement for BEVs

10.1016/j.procir.2022.05.222

relies on the battery design and development, as it is acknowledged that the design stage determines about 80% of the products life cycle environmental impacts [5].

A circular economy (CE) aims to narrowing, slowing and closing resource loops to minimize energy and materials consumption, and negative impacts over time [6]. Thus, CE thinking is relevant for implementation in battery design and development to ensure higher resource efficiency and environmental sustainability. Nevertheless, research on the implementation of circular design criteria for the development of BEVs batteries, from the viewpoint of industrial producers, is scarce. The design improvement of BEV batteries to achieve optimal environmental performance has not been yet comprehensibly addressed in the literature [7]. Accordingly, this work examines the implementation potential of life cycle-based CE design criteria in the development of LIBs for BEVs, based on the perspectives of key industrial stakeholders from the H2020 LIBERTY project, which has the goal of upgrading EV battery performance, safety and lifetime from a lifecycle and sustainability point of view [8].

Nomenclature

BEV	Battery electric vehicle
CBM	Circular business model
CE	Circular Economy
DfX	Design for excellence
EOL	End of life
ICT	Information and communication technologies
IoT	Internet of things
LCA	Life cycle assessment
LIB	Lithium-ion battery

2. Materials and methods

A methodology comprised of four steps was applied (Figure 1). First, a CE design assessment tool was selected and adapted for application to BEVs. Second, relevant industrial stakeholders were engaged for the evaluation of the potential implementation of the CE design criteria. Afterwards, CE design criteria was categorised based on implementation priority according to the relationship between importance and viability. Finally, the potential benefits and trade-offs of implementing each CE design criteria were discussed.

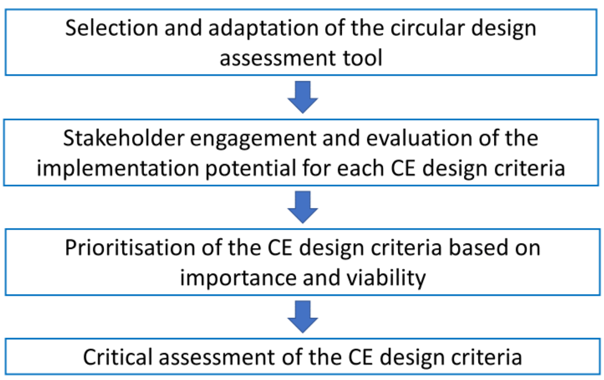

Fig. 1. Methodological steps.

2.1. Selection and adaptation of the CE design assessment tool

The CE design assessment tool developed by CIRCit [9] was selected as baseline to perform the research. This tool lists 28 circularity design criteria [10] and proposes a comprehensive two-way evaluation process based on the importance of each criteria for the product and the level of fulfilment of the criteria for each product concept. Accordingly, by evaluating the implementation potential of each CE design criterion, industrial designers can determine the circularity potential of different product concepts. Nevertheless, the tool was adapted to the context of LIBs design for BEVs, by integrating eco-design criteria gathered from Van den Berg et al. [11], Mossali et al. [12] and Niese et al. [13] and criteria specified by the European directives "2000/53/EC on End of life of vehicles"[14] and "2006/66/EC on batteries and accumulators and waste batteries and accumulators" [15]. This led to the addition of 25 circular design criteria adding up to 53 aspects, which were classified by battery life cycle stage (raw materials, manufacturing, transport, use and end-of-life) (Table 1). The complete list of circular design criteria adapted for BEV batteries is available on demand.

Table 1: Life cycle stage CE design criteria

Life cycle stage	Nº of criteria
Raw Materials	8
Manufacturing	20
Transport	2
Use	10
End of life	13

2.2. Stakeholder engagement and evaluation of the implementation potential for each CE design criterion

The CE design assessment tool was shared with industrial stakeholders from the H2020 LIBERTY project [8]. Eight companies participating in LIBERTY were contacted and asked to provide scores for each circular design criterion based on their technical know-how and involvement in the project.

The CE design assessment tool was shared with the industrial stakeholders (via e-mail) with instructions on the evaluation procedure. Following, a general online meeting was celebrated to explain the needs and the goal of the assessment tool and questions related to the analytical tool were resolved via e-mail and/or further short 1-on-1 online meetings (30´).

Industrial stakeholders were asked to evaluate each of the 53 CE design criteria considering two aspects: (i) importance of the criterion (ii) viability (technical, cost or otherwise) of implementation. Criteria importance was evaluated using a geometrical scale (0 not important, 1 low importance, 3 moderately important, 9 high importance), whereas viability was evaluated arithmetically from 0 (not viable) to 5 (highly viable). Accordingly, the implementation potential for each criterion was the product of importance and viability. This score represents the potential of the criterion to improve the circularity of a BEV battery when applied in the design process. This differs in the scope of previous CE tools [8], where the scores are used as comparison for different design choices based on the fulfillment and importance of the proposed criteria by each design alternative.

2.3. Prioritisation of the CE design criteria based on importance and viability

Building upon the scoring provided by the industrial stakeholders, CE design criteria was prioritised according to their implementation potential in the LIB development for BEVs.

Implementation potential was calculated as a percentage based on the aggregated score of a criterion. Thus, CE design criteria with more than a 50% of implementation potential were considered high priority criteria for industrial implementation. Subsequently, priority CE design criteria were allocated per life cycle stage to get an overview of which LIB life cycle stages were more targeted based on the stakeholders' evaluations (e.g. see Figure 2).

2.4. Critical assessment of the CE design criteria

Finally, a critical analysis of the CE design criteria for LIB development was addressed to highlight potential benefits but also trade-offs, if the implementation of CE criteria is not properly planned and analysed from a life cycle perspective. To simplify the analysis (due to space limitations), the top five priority (high implementation potential) criteria were critically analysed. Nevertheless, the reasons behind the selection for some CE design criteria as non-priority (lower implementation potential) were also discussed, identifying the challenges related to the particular criterion and the opportunities and benefits of a successful implementation.

3. Results and discussion

This section shows the CE design criteria with the highest implementation potential, as considered by the industrial stakeholders followed by a critical analysis and discussion of the findings.

3.1. Circular design criteria for LIB used in BEVs

12 out of 53 circular design criteria show >50% implementation potential in the development of LIBs for BEVs, as shown in Appendix A. The top five scoring criteria are:

- To focus mainly on functionality and quality performance (94%)
- Consider and anticipate legislation (87%)
- Use digitalization, ICT (information and communication technologies) and IoT (internet of things) solutions (69%)
- Avoid using toxic materials and substances (64%)
- Favor cleaner production processes (59%)

Focusing on the LIBs´ life cycle stages, as expected, battery manufacturing represents the stage with the highest potential to accommodate the adoption of CE criteria (Figure 2). On the other hand, the EOL stage is considered the life cycle stage with the lowest potential (just 8%) to accommodate CE design criteria, as LIB manufacturers usually do not have control on waste management.

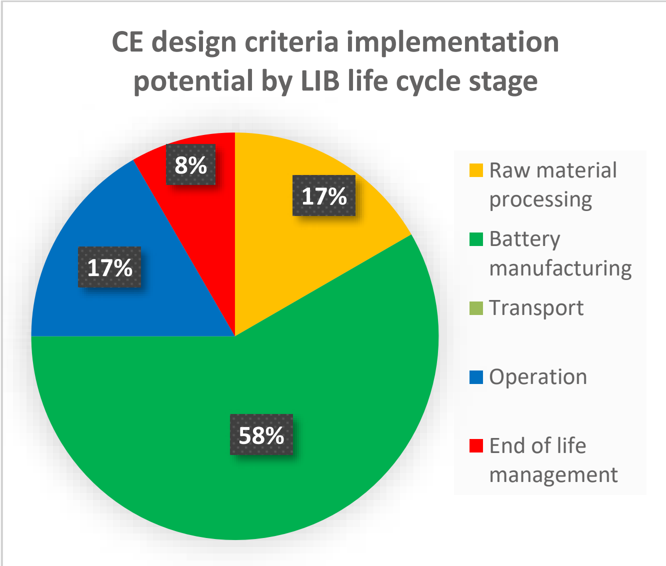

Fig. 2. CE design criteria implementation potential by life cycle stage

3.2. Analysis and discussion of the results

The potential benefits and trade-offs related to the five CE design criteria with the highest implementation potential are discussed in this section.

3.2.1. Focus mainly on functionality and quality performance

LIBs are not fashion-affected products. As "performance model" products, aspects such as make and aesthetics are less important as long as the quality-performance is delivered. For BEVs, the driving range, charging time and driving performance are major requirements demanded by BEVs consumers [16,17]. However, currently the improvement in these aspects is linked to the usage of critical raw materials (e.g. cobalt) [18], as cathode chemistries with cobalt have the highest energy density [19], leading to longer ranges.

3.2.2. Consider and anticipate legislation

The impact of legislation on the BEVs is important to be considered in the design phase as non-compliant batteries, materials or manufacturing techniques could be banned, especially in the EU, where the legislation for the sector, including CE action plans, is being stablished [15,20–22]. Future legislation in the EU aims to further regulate aspects that have not been covered by previous directives [23]. This is most notable in the new proposal for regulation concerning batteries and waste batteries [24], updating the previous directive [15] by, for example, stablishing a threshold for maximum life cycle carbon footprint or introducing measures as “battery passport” and easy access to BMS for SOH diagnosis [24] to favour second life of BEV batteries. Moreover, recycling scenarios are also re-assessed. The directive 2006/66/EC [15] stablishes a 50% recycling rate for batteries with no distinction of recovered material. The upgraded proposal [24] stablishes a minimum recycling of 65% of the battery weight, with a minimum recovery of key metals: Cobalt (90%), Nickel (90%), Lithium (35%), Cu (90%). Implementing CE strategies that would meet current and future legislation is, therefore, a must when designing innovative and sustainable LIBs. However, accessing to robust data is key to support well-informed decision-making. As indicated by Ciez & Whitacre [25], pyrometallurgy recycling method for LIBs can be encouraged by the 50% recycling rate legal requirement, while being less environmentally beneficial than other recycling methods available.

3.2.3. Use digitalization, ICT and IoT solutions

ICT and IoT are considered relevant solutions for improving the operation of LIBs within BEVs. Analyzing the usage behavior and applying preventive maintenance to avoid failures can add high value to the BEVs, while saving resources and reducing impacts over time [26]. Communication with the consumer can also improve the performance of the vehicle, coordinating the route with the charging needs or booking the charging lane [27]. Trade-offs for these strategies are related to a need of sensors that difficult the architecture of the battery and the dismantling and recycling at EOL stage. On the other hand, these sensors could also be used for a safe dismantling and recycling process, by assessing the state of the battery as the first step of EOL processes [28].

3.2.4. Avoid using toxic materials and substances

The presence of critical materials in LIBs promotes the analysis of strategies and alternatives to improve the efficient use and possible substitutes for these materials [29]. Currently the use of critical materials is closely related to the performance of the battery. Thus, the possibility of designing batteries with similar performance and lower toxic materials is under study in the sector, which is considering various battery chemistries [30,31]. However, the use of other materials could cause an increase in the weight and volume of the batteries, therefore impacting the performance and energy requirements of the BEV [32]. This requires further investigation.

3.2.5. Favor cleaner production processes

Improvements LIB manufacturing, such as using recycled materials, green energy or the manufacturing of greater energy density LIBs can greatly impact (positively) the environmental performance of the BEV as a whole [33]. The application of this criterion can benefit other CE criteria, for example higher energy-density LIBs could reduce the manufacturing impacts up to 15% [33], while also being positive for the performance of the BEVs, in line with the first criterion discussed. On the other hand, the implementation of cleaner production techniques can be costly, which can affect implementation in the short-term, as highlighted by the industrial stakeholders.

The high implementation potential of these five criteria indicates that including them in the design process greatly improves the circularity of the LIBs. However, other criteria that could greatly improve the BEVs circularity performance have not shown much implementation potential, as discussed in the next section.

3.3. Challenges and opportunities for the implementation of additional CE design criteria

Analyzing the allocation of priority CE design criteria per life cycle stage, it is especially notable that EOL stage is little targeted by the stakeholders’ evaluations (see Figure 2). The lack of applicability of CE design criteria impacting the LIBs EOL stage is surprising as the general CE literature for BEVs provides multiple strategies for closing materials cycles[34,35]. The cause of the low implementation potential for CE design criteria focused on EOL is their low viability. For example, the “design for recycling” criterion is considered very important for 72% of the stakeholders. However, the comparatively low viability scores of the criterion (medium or lower viability for 87% of the stakeholders) indicate that the implementation of the criterion would not have such positive impacts at the moment, as the recycling of LIBs has not yet been standardized. This calls for further technical research in the recycling procedures of LIBs, to increase the viability of design for recycling, especially as an increasing number of LIBs will reach EOL stage every year [25]. Similarly, the “use of recyclable and recycled material” in the raw material stage is also considered very important by 72% of the stakeholders but low or very low viability for all the stakeholders, due to the high-quality materials required by LIBs. Recent technological improvements in recycling processes [36] could improve the viability using recycled or recyclable material in the short- to medium-term.

Also, there are circular design criteria that have been listed in the tool, but the stakeholders decided to leave them out of the scope of their analysis, as the criteria were related to circular business models (CBM) implementation rather than technical design choices. This is the case for criteria as “servilisation of the battery” or the “standardization of battery collection after EOL”. These criteria are, however, considered to be very promising according to the literature analyzing the resource decupling potential for CBMs [37].

Finally, there are criteria that if implemented properly would benefit or ease the implementation of other CE design criteria. For example, "adoption of ICT and IoT solutions" to the driving of the BEVs could greatly affect the driving range of the vehicle [38], thus improving the "design for quality performance" criterion. These reinforcement between criteria shall be further explored to achieve greater benefits when designing circular and sustainable LIBs for BEVs.

4. Conclusion

This paper presented a list of CE design criteria for LIBs used in BEVs and evaluated their implementation potential according to the views of industrial stakeholders.

The results of the CE design assessment tool have provided great insight regarding the design priorities of the industry, which are centered on the LIBs manufacturing, as this stage presents greater flexibility for the integration of CE strategies. Focusing on the performance quality of the LIBs, complying with current and future legislation and implementing digital, ICT and IoT solutions in the BEV are considered key, along with avoiding the use of toxic materials and the implementation of cleaner production techniques.

Nevertheless, the implementation of some CE design strategies could lead to higher environmental impacts (trade-offs) if not properly implemented, as it is the case of using critical materials, such as cobalt or manganese, to improve battery performance during the use stage. In contrast with the findings on the literature, where design for disassembly and design for recycling are highly discussed topics, designing for EOL has not shown promising results in this work as CE design criteria targeting this life cycle stage is considered to have a low viability in the short-term. However, it is worth noting that the industrial stakeholders involved in the research are battery manufacturers and not waste managers, so the CE design potential for EOL can be different if criteria is analyzed by waste managers, instead.

Future work on this topic could include a deeper assessment on positive or negative correlations between CE design criteria (as addressed by the conventional DfX research) and quantification of the influence of CE design criteria on the resource consumption and environmental impacts of the LIBs, by coupling adequate CE indicators with robust LCA-based impact assessment approaches. Likewise, analyzing how CE design criteria can affect the design of CBMs and value chains, and vice-versa, is an interesting research line to identify strategic intervention areas to pursue CE innovation activities leading to greater resource and environmental savings on the BEV industry and beyond.

Acknowledgements

The authors of this work would like to thank all the participants of the Liberty project for the opportunity to develop and share this tool.

LIBERTY has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 963522.

The document reflects only the author's view, the Agency is not responsible for any use that may be made of the information it contains.

Appendix A. List of the high implementation potential design criteria

The following table lists the 12 circular design criteria that are considered highly implementation potential.

Life cycle stage	General criteria	Implementation potential
Use	Focus mainly on functionality and quality performance	94%
Manufacture	Consider and anticipate Legislation	87%
Use	Use digitalization, ICT and IoT solutions	69%
Raw materials	Avoid using toxic materials and substances	64%
Manufacture	Favour cleaner production, processes, machines and equipment	59%
Raw materials	Use durable and robust components and materials	57%
Manufacture	Consider compatibility of the product	55%
Manufacture	Design for reduced energy consumption and usage of renewable energy	53%
Manufacture	Design for long life	51%
Manufacture	Simplify product architecture	51%
End of Life	Investigate current and upcoming laws and regulations (focused on 2nd/end of life)	51%
Manufacture	Provide accessible electrodes at pack level	51%

References

[1] Aichberger C, Jungmeier G. Environmental life cycle impacts of automotive batteries based on a literature review. Energies 2020;13. https://doi.org/10.3390/en13236345.

[2] Messagie M. Life Cycle Analysis of the Climate Impact of Electric Vehicles. Transport & Environment 2017.

[3] Mayyas AR, Omar M, Hayajneh M. Vehicle's lightweight design vs. electrification from life cycle assessment perspective. Journal of Cleaner Production 2017;167:687–701. https://doi.org/10.1016/j.jclepro.2017.08.145.

[4] European Commission. Communication from the commission to the European Parliament, the council, the European economic and social committee and the committee of the regions on the 2017 list of Critical Raw Materials for the EU. 2017.

[5] European Parliament. Ecodesign directive: from energy efficiency to recycling https://www.europarl.europa.eu/news/en/headlines/society/20180522STO04021/ecodesign-directive-from-energy-efficiency-to-recycling (accessed November 22, 2021).

[6] European Parliament. Circular economy: definition, importance and benefits https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits (accessed November 22, 2021).

[7] Zhang C, Liu Y, Qian Y, Bao H. An optimization framework of electric vehicle (EV) batteries for product eco-design. Procedia CIRP 2020;90:366–71. https://doi.org/10.1016/J.PROCIR.2020.01.081.

[8] libertyproject | Lightweight Battery System https://www.libertyproject.eu/ (accessed November 24, 2021).
[9] CIRCit Norden. Focus 3: Circular Product Design and development 2020. https://circitnord.com/wp03-circular-product-design-and-development/ (accessed February 2, 2021).
[10] CIRCit Norden. Guidelines for circular product design and development Table of Content 2020. https://circitnord.com/tools/guidelines-for-circular-product-development/ (accessed November 24, 2021).
[11] van den Berg MR, And Bakker CA. A product design framework for a circular economy. vol. 17. Nottingham Trent University: CADBE; 2015.
[12] Mossali E, Gentilini L, Merati G, Colledani M. Methodology and Application of Electric Vehicles Battery Packs Redesign for Circular Economy. Procedia CIRP 2020;91:747–51. https://doi.org/10.1016/j.procir.2020.01.139.
[13] Niese N, Pieper C, Arora A, Xie A. The Case for a Circular Economy in Electric Vehicle Batteries | BCG https://www.bcg.com/publications/2020/case-for-circular-economy-in-electric-vehicle-batteries (accessed February 2, 2021).
[14] European Commission. Directive 2000/53/EC of the European Parliament and of the council of 18 September 2000 on end-of life vehicles. 2013.
[15] European Commission. Directive 2006/66/EC of the European parliament and of the council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC. 2006.
[16] Deloitte. 2020 Global Automotive Consumer Study. 2020.
[17] Neaimeh M, Salisbury SD, Hill GA, Blythe PT, Scoffield DR, Francfort JE. Analysing the usage and evidencing the importance of fast chargers for the adoption of battery electric vehicles. Energy Policy 2017;108:474–86. https://doi.org/10.1016/J.ENPOL.2017.06.033.
[18] Gourley SWD, Or T, Chen Z. Breaking Free from Cobalt Reliance in Lithium-Ion Batteries. IScience 2020;23:101505. https://doi.org/10.1016/J.ISCI.2020.101505.
[19] What is the Energy Density of a Lithium-Ion Battery? https://www.fluxpower.com/blog/what-is-the-energy-density-of-a-lithium-ion-battery (accessed November 24, 2021).
[20] European Commission. Directive 2009/125/EC establishing a framework for the setting of ecodesign requirements for energy-related products (recast) (Text with EEA relevance) 2009.
[21] European Commission. Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions. A new Circular Economy Action Plan for a cleaner and more competitive Europe. 2020.
[22] Halleux V. New EU regulatory framework for batteries. 2021.
[23] Malinauskaite J, Anguilano L, Rivera XS. Circular waste management of electric vehicle batteries: Legal and technical perspectives from the EU and the UK post Brexit. International Journal of Thermofluids 2021;10:100078. https://doi.org/10.1016/J.IJFT.2021.100078.
[24] European Commission. Proposal for a regulation of the European parliament and of the council concerning batteries and waste batteries, repealing directive 2006/66/EC and amending regulation (EU) No 2019/1020, COM (2020) 798/3. 2020.
[25] Ciez RE, Whitacre JF. Examining different recycling processes for lithium-ion batteries. Nature Sustainability 2019;2:148–56. https://doi.org/10.1038/s41893-019-0222-5.
[26] Urooj S, Alrowais F, Teekaraman Y, Manoharan H, Kuppusamy R. IoT Based Electric Vehicle Application Using Boosting Algorithm for Smart Cities. Energies 2021, Vol 14, Page 1072 2021;14:1072. https://doi.org/10.3390/EN14041072.
[27] Smiai O, Bellotti F, Gloria AD, Berta R, Amditis A, Damousis Y, et al. Information and Communication Technology Research Opportunities in Dynamic Charging for Electric Vehicle. 2015 Euromicro Conference on Digital System Design, 2015, p. 297–300. https://doi.org/10.1109/DSD.2015.111.
[28] Elwert T, Goldmann D, Römer F, Buchert M, Merz C, Schueler D, et al. Current Developments and Challenges in the Recycling of Key Components of (Hybrid) Electric Vehicles. Recycling 2015;1:25–60. https://doi.org/10.3390/recycling1010025.
[29] Song J, Yan W, Cao H, Song Q, Ding H, Lv Z, et al. Material flow analysis on critical raw materials of lithium-ion batteries in China. Journal of Cleaner Production 2019;215:570–81. https://doi.org/10.1016/J.JCLEPRO.2019.01.081.
[30] Wood M, Li J, Ruther RE, Du Z, Self EC, Meyer HM, et al. Chemical stability and long-term cell performance of low-cobalt, Ni-Rich cathodes prepared by aqueous processing for high-energy Li-Ion batteries. Energy Storage Materials 2020;24:188–97. https://doi.org/10.1016/J.ENSM.2019.08.020.
[31] Iturrondobeitia M, Akizu-Gardoki O, Minguez R, Lizundia E. Environmental Impact Analysis of Aprotic Li-O_2 Batteries Based on Life Cycle Assessment. ACS Sustainable Chemistry and Engineering 2021;9:7139–53. https://doi.org/10.1021/acssuschemeng.1c01554.
[32] Hofer J, Wilhelm E, Schenler W. Optimal lightweighting in battery electric vehicles. World Electric Vehicle Journal 2012;5:751–62. https://doi.org/10.3390/WEVJ5030751.
[33] Hall D, Lutsey N. Effects of battery manufacturing on electric vehicle life-cycle greenhouse gas emissions. 2018. https://doi.org/10.1088/1748-9326/11/5/054010.
[34] Thompson D, Hyde C, Hartley JM, Abbott AP, Anderson PA, Harper GDJ. To shred or not to shred: A comparative techno-economic assessment of lithium ion battery hydrometallurgical recycling retaining value and improving circularity in LIB supply chains. Resources, Conservation and Recycling 2021;175. https://doi.org/10.1016/j.resconrec.2021.105741.
[35] Kamper A, Triebs J, Hollah A, Lienemann C. Remanufacturing of electric vehicles: Challenges in production planning and control. Procedia Manufacturing 2019;33:280–7. https://doi.org/10.1016/J.PROMFG.2019.04.034.
[36] Northvolt produces first fully recycled battery cell https://northvolt.com/articles/recycled-battery/ (accessed November 26, 2021).
[37] Olsson L, Fallahi S, Schnurr M, Diener D, van Loon P. Circular business models for extended ev battery life. Batteries 2018;4. https://doi.org/10.3390/batteries4040057.
[38] Mruzek M, Gajdáč I, Kučera Ľ, Gajdošík T. The Possibilities of Increasing the Electric Vehicle Range. Procedia Engineering 2017;192:621–5. https://doi.org/10.1016/J.PROENG.2017.06.107.