DRIVES AND BARRIERS FOR CIRCULAR ION-LITHIUM BATTERY ECONOMY: A CASE STUDY IN AN AUTOMOBILE MANUFACTURER

Ana Paula Louise Yamada Macicieski[1[0000-0001-7118-7202]] Enzo Domingos [2[0000-0003-4847-2157]], Juliana Hoffmann[1], Luciana Rosa Leite[1[0000-0002-7240-9070]] and Carla Roberta Pereira[3[0000-0001-5213-3671]]

[1] Santa Catarina State University, Joinville, SC, BRAZIL
2 Polytechnique Montréal, Montréal, QC, CANADA
3 The Open University Business School, Milton Keynes, United Kingdom
enzogdomingos@gmail.com

Abstract. The growing concern for sustainability and the development of new technologies have made the electric vehicle one of the solutions and alternatives for global mobility. However, the increase in sales of these vehicles also impacts the amount of lithium-ion batteries produced, which encompass rare mineral extraction processes. Therefore, the concept of circular economy has been explored and applied by organizations, aiming to close the product life cycle, reduce the demand for resources and improve the supply chain. Through a single case study, the objective of this paper is to identify the drivers and barriers in the implementation of the circular economy for lithium-ion batteries used in electric cars. To this end, semi-structured interviews were conducted with three employees of a car manufacturer located in Brazil. From the content analysis, thirteen drivers and sixteen empirical barriers were identified. The unavailability of national technology and qualified suppliers for the implementation of the second and third use of batteries were identified as the main barriers. Regarding the drivers, objectives and strategies of the organization and regulations (governmental and environmental) were highlighted as the main boosters. We believe such results can help those organizations that intend to apply the circularity model to electric vehicle batteries to anticipate drivers and barriers and hence explore the opportunities presented in this study.

Keywords: Circular Economy, Electric Vehicles, Lithium-Ion Batteries

1 Introduction

The Industrial Revolution was one of the points of transformation of contemporary society, which altered the way of manufacturing enabling mass production and defined the model of economy, which remains to the present day. This model is defined as linear, in which materials are extracted, transformed and discarded. However, this model is reaching its physical limits, because natural resources are finite and the accumulation and generation of waste is inevitable [1]. Therefore, circular economy (CE) emerges as an alternative to the linear economy model, being designed to close the life cycle of a product, through the 9R's (in particular: Reduction, Reuse and Recycling) thus making production and consumption more sustainable and keeping the value and usefulness of products and resources [2, 28].

At the same time, companies are seeking the sustainability of their business, having as one of the objectives to achieve competitive advantages in the market, through the development of new products and technologies, while seeking to reduce environmental impacts and the emission of polluting gases. One of these innovations is the electric vehicles or EVs. According to the International Energy Agency [3], worldwide sales of EVs doubled in 2021, reaching a record of 6.6 million new vehicles, which is equivalent to approximately 9% of sales global levels. Other authors indicate that the trend in the coming years is the growth of the production of EVs, because they are a great alternative for conventional vehicles to combustion, which depend on fossil fuels and have higher rates of carbon emissions [4-6].

However, one of the concerns arising from this growth is the availability of the raw materials used in batteries of the EVs, which are usually lithium-ion type, because the elements required for production such as lithium, cobalt, nickel, manganese and graphite are on the European Union's list of critical raw materials [7]. Lithium is expected to increase demand by six times by 2030 [3]. Thus, the low availability of these resources and the high demand induce increased prices, impacting the production costs of the EVs, since the battery is one of the main components and corresponds to approximately 40% of the total cost of the vehicle [6, 8]. Furthermore, the supply of critical materials for the production of EVs is also susceptible to risks due to unequal geographical distribution and almost monopolistic control of necessary resources [5].

Taking into account the current economic scenario, studies by the Ellen MacArthur Foundation [9] and the European Commission [10] indicate that the circularity model assists in economic development, generating jobs and reducing a country's social inequality, as well as increasing resource efficiency and contributing to innovation.

Drawing on this context, the present study aims to identify the drivers and barriers to the implementation of circular economy for lithium-ion batteries used in electric cars. To do so, a single case study was conducted in a rental car manufacturer in Southern of Brazil. We believe the outcome of this study can bring initial contributions to organizations in the transition to the circular economy, especially the ones in the automotive sector.

2 Theoretical Rationale

2.1 Circular Economy

According to Kirchherr, Reike and Hekkert [2], CE is a new field of study, as about 73% of the definitions are from the last 5 years. They also indicate that many studies on CE are conducted by non-academic figures, defined as gray literature [11, 12, 27]. Ac- cording to the Ellen MacArthur Foundation [9], CE is "an economy that is restorative or regenerative by intent and design."

More recently, researchers and professionals have identified and highlighted the various existing drivers [e.g. 13, 14] for the implementation of the CE, in order to overcome many barriers present in this process [e.g. 15, 16, 27]. Comparing with innovation, Jesus and Mendonça [15] indicate that drivers and barriers can be divided into "harder" (tech- nical and economic type) and "softer" (regulatory and cultural aspects) - Table 1. In addition, the authors define drivers as factors that allow and encourage the transition to CE, while barriers are impediments or bottlenecks that obstruct this change. In general, there is not only a driver or barrier that has greater prominence, but a mixture of factors that facilitate and limit, deriving from particular conditions where the organization is inserted.

Table 1. Typology and definition of drivers and barriers for CE

		Drivers	Barriers
"Harder" factors	Technician	Availability of technologies that facilitate resource optimization, remanufacturing and regeneration of by-products such as insum for other processes, development of convenient sharing solutions and with a superior consumer experience.	Inadequate technology, delay between design and dissemination, lack of technical support and training.
	Economical/ Financial/ Marketing	Increased demand for resources and consequent pressure of resource exhaustion, increased cost of resources and volatility of supply, leading to incentives for cost reduction and stability solutions).	Large capital requirements, significant transaction costs, high upfront costs, asymmetric information, uncertain return and profit.
"Softer" factors	Institutional/ Regulatory	Increasing environmental legislation, environmental standards and waste management guidelines.	Misaligned incentives, lack of a favorable legal system, poor institutional structure.
	Social/ Cultural	Social awareness, environmental literacy and changing consumer preferences.	Rigidity of consumer behavior and business routines.

2.2 Electric Vehicles

Unlike combustion vehicles that have only one internal combustion engine, the Electric vehicles (EVs) use an electric propulsion system, consisting of an electric motor that uses the chemical energy stored in rechargeable battery. This energy is converted into electric energy to power the engine, being transformed into mechanical energy, enabling the movement of the vehicle [17]. Therefore, the fuel of electric vehicles is electricity, which can be obtained in different ways [18]: Connecting directly to the external source of electricity, for plugs or overhead cables; using the electromagnetic induction system; from the reaction of hydrogen and oxygen with water in a fuel cell; or by means of mechanical braking energy (regenerative braking, in which energy is obtained by braking the vehicle).

Batteries are considered the main component and the most critical technology of an EV, as they have a key role in the context of electric mobility and the highest cost in the value chain [4]. In general, the battery assembly encompasses four elements: the cooling system, the battery cell, the packaging and the battery management system [19].

Several studies [e.g. 20, 21] demonstrate that lithium-ion batteries can be remanufactured at a cost equivalent to 60% of a new battery, in addition to reducing carbon emissions and resource consumption. Additionally, other authors [22, 23] indicate a range of possibilities of redirection of batteries, mainly in the use in energy storage systems, allowing the increase of the service life of almost 10 years.

3 Method

The first stage of this research involved the identification of the gap and the development of the theoretical rationale. Next step comprised the case study conduction through data collection from semi-structured interviews, followed by analysis and interpretation of the data. Finally, the empirical elements of the case study will be compared with the knowledge gained from the literature, in order to discuss the results and draw the conclusions and final considerations of the study.

Yin [24] points out that the choice of single case study is appropriate under several circumstances, such as having a case that can "represent a significant contribution to the formation of knowledge and theory, confirming, challenging, or expanding the theory". Therefore, the choice of the single case study is justified, because the selected "case" is a national innovation, which enables the sustainable growth of electromobility, both locally and globally.

Thus, the object of the case study is a manufacturer of premium automobiles and motorcycles, recognized for developing initiatives focused on circular economy, sustainability and reducing emissions carbon dioxide. The company has two industrial units in Brazil - one responsible for the manufacturing of motorcycles, and the other for vehicles. In addition, the company also has a financial services unit located in São Paulo, which offers financing options and consortia. This study focus on the manufacturing of vehicles, located in the southern region of Brazil. This unit has developed the model of circularity of lithium-ion batteries, used in electric vehicles sold in the country, which are imported from other factories of the brand. . The infrastructure for the activities of assembly, bodywork/welding, painting and logistics was built in 2014, and it has currently around 600 direct employees being responsible for the manufacturing of four models to combustion.

The semi-structured interviews were designed considering not only aspects about the elements which lead to the adoption of lithium-ion batteries circular economy, but also the barriers to its implementation in the company. In order to present the theme and schedule the interviews, the employees were contacted by e-mail or in person. The three employees (plant director, manufacturing manager, and outsourced technician, identified respectively as interviewee A, B and C) selected for the interviews had great influence or active participation in the implementation of the circular economy model of lithium-ion batteries. The interviews took place in person in October 2022, and all of them were recorded to allow further transcription and analysis. In addition, other internal and external communication materials and sustainability reports of the company were also used as secondary data, providing support for the analysis.

4 Findings

Aware of the need for more sustainable manufacturing of components that are inserted in electric vehicles, such as the electric motor, high-voltage storage and battery cells, the organization in study initiatted efforts towards this aim. Thus, based on the shared responsibility with its suppliers, distributors and concessionaires, the organization ensures the proper management of components. One of the business initiatives offered to all EVs' owners is the free collection of batteries that are at the end of the life cycle. Figure 1 presents the circular economy model, which was designed by the company's environmental area, for lithium-ion batteries of one of the models of EVs.

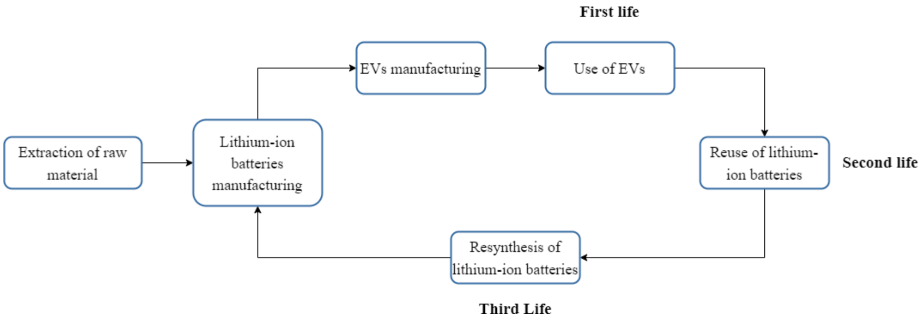

Fig. 1. Circular Economy model for EVs lithium-ion batteries

In this proposed model, the process begins with the extraction of the raw materials needed for the production of lithium-ion batteries, which will be later included in the manufacture of the EVs. After manufacturing, electrical models are made available for sale and use, which are called as the "first life" of the battery. The end-of-cycle phase of it occurs when the storage capacity reaches about 80% of the original value [25].

When this certain level is reached, the batteries must be collected by the dealers for replacement and then forwarded to their second use or "second life", in which are redirected to store electricity from solar panels. This system allows you to create a fast charging station for EVs, which can operate both connected and disconnected from the public power grid, enabling an infrastructure of sustainable recharge in regions where there is no access to the public electricity grid.

The "third life" of the lithium-ion battery is when there is no possibility of recharging solutions. Now the materials are extracted for resynthesis, that is, for the production of new batteries. This process aims to recycle rare chemical elements through the hydrometallurgy process, which is more sustainable when compared to pyrometallurgy (the most applied technique nowadays).

4.1 Identification of Drivers and Barriers

Drivers. Thirteen drivers (or factors that promote the transition to CE) were identified in the content analysis of the interviews and classified by type (internal/external) and factors (technical, institutional/regulatory, economic/financial/marketing and social/cultural).

Interviewee A is responsible for the strategic management of the industrial plant and has been working in the organization for 15 years. They mention two internal drivers (Driver D1 and D2) and two external drivers (D3 and D4), focusing mainly on the technical factor, emphasizing that there was no technology available at the time, so innovation was paramount to allow the implementation of the model, which would help promote the brand. According to them, "*the main impulse was the issue of recycling the battery*" (D1), and the use of the circular economy emerged as a possibility to avoid the direct recycling of the battery (D2), since this process was not yet fully understood at the time of implementation when the project started (2014). As external factors, this interviewee suggests that the project of circular economy was promoted because it was an innovation at the time (D3). As a matter of fact, the interviewee mentions that "*the name of the company was also benefited, because then there were several stakeholders investing money in the products [...]*" (D4).

The innovation issue was also mentioned by interviewee B (9 years at the company) when they mention that the company has an innovation acceleration program (D8). As they argue, "*The program was conducted to propose the automotive lithium-ion battery circular model to a partner company, which worked only with computer lithium batteries. Thus, the company's acceleration program fostered innovation in partner companies, enabling the circularity model to work*". Interviewee B has the responsibility of managing the environmental area of the plant, and besides the innovation program, he comments on two other internal drivers, one of a more regulatory nature (D5) and another linked to the technical factor (D6). As D5 this interviewee mentions the fact that the organization has always been a pioneer in the adoption of sustainability strategies (D5), and that "*within this strategic plan culture, the employee has the responsibility, which today they call circularity, to have their products from the design thought to the end of life, the proper disposal. The perspective of how to achieve circularity before discarding the product and how to develop the technique for this model"* (A7).

Also highlighted by interviewee B, an external driver identified (D7): the National Solid Waste Policy (PNRS), a national law enacted in 2010, which requires the proper disposal of solid waste generated by organizations, was received with ease by the company. According to interviewee B, "*In a reverse logistics program, the National Solid Waste Policy, which involves some items of post-use of the vehicle, it was noticed that only one point of the law had not yet been solved and was in progress. In this case, the destination of high voltage batteries from electric vehicles."* This point was solved in the circular economy model proposed by the company, from the aforementioned avalanches as company's sustainability strategy, together with the internal innovation and acceleration of ideas program were the main drivers for the implementation of CE lithium-ion batteries, used in EVs.

Contrary to what was exposed by previous interviewees, the outsourced employee (interviewee C) presents more external drivers (D9, D10 and D11) than internal (D12 and D13), most of which are related to institutional/regulatory factors. The interviewee emphasizes the importance of the Paris Agreement, ISO 14001 and PNRS, in addition to sustainability as a strategic objective of the brand, to ensure the application of circularity in products manufactured by the company. According to this interviewee, the fact that the company is European also contributed to boost the battery circularity project, "*The circular economy comes mainly from the European industries, especially regarding the Paris Agreement. When the climate agreement comes into force, they say: we have to reduce the emission of CO_2, otherwise the planet will heat up, and so on. Then a series of actions start to be taken both by the government and by the companies to try to achieve this reduction*". Thus, they point out that both the concern with sustainability as a strategic focus of the company and the implementation of the circular economy are responses to external demands.

It is also important to mention that interviewee C was the only one to highlight a social and cultural factor as a driver, indicating that the responsibility as an environmental engineer is to seek better alternatives to the processes carried out in order to avoid negative environmental impacts.

Barriers. The same categorization of the drivers (by type and factor) was used for the barriers. According to interviewee A, the greatest challenges faced for the adoption of CE for lithium-ion batteries of EVs are classified as internal and technical barriers (B1 and B2), since it was necessary to develop knowledge and new technologies to enable the design of the second and third use of batteries. They mention that such barriers range from "*the challenge of knowing how the power bank technology, for example, would work using lithium-ion batteries in the second life*", to more operational issues such as "*the length of the cable, some cars have a plug in the front, some cars have a plug in the back, and this changes the design of the product, and therefore the circularity process*". In addition, the interviewee points out that the greatest external challenge (B3) is to expand and insert this model in the market, in their words, "*how it would be to really sell this model of circular economy to whoever is interested*".

Eight other challenges are presented by interviewee B, which covered all four classification factors (technical, social/cultural, institutional/regulatory, economic/financial/marketing). The external technical factor presented the highest number of barriers (B4, B5 and B6), since there were no qualified national suppliers to develop the recycling and redirection solution of batteries, according to the CE model elaborated by the company. For example, he mentions the search for "*developing a national technology*" so that the lithium-ion batteries do not need to return to Europe for the recycling process. This would reduce costs and risks in the supply chain. Thus, according to interviewee B, "*since 2018, we have been looking for a logistics operator that could provide a solution for the disposal of these batteries, among other reverse logistics items, and since May 2020 we have been looking for recycling solutions at the end of battery use, because this logistics operator was not doing it, and was not finding it*".

In addition, another prominent factor was related to the external social/cultural environment (B7 and B8), due to the demand to raise awareness among concessionaires and consumers about the importance of collection and referral lithium-ion batteries for the company. Other difficulties related to institutional/regulatory (B9 and B10) and economic/financial/marketing (B11) factors reveal the importance of communicating strategic planning and concessionaires and the after-sales team, in order to ensure the continuity of the model.

Interviewee C mentions five barriers, two of which are internal social/cultural (B12 and B13) indicating that lack of awareness and resistance to change occur during the implementation process of innovation, as well as in the application of the circularity of the VEs batteries. In this sense, the interview mentions that "*the political effort is very big, you have to talk to a lot of people*" to make the circularity project happen - from the consumers to the operators of the model. In addition, barriers related to the economic/financial/marketing factor of the external (B14) and internal (B15) types show the need to present financial or (such as the markets), both for partner companies and for the board, in order to enable the implementation of the CE. Another barrier indicated was internal institutional/regulatory (B16), since to convince senior management it was necessary to demonstrate the importance of the circularity system. According to the interviewee, this barrier occurs because there is difficulty in monetizing the return to the business, "*the return is sometimes intangible*”. For example, the return on aligning the brand with the market expectations is intangible for the production director.

5 Conclusion

This study drew upon the theoretical results of Agyeman *et al*. [26] and Jesus and Mendonça [15], in which the barrier and driver were classified by type (internal/external) and factors (technical, institutional/regulatory, economic/financial/marketing and social/cultural). In summary, 14 out of 16 empirical barriers may be associated with barrier factors presented in the literature. The interviewees pointed out that the unavailability of technology and national suppliers trained for the application of the second and third use of batteries were the most critical barriers faced. In addition, some difficulties related to business partners were also mentioned since the development of technology and the obtaining of batteries depend on the support of dealerships and specialized companies.

However, no corresponding barriers were found in the literature for elements of communication and financial return of EC. For instance, the barrier related to the customer communication challenge, which is critical to ensure the return/delivery of lithium-ion batteries to the company. In the same vein, there is the intangibility of the return of the circularity model for EVs lithium-ion batteries can hinder the adoption of CE. These points can be considered opportunities for the development of battery supply chains considered in this work.

Two drivers for the circular economy of lithium-ion batteries of electric vehicles showed greater prominence in the case studied, namely: objectives and strategies of the organization and regulations (governmental and environmental impacts). On the other hand, the barriers with the highest number of mentions refer to the unavailability of technology and national partners to enable the application of the second and third use of batteries lithium ion.

In practice, the strategies proposed by the company were developed in partnership with an educational institution and four private companies, in addition to a public educational institution. This CE model allows to close the life cycle of the lithium-ion battery (used in one of the electric models of the brand) and enable the expansion of electric mobility as well as the reduction of carbon emissions and raw material extractions. Furthermore, results can support organizations that intend to implement the circular economy model for lithium-ion batteries, whether they are vehicle manufacturers or other stakeholders, to anticipate and prepare for the barriers faced during the process. The results of this work can help organizations that intend to implement the circular economy model for lithium-ion batteries, whether they are vehicle manufacturers or other interested parties, to anticipate the levers and barriers faced during the process. In addition, such elements present themselves as opportunities not yet explored, which can be used for future applications.

It is noteworthy that like every study, the present study has some limitations. One of them is related to the technical procedure chosen; because it is a single case study, it is not possible to generalize the results obtained, i.e., the drivers and barriers empirically identified may be different in other contexts. Therefore, for future studies, it is recommended to use a case study with multiple sources of analysis, to contemplate suppliers and consumers, since the present study focused on the micro approach, under the vision of only one company.

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