# A New Business Model for the Circular Economy of Electric Vehicles

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**Abstract.** The market for electrical vehicles (EVs) is expected to show constant growth in the next years. However, Europe is not prepared to manage such a massive flow of electric vehicles at the End-of-Life (EoL). Consolidated value chains including recyclers, remanufacturers, and dismantlers able to treat key parts of EVs efficiently and safely at the EoL (such as batteries) do not exist at the needed industrial scale due to their novelty and complexity which requires innovative technologies and methods.

Furthermore, the huge uncertainty on the volume of parts, their EoL conditions, materials cost fluctuations, and market acceptability discourage companies from starting new recycling/remanufacturing businesses. This carries the risk of delaying the consolidation of European value chains specialized in the EoL management of EVs. In order to address these challenges, the present research, which was carried out in the frame of the H2020 "CarE-Service" European-funded project, proposes a new circular business model for the EoL management of EVs.

**Keywords:** Circular Economy · Automotive Supply Chain · End-of-Life vehicles management

## 1 Introduction

With growing awareness of climate change, the transportation sector is one of the main areas for carbon reduction strategies [1]. The advantages of lithium-ion batteries (LIBs) as the power component for EVs as well as the higher efficiency of EVs compared to internal combustion engines are creating a revolution across the sector. During the last decade, EV production has drastically increased from a few thousand to 11.3 million EVs in 2020 [2]. In order to meet existing government policies, more than 142 million EVs will be on the road in 2030 and this could increase even more.

The electrification trend goes in the direction of sustainability because it reduces the recourse to fossil fuel, and it raises also challenges associated with EVs manufacturing and EoL supply chains [3, 4]. Large quantities of critical raw materials (Fe, Al, Co, Ni, Li, etc.) will be necessary to produce batteries and other added-value components


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of EVs, with the consequent need for intensive mining processes [5]. Thus, reusing and recycling strategies for EVs should be systematically pursued. However, proper collection and transportation of end-of-life vehicles (ELVs) [6], secure battery removal from vehicles, and efficient disassembly processes of valuable parts require specific knowledge, trained personnel, and special tools and equipment to guarantee safe EoL treatment processes that also do not damage the environment [7–9]

Circular economy (CE) aims to maintain the value of products, components and parts through reuse, repair, remanufacturing, upgrade, and recycling approaches [10]. We are in a transition period in which the number of EVs reaching their EoL increases while Europe is not prepared to manage them properly [10, 11, 13]. Due to the current low number of EVs at EoL, the availability of spare parts from EVs is insufficient. Therefore, the market for reuse and remanufactured parts from EVs is limited and uncertain and reverse supply companies are discouraged from investing and offering EoL parts services [13, 14]. Besides, there is still a lack of consolidated, high-scale reuse and recycling value chains specialized in the EoL treatment of EVs.

To address the aforementioned challenges, this paper proposes a new circular economy business model for the EoL management of EVs. The new business model is based on innovative dismantling technologies and an Information and Communications Technology (ICT) Platform for efficient integration and coordination of all stakeholders of the circular EVs value chain as well as for the establishment of a trusted marketplace of remanufactured parts and recycled materials.

## 2 State of the Art

Every year, millions of vehicles in Europe reach the end of their life. The EU Directive 2000/53/EC imposes obligations to increase the recovery of all ELVs in order to recycle and reuse parts and materials accounting for 95% of an average vehicle weight [8]. Since a vehicle is a complex product composed of thousands of parts with different materials, ELV recovery is a complicated process [9]. The establishment of a circular economy approach is of paramount importance to guarantee future sustainability in the automotive industry and exploit the economic potential offered by reusing various parts and components the way they are disassembled from an EV for spare market; remanufacturing by repairing and replacing some components from disassembled parts to make them usable in the same or different application and recycling of high-value components of post-use EVs to extract the raw materials from parts that are known as waste or are not reusable or manufacturable [10]. However, due to the novelty of EVs, such an approach is not fully employed [14]. Our investigation on existing scientific literature shows that there is still a lack of circular business models for ELVs management at the supply chain level and issues such as reverse logistics [3, 9, 15], optimization models for closed-loop supply chain [7, 16], recovery infrastructure and disassembly [8] are at the center of studies.

Several high-added-value components are not systematically recovered and they are part of the undifferentiated flow of automotive waste that is recycled through shredding and chemical processes after the removal of hazardous materials [17]. In terms of materials, it can be estimated that ferrous and non-ferrous metal parts represent 60% to

70% of the overall materials. At the moment, after removing reusable and recyclable vehicle parts, the hulk is compressed and transferred to a shredder, whose task is mainly to recover metals [18]. The content of techno-polymers (advanced polymers with high mechanical properties that substitute metals to reduce vehicle weight) in EVs is higher than in traditional combustion vehicles and it is expected to increase significantly in the next years [9]. The automotive post-use techno-polymers are not currently recovered and recycled. Thus, there is a high potential to improve sustainability by introducing circular strategies for metal and techno-polymer materials such as re-manufacturing or recycling. In addition, with the introduction of EVs, batteries pose severe challenges to dismantling as operations are mainly manual and dangerous [3, 17, 19]. Furthermore, there is a lack of sufficient information about the performance of retired batteries and the lack of new market opportunities for second-use applications [10, 16].

Besides single solutions to address various materials and parts, proposals of systemic supply chain approaches are missing. The automotive supply chain actors act in a fragmented way which slows down the establishment of consolidated circular chains [14].

## 3 Methodology

This article presents the results of the "CarE-Service" project, a European H2020-funded project aimed at establishing new technologies and business models for the circular economy of EVs (Grant Agreement number 776851). Several supply chain stakeholders such as automotive OEMs, recyclers, remanufacturers, dismantlers, technology providers, and ICT Platform developers were involved to design a new circular business model for the EoL of EVs, to provide requirements for the dismantling of critical EVs parts (e.g. Batteries), as well as to test new technologies and support economic simulations for sustainability assessment [20].

8 in-depth interviews with stakeholders at different levels of the supply chain and two workshops were carried out to collaboratively define the pillar of the future circular business models and the specifications of the ICT Platform that will support it.

The stakeholder network diagram was used, as an instrument to help practitioners identify partners and define To-Be network relationships (Fig. 1). The business model canvas was used as a framework to design the new business model [21]. Finally, the ICT Platform was developed according to the Agile framework (Scrum) methodology. During each "sprint", incremental developments were tested and validated by stakeholders engaged in the project.

After the development of the business model, ICT Platform, and advanced dismantling solutions an integrated economic assessment was carried out using Discounted Cash Flow techniques (DCF), considering an assessment period of 10 years and calculating indicators such as the Net Present Value (NPV) and the Pay Back Time (PBT).

## 4 Results

### 4.1 The Smart Movable Modules (SMMs)

EVs are "new products" for dismantlers and require new skills and disassembly technologies/processes that are too sophisticated and/or expensive to be acquired in a short time,

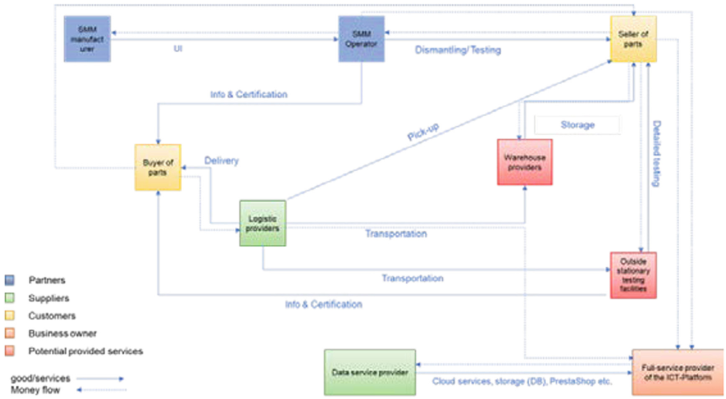


**Fig. 1.** CarE-Service stakeholder network diagram

especially considering the relatively limited market in this transition phase. Robotized battery disassembly technologies and advanced testing methods have been developed in CarE to be transportable inside a container. These “Smart Movable Modules” (SMMs) can be available on demand to dismantlers as pay-per-service, according to the volumes of processed EVs.

The focus of the disassembly SMM is the dismantling of the battery packs. A flexible robotized solution, able to recognize and adapt to the specificities of various battery packs, extracts battery modules by cutting the external cover of the pack, drilling the external case, removing screws, connector cutting, and module grabbing. Since this operation is designed to be handled by an operator managing the robot, batteries with different characteristics are trained on the robot.

The testing SMM is dedicated to testing disassembled metal and techno-polymeric parts and components from EoL vehicles. The testing of the metal parts focuses on the geometrical evaluation and physical properties of metals that can influence downstream re-use and remanufacturing processes. For techno-polymers, non-destructive tests are carried out to characterize the material of dismantled parts with the goal of optimizing recycling.

The two modules can operate together or separately. SMMs are connected to the CarE-Service ICT Platform (4.2) to immediately showcase the disassembled and tested parts for reuse or further remanufacturing/recycling processes. This guarantees that the parts disassembled and exchanged in the CarE-Service community have known characteristics and justified prices, decreasing the typical uncertainty of traded EoL parts.

### 4.2 A New Integrated CarE-Service ICT Platform for the EOL Management of EVs

A new ecosystem, the CarE-Service Community, has been created through the CarE-Service ICT Platform. It is built on the business relationship among different stakeholders, from different industries and trade levels (Fig. 2). All the members of the CarE-Service Community can benefit from the services offered, such as the marketplace, the SMMs, and the logistic services.

Based on the value proposition of the business model, for all the targeted customer segments the platform offers a demand-driven trading marketplace of high-added-value parts and components from EVs. It also gives access to the dismantling and testing services (via SMMs that are booked through the Platform) and to logistic services such as transport of the purchased parts. The main advantage is the combined use of the SMMs and the marketplace, as this makes the platform stronger and more competitive in the market against other existing marketplaces, as the standardized dismantling and testing processes ensure the quality of the traded parts. In addition, users can receive support and services for the dismantling and upcycling of EVs parts and request that new products are added to the marketplace.


**Fig. 2.** CarE-Service community systemic view

A client application was created for the operators of the disassembly SMM, with a double purpose: First to keep the data of the dismantling process updated on the marketplace with a direct link from the operational field to the Platform. Second, for connecting to a knowledge database where all the information about performed processes to implement a sort of machine learning approaches are stored. In this way, the SMM operators can be guided in the disassembly of various types of batteries.

Another client application was developed to enable two-way information exchange between the Platform and the testing process carried out in the testing SMM. The application is based on a guided process for the selection and inspection of cores (used automotive parts) under the name "CoremanNet"[1], which was expanded for the selection of batteries, metal parts and techno-polymers coming from EoL EVs. The selection process is a guided process and proceeds according to criteria that the operator selects from predefined values on a list. At the end of the selection, all the information provided by the operator is posted on the marketplace as the characteristics of the part, while the part is already assigned to its owner (seller on the marketplace).

The logistics feature provides shipment management to the marketplace and it is based on the "Circul8"[2] Platform. Companies need to be approved by the Platform before they can act as an official logistics provider for the marketplace. Through decision matrixes, the logistics feature determines the optimal route and price for the marketplace order based on a set of criteria, like the container type, regions of buyer and seller, or weight. Logistic providers can access logistics features such as downloading reports, managing orders or placing custom quotations.

The "drop-off locations" feature allows external stakeholders (car dealers, workshops, municipalities, or even car owners) to find local dismantlers who are community members. This feature fulfills the gap between the marketplace and the market of the EoL EVs and feeds the marketplace with parts.

### 4.3 Impact and Sustainability of the CarE-Service ICT Platform

The result of the economic simulation depends on the technical evolution in battery remanufacturing and recycling, metal remanufacturing, and techno-polymers recycling value chains developed through the project. The technical solutions from three value chains of battery, metal and techno-polymers at ELVs quantified the capacity of producing remanufactured and recycled parts. Using the forecasted number of EoL EVs over the next 10 years led us to evaluate the economic sustainability of such a consolidated community described in Sect. 4.2. Hypothetically only 3–5% of such a market is considered to be treated via the CarE-Service network.

To evaluate such sustainability, DCF and NPV analysis for 10 years of business operation is adopted from years 1 to 10 (Formula 1), where CF stands for cumulated Cash Flow and is divided by the interest rate (r) per number of years:

$$\mathrm{DCF} = \mathrm{CF}_1/(1+\mathrm{r})^1 + \mathrm{CF}_2/(1+\mathrm{r})^2 + \ldots + \mathrm{CF}_\mathrm{n}/(1+\mathrm{r})^\mathrm{n} \quad (1)$$

Several key variables to quantify costs and revenues are linked to this formula. Costs are mainly the operation and development costs of such a platform while revenues are generated mainly from fees per sold remanufactured/recycled parts plus the percentual share of SMM services. Since the availability of EoL EVs at the moment is limited, it is assumed that the CarE-Service ICT Platform market segment will mainly support groups of Small to Medium Sized Enterprises (SMEs) of remanufacturers, recyclers and service providers. Therefore, the number of stakeholders (dismantlers, remanufacturers, recyclers and service providers) that trade various parts inside the platform are cumulated for each year as key variables to multiply into the single cost-revenue block.

[1] Coremannet, Circular Economy Solutions GmbH, [Online]. Available: https://www.coremannet.com/home/.

[2] L. Software, ""Landbell Software," [Online]. Available: https://landbell-software.com/.

The CarE-Service ICT platform will have a forecasted turnover ranging from 1 million Euro (M€) to 10 M€ from year 1 to year 10 respectively with an overall NPV of 13 M€. In this simulation, the number of stakeholders in the considered evaluation period ranges from 60 to more than 600 in year 10. Following the same methodology and according to key variables such as the number of customers (mainly small to medium-sized dismantlers who can hardly afford the high investment costs of dismantling machinery), volumes of disassembled batteries over 10 years considering the incremental rate of batteries at EoL; the price per disassembly and testing services by SMMs company, the business for the SMMs is found to be sustainable with an NPV of 5 M€ over 10 years. In this simulation, the number of operating SMM will range from 28 SMMs and 27 SMM in year 1, up to 124 SMM in year 10 which will allow meeting the demand of the increasing EoL EVs.

## 5 Conclusion

In the automotive sector, new business opportunities can be exploited and considerable environmental savings can be achieved by adopting circular economy strategies for EVs. At the moment, there is a lack of a consolidated supply chain to help this transition toward the circular economy and stakeholders in the supply chain act in a fragmented way. This paper proposed a new business model supported by advanced disassembling technologies and a cloud-based platform that coordinates the EoL supply chain actors.

The CarE-Service Platform provides a marketplace with virtual stores, where the car parts can be placed to be sold to any other member of the community. The ICT Platform, at its core, also acts as a demand-driven platform where any player can request specific products. Finally, the SMMs integrated with the CarE-Service platform allow the community to seamlessly dismantle car parts based on industry best practices and add value to these parts by testing, certifying them, and proposing the best possible purpose. What makes the CarE-Service Platform business models unique are B2B Platform specialized in the circular economy of EVs; Integration and orchestration of all the stakeholders of the new EV reverse chains; Offering dismantling and testing services on-demand through an integrated business model with SMMs; Unbiased testing and certified parts to reduce uncertainties of the circular business.

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