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Perspective

Second Life of Lithium-Ion Batteries of Electric Vehicles: A Short Review and Perspectives

Carlos Henrique Illa Font [1,†], Hugo Valadares Siqueira [1,2,†], João Eustáquio Machado Neto [1,†], João Lucas Ferreira dos Santos [2,†], Sergio Luiz Stevan, Jr. [1,†], Attilio Converti [3,*,†] and Fernanda Cristina Corrêa [1,†]

1 Graduate Program in Electrical Engineering, Federal University of Technology—Paraná—UTFPR, Ponta Grossa 84017-220, PR, Brazil
2 Graduate Program in Industrial Engineering, Federal University of Technology—Paraná—UTFPR, Ponta Grossa 84017-220, PR, Brazil
3 Department of Civil, Chemical and Environmental Engineering, University of Genoa, Pole of Chemical Engineering, Opera Pia, 15, 16145 Genoa, Italy
* Correspondence: converti@unige.it
† These authors contributed equally to this work.

Abstract: Technological advancement in storage systems has currently stimulated their use in miscellaneous applications. The devices have gained prominence due to their increased performance and efficiency, together with the recent global appeal for reducing the environmental impacts caused by generating power or by combustion vehicles. Many technologies have been developed to allow these devices to be reused or recycled. In this sense, the use of lithium-ion batteries, especially in electric vehicles, has been the central investigative theme. However, a drawback of this process is discarding used batteries. This work provides a short review of the techniques used for the second-life batteries of electric vehicles and presents the current positioning of the field, the steps involved in the process of reuse and a discussion on important references. In conclusion, some directions and perspectives of the field are shown.

Keywords: second-life batteries; electric vehicles; BESS; lithium-ion batteries

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1. Introduction

Currently, one of the main concerns of modern society is related to climate change and how to reverse this situation. The major challenge in reducing climate change is the ability to achieve carbon neutrality, whereby emissions are low enough to be safely absorbed by the natural system [1–3]. Increasing demands for decarbonization of the transportation sector have resulted in the demand for electric vehicles (EVs) [4]. In the last decade, EVs have been developed very rapidly and will soon be replacing conventional vehicles [5].

Lithium-ion batteries (LIBs) are the main energy storage technology for these vehicles due to their high gravimetric and volumetric energy density, long life, low maintenance, high power capability, low self-discharge, and their lack of a memory effect [6,7]. Due to these characteristics, they are the preferred power source for EVs and they are the most important power component in EVs, but also the most expensive, costing almost half the cost of a vehicle. In the coming decades, the demand for EVs is expected to further increase; thus, production in the lithium-ion market is predicted to grow exponentially [4].

According to Haram et al. [8], in automotive applications, lithium-ion batteries do not have optimal operating conditions; they typically endure more than 1000 charge/discharge cycles for 5 to 8 years and are also subject to a wide temperature range between 20 °C and 70 °C, a high depth of discharge (DOD), and high charge and discharge rates.

Most manufacturers of electric/hybrid vehicles suggest replacing the batteries when their capacity reaches typically 70% to 80%, as this represents a considerable loss of range for the vehicle. When the battery pack of an electric vehicle becomes unable to meet the imposed demand, the pack is removed from the vehicle, thus marking the end of its automotive life. Given this scenario, the concept of utilizing the large quantity of batteries that would be retired for a second life stands out. The denomination used for these batteries is second-life battery (SLB), and EVs are currently being considered as the primary source of these [9]. Therefore, while providing an interesting insight into increasing battery life in EVs, more extensive research is necessary to determine when to retire these batteries, and how they can be used in a new application, a second-life application. Once the first generation of EVs has retired, these batteries will now enter the scene to unite the existing batteries generated from electronics devices, making it an opportune moment for research in this area for which there is a vast field to be explored.

Figure 1 illustrates the useful life of batteries. In phase 1 of a battery application, the construction of the batteries and the modularization (packaging) for different applications are indicated. Especially for automotive use, battery packs are usually composed of hundreds of smaller modules to increase the final block voltage and current. Phase 2 illustrates the battery usage time in the first cycle, which has a durability of 8–12 years. The continuous monitoring of the batteries (individual modules) can allow monitoring of the "health" of the battery and helps to define the best time for recycling it. When a battery pack is removed for recycling (phase 3), the individual modules are evaluated, and the batteries are regrouped. The lifespan of second-life batteries goes from 6 to 30 years [10] depending on the application (exemplified in phase 4), with the main ones being: Grid and off-grid stationary applications, mobile applications (those that support EV charging stations), and small electronic devices. At this stage, monitoring the batteries is also important to monitor their aging. At the end of this phase, when the batteries can no longer offer sufficient autonomy, the batteries must be dismantled and given an adequate final destination. All of the disposal processes must be monitored somehow by the individuals responsible for correct waste disposal.

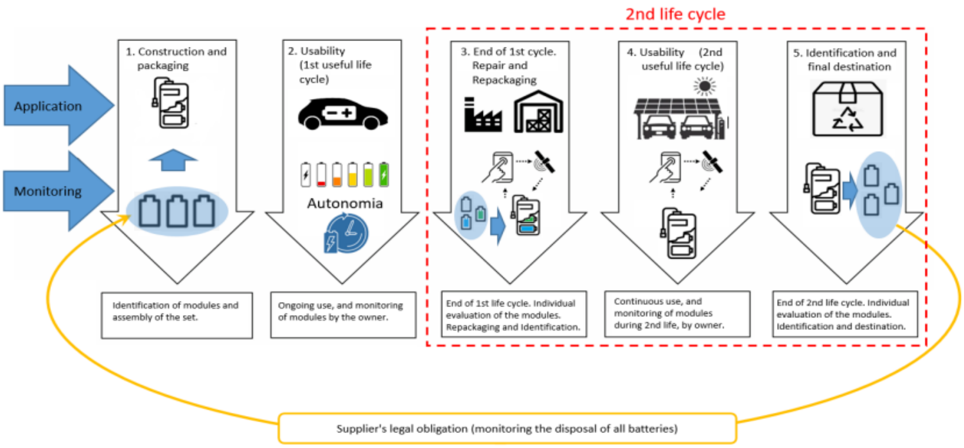

Figure 1. Block diagrams of phases of the battery (applications and monitoring).

With an eye to battery capacity monitoring, Figure 2 shows the battery life range as a function of the battery capacity. When the batteries of electric vehicles reach about 70% to 80% of their capacity, it is considered that their application in electric mobility is over, with this being the end of its first life. The second life of batteries starts when they have a capacity between 80% to 70% and 30%, with it being possible for them to be used in several stationary applications. After their capacity reaches 30% or below, the batteries should be sent for recycling.

Thus, it is mandatory in the development of methodologies for the battery pack disassembly process, as well as in the methodologies for the classification of second-life batteries, to select which second-life batteries can be directed to a particular application. In addition, it becomes necessary to track these batteries in second-life applications through connectivity, since the automotive original equipment manufacturer (OEM) will be responsible for the final retirement of these batteries.

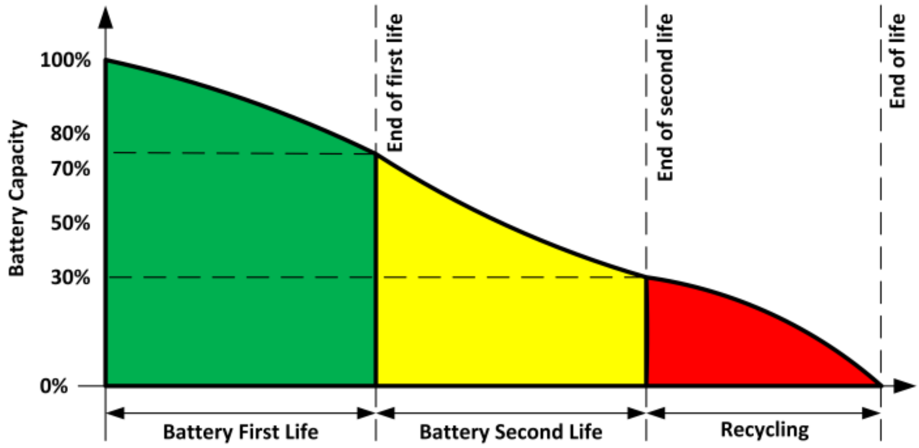

Figure 2. Plot of EV battery life range as a function of battery capacity.

Therefore, given the above discussion, this study aims to provide an overview of the available systematic review articles found in the literature on bibliometric analysis and the PRISMA (preferred reporting items of systematic reviews and meta-analyses) [11] methodology with the help of VOSviewer software (Leiden, The Netherlands), intending to raise the most relevant points according to the perspectives of automotive battery reuse, as well as discussing the most relevant concepts around this topic.

2. Second-Life Batteries: Recycling and Reuse Process

Discarding cellphone and laptop batteries has raised concerns about possible second use, as long as recycling resources are not enough. Although lead acid (Pb-acid) battery recycling is relatively well known, at the moment, recycling for predominantly lithium-ion (Li-ion) technology is not. From an economic and environmental point of view, it would be a waste not to harness the potential energy of second-life batteries by simply disposing of them in landfill. The number of man-hours and financial resources invested would not be fully used. The costs of the chemical components that make up lithium-ion batteries are not cheap and have increased significantly in recent years since orders have increased [12]. An example is lithium cobalt oxide (LCO) which is one of the most significant and widely used cathodes in batteries in electronic devices and EVs. However, Co is a less abundant mineral product (0.0023% in the Earth's crust) and is difficult to mine. In addition, issues of geopolitical instability in Africa make it difficult to mine the region where the product is most found. All these factors have led to an increased price of Co from USD 26,500 per ton in September 2016 to USD 94,250 per ton in March 2018 [13,14].

Using these batteries after their first use is economically wasteful, significantly so when the second life can include a considerable value for their use. Slattery et al. [15] carried out a comprehensive investigation to identify the valuable material produced from used EV batteries that may eventually become waste. This research found that 3.4 million kg of lithium-ion battery cells from EVs could enter the residual disposal stream by 2040. These battery cells would comprise materials with zero recycled value (such as graphite) and some others which demand a large amount of energy from their natural sources, such as lithium, nickel, aluminum, and cobalt.

Direct recycling after the first life also presents the problems of being unfeasible due to the complexity of the process and the recovery of a small amount of material at a higher cost than the new material. According to Kautz et al. [16], Li-ion batteries only contain 2–7% lithium in their total weight. However, obtaining such material by recycling is five times more expensive than obtaining it from natural sources. The only material worth recycling is cobalt, but new investigations are being made to develop battery technologies that reduce or omit the use of this material for more stable and cheaper substances. The target is to develop cobalt-free batteries [16].

Therefore, a second life can help with the better use of economic resources and reduce the pollution caused by materials that are not useful after recycling [15]. As used batteries are being massively produced daily, proper investigations on their second-life use are now more critical than ever and are paramount to meet the United Nations sustainable development goals (SDGs).

In Europe, several vehicle manufacturers, particularly the pioneering companies in the electric vehicle market, have implemented alternatives to the use of second-life batteries in different energy storage systems, from small residential systems to containerized solutions in distribution systems [17]. Most of these projects are not commercial yet, which indicates that the research field is just getting started. The University of California (Davis) has employed a second-life energy storage system (ESS) using Nissan Leaf EVs in its "RMI Winery Microgrid Project". Second-life battery research projects have also been conducted at the Rochester Institute of Technology and the University of California (San Diego) [18].

Research and development (R&D) projects have also been conducted by industrial entities. These efforts include collaboration between BMW, Vattenfall, and Bosch, which who built a 2 MW, 2800 kWh second-life battery energy storage system (BESS) in Hamburg, Germany, to support the power grid. The batteries were collected from over a hundred vehicles [12].

However, the re-manufacturing process for EV batteries presents inherent challenges. Each battery cell manufacturer uses a different cell type, which requires a unique kind of module. These modules are reciprocally unique in respect to connection [19]. Therefore, even ignoring the different cell chemistry employed, the process that follows the disassembly of used batteries is entirely arbitrary. To overcome this problem, a procedural methodology, such as the flowchart proposed by Dalala et al. [20], must be employed. The first step is to disassemble the car pack to obtain the batteries. In this case, the batteries consist of several individual cells. As different manufacturers use different types of cells with different packaging, the disassembled components can be categorized to facilitate the selection of components for a given application [21].

Pack disassembly begins with a survey of the available manufacturer/assembler literature to analyze the previous risks and discover the infrastructure/equipment necessary. Next, one must proceed to the preparation of the workplace, signaling and delimiting the dismantling area. During the entire disassembly process (from the opening of the car to the disconnection and final separation of the modules), it is necessary to use personal protective equipment for electricity and adopt safety procedures to avoid or mitigate the risk of accidents.

Considering that the pack is already outside the vehicle, the disassembly until obtaining the cells consists of the following steps:

- Removal/extraction of covers or opening of the car;
- Removal of protections/covers/insulation covers;
- Disconnection and isolation of low-voltage harnesses;
- Disconnection and isolation of high-voltage harnesses and buses;
- Battery management system (BMS) removal;
- Removal of electrical protection devices;
- Loosening of module fasteners;
- Module removal;
- Cell separation and visual analysis.

A system that uses second-life batteries must be implemented with similar characteristics regardless of the application. After disassembling the battery pack, all of the batteries must be tested and sorted. Furthermore, their power and capacity are defined by the behavior of the cell with the lowest capacity. In this way, to characterize the cells in terms of voltage, capacity, and the state of health (SoH) is a critical task.

A three-stage assessment method was introduced by Castillo-Martínez et al. [22]. The first step is the visual inspection, which reveals cells or modules with apparent physical damage, which can be immediately rejected. The second stage consists of checking the voltages of the remaining batteries. Those that prove to be suitable are submitted to the third stage, the evaluation of the SoH. In practice, battery aging is observed by the gradual decrease in nominal capacity. SoH estimation is one of the main procedures that must be present in the BMS. Based on the SoH estimation, it is possible to ensure reliable operation of the battery and predict its lifetime [23]. However, estimating the SoH is a challenge due to the non-linear behavior of the battery

In the literature, several SOH estimation methods are described. It is possible to group them into three categories [23]:

- Experimental methods: these are simple and direct methods but are time-consuming and require specific equipment to carry out measurements. This procedure is not recommended for estimation in real time or when the battery is operating. An example is the method of measuring the battery's internal resistance, which increases with the decreasing of the SOH;
- Model-based methods: this type uses models of battery behavior, such as the dual polarization electrical model. They are based on algorithms and require computational effort. They can be used during battery operation. An example is the Kalman filter estimation [24];
- Methods based on machine learning: these methods combine both experimental techniques and model-based approaches. Allowing to work with non-parametric data, they are robust and accurate. In addition, they request the processing capacity to implement the algorithms and an adequate database for better performance. The estimation of SOH using fuzzy logic or neural networks are examples of this class.

Monitoring battery parameters is of crucial importance. Through this, the user and the manufacturer can obtain information on its useful life. It is through the observation of parameters, such as voltage, current, temperature, and charging time, that the user can verify performance drops.

Thinking about real-time monitoring, through the different protocols that support the Internet of things (IoT) concepts, all relevant battery data can be measured and transmitted to the cloud, where, in addition to monitoring, it is possible to build digital twins for battery systems. In it, diagnostic algorithms evaluate the data remotely, providing real-time assessments for battery charge level and aging [25,26].

From another perspective, controlling the useful life of the individual parts of a battery pack is necessary for manufacturers. They must continuously track the rearrangements of subsets for their use in second life, in order to monitor their replacement or disposal in a controlled manner. Thus, they are able to properly dispose of them, in accordance with legal and environmental premises. Beyond the electrical parameters, identification parameters can also be the focus of information on connectivity devices.

Considering these perspectives, the different types of sensors and communication protocols must be evaluated according to the premises and norms to be defined. The analysis of different current, voltage and temperature sensors is necessary. In addition, they are used for the evaluation of different radio frequency identification devices (RFIDs) sensors and different near field communication (NFC) connectivity devices, based on the IEEE 802.11 g and IEEE 802.15.4 standards (Lora) [27,28].

From an economic perspective, second-life battery solutions may be divided into two commerce types. The first corresponds to their application in large-scale energy systems, such as their support in wind farms or solar plants (electricity generation from renewable energy sources) and in electricity distribution. Considering the intermittent feature of renewable energy sources, the employment of SLBs as energy storage devices can be justifiable. The second type is small-scale applications, comprising both residential and commercial consumers, such as telecommunications enterprises, data centers, distribution, food, and office buildings, among other application [29].

Casals et al. [10] highlighted the new expectations in the electricity sector. To improve the competitiveness of EVs, the automotive industry includes the second life of batteries, positioning them as affordable energy storage systems (ESS) for stationary applications. This system is called a second life battery energy storage system (SLBESS).

The most prominent application of an SLBESS is in operation together with a renewable generation source and an EV charging station, performing a microgrid energy system. It enables a sustainable solution for electric mobility since EV batteries find reuse before recycling and part of the electric energy used for recharging the vehicle comes from a renewable source [30].

Figure 3 presents the block diagrams of two types of microgrid concepts. In the AC microgrid, all of the equipment is directly connected to the AC mains while in the DC microgrid, the equipment is connected to a DC bus, which has a single connection with the AC mains. In both cases, the energy management system (EMS) controls the power 202 flow between the individual pieces of equipment in the microgrid [30].

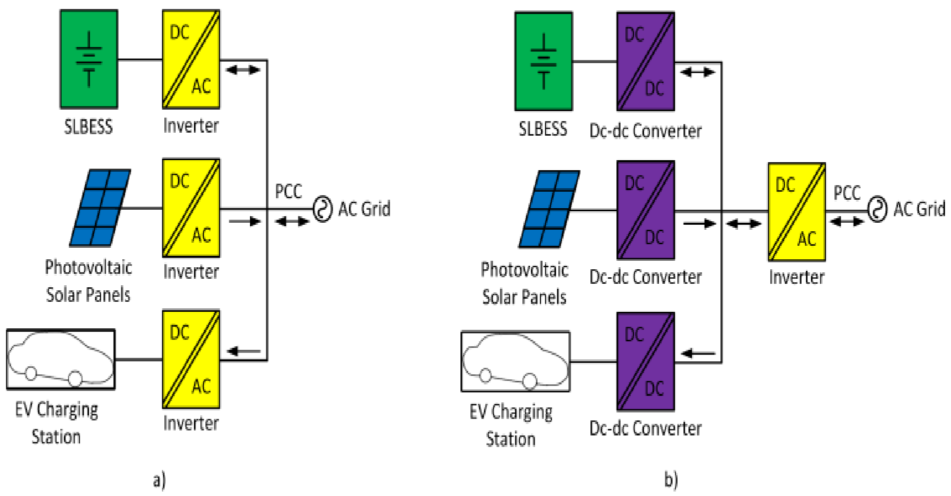

Figure 3. Block diagrams of microgrids with an SLBESS: (**a**) the AC microgrid and (**b**) the DC microgrid.

3. Second-Life Battery Approaches

For the preparation of this review, PRISMA methodology was used. The main points for delimiting the scope and determining the eligibility and exclusion criteria are indicated below.

The scoping review was carried out with the aim of systematically mapping the research carried out in this area, as well as identifying any gaps in existing knowledge. Additionally, the following research questions were formulated: "What are the main destinations of batteries for automotive use?" and "What are the limitations and possibilities of use from a second-life perspective?"

To be included in the review, papers needed to measure or focus on specific dimensions of the second life of batteries, they needed to be peer-reviewed journal papers published between the period of 2018–2022 (of the last 5 years, focusing mainly on the last 3 years), written in English, developed in the conceptual framework (e.g., time–life, destination, second life, reuse, battery monitoring charge, and battery monitoring health). Papers were excluded if they did not fit into the conceptual framework of the study.

To identify potentially relevant documents, the following bibliographic databases were searched from 2018 to December 2022: IEEE, MDPI, and SCOPUS. The search strategies were elaborated and later refined through team discussion, resulting in a set of just over 35 articles relevant to this approach.

To visualize the incidence of search terms, as well as the interconnection of these terms in the references, we used the VOSViewer for constructing and visualizing bibliometric networks.

Figure 4 illustrates the clusters based on the incidence of the main keywords in the sample set of selected articles. It is possible to verify the formation of three clusters in the information network: the first one (in blue) where the ideas of estimating the charge and health of batteries are concentrated; the second (in green) where issues of recycling, assembly, and disassembly, reuse, and the second life of batteries appear correlated; and the third (in red) where the applications of lithium-ion batteries, applications in vehicles and storage systems stand out.

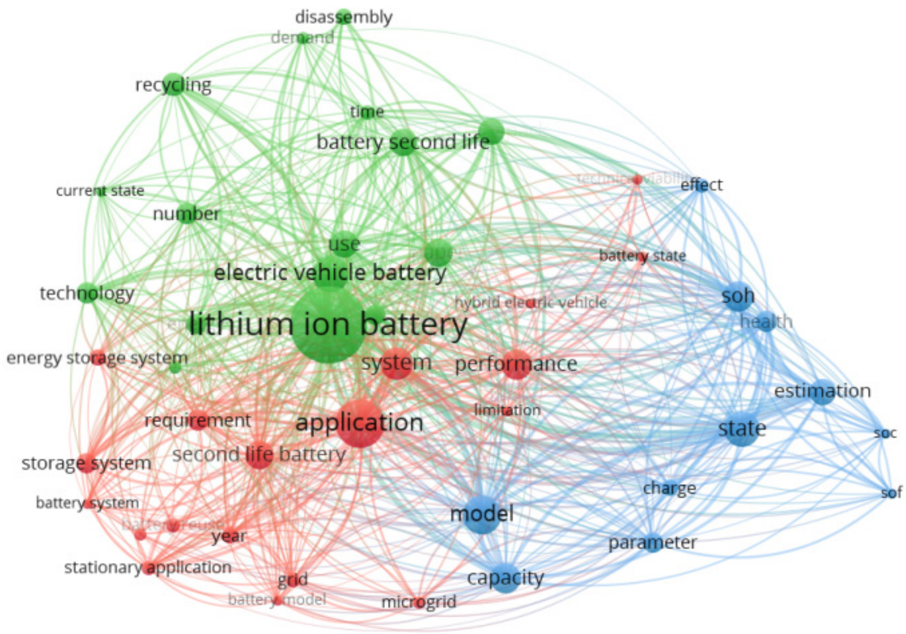

Figure 4. Cloud and word network obtained by bibliometric analysis with the software VOSViewer.

3.1. Battery Performance Estimation

Knowledge of the internal parameters of retired batteries, as well as obtaining accurate algorithms for estimating the RUL and SOH in the rerouting phase, is vital to ensure their satisfactory operation and increase the life of the SL. Thus, several works have been carried out to enable this important task. Bhatt et al. [31] presented machine learning models based on MLP, LSTM, and CNN for predicting the second-life useful capacity of the discarded batteries that were proposed. The models were trained using the operational data from first life, from 100% to 80% SOH. For this analysis, the authors explored four input cases from the charging profile and another four from the discharging profile. The performance of the models was compared by the baseline model (persistence) and after selecting the best prediction model with appropriate input selection. The analysis showed that by selecting the input parameters from the discharging profile, the proposed models could predict the discharging capacity more accurately than the charging profile.

Traditional characterization methods require long testing times and specific equipment, which result in high costs that may jeopardize the economic viability of SL. Braco et al. [32] proposed a novel, fast characterization method that allows for estimating capacity and internal resistance at various states of charge for reused cells, modules, and battery packs. Three estimation models were proposed. The first is based on measurements of AC resistance, the second is based on DC resistance, and the third combines both resistance types. These models are validated in 506 cells, 203 modules, and 3 battery packs from different Nissan Leaf vehicles. The results achieved are satisfactory, with them reducing testing times from more than one day to 2263 min per cell, while the energy consumption was lowered from 1.4 kWh to 1 Wh.

The work from Sanz-Gorrachategui et al. [33] considered the RUL estimation problem and proposed several health indicators (HIs), some of which have yet to be explored, along with simple yet effective estimation and classification algorithms. These algorithms include classification techniques such as regularized logistic regression (RLR) and regression techniques such as multivariable linear regression (MLR) and multilayer perceptron (MLP). A multiple-expert system combining said techniques was proposed as a more advanced solution. The performance of the algorithms and the features was evaluated on a recent lithium iron phosphate (LFP) data set from the Toyota Research Institute. This work obtained satisfactory results in estimating RUL cycles with errors down to 49 roots mean square error (RMSE) cycles for cells that live up to 1200 cycles, and 0.24% indicates a relative error (MRE) for the prediction of the evolution of capacity.

Bockrath et al. [34] presented an accurate state of health (SOH) estimation algorithm using a temporal convolutional neural network (TCN) for lithium-ion batteries (LIBs). With its self-learning ability, this data-driven approach can model the highly non-linear behavior of LIBs due to changes in environmental and working conditions all along the battery lifetime. The provided network is trained and tested with data from commercial industry applications in the energy storage domain. It has been shown that even for dynamic load profiles, the TCN achieves a mean squared error (MSE) of less than 1.0%. This approach can drastically reduce the uncertainty of the heterogeneous performance and characteristics of retired electric vehicle batteries.

In the paper presented by Castanho et al. [35], the authors reported that the literature points out several approaches to accomplish SoC estimation, presenting high error, low reliability, and high computational costs. From this perspective, they proposed a model to perform SoC estimation in lithium-ion batteries for electric vehicles in four different scenarios. It was used multiple linear regression (MLR) with spline interpolation (SPL-MLR) and the generalized linear model (GLM). The models were calibrated by three bio-inspired optimization metaheuristics: a genetic algorithm (GA), differential evolution (DE), and particle swarm optimization (PSO). The computational results obtained for the training and test sets indicate that the MLR-PSO achieved the best overall results, with it being the best predictor for all of the case studies.

Since battery aging has a non-linear behavior, SoH estimation is a bottleneck for battery performance classification. Methods based on artificial intelligence have great potential to be standard solutions due to high accuracy, adaptability, and real-time operation.

3.2. Battery Disassembly

In general, the abusive use of lithium-ion batteries due to overload or short circuiting can lead to fire or even explosions; therefore, an evaluation of the batteries in their disassembly stages is very important. There are electrical hazards especially when the battery is not completely discharged at the start of the process and all work must be completed under voltage. This is the case if the battery is dismantled for a second use of the modules. Current flow caused by a bypass also causes strong temperature development, which can lead to overheating and self-explosion. Even the disassembly of deeply discharged batteries also involves health and environmental risks due to mechanical or chemical actions that can result in toxic and generally highly flammable compounds, which in turn increases the risk of explosion [36].

In the investigation of Tao et al. [37], the authors presented a discussion of LBIs' recycling techniques and how this can improve energy and environmental sustainability. LIBs with higher specific energy show better life-cycle environmental performances, but their environmental benefits from second-life application are less pronounced. Direct cathodic recycling is considered to be the most effective in reducing lifecycle environmental impacts, while hydrometallurgical recycling provides limited sustainability benefits for high-performance LIBs. Batteries with less aluminum and alternative anode materials such as silicon-based anodes can enable more sustainable recycling. Compared to the direct recycling of LIBs after electric vehicle use, the energy use of LIBs recycled after their second life can be reduced by 8 to 17% and 2 to 6%.

Disassembly of lithium-ion battery systems from automotive applications is a complex and therefore time-consuming and expensive process due to a wide variety of battery designs, flexible components such as cables, and potential hazards caused by high voltages and the chemicals contained in the battery. To illustrate the procedures, Or et al. [38], Gumanová and Sobotová [39] presented 24 disassembly steps to separate the battery modules/cells for further processing, using a Volkswagen Jetta Hybrid System and an Audi Q5 Hybrid System, respectively, as a case study. The majority of the steps were carried out by hand, and it was concluded that full automation of the disassembly process is quite complex and expensive. Nevertheless, if the number of battery packs increases, a semi-automated disassembly process can be considered.

In the paper presented by Hellmuth et al. [40], the authors discussed an assessment of the automation process of battery pack disassembly based on two indicators: the technical ability of a disassembly process to be automated (TAA) and the necessity to automate the corresponding disassembly operation (NA). On considering the Audi Q5 HEV battery, it has been concluded that most of the unscrewing operations should be automated while most of the lifting operations should be performed by human workers.

A method of using a robotic arm for the disassembly of an EV battery pack was presented in the work of Kay et al. [41]. The main use of the robotic arm was in the cutting tool for extracting the battery modules. The conclusion is that human and robot collaboration is the best choice for the disassembly processes, since it reduces the risks faced by the technicians during the cutting process and requires fewer man-hours for the whole process.

Perspectives regarding disassembly processes point to the use of semi-automated processes due to wide battery variety, ergonomics, safety, and cost. Thus, it will be essential to create tools and workstations, as well as train specialized human resources with strong skills in safety to meet the standards and certifications J2997—Standards for Battery Secondary Use, UL 1974—ANSI/CAN/UL Standard for Evaluation for Repurposing Batteries, and DGUV 200-006—Training for Work on Vehicles with High-Voltage Systems.

3.3. Battery Application

Casals et al. [10] presented a theoretical study to analyze the remaining useful life (RUL) of second-life batteries in four stationary applications: support for the fast charging of electric vehicles, self-consumption, area regulation, and the delay of streaming. Based on SOH and SOC simulation, for the four scenarios, the results showed that all of the case studies ended up with a battery life of more than 5 years, and three of them lasted more than 10 years before needing any replacement.

In the work of Chai et al. [42], the authors discussed a comprehensive evaluation framework for testing second-life batteries. The framework considers three parts: a model for battery degradation, the battery retirement mode, and the application of the a BESS in a power system. The SLBESS is proposed to mitigate load and wind power forecast errors and to mitigate the cost.

An optimization methodology for the operation of a microgrid composed of a wind turbine, PV panel, and a Li-ion BESS is presented in [43]. The effects of capacity fading and temperature were examined in the study. The sensitivity analyses for the different renewable penetrations, the portion of EVs, and the reduction in the demand in the summer demonstrated that the increasing rate of the life cycle cost (LCC) is directly proportional to the renewable penetration and the LCC was increased by six times from the renewable penetration rate of 30–100%.

Martinez-Laserna et al. [44] presented a study that sought to evaluate the technical capabilities of retired electric vehicle batteries in two different second-life applications, with the first being a residential demand response management application and the second being an application of energy smoothing for a grid-scale photovoltaic power plant. They used retired batteries with different first-life aging histories and at varying levels of SOH. The authors concluded that 70–80% of the remaining capacity as a standard automotive battery retirement criterion proved inadequate. They asserted that only cells taken from automotive service while still in an early stage of degradation would provide long-lasting second-life aging performance. Lastly, they concluded that not all cells might be eligible for potential second-life use, and correctly tracking first-life battery aging data would be crucial for selecting the most suitable second-life batteries.

Future prospects for using second-life batteries are in stationary applications. The main application probably will be in battery energy storage systems in AC or DC microgrids, providing short-term and long-term ancillary services such as power smoothing for solar photovoltaic and wind renewable generation, peak shaving, and voltage support.

4. Discussion and Perspectives

The studies on and technologies of second-life batteries are paving the way for electric mobility in agreement with sustainable development, environmental protection, and the circular economy as well as meeting different policies such as the Net Zero Coalition, the compliance with solid waste, environmental social governance (ESG), and the SDGs of the United Nations. For batteries to be used in a second-life applications, it is essential to generate technologies for the processes of disassembly, classification, connectivity, traceability, and the development of energy storage systems with second-life batteries. The second-life batteries of electric vehicles have the potential for innovation in the following areas:

- The methodology for the battery classification process: to classify batteries according to their SOH algorithms based on artificial intelligence, neural networks and machine learning can be used. The development of these algorithms and their application is a topic at the forefront of knowledge both from a theoretical and technological point of view;
- Development of dedicated BMSs: the BMS plays a vital role in the correct and safe operation of each battery and the entire energy storage system. BMSs removed from vehicles' battery packs cannot be reused, as they are designed to operate with the number of batteries in the vehicle and with the specifications demanded by the automotive application. Therefore, new dedicated BMSs must be designed and developed for the application of second-life batteries;
- Development of the connectivity system: this system will allow real-time monitoring of the individual parameters of each battery. The project has the potential for innovation in terms of sensors, communication, and the processing of collected data. The question of controlling the useful life of the individual parts of a battery pack is necessary for the manufacturer, who has the obligation to continuously track the rearrangements of subsets for use in second life, identifying the entire set so that, in a short future, they can monitor their replacement and/or disposal in a controlled manner and thus be able to properly dispose of them, in accordance with legal and environmental premises. In this way, in addition to electrical parameters, identification parameters can also be the focus of information on connectivity devices;
- Development of the SLBESS: the design must take into account mechanical, electrical, thermal, and safety constraints. As it is a multidisciplinary project, computational tools that provide numerical simulations in multiple physics domains must be used, particularly those that employ finite element methods and/or computational fluid dynamics. Additionally, computer-aided design (CAD) tools must be used to design the cabinet focusing on the constructive characteristics of the cabinet, the fixing of the batteries inside the rack, the positioning of the electrical and thermal sensors, and the positioning of the harnesses and cabling, control, protection, and cooling devices, among others.

Although technologies have been developed for the use of automotive batteries in second-life applications, there has not yet been a business model mature enough for these batteries and their applications to reach a commercial scale.

5. Conclusions

The number of electric vehicle sales has grown exponentially in the last decade, and consequently, the number of lithium-ion batteries to be retired shortly will also increase. This raises the concern of what to do with the massive number of batteries available, which still retain 70 to 80 percent of their initial capacity and are no longer helpful for vehicle applications but are still very much needed for other applications.

In this way, we can summarize the most important points regarding the second life of lithium-ion batteries:

- The battery pack disassembly process is complex because each manufacturer performs the assembly process differently. In addition, the disassembly process requires qualified people with personal protection to avoid the risk of accidents;
- Continuous monitoring of the internal parameters of the battery so that the right moment to replace the battery application can be estimated;
- To assemble the pack with the second-life cells, it is necessary to ensure that the cells are in excellent condition by checking the SoH and joining cells with similar use characteristics, with the classification process becoming essential;
- Several techniques, including machine learning, have been used for the classification process for knowing the internal parameters of the cells, their SoC, and their remaining energy, and so it is possible to assemble second-life packs with cells whose parameters are similar;
- All of the steps involved in using second-life batteries must follow a methodology capable of making the whole process reliable, safe, and cost-effective in systems and equipment to reach a higher technology readiness level.
- Together with generating energy through renewable sources to recharge electric vehicles, the second life of lithium-ion batteries is fundamental for sustainable electric mobility, promoting a new business model and the circular economy.

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Abbreviations

The following abbreviations have been used in this manuscript:

BESS	Battery energy storage system
BMS	Battery management system
CAD	Computer-aided design
DE	Differential evolution
DOD	Depth of discharge
ESG	Environmental social governance
EV	Electric vehicle

GLM	Generalized linear model
GM	General Motors
HI	Health indicators
IEEE	Institute of Electrical and Electronics Engineers
LCC	Life cycle cost
LFP	Lithium iron phosphate
LIB	Lithium-ion battery
MDPI	Multidisciplinary Digital Publishing Institute
MLP	Multilayer perceptron
MLR	Multiple linear regression
MRE	Mean relative error
NFC	Near-field communication
PPE	Personal protective equipment
PRISMA	Preferred reporting items of systematic reviews and meta-analyses
PSO	Particle swarm optimization
R&D	Research and development
RFIDs	Radio frequency identification devices
RIM	Robert Mondavi Institute
RMSE	Roots mean square error
RUL	Remaining useful life
SDGs	Sustainable development goals
SLB	Second-life battery
SLBESS	Second-life battery energy storage system
SoC	State-of-charge
SoH	State-of-health
TCN	Temporal convolutional neural network

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