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Reviewing Regulations and Standards for Second-Life Batteries

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Abstract: The transportation sector significantly contributes to greenhouse gas emissions, thus imposing significant environmental hazards. In response, many nations have begun promoting Electric Vehicles (EVs) as an ecologically sustainable substitute for traditional combustion vehicles. Lithium-Ion Batteries (LIBs), characterized by their high energy density, extended lifespan, and relatively low self-discharge rate, have become the suitable energy storage system for EVs, advancing the field of sustainable transportation. The decreasing cost of LIB production has primarily driven this progression, realized through a combination of economies of scale, advancements in electrode materials and cell design, and refinements in manufacturing processes. All these elements collectively contribute to the cost reduction of LIBs. A foreseeable implication of this trend is an expected surge in LIBs that will exhaust their operational lifespan and, consequently, be cast away into the environment. One mitigating strategy for this impending environmental issue involves collecting these spent EV batteries, reconfiguring them, and repurposing them for applications with less rigorous weight, performance, and size prerequisites. This approach would not only prolong the utility life of the batteries but also ameliorate their environmental impacts. Nevertheless, second-life batteries are anticipated to exhibit a higher rate of gas evolution, necessitating comprehensive testing and readjustments to ensure safe operation in secondary applications. The regulatory framework encompassing the second-life battery sector still needs to be defined regarding norms, technical standards, and legislation. This paper aims to elucidate the primary regulations and technical standards proposed thus far in the second-life battery marketplace. The results underscore the exigency for neutral evaluative entities, such as universities, research centers, and governmental institutions, to perform an unbiased assessment of the second-life battery market. This would pave the way for novel technical standards and legislative measures specifically tailored to this emerging sector.

Keywords: Second use; Reuse; Lithium-Ion Batteries; Second-Life Batteries; Standards; Technical Standards; Regulations; Legislation; Circular Economy

1. Introduction

In recent years, the automotive industry has observed a growing interest in Electric Vehicles (EVs) as an alternative to conventional internal combustion engine vehicles, primarily due to their potential to reduce greenhouse gas emissions and mitigate the effects of climate change. This interest has been driven by developments in EV technology, including battery performance, power electronics, and motor efficiency. In addition, government policies and incentives designed to promote the adoption of low-emission vehicles have contributed to the expansion of the market for electric vehicles. The ability of EVs to reduce CO_2 emissions depends on the source of electricity used to power them, with electricity from renewable sources, such as solar or wind, offering the most significant environmental benefit. Therefore, the increasing adoption of this type of vehicle is motivated - among other factors - by the need to decarbonize the energy transportation sector and is associated with the decrease in the cost of Lithium-Ion Batteries (LIBs) [1–4].

Batteries unavoidably deteriorate over time in the context of electrochemical energy storage systems, resulting in a decline in both storage capacity and power output capabilities [5–7]. Original Equipment Manufacturer (OEM) recommendations for EVs often advocate for a battery replacement approach based on the battery's operational efficiency declining to roughly 70-80% of its initial full capacity.

According to data-driven forecasts based on empirical investigations, the lifespan of such batteries in EVs is projected to be 8 to 12 years [8–10]. Following this timeframe, it is expected that these electrochemical energy storage systems will fail to meet key performance metrics, precisely the rate of energy transfer (acceleration), the time required for full recharge (charging time), and the maximum achievable distance on a single full charge (range) [10].

The growing EV sales and the intrinsic degradation of their accompanying battery systems create substantial issues for these energy storage devices' End-Of-Life (EOL) management. Inadequate battery management solutions as these batteries approach their EOL can negate the environmental benefits of switching from internal combustion engine automobiles to EVs.

EOL batteries from electric vehicles can be disposed of in landfills, recycled [4,11–13], reassembled [14], or even reused [15–18]. Notably, batteries contain heavy and toxic elements that pose significant hazards to environmental integrity and human health. As a result of the possibility of soil contamination and increased environmental burden, landfill disposal is not acceptable [19].

Recycling is an alternate management technique that involves the extraction of the chemical components of the batteries. However, given the current level of technological maturity, this process remains prohibitively expensive, implying that substantial technological improvements are required to improve its economic feasibility [15,20].

Energy storage devices, such as batteries outside the recycling feasibility barrier, are frequently incinerated [21]. This incineration takes place mainly in an open setting with no specific infrastructure for the containment and filtering of emitted heavy metals such as Cadmium (Cd), Copper (Cu), Nickel (Ni), Lead (Pb), and Zinc (Zn).

Unregulated incineration can have severe consequences for public health. In exposed populations, the discharge of these metals can increase the prevalence of respiratory illnesses and cause kidney problems [22]. Simultaneously, an environmental cascade effect occurs, resulting in negative consequences such as land ecosystems and aquatic bodies contamination. Proper management measures are essential to avoid these potential health and environmental hazards.

Currently, several nations lack the necessary infrastructure to carry out battery recycling processes. These countries may not have the necessary technological components, financial resources, or logistical capacity to recycle many batteries. Therefore, these nations should not export their waste batteries to other regions with recycling capacity [23]. It is essential to mention that the translocation strategy, despite being seen as a short-term contingency measure for small companies to manage large amounts of battery waste, is prohibited in most countries. Furthermore, this solution is not economically viable for larger quantities in the medium and long term. This lack of sustainability results from the high transportation costs, the present stage of development of specialized recycling companies, and the immaturity of the recycling process itself. Moreover, due to the hazardous nature of this type of waste, the transportation of second-life batteries requires special precautions. Multiple jurisdictions prohibit the exportation of such electronic devices to prevent developing nations from becoming significant electronic waste dumping grounds [23].

Recycling is a process that can be postponed if the option of re-use is considered. For example, the EV retired batteries can be re-used in less demanding grid applications such as peak shaving, frequency regulation, voltage regulation, charging stations for EVs, and short-range cars (e.g., trucks and golf carts) [15,24,25].

Second-life batteries have a competitive price, performance, and service life compared to other battery technologies, such as lead-acid batteries used in stationary applications [9,15,26]. The battery cost is approximately 50% of the EV cost, which makes the Battery the most expensive component of this type of vehicle [27–30]. Therefore, reducing the initial cost of batteries through reuse can make the price of EVs more commercially competitive and increase the penetration of EVs in the market.

Battery and automobile manufacturers want to reuse batteries directly, without the need for handling and disassembly, as this will avoid costly and unnecessary testing and will be less likely to make reuse unviable commercially. However, in some cases, it may be necessary for the batteries to be disassembled, remanufactured, and/or for the modules to be recombined.

The market for reused batteries is relatively new and has been driven by the development of new policies and strategies developed by government agencies. Policies that encourage the reuse of batteries are essential to reduce the uncertainties in this market and may occur through federal and state tax credits, discounts, and other financial support. Therefore, the legislation impacts the construction of business models, and each aspect is essential when considering the technical and ecological feasibility of the second use, reuse, and recycling of batteries [31].

It is essential to mention that existing legislation and technical standards focusing on second-life batteries are limited. Despite the growing number of public policies, regulations, and technical standards proposed in recent years, there are still some questions in the literature that requires attention:

1. Who will own the batteries at the end of their life?
2. What test procedures can be performed to diagnose the State of Health (SoH) and ensure the quality of second-life batteries?
3. What technical standards exist and can be applied to second-life batteries?
4. What public policies encouraging the second-life battery market have been adopted in the European Union (EU), the United States of America (USA), and China?
5. Can the principle of producer responsibility be applied to second-life batteries? Can the ownership of the batteries be transferred to third parties? If so, in which cases?
6. Can second-life batteries be imported/exported?
7. Is there a possibility of transporting batteries between countries? If so, under what conditions?
8. What tests can be performed to determine the quality of used EV batteries?

To answer these questions, the present work aims to analyze the similarities between the technical standards proposed in the world and the need for elaborating or adapting new standards and harmonizing the existing standards in different countries. This work also investigates possible regulatory and legislative barriers for the second-life battery market at the European and international levels.

2. Definitions

The literature contains several legislations and technical standards that do not present a definitive and precise interpretation of the word "*second use*". In other words, it is possible to say that this term still needs a proper definition in the Battery Directives. This lack of well-defined terms, including but not limited to "*second use*", "*reuse*", "*remanufacturing*", "*refurbishing*" and "*recycling*", can cause significant issues among industry stakeholders and pose a significant risk to future management of end-of-life EV batteries. According to the literature, distinguishing between "*second use*" and "*reuse*" is very important. The term "*reuse*" is commonly interpreted as a procedure in which EV batteries or non-waste components are used for their original intended function, namely EV operation [32,33]. Another definition of "*reuse*" described in [34] summarizes the concept as "*the straightforward application of a product with no modifications*". The definition described in [34] differs from the view offered in the Battery Directive. The authors neglect to consider the end application for which the battery will be utilized.

In contrast, the Battery Directive provides a more extensive explanation, indicating that "*reuse*" occurs when the product is deployed for its original purpose. However, it is crucial to note that the definitions presented in the battery directives are unclear and often confused by industry and academia sectors. The Battery Directives must include a legislative alignment toward a uniform set of standards relevant to end-of-life EV battery management to alleviate industry conflicts and ensure a sustainable future for these batteries.

The concept of "*remanufacturing*" has been explained as follows in [35]: " *The largely aesthetic improvement of a product, which may involve making it look like new, with limited functionality improvements*". However, it is not clear what is considered a significant aesthetic improvement of the product. The typical market scenario for remanufactured EV batteries includes a one-year warranty from the remanufacturing entity. Remanufacturing may be a viable option for batteries with diminished capacity. However, the feasibility of this procedure for automotive batteries is questionable, according to the available literature [34]. This is primarily due to the perception that remanufactured batteries may not meet the exact capacity specifications of brand-new batteries. In remanufacturing processes, it is essential to consider the need for legislative guidance and standardization. Without a clearly defined legal framework, the safety and quality of remanufactured batteries may vary. Therefore, establishing standards and protocols for remanufacturing, perhaps as part of the Battery Directives, could assure dependable, safe, and sustainable products while promoting resource conservation and waste reduction.

There is terminological ambiguity between the terms "*repair*" and "*reconditioning*" in the industrial sector. According to existing literature, "*repair*" is typically defined as the correction of one or more malfunctions, whereas "*reconditioning*" refers to the modification or alteration of individual battery components to restore the battery's operational capacity [34,35]. In both of these procedures, however, the assurance typically associated with a new battery, such as a warranty, is typically absent.

The legislative framework could benefit from clarifications regarding the ambiguity of these terms. It is essential to establish a clear, standardized definition within the relevant Battery Directives that outlines the criteria for each process, possibly outlining what procedures constitute "*repairing*" or "*reconditioning*" and what warranty levels, if any, should be associated with each. These legislative details could reduce confusion and improve industry-wide standardization, ensuring stronger consumer protections and safety regulations.

"*Remodeling*" is just changing the aesthetic characteristics of the battery without improving the product's technical aspects. Recycling refers to mining the chemical components of the battery and inserting these chemical components in the process of making a new battery or other product [34,35].

In [34], the authors propose an improvement in the definition of the terms "repair", "*Refurbishment*" and "*reconditioning*" that were presented in [35]. In [34], the authors state that it is necessary to consider the product warranty period and its useful life. To complement the definition of these terms, the authors proposed a new definition for "*remanufacturing*", "*refurbishment*" and "*reconditioning*" stating that for the product to be classified according to these terms, it is necessary to consider the warranty period and the useful life and therefore, the product must be outside the warranty period or have reached the end of its useful life.

The process of disassembling that is inherent to '*remanufacturing*', '*refurbishment*', or '*reconditioning*' the batteries by third parties can expose the industrial secrets of this product and, to maintain the confidentiality of the company's data and know-how, the battery manufacturers avoid and are resistant to allowing other parties to disassemble their product. Most battery manufacturers prefer '*reuse*' or '*second use*' over '*remanufacturing*' since disassembling and opening batteries mean higher cost, time, and energy consumption. According to Directive 2012/19/EU [33], Member States must ensure the removal and disassembly of EV batteries without imposing obstacles or delay and at a reasonable cost. However, this rule becomes mandatory if this fact puts the product's industrial secrets at risk. Battery manufacturers are also motivated to standardize their modules to facilitate recycling and reuse.

Moreover, there are uncertainties about how replacing battery components can affect the patent monopoly and expose the product's industrial *know-how*. Replacement of battery components can occur in three ways [34]:

1. Replacement of battery components and reinsertion of these components in the module with a warranty equal to the time remaining for the Battery to reach its useful lifetime established in the warranty. For example: if the Battery fails after three years of operation in the EV, the Battery may have its defective components replaced and reinserted in the EV with a 5-year warranty (total in 8 years, which is the warranty that manufacturers are expected to provide for the operation of batteries in EVs).
2. Another possibility is the replacement of components and reinsertion of the Battery in the EV, however, with the warranty of a new battery (it is expected to be around eight years). For example: after three years of operation on the EV, there is a battery failure, and it is necessary to repair it. Defective components can be replaced, and the Battery can be reinserted into the EVs. However, with the 8-year warranty, disregarding the three years that the Battery operated in the EV.
3. Another possible scenario is using components from two or more batteries to form a battery that will be reinserted into the EV. For example, the battery in an EV fails, and the manufacturer uses components from another battery or several other batteries to replace the defective component of the defective battery.

However, there is uncertainty in all these scenarios because it is challenging to distinguish remanufacturing from making a "new battery" and whether the industrial secrets of that Battery were exposed through data access and the Battery's electronic circuit [34].

The Battery Directive 2006/66/EC defines the "producer" of batteries as being "the person in a Member State who supplies or makes available to third-party batteries or accumulators (including those incorporated into appliances or vehicles) within the territory of that Member State for the first time on a professional basis". The Directive clarifies the roles and responsibilities within the battery manufacturing and distribution supply chain. Suppose a battery manufacturer or domestic importer transfers a battery to a retail entity. The retail entity is deemed to be the battery's initial market introducer. Following the stipulations of this Directive, the retailer has deemed the producer and is thus held responsible for the ultimate destination of the battery.

This Directive establishes the legal framework for the responsibility associated with positioning batteries on the market and their eventual disposal. The Battery Directives must provide explicit roles and responsibilities to prevent ambiguity and ensure the proper management, recovery, and recycling of spent batteries. This can ensure that all supply chain participants, including manufacturers, importers, and retailers, adhere to regulations intended to promote environmental sustainability and efficient resource management.

Depending on the business model adopted by a company, "ownership" and "user" of a battery may not coincide. This scenario may occur if the battery is still under warranty or if the battery is provided as a service as opposed to a commodity. In the latter scenario, the battery or vehicle manufacturer may assess rental fees based on parameters such as total distance traveled or duration of use.

When batteries are provided as a service, the battery may be owned by the battery manufacturer, the automotive manufacturer, or a car rental company. Therefore, the end user is typically the renter of the vehicle. However, it is essential to observe that in this context, the end user is merely a consumer of the service and does not own the battery. This model adds a layer of complexity to battery lifecycle management and must be considered when developing and implementing regulations and standards about battery usage and disposal.

3. Methodology

To facilitate the exploration, discussion, and juxtaposition of existing legislation and standards, this systematic review adheres to the following steps: (i) identifying relevant research studies, (ii) selectively filtering these studies, (iii) evaluating and summarizing the most pertinent information gleaned from these studies, (iv) categorizing and consolidating analogous information, and (v) comparing and extracting pertinent data. This methodical approach assures a thorough and objective analysis, facilitating an informed comprehension of applicable legislation and standards.

The first stage of the study involved formulating a strict protocol about the work's purpose, i.e., formulating the primary and secondary research questions. During this phase, keywords, the paper's selection criteria, the databases in which the positions will be searched, and the working languages under consideration were also defined. The papers were located by executing the following strings in the database search engines: "*legislation* AND *second-life batteries*", "*extended producer responsibility* AND *lithium-ion batteries*", "*recycling* AND *EV batteries*", "*reuse* AND *EV batteries*", "*battery recycling*," and "*EV standards*".

This systematic review identifies and discusses the most essential technical standards and laws. Table 1 presents the criteria for including and excluding works in this review.

Table 1. Inclusion and exclusion protocol.

Inclusion	Exclusion
Automotive battery legislation.	No having access to the full text.
Legislation and technical standards aimed at reusing and recycling automotive batteries.	It does not discuss technical standards and legislation for batteries.
The paper describes testing and monitoring techniques for EV batteries.	The paper was not written in English.

Source: Prepared by authors.

4. Legislation

EVs are set to solidify their market position further, and it is critical to develop government regulatory frameworks that oversee the battery industry and encourage the adoption of environmentally benign and safe modes of transport. Such public policies could lead the industry toward more sustainable practices while promoting the wider acceptance and advancement of EVs, significantly contributing to reducing greenhouse gas emissions and mitigating climate change. These public policies must be effective, and the industrial sector, universities, and government agencies must participate in preparing them. Universities are neutral entities that can educate the public on the advantages of purchasing second-life batteries, the procedures for operating energy storage systems constructed with second-life batteries, and the operating standards necessary to ensure the expected security of second-life storage systems.

Cooperation across the entire ecosystem of the second-life battery market is critical to making it feasible for industries to implement automotive battery reuse business models and be responsible for generating innovation and new jobs by reusing EV batteries. The implementation of a circular economy in companies can be achieved using components until resources are depleted, and this may be possible through the reuse of batteries and/or the use of valuable battery components, which is possible with recycling. Recycling complements the closed-loop cycle of this product, recovering the chemical components of the Battery and feeding back the loop of the product's life cycle.

For companies to enter the second-life battery market, they must know the legislation, as it may be a barrier to their business. The legislation of a particular country or region can promote the insertion of new companies when it is less stringent and can limit the attraction of new market players compared to when it is more stringent. Therefore, the legislation may enable or restrict the entry of used EV batteries into the market. New legislation or adaptations of existing legislation should be proposed to reduce market uncertainties, making it more transparent and safer for players to invest in the technological development of their processes and promoting the circular economy effectively [36].

Government, industry, academics, and society are alarmed by the rising number of EV sales because it is anticipated that the number of batteries reaching the end of their useful life will rise. Public policies must incentivize businesses to search out methods to manage LIBs that have ended their useful lives. These public policies are also necessary to prevent developing nations from becoming electronic waste dumps and to ensure that no "missing" or "orphaned" batteries are disposed of in inappropriate locations [37].

Legislation is required to ensure that new and used automobile batteries introduced into the market meet performance and safety requirements in primary and secondary EV applications. Several non-governmental groups have led in developing technical standards to facilitate and regulate the use of batteries in EVs and their future life. The International Electrotechnical Commission (IEC), the International Organization for Standardization (ISO), the International Society of Automotive Engineers (SAE), the European Committee for Standardization (ECS), and the European Committee for Electrotechnical Standardization (CENELEC) are among these non-governmental organizations. Furthermore, several national organizations, such as the British Standards Institution (BSI) and the Japanese Industrial Standards Committee (JISC), are involved in the formulation of these standards [38]. This collaborative effort in standardization initiatives aims to provide a high battery performance and safety level, boosting consumer confidence and facilitating EV adoption. Furthermore, these standards are crucial in formulating and implementing important legislation to control the battery business.

Although the standards proposed by various organizations are not legally binding or mandatory for battery and EV manufacturers to comply with, the regulations are constituted as national legal standards, are enforceable by Law, and are promulgated by government authorities. These regulations outline electric vehicles' technical and safety requirements and their batteries.

According to the manufacturers' claims, batteries validated per these regulations should function as expected until the end of their useful life. However, numerous fires originating from electrical equipment and battery-powered vehicles have been documented. The risk of such fire incidents is anticipated to increase for batteries that have been repurposed [39]. This highlights the significance of stringent safety standards and regulatory supervision for both new and used batteries, as well as the need for ongoing review and improvement of these standards and regulations to guarantee the highest levels of safety and performance.

For companies to enter the second-life battery market, the risks of this new business must be mitigated. One of the main risks reported in the literature is the property of the battery. It is still being determined who will be the batteries' owner when they reach the end of their useful life, and there is also no definition of who will be responsible for recycling the electrochemical waste of these batteries. This doubt may be more significant because the ownership of the battery can be transferred over its life cycle. After the battery is placed on the market during the warranty period, the battery may be owned by a specific company (X), a battery manufacturer, an automobile manufacturer, or a car rental company. A company (Y) can provide the battery warranty, and the responsibility for the correct battery use can be with a user (Z). In this case, there will be a chain of responsibility between each party, and one party may be penalized if they do not comply with some of the requirements signed in the contract.

The warranty period may be sufficient to cover the entire period the battery operates on the EV. The Original Equipment Manufacturer (OEM) usually offers a warranty based on two criteria: battery life and mileage traveled. The battery life warranty provided by most manufacturers is eight years or more and is generally valid for up to 100,000 miles traveled (may vary depending on the manufacturer). There is a challenge for battery and automobile manufacturers who offer a product warranty because replacing a battery within the warranty period can range from $5000 to over $16,000. Therefore, battery manufacturers want to avoid having to change the battery during the warranty period, and to do so. They can take measures to monitor the battery from production to consumption [36].

Novel commercial strategies can be based on battery swapping, designed to ameliorate the prevalent 'range anxiety' among EV owners. In this business model, the EV owner drives the vehicle until the battery is depleted, analogous to a conventional vehicle with nonrenewable petroleum reaching a low fuel level. The owner then proceeds to a battery exchange facility analogous to a gas station. The vehicle's depleted battery is replaced with a fully charged one at this location. This allows the battery proprietor to recharge the vehicle in less than 15 minutes, like refueling conventional fuel vehicles.

For this business model to operate without difficulties, the swapped batteries must be compatible with the vehicle, has the exact specifications, are free of unauthorized modifications, and are subject to the same utilization conditions; they must be identical. If an identical match is impossible, a mechanism must be in place to compensate one party for receiving a defective battery [40]. This emphasizes the significance of standardization in battery design and specifications and may result in new regulations or guidelines governing the operation of battery swapping stations.

Legislation should address these different types of business models that may be traditional, or service based. In the traditional business model, ownership of the Battery is transferred to the EV owner and then returned to the OEM, making them responsible for reusing or recycling it. In service-based business models, the battery or car manufacturer rents the battery to a company or a customer and captures value by charging for battery usage according to the number of cycles and the mileage traveled. In this business model, the complexity of battery ownership is reduced because battery ownership remains with the battery manufacturer, automobile manufacturer, or car rental companies. Monitoring the Battery during use is essential to prevent batteries from being used in EVs after reaching the "aging knee" or reaching the limit of 70 to 80% of the remaining charge. The owner of the EV must use the batteries by the terms of use of the batteries and follow the manufacturers' instructions so as not to prevent their reuse [34].

However, business models that offer batteries as a service are still not widely adopted by customers for various reasons, including a lack of promotion, a battery swapping platform, and a battery analytics platform [31,41]. Companies will choose a traditional or service-based business model according to each country's legislation, strategies, and customer acceptance criteria [34]. Furthermore, the battery as a service paradigm is more promising for company fleets, breaking the tight coupling between vehicles and their batteries. The choice of keeping the ownership of the batteries or outsourcing charging services is given to the fleet manager.

It is not yet clearly defined by regulations which will be responsible for the battery after use in EVs. Both battery and EV manufacturers are interested in the owners returning batteries after vehicle use, so they can reuse them in different secondary applications, increasing their revenue. There may be a conflict of interest between battery and automobile manufacturers because neither has an interest in conveying ownership of the Battery to the other, thereby losing access to the profitable second-life battery market. However, the benefits of exploiting the second-life battery market can be shared among the actors if the battery's history is tracked and each actor is compensated in proportion to their contribution (for instance, a company that will incur costs associated with battery recycling will receive a higher value than a company that had a more negligible contribution). It is also possible that the owner of an EV participates in the chain receiving benefits for taking care of the temperature and battery charge, driving on roads with suitable conditions, not having aggressive behavior behind the wheel, and consequently preserving the battery's SoH. On the other hand, a user who stresses the battery during the first life may not receive benefits or be penalized for such potential abuse behavior [25,34,39,42,43].

Transferring battery ownership from battery manufacturers to vehicle manufacturers can expose the product's industrial secrets in some cases, such as (i) if there is a need for data sharing, it is difficult to determine which battery data can be shared in a way that does not expose any competitive advantage of the company and, (ii) if the vehicle manufacturer can open the battery and do the reverse engineering process. Therefore, the transfer of ownership must be done with well-drafted contracts or on a secure data-sharing platform to avoid damage to the brand [41]. Accidents involving batteries can occur, so it can be challenging to determine whether the cause of the accident was the battery manufacturer or the vehicle manufacturer if there is no battery tracking throughout your supply chain [25,34,39,42,43].

In business models in which ownership of the second-life battery is transferred from the battery or vehicle manufacturer to a company responsible for constructing an energy storage system, that company must assume liability in the event of an accident [31]. Therefore, it is probable that the manufacturer of energy storage systems constructed with second-life batteries will require access to all battery data (e.g., temperature, currents) to know the Battery's history and ensure that the Battery will perform as expected in a second application. However, it may not be possible for battery or automobile manufacturers to transfer ownership of the batteries and disclose their data due to the risk of losing their expertise. Conversely, the manufacturer of energy storage systems with second-life batteries must have sufficient knowledge and data to evaluate battery condition, performance, and quality. Suppose battery, vehicle, and energy storage system manufacturers collaborate and share trusted data on the battery, each from their perspective. In that case, second-life battery applications will be simplified, as the battery manufacturer may have knowledge of the battery but be unaware of its behavior in a secondary application. On the other hand, manufacturers of energy storage systems know little about the specific phenomenon that occurs in these batteries and how to integrate batteries into secondary applications (stationary or mobile). For this reason, it is crucial to define technical standards for second-life batteries to conduct a comprehensive evaluation [44].

The players in the battery market must know the legislation so that, according to their responsibilities, they elaborate and modify their business model aiming at the reuse of batteries and optimization of their battery recycling process, and the proper disposal of components that cannot be recycled or reused [36].

Automakers are mandated by EU law to collect batteries at the end of their useful life [36]. If batteries become a new product, responsibility can be transferred [43]. In this instance, there are still unanswered questions regarding the remanufacturing of batteries and the modifications required for second-life batteries to become new products; for instance, does replacing a defective cell render the battery a new product? According to the principle of producers' responsibility, for second-life batteries to be classified as a new product, they must be used for a different purpose, perform a different function, and have a new brand before their ownership can be transmitted [20,45].

These general aims established by the Batteries Directive [46] are shared across the EU, but how each Member State will achieve these goals is subject to national Law. As a result, it is possible that one Member State's recycling process or system may not be suitable for another Member State [36].

The battery guidelines do not classify batteries as hazardous waste. It is important to note that no universal criterion is adopted to declare the Battery as a waste. As a consequence, batteries are classified as hazardous waste from the moment the batteries are declared waste, they receive a set of stricter rules for handling, transporting, and treating this waste, which can prevent reuse and recycling. Currently, the last battery user is responsible for declaring this Battery as a waste regardless of the conditions in which these batteries are found. Therefore, standardizing criteria to classify EV batteries as waste is essential so that the EV owner does not declare the Battery as waste and that OEMs can collect it and reuse it in a less demanding application. In this case, the principle of producers' responsibility must be applied in such a way that the ownership of the battery remains with the manufacturer even though the Battery has a lifetime in an EV [36]. In the EU, Directive 2008/98/EC allows the transfer of batteries from one party that owns them to another so that batteries can be reused instead of being declared as waste.

Countries are expected to implement the concept of paying producers. That is, the producer will be responsible for paying for recycling the product he inserts on the market. Public policies can implement the concept of reward/punishment, which consists of punishing the producer if recycling goals are not met or providing incentives for the producer if that producer reaches the established goals. It will be interesting if these public policies allow producers who exceed the recycling targets to negotiate their credits with other companies that do not reach their goal [19].

4.1. United States of America (USA)

The United States enacted the 'Battery Act' in 1996, officially known as the Law for the Management of Rechargeable Batteries and Mercury-Containing Batteries [45]. This legislation outlines the responsibilities associated with the waste management of Nickel-Cadmium (Ni-Cd) and Small Sealed Lead Acid (SSLA) batteries and mandates labeling and recycling protocols. However, this legal document does not include Lithium-Ion Batteries (LIBs) and Nickel-Metal Hydride batteries

(NiMH) within its scope of application. If they do not contain heavy metals, LIBs are not considered hazardous waste. Including such elements could harm the product's environmental balance and human health. This statement emphasizes that distinct regulatory frameworks govern various types of batteries. Consequently, legislation must continue to evolve to accurately reflect the variety of battery technologies and their respective environmental and health impacts. This ongoing adaptability will ensure that battery technology regulation remains robust, comprehensive, and in step with technological advancement.

LIBs are classified as hazardous waste because they have toxic components and are regulated by the Universal Waste Law, which makes it mandatory to comply with a set of rules and procedures for collection, treatment, and recycling to avoid inappropriate disposal of this type of waste.

Due to the complexity of the concessionaire's regulations, the use of batteries in a second application may be problematic. In addition to utility regulations, federal regulations do not offer grid energy storage facilities any incentives. However, the Federal Energy Regulatory Commission (FERC) approved Order FERC 784 in 2013, recognizing energy storage as a generating resource and allowing financial incentives to be directed to energy storage facilities, thereby encouraging the network connection of energy storage systems [26].

Similarly, Order FERC 792 represented a significant advance by allowing energy storage to connect to the network because it is a qualified energy source. However, a business model that presents renewable energy storage as the primary resource capable of altering the structure of electricity markets is still required [25].

In the year 2019, the government of the USA launched the first US Department of Energy (DOE) LIBs recycling laboratory that was named Recell, led by Argonne National Laboratory (ANL), to boost recycling industries and make them globally competitive by reducing the country's dependence on buying foreign raw materials for LIBs. This laboratory has a focus on four areas as a priority:

- Recycling processes that enable the direct recycling of the cathode so that the recovered materials are reinserted in the Battery, avoiding expensive reprocessing processes;
- Development of recycling technologies that increase company revenue;
- Development of new battery designs that facilitate recycling and reuse;
- Computational tools for modeling and validating recycled batteries.

4.2. South Korea

South Korea is a promising market for second-life batteries, and in the year 2015, a program was started to promote pilot projects that apply second-life batteries as a stationary energy provider with a backup function. Furthermore, South Korea and China are the countries that receive the most used batteries for recycling. According to [1], it is estimated that in 2018 about 69% of the LIBs recycled in the world were recycled in China, and 18.55% were recycled in South Korea.

Unlike other countries or economic regions, such as Europe, which apply producers' responsibility, in South Korea, the Clean Air law states that the government is responsible for recycling or reusing batteries. South Korea has some companies with pilot projects that apply second-life batteries, such as Jeju Techno Park.

4.3. Africa

Africa is a continent that has numerous places where people live in extreme poverty, and electricity can contribute to the region's economic development. In Africa, blackouts and brownouts are also common; therefore, integrating second-life batteries into systems that increase the reliability and availability of energy can be promising for the country's development.

There are some projects like the Faraday Battery Challenge project that investigate economic viability and have implemented an energy storage system built with second-life batteries integrated with photovoltaic systems for homes in Kenya.

4.4. Latin America

Latin American countries have a comprehensive solid waste management regime. However, due to insufficient infrastructure for collecting and recycling EV batteries, around 55% of battery solid waste is sent to landfills.

Countries like Brazil, Chile, Colombia, Costa Rica, Paraguay, and Peru, have regulations, and some countries have industries that recycle lead-acid batteries. However, recycling LIBs is still a challenge for these countries because they do not have industrial facilities with this technology, and therefore the EV batteries are generally exported to other countries in Europe and the USA.

Despite the infrastructure challenges these countries face, there is a desire for these countries to implement the principle of producer responsibility, e-waste collection programs, and batteries. Some Latin American countries, such as Brazil, have extensive territory and a favorable climate for deploying alternative energies such as photovoltaics and wind, and, therefore, business models that connect second-life batteries in parallel with renewable energy systems can be promising and economically viable.

4.5. Europe

In the EU, there is an effort to unify and reduce the difference between battery laws and reduce the impacts of batteries on the environment and society, which is the reason for the development of the Battery Directives. According to the battery guidelines, the producer is responsible for collecting and recycling the batteries. The directives also set the collection targets and the level of efficiency of the recycling process that must be achieved for all types of batteries across Europe [36].

The European Battery Directives classify portable, automotive, and industrial batteries. However, the directives are pretty old. Therefore, EV batteries fall into the "industrial" category and not as "automotive" batteries. As per the Directive, automotive batteries are only 12V lead-acid batteries that power EVs; therefore, EV producers are not responsible for collecting batteries and participating in the recycling targets [36].

The principle that needs to be followed by battery manufacturers is that those who sell the batteries on the market for the first time are required to "take back" the batteries and are also required to treat and recycle the battery residue as well. Therefore, EU Member States must ensure that battery producers protect their products in a way that facilitates batteries to be easily removed from EVs and establish that EV producers are required to provide only information to EV owners about the type of Battery, necessary care, how to remove batteries safely, how to return batteries and what damage the improper disposal of batteries can cause to the environment and society. The battery guidelines provide that batteries can be permanently attached to the EV when the manufacturer needs to protect their product or when non-permanent battery attachment increases the risk of loss of data integrity, performance, continuity of supply, and safety of batteries [36].

According to the Battery Directive 2006/55/EC, at least 50% of the materials used in LIBs and nickel metal hydride must be recycled, i.e., the nickel-cadmium chemicals with the minimum rate of 75%, lead acid must be 65%, and the minimum efficiency for the recycling process of other types of batteries must be 50%, as well as for LIBs [45,51].

On 10th December 2020, the European Commission presented a new regulation entitled "Proposal for a Regulation on Batteries (PRB)" [52] of batteries which aim to ensure that batteries that are inserted in the European market from that date have adequate safety and sustainability. This regulation was incorporated into the Batteries Directive to establish targets for collecting and recycling batteries, as well as the specifications for labeling and removing batteries from vehicles. This regulation also prohibits the sale of batteries that are composed of hazardous substances. An essential feature of this regulation is that it applies to all types of batteries, regardless of their chemical characteristics, size, and design [53].

According to this regulation, as of 1st January 2027, batteries must have declared the amount of chemical components cobalt, lithium, lead, and nickel that have been recycled. The legislation states that by January 1, 2027, companies must recycle at least 12% cobalt, 85% lead, 4% lithium, and 4%

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nickel obtained from batteries. These levels will be increased from 1st January 2035, when companies are expected to recycle 20% cobalt, 10% lithium, and 12% nickel [53].

The Battery Directive 2006/55/EC also prohibits the use of mercury, the incineration, and the disposal of batteries classified as "industrial" and holds the producer responsible for all costs of the information campaign and the costs of collection, transportation, treatment, and recycling. In addition, battery producers and any third-party company acting on behalf of the battery producer cannot refuse to return used batteries regardless of chemistry and origin. In Europe, the battery directive specified in September 2012 that at least 25% of spent batteries should be collected, and in September 2016, that percentage increased to 45%. PRB [53] established that the collection of portable batteries must reach at least 65% in 2025 and 70% in 2030.

The significant policies that regulate the use, collection, treatment, and recycling of batteries in the EU are the Batteries Directive (Directive 2006/66/EC) [45], End of Life Vehicles Directive (Directive 2000/53/EC) [54], Regulation for Registration, Evaluation, Authorization, and Restriction of Chemicals (Regulation (CE) 1907/2006).

Directive 2000/53/EC [54] was the first waste directive in the EU and addressed the end-of-life of automotive components, including batteries. This guideline introduced the concept of expanded producer responsibility and addressed aspects related to the vehicle's life cycle and treatment operations. This Directive also prohibits the use of cadmium in batteries classified as "industrial", a category in which EV batteries are classified.

Several EU countries have proposed policies to encourage second-life batteries in Europe. Directive 2006/66/EC [45] aims to mitigate the environmental impacts of batteries and accumulators by regulating that's collection, manufacture, and disposal. Directive 2006/66/EC established: (i) battery waste management standards, (ii) maximum amounts of some chemicals and metals in batteries, (iii) used battery collection rates, (iv) financial responsibility for programs, (v) the rules covering most stages of this legislation, including labeling, (vi) documentation and administrative matters, and (vii) the obligations of authorities, manufacturers, sellers, and importers.

Directive 2006/66/EC [45] states that EV battery manufacturers or third parties must establish collection schemes for discarded EV batteries that are not collected according to the schemes established by the Directive and that all collected batteries must be recycled. This Directive also establishes that EV batteries cannot be disposed of in landfills and must be recycled according to the established goals.

The principle of Extended Producer Responsibility (EPR) requires producers to be physically and financially responsible for the entire life cycle of products and packaging, so they must have the resources to manage them through reuse, recycling, or energy production and can delegate them to third parties. In addition, EPR establishes that producers are responsible for the environmental impacts caused by their products. In this way, the government transfers responsibility for waste management to the producer through several directives, such as Directive 2006/66/EC.

Article 16 of Directive 2006/66/EC states that the 29 member states of the EU must finance the costs of collecting, treating, and recycling all industrial waste and automotive batteries. In many developing countries, such as Brazil, no regulation still makes battery producers responsible for their products. Therefore, a shared management system is adopted in which manufacturers, municipalities, and consumers share responsibility for managing electronic waste

Directive 2006/66/EC and Directive 2000/53/EC established that a vehicle manufacturer is also considered a battery producer if it places the Battery on the market in the car in a particular country on a professional basis. Directive 2008/98/EC defines using batteries only for the same purpose and original applications. That is, it does not deal with the application of batteries in secondary applications. In addition, Directive 2000/53/EC includes a warning that reuse means that end-of-life EV components should only be used for the same purpose, which also requires policies that aim to enable or encourage the use of second-life batteries in applications other than their first use.

Directive 2008/98/EU [31] presents the definitions of waste and recycling, as well as the concepts of waste management as the extended responsibility of the producer. This legislation encourages the producer (battery manufacturer) to plan recycling and reuse from the product design stage. In addition, producers (manufacturers) are responsible for reducing environmental impacts and other damages that a battery generates at the end of its useful life.

Directive 2013/56/EU [55] replaces Directive 2006/66/EC and eliminates related exemptions for batteries and accumulators containing cadmium in cordless power tools. That Directive also banned the use of mercury in all batteries and changed the batteries' market placement and removal capacity. According to the battery directives, the producer must retake the batteries without possibly refusing the return and cannot charge a fee to accept batteries classified as industrial. However, there is still no definition of who this "producer" would be.

In the EU, only one recycling company, Umicore, performs cathode recycling. Other initiatives exist in France with SNAM and Recupyl, Germany with Redux, and Switzerland with Batrec. However, these initiatives do not yet integrate these materials into producing new cathodes, feeding the production cycle [46].

4.6. China

The Chinese government aims to manage the Battery from the start of production to disposal. In this sense, the government enacted the Technical Policy on the Prevention of Pollution of Discarded Appliances and Electronic Products to reduce electronic waste and promote its reuse and recycling. This policy aims to control the sources of pollution and product recycling, which means that the government is concerned with both the disposal of existing waste and the sources that generate this waste [22].

The technical policy on the Prevention of Pollution of Electronic Devices and Products aims to reduce, minimize and encourage the reuse and recycling of electronic products through measures such as creating a fund to encourage the development of electronic waste recycling systems. By regulating the Recycling and Waste Disposal of Electrical and Electronic Equipment, China applies the producer responsibility principle, which gives the producer the responsibility to pay for the collection, labeling, and recycling of their product [22]. However, this policy does not yet implement procedures that facilitate the collection and logistics of electronic waste, such as batteries [56].

In 2008, China published Administrative Measures for the Prevention of Pollution (MAPP) of electronic waste that aims to apply the principles of producer responsibility and regulate the activities of disassembly, recycling, and disposal of electronic waste [22]. According to MAPP, recycling companies must have an operating license issued by the government and inform which hazardous components are present in the Battery, their composition, expected life, and environmental protection information.

The Ministry of Industry of China has implemented a set of rules that apply the concept of EPR to ensure that EV manufacturers are responsible for collecting, treating, and disposing of batteries. In addition, EV manufacturers must establish service points, collect used batteries, and store and transfer batteries to recycling points.

Battery manufacturers are responsible for automating and standardizing the product, making them easy to disassemble and recycle. The Chinese government also obliges battery manufacturers to provide technical support to EV manufacturers to make battery storage and disposal possible. The work presented in [19] investigates the three possible scenarios for the industry to develop its recycling process. The authors investigated a scenario without government subsidies, with subsidies, and another scenario with implementing a reward and penalty mechanism. Policies were classified into three categories: subsidies, punitive, and traceability [11].

Subsidy policies are government incentives to replace conventional vehicles with vehicles that use new energy, such as EVs. An example of this type of policy was the "Provisional financial subsidy measures for demonstration and expansion of energy-saving vehicles and new energy vehicles in pilot cities," which provide single fixed subsidies paid to vehicle buyers. Vehicles for personal use have not yet been included in the policy. Mention may also be made of the "Provisional financial subsidy measures for the private purchase of a new energy vehicle in pilot cities" and the "Management approach for the private purchase of battery EVs in Beijing (test implementation)" [19].

Punitive policies aim to punish Battery or automobile manufacturers who fail to achieve battery reuse and recycling targets, including if failed to implement government policies. An example of this type of policy is the "Pilot Scheme for EV Battery Recycling System in Shenzhen", which proposes punishing companies that defraud, refuse to provide information, and/or fail to comply with recycling obligations. Finally, the traceability policy consists of policies that track, monitor, and supervise batteries throughout their life cycle in order to assign, among other things, those responsible for batteries during their life cycle [19]. Table 2 presents a summary of the primary laws that exist in China that can contribute to the reuse of EV batteries.

Table 2. Summary of the laws in China focusing on battery reuse and recycling.

Legislation	Year	Description
International transport of dangerous goods by road (in French, Accord européen relatif au transport international des marchandises Dangereuses par Route (ADR))	1957 (updated in 1975, 1985, 2011 and 2015).	ADR is an international agreement that aims to regulate the transport of dangerous goods to reduce the number of accidents caused by the transport of dangerous goods. This agreement defines dangerous goods' packaging, classification, labeling, and certification requirements. Dangerous goods are items and substances that are prohibited or that must be transported under specific conditions and are classified into nine classes, namely: toxicity, corrosivity, flammability, and reactivity. This agreement changed on August 21, 1975, and became effective on April 19, 1985. The agreement still underwent changes and updates in 2011 and 2015.
Law on the Prevention and Control of Environmental Pollution by Solid Wastes	1995 (updated in 2015 and effective in 2016).	This law aims to prevent and control pollution by solid waste and, for that purpose, prohibits the import, dumping, and disposal of solid waste except for cases where the government issues a license.
Law on Clean Production Promotion	2002 (updated in 2012)	This law forces companies to improve their processes to promote clean production. This law provides funds for lime production and can reduce or exempt small and medium-sized companies from value-added taxes to promote clean production.
Waste Electrical and Electronic Equipment (WEEE) Pollution Prevention Administrative Measures (SEPA No. 40)	2008	These administrative measures aim to eliminate pollution and contamination of people due to the disassembly, recycling, and disposal of electronic waste. These measures also present a scheme for licensing companies specializing in recycling electronic waste.
Interim Measures to Encourage the Purchase and Use of New Energy Vehicles in Shanghai	2014	The Shanghai municipal government provided financial incentives for recycling each EV battery. That incentive was 1000 RMB.
EV Battery Recycling Technology Policy	2015	Through this policy, the government aims to provide financial incentives for second-use companies and material extraction companies.
Circular Economy Promotion Law	2018	This law aims to promote the circular economy in companies, improve resource use efficiency, avoid environmental damage, and promote sustainable development. In order to achieve these objectives, this law implements a system of planning and statistical analysis of waste, and the current scenario implements fiscal and tax

		control and applies the EPR system. This law also provides tax incentives, monetary funds, loans, and credits to enable companies to implement the circular economy.
Pilot Scheme for EV Battery Recycling System in Shenzhen	2018	This public policy punishes industries that commit fraud or refuse to comply with recycling obligations. If the company does not fulfill its recycling obligations, its information will be inserted in the credit protection agencies.

Source: Prepared by authors.

5. Discussion

Technical standards and legislation can help industries change their traditional economic model to the circular economy model. Public policies can help participants in the second-life battery market and companies focused on recycling to make decisions and develop viable business models. However, legislation and technical standards for both recycling and second-life batteries are still in their infancy and are insufficient to mitigate all risks in the EV battery business. There are doubts regarding the ownership of batteries and what responsibilities will be assigned to battery producers and owners throughout their life cycle.

However, legislation and technical standards for both recycling and second-life batteries are still in their infancy and are insufficient to mitigate all risks in the EV battery business. There are doubts regarding the ownership of batteries and what responsibilities will be assigned to battery producers and owners throughout their life cycle.

China and Europe have led the way in drafting legislation and technical standards and have made significant progress. Among these policies, the major ones are the principle of EPR, and the leading technical standard for reusing batteries is UL 1974. Europe and China have clear targets for battery recycling, i.e., Europe established that 50% of the weight of batteries that reach the end of their useful life be recycled, and China considers the targets different according to the applied recycling process.

Developing countries still face shortages of technical norms and standards and are lagging in implementing battery reuse and recycling. It is expected that the standards in these countries will be developed based on the standards that already exist in Europe, China, and the USA and that companies will import the technology to implement the reuse and recycling of batteries from developed countries.

The current scenario of economic crisis motivated by the pandemic caused by Covid-19, associated with the implementation of the principle of producer responsibility in some countries and the emergence of new regulations has motivated the industries to seek cooperation to survive in the increasingly competitive market and achieve the goals of recovery, recycling, and reuse of EV batteries. There is still no definition of what modifications to used batteries are sufficient to consider the remanufactured Battery or whether a new product has been developed. The definition of these parameters is fundamental to warranty the intellectual protection and the protection of the industrial secrets of the product. Table 3 presents a comparison between the different regulations and standards that exist for recycling and reusing batteries.

Table 3. Summary of the principal regulations in the area of batteries in the different regions of the world.

Status	China	Europe	USA	Japan	Korea	Africa	South America	India
Regulations on EV batteries for recycling	✓	The Battery Directive 2008/98/EC allowed batteries to be transferred from one party to another without being declared waste.	-	-	Clean Air Conservation was announced in 2004 and implemented in 2005 to monitor the pollution of cars with diesel emissions.	-	-	-
General Regulation on LIB Batteries	✓	✓	The USA has federal waste regulations that regulate batteries according to the status of each type of Battery.	The Law on the Promotion of the Effective Use of Life Resources promotes the reduction of waste, reuse, and recycling of batteries.	-	-	-	-
Regulations on second-life batteries	✓	The Battery Directive 2008/98/EC allowed batteries to be transferred from one party to another without being declared waste.	-	-	Clean Air Conservation was announced in 2004 and implemented in 2005 to monitor the pollution of cars with diesel emissions.	-	-	-
Extended Producer Responsibility	✓	✓	✓	-	-	-	Some countries, such as Brazil, but not all countries in South America.	-
Recycling Efficiency Target	✓	-	-	-	-	-	-	-

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Leading players who are investing in second-life battery projects	The legislation establishes that the efficiency for recycling Ni, Co, and Mn must be 96% for the Hydrometallurgical process and 97% for the Pyrometallurgical recycling process to obtain nickel and rare earth.	The battery directive states that 50% of the total weight of batteries that reach the end of their useful life must be recycled.	-	-	-	-	-	-
Leading players who are investing in second-life battery projects	Yinlong Energy, Build Your Dream (BYD), GreatWall Power	Daimler GETEC/The Mobility House Remondis/ EnBW (Germany), Renault (UK), Umicore (UK), Connected Energy (UK), Relectrify (Australia), Bosch (Alemanha), Siemens (Alemanha), Vattenfall (Germany), BMW (Germany), Audi (Germany), Volkswagen (Germany), Fortum (Finlândia), Acceleron (UK).	General Motors, ABB, Spires New Technologies Inc (SNT), Chevrolet, Florida Power & Light, FreeWire.	4R Energy, Honda, ITAsset Partners (ITAP), Mitsubishi, Nissan.	-	Eaton	-	-
Major Recycle Associations of LIB	Waste Battery Recycling Committee China	European Battery Recycling Association and ReCharge	NAATBatt	Battery Association of Japan	Korea Battery Industry Association	The South African EV Association is still looking for	-	-

	Battery Industry Association					viable projects for battery recycling.		
Summary	Current policies aim to promote the reuse of batteries through recycling by encouraging advertising campaigns, transparency, and research and development projects. Policies focusing on recycling aim to improve the efficiency of the recycling process and process technologies.	The policies seek to enable the reuse and recycling of EV batteries. Europe has some industrial facilities with mature technology recycling processes, and EV manufacturers are aware of the benefits of battery reuse and recycling.	There is still no specific legislation for EV batteries. The main recycling the laboratory is ReCall, led by Argonne Laboratory.	Japanese car manufacturers have proposed several battery recycling projects. The Electrical and Material Safety Act imposes a set of rules for LIBs. Japan had the first UL 1974 certified group, the joint venture (Sumitomo and Nissan) called 4R Energy.	South Korea still seeks, through projects in cooperation with universities, to have its first EV battery recycling facility.	-	South American countries still face problems managing lead acid batteries that reach the end of their useful life. The insertion of LIBs in the EV market will be a problem yet to be solved. No specific laws still regulate the recycling and reuse of this type of battery.	India also has no regulations that encourage the reuse and recycling of EV batteries.

Source: Prepared by authors.

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Tests are essential to protect operators who often rely on battery specification sheets, and testing procedures prove that battery capacity values can differ by up to 20% from those specified on specification sheets. For this reason, the testing procedures need to be more assertive, increase reliability, and lower the risk of defects due to nonreal performance.

The development of new standards will ensure that batteries have satisfactory performance and safety. Second-life batteries need to be evaluated to determine whether they will perform and perform appropriately in a second application. For this, these batteries are subjected to a set of thermal and electrical tests that must be non-destructive, as well as being able to assess the main parameters of the batteries, among them, the SoH, the State of Charge (SoC), the voltage and the current [62].

In 2018, the UL 1974 standard was published to certify that the process of reusing batteries that were used initially is configured for a specific application, such as EVs, so that they can be used in another application, for example, in energy storage. Although this standard primarily focuses on reused lead-acid batteries, it also includes reused EV batteries and can increase customer confidence to enable second-life battery business models [62].

This standard is the first "manufacturing process" to ensure safety for remanufactured batteries in secondary applications. To assess the condition of the batteries, this procedure considers the tracking of charge and electric discharge rates. However, despite the publication of this standard, it is still challenging to identify and map all battery characteristics considering the different chemicals and variations in the design [62].

This protocol ranges from the batteries' classification and a visual assessment to the internal processes' audit process and the safety criteria necessary to guarantee the functioning of the companies responsible for reusing the batteries. To obtain UL 1974 certification, reused batteries must also obtain UL 1973 certification [50].

The UL 1974 standard recommends that the following tests be carried out for the certification of batteries [50].

- Measurement of Open Circuit Voltage (OCV);
- Insulation test for high input voltage;
- Capacity test;
- Measurement of internal resistance;
- Verification of Battery Management System (BMS) control algorithms and protection components;
- Test cycle discharge/charge;
- Self-discharge.

The UL 1974 standard declared the expiration date of the batteries to be mandatory. This had not yet been specified in previous battery standards, and it is a challenge for battery manufacturers to estimate their lifetime because the charge status of the batteries is not 100%, and the lifetime of the batteries will depend on a wide variety of factors such as conditions of use and application. Although this new standard helps to classify the condition of reused batteries, it is still not enough to ensure that batteries maintain the open circuit voltage, but when in operation, the voltage drops, and they are short-circuited. It is also unclear whether this pattern is sufficient to predict battery failure.

6. Conclusions

Public policies increasingly attribute responsibility to the producer for providing adequate conditions for EV batteries to be properly collected, treated, and recycled. Despite this, the lack of public policies is still a barrier for new business models to be developed and, therefore, it is essential that new laws and updates to existing laws that define some terms such as “second use” to encourage companies to think about recycling from the product design stage and better define your strategies for entering the market by improving your recycling structure and implementing the circular economy effectively.

Business models that aim to provide the battery as a service, not a product, are more promising. Companies are also interested in owning battery ownership throughout their life cycle to increase revenue. This type of business model will motivate and give confidence to the customer to use a battery in their EV or an energy storage system built with used batteries ensuring that the battery will have adequate performance and safety.

There are limited specific United Kingdom or European standards for reusing lithium-ion batteries (LiBs) in the current context. This represents a significant regulatory void and may have far-reaching consequences. On the one hand, the absence of established standards may hinder the growth and development of the second-life battery industry, as safety, performance, and accountability may be dubious for businesses. Alternatively, the absence of regulations could inadvertently encourage unsustainable or unsafe practices, posing potential environmental and safety hazards. In addition, this regulatory void could restrict opportunities for maximizing the total lifecycle value of LiBs, resulting in the loss of economic and environmental efficiencies. In order to encourage the safe, sustainable, and economically viable second-life use of LiBs in the United Kingdom and Europe, it is crucial to develop specific and exhaustive standards.

The existence of several EV battery chemicals imposes uncertainty on the market and discourages producers from investing to make the company's recycling process more efficient. New standards aimed at reusing and recycling batteries should consider the different chemicals that LIBs have and should be quick and inexpensive to make the circular economy economically feasible in industries.

7. Patents

There are no patents resulting from this work.

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