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Stationary, Second Use Battery Energy Storage Systems and Their Applications: A Research Review

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Abstract: The global demand for electricity is rising due to the increased electrification of multiple sectors of economic activity and an increased focus on sustainable consumption. Simultaneously, the share of cleaner electricity generated by transient, renewable sources such as wind and solar energy is increasing. This has made additional buffer capacities for electrical grids necessary. Battery energy storage systems have been investigated as storage solutions due to their responsiveness, efficiency, and scalability. Storage systems based on the second use of discarded electric vehicle batteries have been identified as cost-efficient and sustainable alternatives to first use battery storage systems. Large quantities of such batteries with a variety of capacities and chemistries are expected to be available in the future, as electric vehicles are more widely adopted. These batteries usually still possess about 80% of their initial capacity and can be used in storage solutions for high-energy as well as high-power applications, and even hybrid solutions encompassing both. There is, however, no holistic review of current research on this topic. This paper first identifies the potential applications for second use battery energy storage systems making use of decommissioned electric vehicle batteries and the resulting sustainability gains. Subsequently, it reviews ongoing research on second use battery energy storage systems within Europe and compares it to similar activities outside Europe. This review indicates that research in Europe focuses mostly on "behind-the-meter" applications such as minimising the export of self-generated electricity. Asian countries, especially China, use spent batteries for stationary as well as for mobile applications. In developing countries, off-grid applications dominate. Furthermore, the paper identifies economic, environmental, technological, and regulatory obstacles to the incorporation of repurposed batteries in second use battery energy storage systems and lists the developments needed to allow their future uptake. This review thus outlines the technological state-of-the-art and identifies areas of future research on second use battery energy storage systems.

Keywords: low-carbon society; stationary energy storage system; second use; hybrid storage; battery applications; trends; barriers; outlook

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1. Introduction

Europe and the rest of the world are forging a path towards a low-carbon future by establishing targets for drastically reduced environmental impacts as described in the Paris Agreement [1]. Clean, renewable sources like wind and solar energy must be used, in combination with the electrification of sectors of activity, to reach international sustainability targets [2–4]. However, the transition from fossil fuels to low-carbon energy sources is hindered by the ever-increasing global demand for energy [5] as well as the lack of reliability of renewable sources. Apart from the obvious transition on the supply side, the transition to a low-carbon society will also require that the traditional processes on the demand side, like transportation, be electrified (Figure 1) [6,7]. As increased electrification causes high stress on the electrical grid, there is a need for either an expansion or upgrade of the electrical grid or measures to compensate for imbalances between supply and demand [8,9]. The buffer capacities of today's electrical grids are not able to handle this challenge [10].

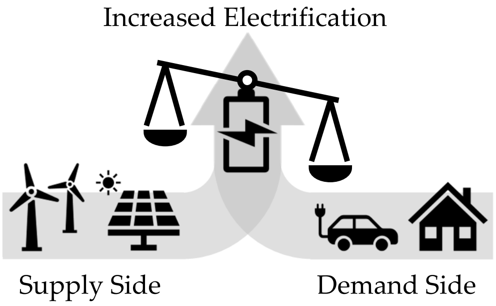

Figure 1. The pathway towards a low-carbon society utilizing cleaner production and consumption of electric energy.

The key to a sustainable future for Europe is improving the European electrical grid and buffer capacities. This involves making the grid (1) more flexible to integrate increased electricity generation from renewable sources [11] and (2) more efficient and reactive to meet future demands from increased electrification, especially from the transport sector. Investing in new grid infrastructure or upgrading it is costly [12]. Buffer capacities, especially when close to generation and demand, help smooth supply and demand profiles and relieve grid fluctuations. This means that new infrastructure or expensive upgrades to the grid can be partially avoided by adding buffer capacities [13]. Buffer capacities are mainly found as centralised, large-scale power plants, such as pumped storage hydropower plants. Unfortunately, such power plants are limited by infrastructural considerations [14]. Therefore, additional modular systems are needed to compensate for supply and demand imbalances [15]. Battery energy storage systems (BESSs) have been investigated as an alternative to solve the grid and buffer capacity challenges of the future [16–18]. By using batteries, it is possible to balance demand and thus ensure that transient renewable energy, such as wind and solar energy, can be used when needed, not just when generated [16]. BESSs normally do not reach the storage capacities of large-scale units and are mostly found as distributed, small-scale units. They can work as small-scale, standalone units or large capacity, aggregated units [19]. Results from the large research project MONA (Merit Order Netz-Ausbau) in Germany [20] proved that storage systems in general, and BESSs in particular, can reduce the need for such expansion. However, this requires cost-effective BESSs [21].

A solution to reduce costs for stationary applications is to rely on decommissioned electric vehicle (EV) batteries [17,22]. In this paper, the term EV refers to full battery electric vehicles (BEVs) as well as plug-in hybrid electric vehicles (PHEVs). BEVs mostly refer to vehicles that run entirely on electricity, while PHEVs are hybrid electric vehicles whose batteries can be recharged by external electricity sources as well as by their internal combustion engines. The average battery capacity of BEVs and PHEVs is currently around 50 kWh and 11 kWh, respectively [23]. In 2019, the total stock of EVs exceeded 7.2 million units. Based on the Sustainable Development Scenario, a global market share of 30% could be reached by 2030 [24]. BEVs and PHEVs combined now represent 3% of all vehicles sold in the European Union (EU) (Figure 2a). Norway is the global leader in EV sales based on the market share (Figure 2b), where nearly 56% of new vehicle purchases in 2019 were either hybrid or fully electric [25]. This could be a model for the EU to follow. With the rising deployment of EVs, a large number of decommissioned batteries will be available for the foreseeable future. These, in turn, offer an economic and sustainable source for stationary BESSs.

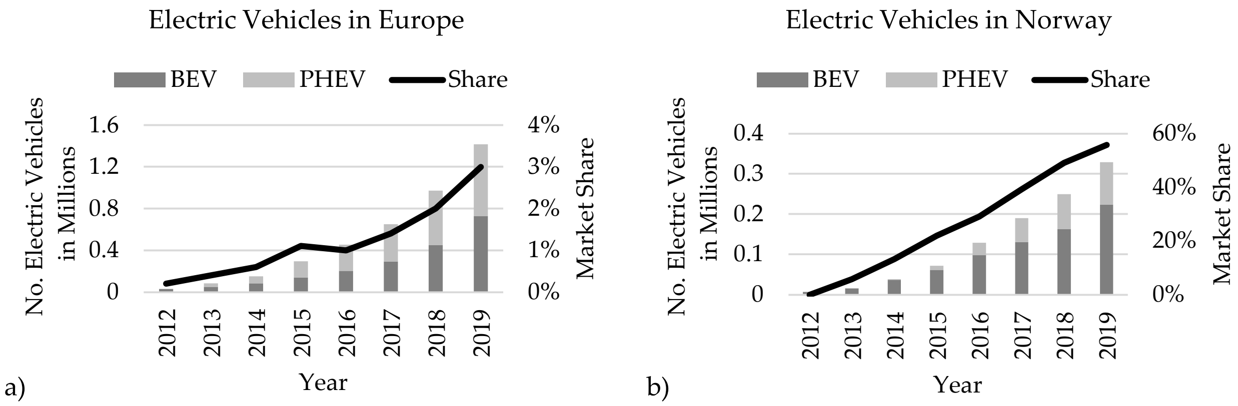

Figure 2. Number and share of electric vehicle sales in (**a**) Europe and (**b**) Norway, adapted from [25].

In EVs, the entire battery is often referred to as a battery pack. The battery pack typically consists of several battery modules which are comprised of individual battery cells in either a pouch, cylindrical, or prismatic cell format [26] (Figure 3).

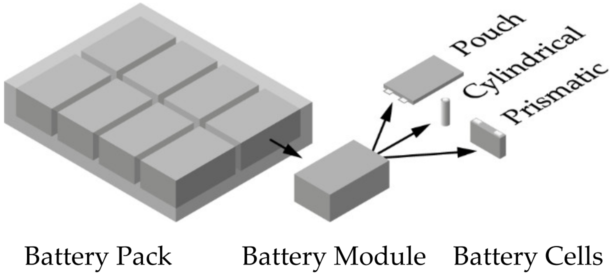

Figure 3. Battery assembly in an electric vehicle.

EV batteries are replaced before they reach their physical end of life, typically when they reach 70–80% of their initial capacity due to limited cruising range. Depending on the cell chemistry and the cell design or cell assembly, such batteries can still be used for less-demanding applications such as stationary BESSs [27]. The ageing of the battery is influenced by several factors such as temperature and driving style [28]. The literature is limited when it comes to the differences in capacity fade between BEVs and PHEVs. Second use also reduces the ecological footprint by reducing the need for new batteries (and thus new materials) for storage systems as well as by extending the lifespan of existing batteries and slowing the flow of used batteries that have to be recycled [29]. As an example, the calendar life for lithium-ion batteries is nearly 20 years [27,30] and the EV use phase is just about 8 years [31] (dependent on driving and charging behaviour [32]).

The second use storage system potential can be estimated by simulation. Different types of models are used to investigate the battery design, estimate the performance, and simulate electrical circuits. M. Chen et al. [1] differentiated between (1) electrochemical models to understand the battery fundamentals and optimise the design, (2) mathematical models to predict system-level behaviour such as efficiency or capacity, and (3) electrical models (equivalent circuit models) to investigate the storage system integration. Electrical models can further be classified as (1) simple models, (2) Thevenin-based models, (3) impedance-based models, (4) runtime-based circuit models, (5) combined electrical circuit-based models, and (6) generic-based models [33]. In addition, model extensions can be added to describe the state-of-health/lifetime [34–36] and the optimal electrical components/equipment replacement [37,38]. The models can be used in optimisation algorithms to determine the battery operation for different applications. To verify the simulation results and further assess the BESS potential, field tests are performed. To test the BESSs in the field, research and industrial stationary storage units have been developed, built, deployed, and operated. Industrial storage systems mostly focus on one of the few economically feasible applications of BESSs: the provision of primary frequency control [39–43]. Such storage systems have been deployed and are operating in several EU countries, mostly as a joint venture between vehicle manufacturers and utility companies. This review paper investigates research activities on second use stationary BESSs in Europe. After describing how literature for the review was selected and clarifying the most important terms and definitions around second use, suitable battery applications are reviewed. A mapping of research-based second use BESSs in Europe is used to give an indication about current activities and is followed by a brief discussion about the trends outside of Europe. Finally, barriers and future developments are examined.

2. Second Use: Terms and Definitions

Various terms and definitions are used to describe the process of using spent batteries in a new, different application. For example, the terms "second use" [44], "second life" [45], and "reuse" [31] have all been used for such a purpose. In addition, these terms have been used in various EU legislation, but no proper definitions are available [46]. Those phrases can have different meanings even though they describe the same goal, which is to extend the lifetime of a product or its components in order to reduce or eliminate waste. There are two approaches to achieve this goal: (1) a product or its components are used again for the same purpose, application, function, or context for which they were initially developed, and placed on the market, or, (2) a product or its components are used for a different purpose, application, function, or context.

2.1. Reuse

Reuse means that a product or its components are reviewed (diagnosed), repaired, restored, refurbished, reconditioned, replaced, rebuild, remanufactured, or reassembled with original new or used components resulting in second-hand products or components which are used again for the same purpose, application, function, or context. It is a common procedure for internal combustion engines in vehicles, since broken engines can be remanufactured and reused for much lower environmental and economic costs than manufacturing new ones [47]. Similarly, in the case of an EV, it means that the battery or its components are used again in an EV as a traction battery.

2.2. Second Use

Second use, also called second life, means repurposing a product or some components used for a different purpose, application, function, or context. Second use also means that the legal liability lies with the new producer. Using internal combustion engines from a vehicle in a generator unit would be considered second use. Similarly, using an EV battery or its components in a stationary energy storage system would be considered second use.

3. Method

This work is based on a structured literature review and a consultancy of academic, legislative, and industrial stakeholders. The research articles, reports, documents, etc. this review is based on, were found using databases of academic publishers such as Elsevier, MDPI, and IEEE, and in general, using search engines such as Google. The terms and definitions listed in Section 2 were used as keywords in combination with "stationary battery energy storage" and "applications". Project owners were contacted to back up the information given in Section 2. The verified information was stored, sorted, and structured in a database before the most relevant data was extracted for this review paper. In addition, the members of the European Technology and Innovation Platform—BatteRIes Europe [48] provided valuable input for each Section of this paper.

4. Battery Energy Storage Systems: Applications

G. Fitzgerald et al. [49] identified three different stakeholder groups and 13 different application areas for BESS in general, whereas G. Reid et al. [50] identified four stakeholder groups and 14 possible application areas, in particular for second use BESSs. G. Fitzgerald et al. [49] identified transmission system operators, utility companies, and customers as stakeholders while G. Reid et al. [50] identified utilities companies (including transmissions system operators), commercial, industrial and residential consumers, and off-grid systems as stakeholders. G. Reid et al. [50] also included off-grid systems under applications. Based on these reports, three combined stakeholder groups can be identified, namely "in-front-of-the-meter", "behind-the-meter", and "off-grid". "In-front-of-the-meter" refers to power that must pass through an electric meter before reaching a customer, while "behind-the-meter" refers to power that can be used on-site without passing through a meter. With such a classification, the stakeholder groups and corresponding application areas are listed in Table 1.

Table 1. Stakeholder groups and corresponding application areas [49,50].

Stakeholder Groups	Applications	Description
In-front-of-the-meter	Energy arbitrage	Electrical energy is purchased and stored when the energy prices are low and sold or used when the energy prices are high.
	Frequency control	Frequency control ensures that the grid frequency is held within a defined tolerance band to avoid grid instability. Primary, secondary, and tertiary frequency control, which act in different time domains, are done to balance supply and demand.
	Spinning/Non-spinning reserve	Spinning reserves are online generation capacities that can compensate for unexpected events like generation outages. Non-spinning reserves can compensate for such unexpected events within a short period of time.
	Voltage support	The grid voltage is maintained within a defined range to ensure that real and reactive power generation matches demand.
	Black start	Black start generation units are needed to restart generation at larger power stations, mainly thermal power stations, after a blackout, to recover the grid operation.
	Resource adequacy	Existing power plants can be combined with energy storage units to manage peak demand without adding generation capacity, thus reducing investment costs and associated risks.
	Transmission/Distribution deferral	Reduces utility investments in transmission/distribution system upgrades which are necessary to meet future demands.
	Transmission congestion relief	In order to reduce congestion along transmission lines with high demand and the resulting requests for redispatch [51], battery storage units can be installed downstream of the transmission lines.
Behind-the-meter	Time-of-use bill management	Shifting energy purchases to periods of low prices and using stored energy when the prices are high (price incentivised demand optimisation [52,53]).
	Increased self-consumption	Minimising the export of locally generated electricity, e.g., by photovoltaic systems, while increasing self-consumption, or by using locally generated electricity to provide an auxiliary source for power demands such as EV fast-charging.
	Demand charge reduction	Demand reduction (peak shaving) during times of peak demand to reduce the quantity of power bought at premium prices. This applies mostly to commercial customers but, based on regional/national tariffs, also to residential customers.
	Backup power	Backup power can be obtained from storage systems for short or medium time periods if a grid failure occurs.
Off-grid	Off-grid	Off-grid systems are systems that are not connected to the main electrical grid and are mostly small. Such systems need generation units, consumers, as well as buffer capacities to balance supply and demand.

5. Second Use Storage Systems in Europe

Second use storage systems based on EV batteries are being developed, implemented, and tested by industries, private consumers, and research projects. Industrial-scale second use storage systems are mostly business-to-business solutions based on battery packs, with a capacity ranging from several kWh up to several MWh [43,54–59], and internal research and development projects with a capacity of several kWh [60,61]. These storage systems are often built by industry consortia consisting of EV manufacturers, utility companies and technology developers, and are mostly used for primary frequency control and demand charge reduction. Second use storage systems for private consumers are often used in combination with a photovoltaic system to increase their self-consumption. Such systems are mainly based on battery modules and reach a capacity of up to several kWh. Such storage systems are available on the market as out of the box solutions [62,63] or may be custom built. Global, ongoing, custom second use projects are listed in the second life storage database [64]. In Europe, second use, especially on the battery cell level, is uncommon due to the high effort and labour costs for repurposing [65].

The applications and properties of storage systems in research are not quite as transparent. In Table 2, second use storage systems being researched in the EU and European Free Trade Association are mapped and classified based on Table 1. It shows that nearly all storage systems are based on lithium-ion batteries from BEV, mostly making use of spent batteries from Nissan, Renault, or Volkswagen which mainly use NMC (nickel-manganese-cobalt, the cathode composition) based battery chemistry. Some storage systems combine old and new cells, but always with the same chemistry. The capacities and power in-/outputs are rather low compared to industrial storage systems. Further, Table 2 shows that most storage systems in research are developed for "behind-the-meter" applications, most commonly to increase self-consumption. Often, several applications are investigated, also partly by simulation (sim), but not simultaneously.

Table 2. Second use energy storage systems in Europe and their applications.

State	Project	Duration	Battery Technology	First Use	Applications	Comment	Capacity (kWh)	AC Power in/out (kW)	New/Old	Source
Austria	Smart City Rheintal	2012–2015	Sodium– nickel chloride	Think City	- Time-of-use bill management - Energy arbitrage	Two storage systems	28.2	1.5/8.2	0/100	[66]
							28.2	1.5/8.2	0/100	
	SCORES	2017–2021	Lithium-ion	Formula E charging stations	- Increased self-consumption		31.95	80/80	0/100	[67,68]
Denmark	READY	2014–2019	Lithium-ion	Nissan Leaf	- Increased self-consumption	Hybrid storage using spent and new batteries	130	40/40	60/40	[69,70]
France	ELSA	2015–2018	Lithium-ion	Renault Kangoo	- Energy arbitrage - Demand charge reduction - Resource adequacy (sim)	Applications tested and simulated	88	80/80	0/100	[71,72]
	ELSA	2015–2018	Lithium-ion	Nissan Leaf	- Energy arbitrage - Demand charge reduction		192	144/144	0/100	[72,73]
	SCORES	2017–2021	Lithium-ion	Formula E charging stations	- Increased self-consumption		63.9	160/160	0/100	[67,68]
	IRIS	2017–2022	Lithium-ion	Renault Kangoo	- Increased self-consumption		30	10/10	0/100	[74,75]
Germany	ELSA	2015–2018	Lithium-ion	Renault Kangoo	- Increased self-consumption		66	72/72	0/100	[72,76]
	ELSA	2015–2018	Lithium-ion	Renault Kangoo	- Energy arbitrage (sim) - Frequency control (sim) - Voltage support (sim) - Transmission congestion relief (sim) - Increased self-consumption	Applications tested and simulated	66	18/72	0/100	[72,77]
	NETfficient	2015–2018	Lithium-ion	Nissan Leaf	- Increased self-consumption	Two storage systems	24	5/5	0/100	[78–80]
							24	5/5	0/100	
	Mobility2Grid	2019-	Lithium-ion	Audi e-tron	- Different “in-front-of-the-meter” and “behind-the-meter” applications are planned	Applications planned	1900	1250/1250	0/100	[81]
Italy	ELSA	2015–2018	Lithium-ion	Renault Kangoo	- Frequency control - Voltage support - Increased self-consumption - Demand charge reduction	Applications tested in two different scenarios	66	72/72	0/100	[72,82]

Table 2. *Cont.*

State	Project	Duration	Battery Technology	First Use	Applications	Comment	Capacity (kWh)	AC Power in/out (kW)	New/Old	Source
Nether-lands	Pampus Project	2015	Lithium-ion	Custom made electric VW Golf	- Off-grid	System upgrade from 24 kWh to 40 kWh, recently replaced	24 to 40	30/30	0/100	[83–87]
Spain	Sunbatt	2014–2015	Lithium-ion	VW Golf GTE	- Increased self-consumption	System setup further used in simulation studies	35.2	40/40	0/100	[88]
	Stardust	2017–2022	Lithium-ion	Nissan Leaf	- Increased self-consumption	Three storage systems, partly under development	60	60/100	0/100	[89,90]
							200	40/40	0/100	
							60	—	0/100	
	EV-Optimanager	2015–2019	Lithium-ion and lead-acid	Lithium-ion from renewable facilities, lead-acid from forklifts	- Time-of-use bill management - Increased self-consumption	Two lithium-ion storage systems	12 each	10/10 each (DC/DC converter)	0/100 each	[91,92]
						One lead-acid storage system	12	10/10 (DC/DC converter)	0/100	
	REFER Project	2016–2019	Lithium-ion	Renault Kangoo	- Time-of-use bill management - Increased self-consumption		23	10/10	0/100	[93]
Sweden	IRIS	2017–2022	Lithium-ion	Volvo Bus	- Time-of-use bill management - Increased self-consumption - Demand charge reduction		196	84/84	0/100	[94,95]
United Kingdom	ELSA	2015–2018	Lithium-ion	Nissan Leaf	- Resource adequacy - Increased self-consumption - Demand charge reduction (sim)	Applications tested and simulated	48	10/36	0/100	[72,96]
Norway	ReLIEVe	2018	Lithium-ion	Nissan Leaf	- Time-of-use bill management - Energy arbitrage		3.5	3.3/3.3	0/100	[97]
	Energipakke Borg Havn	2018–2020	Lithium-ion	Different EV manufacturers (Mitsubishi, VW, Tesla)	- Increased self-consumption	Each storage system is built from a different EV battery	120	20/20	0/100	[98,99]
							90	10/10	0/100	
							120–150	60/60	0/100	
	INVADE	2017–2019	Lithium-ion	Nissan Leaf	- Time-of-use bill management - Increased self-consumption	15 storage systems	4.6 each	6/6 each	0/100 each	[100–102]
						6 storage systems	10.08 each	6/6 each	0/100 each	
Switzer-land	Second Life	2017-	Lithium-ion	KYBURZ DXP vehicle	- Increased self-consumption	Several pilot storage systems	6	3/3	0/100	[103]
							8	3/3	0/100	
							10	3/3	0/100	

6. Trends and Developments Outside of Europe

As the Global EV Outlook 2020 [24] shows, the worldwide stock of EVs (BEVs and PHEVs) has passed 7.2 million units in 2019. This is an increase of 40% from the previous year. In particular, there were 3.3 million EVs in China in 2019, which is about 47% of the total EV fleet. After China and Europe, the United States (US) are the third largest EV market [24]. Thus, substantial numbers of decommissioned EV batteries will be available in the near future for second use applications. Globally, second use storage systems may serve different applications than the ones in Europe. Therefore, the trends and developments are mapped for developed countries in North America and Australia (including New Zealand) and for developing countries in South America and Africa, and Asian countries, especially for China, Japan, and South Korea.

6.1. Second Use in North America and Australia

The US Department of Energy (DOE) published a report on Solving Challenges in Energy Storage which describes the critical need for energy storage in the electrical grid [104]. It mentions that advanced energy storage systems such as second use BESSs built from spent EVs provide a solution to some of the most critical issues associated with all stakeholder groups, as defined in Table 1. The National Research Council of Canada considers stationary, second use storage systems as a cost-efficient solution in the electrical grid [105]. The governments of Australia and New Zealand have discussed and support repurposing EV batteries for second use storage systems [106,107]. Various projects and applications can be found across North America and Australia. The applications are similar to the ones in Europe, listed in Section 4, and are discussed in detail in [49,50]. BESSs are used for commercial home applications [108,109], research storage system applications [110,111], and industrial applications [112,113]. Ongoing projects show that most second use projects rely on entire battery packs or battery modules (depending on the storage size) due to the high repurposing effort and labour costs.

6.2. Second Use in South America and Africa

In South America and Africa, most storage projects are based on backup power and off-grid applications to power critical infrastructure such as hospitals, schools, and electric lighting. Backup power systems are deployed locally in urban areas to counter frequent power outages. In areas where suitable grid infrastructure is lacking, off-grid solutions, comprised of an energy source such as a photovoltaic system and a battery storage system, offer remote electricity supply [114]. Several projects, supported by EU and US DOE grants, aim to establish off-grid solutions with second use batteries which are generally based on battery modules in the low kWh capacity range [114–116]. On account of their high initial prices and due to limited electrical grid infrastructure, EVs are less common and cannot compete on prices with vehicles with an internal combustion engine at present [117]. Therefore, developing countries are currently dependent on second use batteries and technologies from Europe, North America, Australia, New Zealand, or Asia.

6.3. Second Use in Asia

Second use of EV batteries in Asia is dominated by China, South Korea, and Japan. The application areas are from private consumer applications [118] to industrial applications [119,120] supported by research activities on second use storage systems [121–123]. Unfortunately, there is limited information available about ongoing activities with respect to second use and recycling of batteries, especially for China, even though they are the largest battery manufacturer and consumer in the world [124]. In China, the second use market is developing very quickly, mainly due to government policies and the rapidly growing EV market [125]. The application range is enormous compared to other countries. Even in mobile applications such as utility vehicles, repurposed batteries from EVs are considered [126]. GEM, Chinas largest recycling centre for waste batteries, among others, is working on battery pack regeneration [127] and has developed its own second use modules which can be used in various applications. Battery cells are being repurposed for consumer applications such as small power banks due to low labour costs compared to the battery costs [128]. A large amount of second use EV batteries are deployed in telecommunication infrastructure to back up transmission stations. Thus, high-quality, repurposed EV batteries are replacing lead-acid based backup power systems [129].

7. Barriers and Outlook

Although research in stationary BESSs has delivered promising results, some barriers remain to the widespread adoption of such systems on a commercial basis.

7.1. Economic Barriers

Stationary BESSs remain expensive for energy management [130], independent of whether they are first use or second use storage systems, which slows their implementation [131]. Although battery prices have been dropping due to technological improvements, especially for lithium-ion batteries [132], BESSs are economically challenging for widespread deployment. Even if investment costs drop further, the cycle stability and lifespan of the battery play a decisive role in the economics of such systems. It is therefore a strategic goal of the EU to reduce energy storage costs by 2030 to under 0.05 €/kWh/cycle to be competitive. Earlier research projects have shown the feasibility of second use batteries as stationary BESS. B. Bai et al. [133] give an overview of the economic performance of different BESSs in combination with photovoltaic systems to increase self-consumption. The second use of EV batteries has been the subject of an EU Joint Research Centre (JRC) Technical Report [134]. The report concluded that second use of batteries for stationary applications should be feasible, but that more in-depth research and demonstration sites needed to be developed. The European-funded ELSA (Energy Local Storage Advanced System) project developed several stationary BESSs using second use batteries. The results showed that it was possible to extend the lifespan of batteries in such applications since the economic benefits were two to three times superior to the costs of the systems, and such systems had a clear environmental advantage over other systems [135]. Prices for BESSs are expected to decrease further due to dropping battery cell and auxiliary component costs and economy-of-scale effects [39]. This leads to one of the biggest challenges for second use BESSs: the gap between the price of first use and second use batteries. Since prices for first use batteries are still dropping, future second use costs need to be in line with the falling costs for first use batteries [136]. Furthermore, current BESSs with their control systems are developed for one specific application (e.g., peak shaving) in most cases and cannot handle complex grid management and multiple grid applications [137]. This means that they are often in idle mode, which in turns means that their potential is not fully exploited. As a result, the research focus is moving towards advanced battery controllers for BESSs [138]. In addition, research is also being conducted on BESSs combining different battery technologies based on different battery chemistries and, thus, batteries with different power and energy densities (hybrid BESSs). Consequently, they can serve different grid applications simultaneously and maximise their potential [137,139]. To the author's knowledge, there is currently no control system that can handle hybrid BESSs allowing for complex grid management and multiple grid applications. Developments regarding hybrid storage systems that can simultaneously serve multiple applications are needed to increase the economic value of stationary BESSs.

7.2. Environmental Barriers

Harper et al. [26] estimated that, based on the global EV sales in 2017, 250,000 tons of batteries will need to be recycled just for that year. Discarded batteries will become a substantial waste problem in the future. Ballinger et al. [140] mentioned that lithium-ion batteries are currently the most common battery technology in EVs. Based on the share of different types of chemistries used in lithium-ion batteries, they identified that there are potential supply risks for the critical raw materials such as natural graphite, lithium, and cobalt. Continuous developments of battery chemistry reduce the use of critical materials such as cobalt, making it feasible to recycle spent, high-cobalt-containing batteries to use the material in the next generation of batteries [141]. Unfortunately, the current process for recycling EV batteries is time consuming, dangerous, and inefficient, as recycling technologies have not been able to keep up with the complex chemistry of today's battery cells [142]. Thus, critical materials such as cobalt are partly lost during the recycling process. Manahan [143] stated that as much as 50% of cobalt is lost to tailing, slag, or other wastes, indicating that there is a significant potential to improve its recovery. Lithium-ion recycling processes are currently not efficient since only the most valuable materials such as copper, nickel, and cobalt are recovered [144,145]. Currently, the main recycling methods are pyrometallurgy, hydrometallurgy, and biometallurgy, and they all result in additional environmental issues regarding wastewater, residue, and exhaust gas, which require further downstream treatment [146]. By applying pyrometallurgical processes, materials such as nickel, cobalt, and copper can be recovered effectively today, while aluminium, graphite and lithium are typically lost. Other hydrometallurgical processes can include pre-treatment such as leaching, which allows for the recovery of lithium and aluminium, but at a high cost and high energy consumption [146]. Further processing usually involves burning the remnants of the battery. The modules and/or cells are often sent to Asia for further recycling [147]. Once burned or exported from Europe, these materials are permanently removed from the European battery value chain, thereby reducing material independence in Europe. Current recycling technologies are therefore not sufficient for full reutilisation of critical raw materials and do not meet EU Circular Economy strategies for eliminating waste and pollution in the battery value chain [148]. Second use of batteries, as part of the EU Circular Economy strategies, would reduce the need for extraction of virgin raw materials for new BESSs, extend the life cycle of EV batteries, and thereby reduce the demand for critical raw materials. Furthermore, it would also help to gain time for developing appropriate battery recycling technologies. This would lead to a more efficient use of available resources and address short-term battery waste issues. Finally, it is important not to consider batteries as waste even if they reach their end of life since they contain valuable materials. In addition, public awareness that batteries are valuable at any stage (in use or after reaching their end of life) would help with second use and further recycling.

7.3. Technological Barriers

All steps involved in repurposing EV batteries such as dissembling, handling, characterisation, and reassembly are still mostly done manually and thus have high labour costs. Automation will help reduce costs and make battery handling safer. Efficient automation requires that battery packs, modules, cells, and auxiliary components be designed for disassembly [149]. In addition, proper non-destructive, non-discriminating diagnosis methods to characterise spent batteries after their first life need to be developed [150]. This is critical to allow for fast and efficient sorting of potentially reusable battery packs, modules, or cells with sufficient reliability. Proper diagnoses would make it possible to classify spent batteries as safe and prognosticate their remaining lifetime. In addition, barriers also exist with respect to the auxiliary components needed to run a battery storage system. As one of the most critical parts of the battery setup, the battery management system (which ensures the optimal operation of the battery and performs safety-relevant measurements) is mostly not built to be used in second use applications. Importantly, the possibility of second use should be considered when designing a battery management system. This would reduce electronic waste and allow taking over battery history information as well as the battery control system models (algorithms). This, in turn, would help estimate battery parameters such as state-of-charge and state-of-health [45]. This would ensure the optimal usage of the batteries within the storage system. In addition, open access to the battery management software would make it possible to reconfigure storage system variables, such as capacity and power input/output. Developments in terms of second use for auxiliary electronics such as switches, fuses, AC/DC converters, heating, and cooling systems would help to further reduce BESS costs and electronic waste. Furthermore, increasing transparency and considering second use when developing software and hardware would allow combining batteries from the same type of vehicle with slightly different conditions such as state-of-health. For example, combining small battery packs from PHEV to form larger BESSs. In addition, software and hardware should be capable of combining and operating efficiently with different battery chemistries to form hybrid BESSs.

7.4. Regulatory Barriers

To overcome economic, environmental, and technical barriers, standards and regulations need to be in place. Simple measures such as battery labelling giving indications about the battery chemistry are still missing. This would help to handle and sort decommissioned EV batteries according to their properties and would further improve the recycling process [151]. Labelling would also help to keep track of the batteries and their components to ensure and control optimal circularity [152]. Standardised battery packs, modules, and cells would reduce the complexity across different (vehicle) manufacturers and thus help with the automated sorting for second use as well as for recycling [26]. Since second use storage systems will be sold as new, or separate products, legal liability measures to ensure safety, quality, and warranty from the producer of such storage systems will be needed. Policies regulating handling (especially battery transportation), ownership of waste, recycling, etc. are critical for fair and transparent market conditions and to guarantee the circular economy of batteries in the European battery value chain. This will also lead to a higher reutilisation of batteries and increased battery recycling rates. Reinhardt et al. [46] investigated legislation on second use EV batteries as stationary storage systems in the EU. They concluded that a harmonised policy framework needs to be developed based on existing automotive and energy binding legislation. One important step has been taken by the European Commission by updating the Batteries Directive (2006/66/EC) [153], which aims to minimise the negative impacts of batteries on the environment. A working document of the European Commission [154] showed some of the shortcomings of the current Battery Directive such as not addressing second use, labelling measures, extended producer responsibility, and recycling efficiencies of lithium-ion based batteries. To this end, the European Commission engaged in an Inception Impact Assessment [155] to modernise the EU's batteries legislation, in particular the Batteries Directive.

8. Discussion and Conclusions

Stationary, second use battery energy storage systems are considered a cost-efficient alternative to first use storage systems and electrical energy storage systems in general. Second use reduces the ecological footprint by reducing the need for new batteries (and thus new materials) for storage systems as well as by extending the lifespan of existing batteries and slowing the flow of used batteries that have to be recycled. The remaining capacity of spent electric vehicle batteries is sufficient for less-demanding stationary applications to balance supply and demand in the electrical grid and act as complementary storage for transient, renewable sources such as wind and solar energy. Thus, not only would second use battery energy storage systems make battery life cycles more sustainable, but they would also foster the development of cleaner energy production and consumption. To address the lack of a holistic review of current research activities on the topic, the author conducted a structured literature review and consulted academic, legislative, and industrial stakeholders to (1) identify potential applications for battery energy storage systems, (2) review second use storage systems in Europe, (3) map trends and developments outside of Europe, and (4) investigate barriers and outlook.

There is a range of potential applications for second use battery energy storage systems. These can be assigned to three potential stakeholder groups, namely "in-front-of-the-meter", "behind-the-meter", and "off-grid" stakeholders. While "in-front-of-the-meter" applications mainly focus on maintaining and upgrading the grid, "behind-the-meter" applications focus on personal needs optimisation. "Off-grid" applications enable electrification and thereby replace fossil-based alternatives such as gas lightning. It is in the interest of each of these stakeholders to provide environmentally sustainable yet commercially viable solutions for these applications while simultaneously integrating larger amounts of clean electrical energy. In this regard, second use batteries offer cost-efficient as well as sustainable alternatives to first use batteries.

While in Europe the majority of battery energy storage systems in industrial applications are "in-front-of-the-meter" applications, research focuses on "behind-the-meter" applications. Most research projects try to increase energy self-sufficiency by minimising the export of self-generated, clean electricity, e.g., by photovoltaic systems. Often, different applications are investigated individually, but there is a lack of research on storage systems that can simultaneously serve multiple applications, which would further increase the economic value of second use, stationary storage systems. Such an approach would require hybrid battery systems, which combine different kinds of batteries that are optimised for high-energy and high-power densities. By replacing many battery systems for different applications with one hybrid solution, the sustainability of battery systems can be improved significantly due to the reduced number of batteries and electrical components needed.

The literature review on trends and developments outside of Europe shows that applications in developed countries such as Australia, New Zealand, and those in North America are similar. They focus mostly on optimising existing electrical grids and services while developing countries focus mostly on establishing and maintaining electrical grids and services. While in developing countries off-grid applications dominate, Asian countries, especially China, use spent batteries for all kinds of second use applications, even mobile ones. The repurposing activities show that there is a global increase in the second use of batteries, indicating that there are benefits such as sustainability and reduced costs.

Finally, the paper investigated the barriers to the uptake of second use battery energy storage systems as a sustainable product to foster the deployment of cleaner energy production and consumption. The review shows that the uptake of second use storage systems is heavily dependent on overcoming barriers related to economic and environmental considerations, technological developments, and regulatory factors. Current battery prices, the harsh mining and battery production conditions, as well as limited recycling opportunities, are challenges that need to be addressed. Furthermore, technological challenges related to the manufacture and assembly of battery hardware as well as those related to standardisation of control software need to be overcome to foster the deployment of second use battery energy storage systems. Additionally, there is a need for regulations on national and international levels directly related to the standardisation, transferability, and recyclability of electric vehicle batteries since these factors currently limit the second use of such batteries. Only the combined efforts of research, industry, policymakers, and the general public will make it possible to break through these barriers and thus lead to a more sustainable and environmentally friendly future.

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Abbreviations

AC	Alternating Current
BESS	Battery Energy Storage System
BEV	Battery Electric Vehicle
DC	Direct Current
DOE	Department of Energy
EU	European Union
EV	Electric Vehicle
JRC	Joint Research Centre
MONA	Merit Order Netz-Ausbau
NMC	Nickel-Manganese-Cobalt
PHEV	Plug-in Hybrid Electric Vehicle
sim	Simulation
US	United States

References

1. United Nations. *Paris Agreement*; United Nations: Paris, France, 2015; p. 27.
2. Dincer, I. Renewable Energy and Sustainable Development: A Crucial Review. *Renew. Sustain. Energy Rev.* **2000**, *4*, 157–175. [CrossRef]
3. Saint Akadiri, S.; Alola, A.A.; Akadiri, A.C.; Alola, U.V. Renewable Energy Consumption in EU-28 Countries: Policy toward Pollution Mitigation and Economic Sustainability. *Energy Policy* **2019**, *132*, 803–810. [CrossRef]
4. Villavicencio Calzadilla, P.; Mauger, R. The UN's New Sustainable Development Agenda and Renewable Energy: The Challenge to Reach SDG7 While Achieving Energy Justice. *J. Energy Nat. Resour. Law* **2018**, *36*, 233–254. [CrossRef]
5. IEA. *World Energy Outlook 2019*; IEA: Paris, France, 2019; p. 810.
6. Lajunen, A.; Kivekäs, K.; Vepsäläinen, J.; Tammi, K. Influence of Increasing Electrification of Passenger Vehicle Fleet on Carbon Dioxide Emissions in Finland. *Sustainability* **2020**, *12*, 5032. [CrossRef]
7. Dominković, D.F.; Bačeković, I.; Pedersen, A.S.; Krajačić, G. The Future of Transportation in Sustainable Energy Systems: Opportunities and Barriers in a Clean Energy Transition. *Renew. Sustain. Energy Rev.* **2018**, *82*, 1823–1838. [CrossRef]
8. Guminski, A.; Böing, F.; Murmann, A.; von Roon, S. System Effects of High Demand-Side Electrification Rates: A Scenario Analysis for Germany in 2030. *Wiley Interdiscip. Rev. Energy Environ.* **2019**, *8*, e327. [CrossRef]
9. Brinkel, N.B.G.; Schram, W.L.; AlSkaif, T.A.; Lampropoulos, I.; van Sark, W.G.J.H.M. Should We Reinforce the Grid? Cost and Emission Optimization of Electric Vehicle Charging under Different Transformer Limits. *Appl. Energy* **2020**, *276*, 115285. [CrossRef]
10. Kapustin, N.O.; Grushevenko, D.A. Long-Term Electric Vehicles Outlook and Their Potential Impact on Electric Grid. *Energy Policy* **2020**, *137*, 111103. [CrossRef]
11. Janda, K.; Málek, J.; Rečka, L. Influence of Renewable Energy Sources on Transmission Networks in Central Europe. *Energy Policy* **2017**, *108*, 524–537. [CrossRef]
12. Mueller, D. Grid Extension in German Backyards: A Game-Theory Rationale. *J. Environ. Plan. Manag.* **2017**, *60*, 437–461. [CrossRef]
13. Droste-Franke, B.; Paal, B.P.; Rehtanz, C.; Sauer, D.U.; Schneider, J.-P.; Schreurs, M.; Ziesemer, T. *Balancing Renewable Electricity*; Ethics of Science and Technology Assessment; Springer: Berlin/Heidelberg, Germany, 2012; Volume 40, ISBN 978-3-642-25156-6.
14. Madlener, R.; Specht, J.M. An Exploratory Economic Analysis of Underground Pumped-Storage Hydro Power Plants in Abandoned Coal Mines. *SSRN Electron. J.* **2013**. [CrossRef]
15. Palensky, P.; Dietrich, D. Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads. *IEEE Trans. Ind. Inform.* **2011**, *7*, 381–388. [CrossRef]
16. Ogunniyi, E.O.; Pienaar, H. Overview of Battery Energy Storage System Advancement for Renewable (Photovoltaic) Energy Applications. In Proceedings of the 2017 International Conference on the Domestic Use of Energy (DUE), Cape Town, South Africa, 4–5 April 2017; pp. 233–239.
17. Hesse, H.; Schimpe, M.; Kucevic, D.; Jossen, A. Lithium-Ion Battery Storage for the Grid—A Review of Stationary Battery Storage System Design Tailored for Applications in Modern Power Grids. *Energies* **2017**, *10*, 2107. [CrossRef]
18. Zhang, C.; Wei, Y.-L.; Cao, P.-F.; Lin, M.-C. Energy Storage System: Current Studies on Batteries and Power Condition System. *Renew. Sustain. Energy Rev.* **2018**, *82*, 3091–3106. [CrossRef]
19. Gissey, G.C.; Subkhankulova, D.; Dodds, P.E.; Barrett, M. Value of Energy Storage Aggregation to the Electricity System. *Energy Policy* **2019**, *128*, 685–696. [CrossRef]
20. Regett, A.; Zeiselmair, A.; Wachinger, K.; Heller, C. *Merit Order Netz-Ausbau 2030: Szenario-Analyse—Potenzielle Zukünftige Rahmenbedingungen für den Netz-Ausbau: Abschlussbericht*; FfE Forschungsstelle für Energiewirtschaft e.V: Munich, Germany, 2017; ISBN 978-3-941802-34-6.
21. Comello, S.; Reichelstein, S. The Emergence of Cost Effective Battery Storage. *Nat. Commun.* **2019**, *10*, 2038. [CrossRef] [PubMed]

22. Martinez-Laserna, E.; Gandiaga, I.; Sarasketa-Zabala, E.; Badeda, J.; Stroe, D.-I.; Swierczynski, M.; Goikoetxea, A. Battery Second Life: Hype, Hope or Reality? A Critical Review of the State of the Art. *Renew. Sustain. Energy Rev.* **2018**, *93*, 701–718. [CrossRef]
23. Grelier, F.; Poliscanova, J.; Ambel, C.C.; Bannon, E.; Alexandridou, S. *Electric Surge: Carmakers' Electric Car Plans Across Europe 2019–2025*; European Federation for Transport and Environment AISBL: Brussels, Belgium, 2019; p. 39.
24. IEA. *Global EV Outlook 2020*; IEA: Paris, France, 2020; p. 276.
25. European Commission. European Alternative Fuels Observatory: Passenger Cars. Available online: https://www.eafo.eu/vehicles-and-fleet/m1 (accessed on 7 July 2020).
26. Harper, G.; Sommerville, R.; Kendrick, E.; Driscoll, L.; Slater, P.; Stolkin, R.; Walton, A.; Christensen, P.; Heidrich, O.; Lambert, S.; et al. Recycling Lithium-Ion Batteries from Electric Vehicles. *Nature* **2019**, *575*, 75–86. [CrossRef] [PubMed]
27. Cusenza, M.A.; Guarino, F.; Longo, S.; Mistretta, M.; Cellura, M. Reuse of Electric Vehicle Batteries in Buildings: An Integrated Load Match Analysis and Life Cycle Assessment Approach. *Energy Build.* **2019**, *186*, 339–354. [CrossRef]
28. Jafari, M.; Gauchia, A.; Zhao, S.; Zhang, K.; Gauchia, L. Electric Vehicle Battery Cycle Aging Evaluation in Real-World Daily Driving and Vehicle-to-Grid Services. *IEEE Trans. Transp. Electrif.* **2018**, *4*, 122–134. [CrossRef]
29. Jiao, N.; Evans, S. Business Models for Sustainability: The Case of Second-Life Electric Vehicle Batteries. *Procedia CIRP* **2016**, *40*, 250–255. [CrossRef]
30. Lavoie, Y.; Danet, F.; Lombard, B. Lithium-Ion Batteries for Industrial Applications. In Proceedings of the 2017 Petroleum and Chemical Industry Technical Conference (PCIC), Calgary, AB, Canada, 18–20 September 2017; pp. 283–290.
31. Ahmadi, L.; Young, S.B.; Fowler, M.; Fraser, R.A.; Achachlouei, M.A. A Cascaded Life Cycle: Reuse of Electric Vehicle Lithium-Ion Battery Packs in Energy Storage Systems. *Int. J. Life Cycle Assess.* **2017**, *22*, 111–124. [CrossRef]
32. Schoch, J. Battery Life Optimal Operation of Electric Vehicles. Ph.D. Thesis, Karlsruhe Institute of Technology, Karlsruhe, Germany, 2018.
33. Mousavi, G.S.M.; Nikdel, M. Various Battery Models for Various Simulation Studies and Applications. *Renew. Sustain. Energy Rev.* **2014**, *32*, 477–485. [CrossRef]
34. Guha, A.; Patra, A. State of Health Estimation of Lithium-Ion Batteries Using Capacity Fade and Internal Resistance Growth Models. *IEEE Trans. Transp. Electrif.* **2018**, *4*, 135–146. [CrossRef]
35. Li, Y.; Liu, K.; Foley, A.M.; Zülke, A.; Berecibar, M.; Nanini-Maury, E.; Van Mierlo, J.; Hoster, H.E. Data-Driven Health Estimation and Lifetime Prediction of Lithium-Ion Batteries: A Review. *Renew. Sustain. Energy Rev.* **2019**, *113*, 109254. [CrossRef]
36. Sidorov, D.; Muftahov, I.; Tomin, N.; Karamov, D.; Panasetsky, D.; Dreglea, A.; Liu, F.; Foley, A. A Dynamic Analysis of Energy Storage With Renewable and Diesel Generation Using Volterra Equations. *IEEE Trans. Ind. Inform.* **2020**, *16*, 3451–3459. [CrossRef]
37. Cadini, F.; Zio, E.; Avram, D. Model-Based Monte Carlo State Estimation for Condition-Based Component Replacement. *Reliab. Eng. Syst. Saf.* **2009**, *94*, 752–758. [CrossRef]
38. Yatsenko, Y.; Hritonenko, N. Discrete-Continuous Analysis of Optimal Equipment Replacement. *Int. Trans. Oper. Res.* **2010**, *17*, 577–593. [CrossRef]
39. Müller, M.; Viernstein, L.; Truong, C.N.; Eiting, A.; Hesse, H.C.; Witzmann, R.; Jossen, A. Evaluation of Grid-Level Adaptability for Stationary Battery Energy Storage System Applications in Europe. *J. Energy Storage* **2017**, *9*, 1–11. [CrossRef]
40. Herdlitschka, M.; Schröder, H. *Daimler and Enercity Put Battery Replacement Parts Store for Electric Vehicles on the Grid*; Diamler: Stuttgart, Germany, 2017; p. 4.
41. Herdlitschka, M.; Halwachs, K.; Ballek, D. *Shining Example of the Energy Turnaround: Coal-Fired Power Station Becomes Battery Storage Plant*; Stuttgart, Germany, 2018; p. 4. Available online: https://media.daimler.com/marsMediaSite/instance/ko.xhtml?oid=40586809&filename=Shining-example-of-the-energy-turnaround-Coal-fired-power-station-becomes-battery-storage-plant (accessed on 15 April 2021).
42. Brúch, W.; Hillmer, K.K.; Hoenicke, C. *Ein Zweites Leben für Elektroauto-Batterien*; Munich/Stuttgart/Hamburg, Germany, June 2016; p. 2. Available online: https://group.vattenfall.com/de/newsroom/pressemitteilungen/2016/ein-zweites-leben-fuer-gebrauchte-batterien (accessed on 15 April 2021).
43. Keene, E.R. A Second Life for Batteries: From Energy Usage to Industrial Storage. Available online: https://easyelectriclife.groupe.renault.com/en/outlook/energy/a-second-life-for-batteries-from-energy-usage-to-industrial-storage (accessed on 30 June 2020).
44. Reinhardt, R.; Christodoulou, I.; Gassó-Domingo, S.; Amante García, B. Towards Sustainable Business Models for Electric Vehicle Battery Second Use: A Critical Review. *J. Environ. Manag.* **2019**, *245*, 432–446. [CrossRef]
45. Hossain, E.; Murtaugh, D.; Mody, J.; Faruque, H.M.R.; Sunny, M.S.H.; Mohammad, N. A Comprehensive Review on Second-Life Batteries: Current State, Manufacturing Considerations, Applications, Impacts, Barriers & Potential Solutions, Business Strategies, and Policies. *IEEE Access* **2019**, *7*, 73215–73252. [CrossRef]
46. Reinhardt, R.; Garcia, B.A.; Casals, L.C.; Domingo, S.G. Critical Evaluation of European Union Legislation on the Second Use of Degraded Traction Batteries. In Proceedings of the 2016 13th International Conference on the European Energy Market (EEM), Porto, Portugal, 6–9 June 2016; pp. 1–5.
47. Smith, V.M.; Keoleian, G.A. The Value of Remanufactured Engines: Life-Cycle Environmental and Economic Perspectives. *J. Ind. Ecol.* **2008**, *8*, 193–221. [CrossRef]
48. European Commission. Batteries Europe. Available online: https://ec.europa.eu/energy/topics/technology-and-innovation/batteries-europe_en (accessed on 28 August 2020).

49. Fitzgerald, G.; Mandel, J.; Morris, J.; Touati, H. *The Economics of Battery Energy Storage: How Multi-Use, Customer-Sited Batteries Deliver the Most Services and Value to Customers and the Grid*; Rocky Mountain Institute: Boulder, CO, USA, 2015; p. 41.
50. Reid, D.; Julve, J. *Second Life-Batterien Als Flexible Speicher Für Erneuerbare Energien*; Berlin, Germany, 2016; p. 46. Available online: https://speicherinitiative.at/wp-content/uploads/sites/8/2020/11/05-SecondLife-Batterienflexible-EE-Speicher.pdf (accessed on 15 April 2021).
51. Van den Bergh, K.; Couckuyt, D.; Delarue, E.; D'haeseleer, W. Redispatching in an Interconnected Electricity System with High Renewables Penetration. *Electr. Power Syst. Res.* **2015**, *127*, 64–72. [CrossRef]
52. Faessler, B.; Kepplinger, P.; Petrasch, J. Decentralized Price-Driven Grid Balancing via Repurposed Electric Vehicle Batteries. *Energy* **2017**, *118*, 446–455. [CrossRef]
53. Faessler, B.; Bogunović Jakobsen, A. Autonomous Operation of Stationary Battery Energy Storage Systems—Optimal Storage Design and Economic Potential. *Energies* **2021**, *14*, 1333. [CrossRef]
54. McLennan, S. *Europe's Largest Energy Storage System Now Live at the Johan Cruijff Arena*; Amsterdam, The Netherlands, June 2018; p. 2. Available online: https://uk.nissannews.com/en-GB/releases/release-426229477-europe-s-largest-energy-storage-system-is-now-live-at-the-johan-cruijff-arena (accessed on 15 April 2021).
55. Tim Vogel Projekt. *Covalion*; Tim Vogel Projekt: Wendelstein, Germany, 2017.
56. Lindner, S.; Sluga, C. Second Life Energy Storage: VHH and MAN Testing Use of Second Life of Batteries for EBus Charging Station. Available online: https://press.mantruckandbus.com/second-life-energy-storage-vhh-and-man-testing-use-of-second-life-of-batteries-for-ebus-charging-station (accessed on 30 June 2020).
57. The Mobility House. A Second Life for Electric Car Batteries: Stationary Storage Projects of The Mobility House. Available online: https://www.mobilityhouse.com/int_en/magazine/company/second-life-storage-projects.html (accessed on 30 June 2020).
58. de Latude, A.; Farissier, C. *Groupe Renault Is Launching "Advanced Battery Storage", the Biggest Stationary Energy Storage System from Electric Vehicle (EV) Batteries in Europe*; Boulogne-Billancourt, France, September 2018. Available online: https://en.media.groupe.renault.com/assets/groupe-renault-is-launching-advanced-battery-storage-the-biggest-stationary-energy-storage-system-from-electric-vehicle-ev-batteries-in-europe-21216357-989c5.html?lang=en (accessed on 15 April 2021).
59. Schimpe, M.; Piesch, C.; Hesse, H.; Paß, J.; Ritter, S.; Jossen, A. Power Flow Distribution Strategy for Improved Power Electronics Energy Efficiency in Battery Storage Systems: Development and Implementation in a Utility-Scale System. *Energies* **2018**, *11*, 533. [CrossRef]
60. Botelho, A.; Simões, M. The Second Life of Batteries. Available online: https://www.edp.com/en/innovation/second-life-batteries (accessed on 4 June 2020).
61. Stevens, P.; (EDF SA, France). Personal communication, 25 June 2020.
62. BeePlanet Factory Sustainable Energy for Our Planet. Available online: https://beeplanetfactory.com/en (accessed on 17 August 2020).
63. EcarACCU. Affordable Energy Storage. Available online: https://ecaraccu.nl/homebatteries (accessed on 9 September 2020).
64. Second Life Storage Community Second Life Storage Community. Available online: https://secondlifestorage.com/index.php (accessed on 30 June 2020).
65. Gohla-Neudecker, B.; Maiyappan, V.S.; Juraschek, S.; Mohr, S. Battery 2nd Life: Presenting a Benchmark Stationary Storage System as Enabler for the Global Energy Transition. In Proceedings of the 2017 6th International Conference on Clean Electrical Power (ICCEP), Santa Margherita Ligure, Italy, 27–29 June 2017; pp. 103–109.
66. Faessler, B.; Kepplinger, P.; Petrasch, J. Field Testing of Repurposed Electric Vehicle Batteries for Price-Driven Grid Balancing. *J. Energy Storage* **2019**, *21*, 40–47. [CrossRef]
67. Urbanová, G.; Tat'áková, Z.; Kallab, O. SCORES: D 2.3 Market Analysis on Hybrid Storage Components. October 2019. Available online: https://zenodo.org/record/3706656#.YH1Xx2czaUk (accessed on 15 April 2021).
68. Koell, R.; (AEE INTEC, Austria). Personal communication, 25 August 2020.
69. Mosbæk, R. Battery Pack Solution for Demonstration and the Integration with an Energy System with a High Amount of Renewables—READY. Available online: http://www.smartcity-ready.eu/d-4-2-4-battery-pack-solution-for-demonstration-and-the-integration-with-an-energy-system-with-a-high-amount-of-renewables (accessed on 5 June 2020).
70. Kruse, L.; (Lithium Balance A/S, Denmark). Personal communication, 24 September 2020.
71. ELSA Consortium. ELSA Pilot: Ampere Building at La Défense (SOGEPROM). Available online: https://www.elsa-h2020.eu/Ampere_Building.html (accessed on 5 June 2020).
72. Lapedra, A.; Croce, V.; Ziu, D.; Le Cam, M.; Bode, G.; Gross, S.; Eberl, T. *ELSA: D6.3 Results of Service Evaluation*; ELSA: Munich, Germany, 2018; p. 163.
73. ELSA Consortium. ELSA Pilot: Nissan Europe Office. Available online: https://www.elsa-h2020.eu/Nissan_Europe_Office.html (accessed on 5 June 2020).
74. Barre, P.-J.; Bochetaz, L.; Breitwiller, A.; Caccavelli, D.; Chateau, A.; Chea, D.; De Canson, S.; Guiot, T.; Huerre, G.; Keim, C.; et al. *IRIS: Deliverable 6.3—Launch of T.T.#1 Activities on Smart Renewables and near Zero Energy District; (Nice)*. January 2020. Available online: https://irissmartcities.eu/system/files/private/irissmartcities/d6.3_launch_of_t.t1_activities_on_smart_renewables_and_near_zero_energy_district_nice.pdf (accessed on 15 April 2021).
75. Quinard, H.; (IMREDD, France). Personal communication, 30 September 2020.

76. ELSA Consortium. ELSA Pilot: E.ON Energy Research Center (ERC) at RWTH Aachen University. Available online: https://www.elsa-h2020.eu/EON_Research_Center.html (accessed on 5 June 2020).
77. ELSA Consortium. ELSA Pilot: City of Kempten (Allgäu Region). Available online: https://www.elsa-h2020.eu/City_of_Kempten.html (accessed on 5 June 2020).
78. Tilley, A. *NETfficient: Second Life EV Batteries (WAE)*; Grove: Oxfordshire, UK, 2018; p. 1.
79. Look, O. *NETfficient: Deliverable 5.2—Verified and Validated Storage and Energy Resources, Control Devices and Communication Systems Deployed on Borkum*; Borkum, Germany, November 2017; p. 19. Available online: https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5b651b108&appId=PPGMS (accessed on 15 April 2021).
80. Zackrisson, M.; Hildenbrand, J. Including grid storage to increase the use of renewables case of an island in the North sea. In Proceedings of the Going Green CARE INNOVATION 2018, Conference Program & Abstract Book: Paper presented at 7th International Symposium and Environmental Exhibition, Vienna, Austria, 26–29 November 2018; p. 7.
81. The Mobility House. *Multi-Use Storage at EUREF Campus*; The Mobility House: Munich, Germany, 2019; p. 1.
82. ELSA Consortium. ELSA Pilot: City of Terni, Italy. Available online: https://www.elsa-h2020.eu/City_of_Terni.html (accessed on 5 June 2020).
83. Staal, J. Volkswagen Golf Variant 150 kW ECE. Available online: http://autogetest.nl/ecotests/item/ecotests/volkswagen-golf-variant-150kw-ece.html (accessed on 11 September 2020).
84. Groen, B. *Driving Towards Decarbonisation of Transport: Safety, Performance, Second Life and Recycling of Automotive Batteries for e-Vehicles*. September 2016. Available online: https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/putting-science-standards-workshop-summary-outcomes-driving-towards-decarbonisation (accessed on 15 April 2021).
85. De Ingenieur Hergebruik Autobatterij op Pampus. Available online: https://www.deingenieur.nl/artikel/hergebruik-autobatterij-op-pampus (accessed on 11 September 2020).
86. Broess, K.; (DNV GL AS, Netherlands). Personal communication, 9 September 2020.
87. SIM Holland Pampus Eiland. Available online: https://www.simholland.nl/energie/noodstroomgeneratoren/referenties/categorie/pampus-eiland.html (accessed on 11 September 2020).
88. Casals, L.C.; Amante García, B.; Canal, C. Second Life Batteries Lifespan: Rest of Useful Life and Environmental Analysis. *J. Environ. Manag.* **2019**, *232*, 354–363. [CrossRef]
89. Manteca, F. Giulio Mazzolo Stardust. Available online: https://stardustproject.eu (accessed on 25 June 2020).
90. Pueyo, C. *BeePlanet Factory—2nd Use Storages*; BeePlanet Factory: Navarra, Spain, 2020.
91. Fernandez, G.; Almajano, J.; Garcia, E.; Bludszuweit, H.; Machin, S.; Sanz, J.F. Control Structure for Optimal Demand-Side Management with a Multi-Technology Battery Storage System. In Proceedings of the 2019 24th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA), Zaragoza, Spain, 10–13 September 2019; pp. 754–759.
92. Fernandez, G.; (CIRCE Foundation, Spain). Personal communication, 1 July 2020.
93. Canals Casals, L.; Barbero, M.; Corchero, C. Reused Second Life Batteries for Aggregated Demand Response Services. *J. Clean. Prod.* **2019**, *212*, 99–108. [CrossRef]
94. Löveryd, P.; Selberg, P. *IRIS: Deliverable 7.4—Launch of T.T. #2Activities on Smart Energy Management and Storage for Flexibility (Gothenburg)*. February 2020. Available online: https://irissmartcities.eu/system/files/private/irissmartcities/d7.4_launch_of_tt2_activities_on_smart_energy_management_and_storage_for_flexibility_gothenburg.pdf (accessed on 15 April 2021).
95. Antoniadou-Plytaria, K. Optimal Energy Scheduling of Grid-Connected Microgrids with Battery Energy Storage. Ph.D. Thesis, Chalmers University of Technology, Gothenburg, Sweden, 2020.
96. ELSA Consortium. ELSA Pilot: Gateshead College at Its Skills Academy for Sustainable Manufacturing and Innovation (SASMI) Facility. Available online: https://www.elsa-h2020.eu/Gateshead_College.html (accessed on 5 June 2020).
97. Farmen, S. *Grid Connected Second-Life EV Battery-Pack*; University of Agder: Grimstad, Norway, 2018; p. 61.
98. Pål Erling Johnsen Energipakke Borg Havn. Available online: https://www.enova.no/om-enova/om-organisasjonen/teknologiportefoljen/energipakke-borg-havn---batteriretur (accessed on 5 June 2020).
99. Wingstedt, A.; (Smart Innovation Norway AS, Norway). Personal communication, 4 September 2020.
100. Gjerløw, P. *Invade: Deliverable D10.1—Pilot Specifications*; Oslo, Norway, February 2018; p. 86. Available online: https://zenodo.org/record/3626686#.YH18hWczaUk (accessed on 15 April 2021).
101. EATON. *Datasheet–XStorage Home*. May 2018. Available online: https://www.eaton.com/content/dam/eaton/products/energy-storage/xstorage-home/en-gb/Eaton%20xStorage%20Home%20technical%20sheet.pdf (accessed on 15 April 2021).
102. Hentunen, A.; (VTT Technical Research Centre of Finland Ltd., Finland). Personal communication, 14 September 2020.
103. Post, S. *Energy Storage Unit Pilot Project*; Post CH Ltd.: Bern, Switzerland, 2017; p. 1.
104. U.S. Department of Energy. *Solving Challenges in Energy Storage*; U.S. Department of Energy: Washington, DC, USA, 2019; p. 51.
105. Dann Chow Creating a Second Life for EV/PHEV Batteries. Available online: https://nrc.canada.ca/en/stories/creating-second-life-evphev-batteries (accessed on 1 July 2020).
106. ARENA. The Future of Energy Storage Looks Bright—ARENAWIRE. Available online: https://arena.gov.au/blog/energy-storage-future-looks-bright (accessed on 7 July 2020).
107. Energywise Electric Vehicle Batteries. Available online: https://www.energywise.govt.nz/on-the-road/electric-vehicles/electric-vehicle-batteries (accessed on 7 July 2020).

108. Schmidt, T.; Ligi, A.; Kevin, M.K. *GM and ABB Demonstrate Chevrolet Volt Battery Reuse—World's First Use of Electric Vehicle Batteries for Homes*; San Francisco, CA, USA, November 2012; p. 2. Available online: https://new.abb.com/news/detail/13214/gm-and-abb-demonstrate-chevrolet-volt-battery-reuse-worlds-first-use-of-electric-vehicle-batteries-for-homes (accessed on 15 April 2021).
109. Relectrify Relectrify—Making Energy Storage Affordable. Available online: https://www.relectrify.com (accessed on 3 July 2020).
110. Tong, S.; Klein, M. *Second Life Battery Pack as Stationary Energy Storage for Smart Grid*; SAE: Warrendale, PA, USA, 2014; pp. 1–342.
111. Smith, K.A. *Battery Second Use Analysis and Demonstration: Cooperative Research and Development Final Report, CRADA Number CRD-13 -537*; Golden, CO, USA, October 2018; p. 1476983. Available online: https://www.nrel.gov/docs/fy19osti/72557.pdf (accessed on 15 April 2021).
112. Malcho, M.; Kelly, K.; Basel, S. *Used Chevrolet Volt Batteries Help Power New IT Building*; Milford, MI, USA, June 2015; p. 2. Available online: https://studylib.net/doc/6773333/used-chevrolet-volt-batteries-help-power-new-it-building (accessed on 15 April 2021).
113. Hartline, J. *Toyota Flips the Switch to Sustainable Power at Yellowstone National Park*; Torrance, CA, USA, May 2015; p. 3. Available online: https://pressroom.toyota.com/toyota-sustainable-power-yellowstone-may12/ (accessed on 15 April 2021).
114. Falk, J.; Nedjalkov, A.; Angelmahr, M.; Schade, W. Applying Lithium-Ion Second Life Batteries for Off-Grid Solar Powered System—A Socio-Economic Case Study for Rural Development. *Z. Energ.* **2020**, *44*, 47–60. [CrossRef]
115. Chowdhury, H. Government-Backed Start-up Aceleron to Roll out 4000 Batteries to Kenya. *The Telegraph*, 25 November 2019.
116. University of Oxford Multi-Chemistry Battery Pack Using Second Life Batteries for off-Grid Systems in Developing Countries. Available online: https://globalresearch.admin.ox.ac.uk/article/multi-chemistry-battery-pack-using-second-life-batteries-grid-systems-developing-countries (accessed on 1 July 2020).
117. Ayetor, G.K.; Quansah, D.A.; Adjei, E.A. Towards Zero Vehicle Emissions in Africa: A Case Study of Ghana. *Energy Policy* **2020**, *143*, 111606. [CrossRef]
118. 4R Energy. 4R Energy Corporation. Available online: http://www.4r-energy.com (accessed on 7 July 2020).
119. ITOCHU. ITOCHU Announces Capital and Business Alliance with Automotive Battery Reuse and Recycling Company. Available online: https://www.itochu.co.jp/en/news/press/2019/191028.html (accessed on 6 July 2020).
120. Okuda, K.; Maxfield, N. *Japan Benex, Sumitomo Corp. to Power Plant with Nissan EVs, Batteries*; Tokyo/Isahaya/Yokohama, Japan, April 2018; p. 1. Available online: https://global.nissannews.com/en/releases/release-36a71146ed04eaba0f0dff94b509cd44-japan-benex-sumitomo-corp-to-power-plant-with-nissan-evs-batteries (accessed on 15 April 2021).
121. Jiang, Y.; Jiang, J.; Zhang, C.; Zhang, W.; Gao, Y.; Li, N. State of Health Estimation of Second-Life LiFePO4 Batteries for Energy Storage Applications. *J. Clean. Prod.* **2018**, *205*, 754–762. [CrossRef]
122. Deng, Y.; Zhang, Y.; Luo, F. Operational Planning of Centralized Charging Stations Using Second-Life Battery Energy Storage Systems. *IEEE Trans. Sustain. Energy* **2020**, 1. [CrossRef]
123. La, P.-H.; Choi, S.-J. Novel Dynamic Resistance Equalizer for Parallel-Connected Battery Configurations. *Energies* **2020**, *13*, 3315. [CrossRef]
124. Gu, F.; Guo, J.; Yao, X.; Summers, P.A.; Widijatmoko, S.D.; Hall, P. An Investigation of the Current Status of Recycling Spent Lithium-Ion Batteries from Consumer Electronics in China. *J. Clean. Prod.* **2017**, *161*, 765–780. [CrossRef]
125. Zhang, L.; Liu, Y.; Pang, B.; Sun, B.; Kokko, A. Second Use Value of China's New Energy Vehicle Battery: A View Based on Multi-Scenario Simulation. *Sustainability* **2020**, *12*, 341. [CrossRef]
126. Liu, Z.; Liu, X.; Hao, H.; Zhao, F.; Amer, A.A.; Babiker, H. Research on the Critical Issues for Power Battery Reusing of New Energy Vehicles in China. *Energies* **2020**, *13*, 1932. [CrossRef]
127. GEM Vice President Soichiro Matsudaira, Etc. from Toyota Tsusho Corporation Visited GEM Circulation Industrial Park on Business Tour. Available online: http://en.gem.com.cn/index.php/News/2018/10-16/2369.html (accessed on 25 August 2020).
128. Minter, A. China's Giving Batteries a Second Life. Available online: https://www.bloombergquint.com/opinion/china-s-giving-batteries-a-second-life (accessed on 25 August 2020).
129. Zhu, C.; Liu, K.; Xu, J.; Lu, R.; Yin, B.; Yuan, L.; Chan, C.C. Effect of Remaining Cycle Life on Economy of Retired Electric Vehicle Lithium-Ion Battery Second- Use in Backup Power for Communication Base Station. In Proceedings of the 2017 IEEE Transportation Electrification Conference and Expo, Asia-Pacific (ITEC Asia-Pacific), Harbin, China, 2–5 August 2017; pp. 1–6.
130. Wang, Y.; Wang, B.; Chu, C.-C.; Pota, H.; Gadh, R. Energy Management for a Commercial Building Microgrid with Stationary and Mobile Battery Storage. *Energy Build.* **2016**, *116*, 141–150. [CrossRef]
131. Dusonchet, L.; Favuzza, S.; Massaro, F.; Telaretti, E.; Zizzo, G. Technological and Legislative Status Point of Stationary Energy Storages in the EU. *Renew. Sustain. Energy Rev.* **2019**, *101*, 158–167. [CrossRef]
132. Hannan, M.A.; Hoque, M.M.; Hussain, A.; Yusof, Y.; Ker, P.J. State-of-the-Art and Energy Management System of Lithium-Ion Batteries in Electric Vehicle Applications: Issues and Recommendations. *IEEE Access* **2018**, *6*, 19362–19378. [CrossRef]
133. Bai, B.; Xiong, S.; Song, B.; Xiaoming, M. Economic Analysis of Distributed Solar Photovoltaics with Reused Electric Vehicle Batteries as Energy Storage Systems in China. *Renew. Sustain. Energy Rev.* **2019**, *109*, 213–229. [CrossRef]
134. Bobba, S.; Cusenza, M.A.; Di Persio, F.; Eynard, U.; Mathieux, F.; Messagie, M.; Pfrang, A.; Podias, A.; Tecchio, P.; European Commission; et al. *Sustainability Assessment of Second Life Application of Automotive Batteries (SASLAB): JRC Exploratory Research (2016-2017): Final Technical Report: August 2018*; Publications Office of the European Union: Luxembourg, 2018; ISBN 978-92-79-92835-2.
135. Stöhr, M. *ELSA: Summary*; ELSA: Munich, Germany, 2019; p. 3.

136. DeRousseau, M.; Gully, B.; Taylor, C.; Apelian, D.; Wang, Y. Repurposing Used Electric Car Batteries: A Review of Options. *JOM* **2017**, *69*, 1575–1582. [CrossRef]
137. Stephan, A.; Battke, B.; Beuse, M.D.; Clausdeinken, J.H.; Schmidt, T.S. Limiting the Public Cost of Stationary Battery Deployment by Combining Applications. *Nat. Energy* **2016**, *1*, 16079. [CrossRef]
138. Li, X.; Wang, S. A Review on Energy Management, Operation Control and Application Methods for Grid Battery Energy Storage Systems. *CSEE J. Power Energy Syst.* **2019**, 1–15. [CrossRef]
139. Lacey, G.; Putrus, G.; Salim, A. The Use of Second Life Electric Vehicle Batteries for Grid Support. In Proceedings of the Eurocon 2013, Zagreb, Croatia, 1–4 July 2013; pp. 1255–1261.
140. Ballinger, B.; Stringer, M.; Schmeda-Lopez, D.R.; Kefford, B.; Parkinson, B.; Greig, C.; Smart, S. The Vulnerability of Electric Vehicle Deployment to Critical Mineral Supply. *Appl. Energy* **2019**, *255*, 113844. [CrossRef]
141. Li, M.; Lu, J. Cobalt in Lithium-Ion Batteries. *Science* **2020**, *367*, 979–980. [CrossRef]
142. Mossali, E.; Picone, N.; Gentilini, L.; Rodrìguez, O.; Pérez, J.M.; Colledani, M. Lithium-Ion Batteries towards Circular Economy: A Literature Review of Opportunities and Issues of Recycling Treatments. *J. Environ. Manag.* **2020**, *264*, 110500. [CrossRef]
143. Manahan, S.E. *Environmental Chemistry*, 8th ed.; CRC Press: Boca Raton, FL, USA, 2005; ISBN 978-1-56670-633-9.
144. Ordoñez, J.; Gago, E.J.; Girard, A. Processes and Technologies for the Recycling and Recovery of Spent Lithium-Ion Batteries. *Renew. Sustain. Energy Rev.* **2016**, *60*, 195–205. [CrossRef]
145. Rallo, H.; Canals Casals, L.; De La Torre, D.; Reinhardt, R.; Marchante, C.; Amante, B. Lithium-Ion Battery 2nd Life Used as a Stationary Energy Storage System: Ageing and Economic Analysis in Two Real Cases. *J. Clean. Prod.* **2020**, *272*, 122584. [CrossRef]
146. Zheng, X.; Zhu, Z.; Lin, X.; Zhang, Y.; He, Y.; Cao, H.; Sun, Z. A Mini-Review on Metal Recycling from Spent Lithium Ion Batteries. *Engineering* **2018**, *4*, 361–370. [CrossRef]
147. Danino-Perraud, R. *The Recycling of Lithium-Ion Batteries: A Strategic Pillar for the European Battery Alliance*; Études de l'Ifri; Ifri: Paris, France, 2020; ISBN 979-10-373-0135-2.
148. European Commission. *Circular Economy Action Plan—For a Cleaner and More Competitive Europe*; European Commission: Brussels, Belgium, 2020; p. 28.
149. Herrmann, C.; Raatz, A.; Andrew, S.; Schmitt, J. Scenario-Based Development of Disassembly Systems for Automotive Lithium Ion Battery Systems. *Adv. Mater. Res.* **2014**, *907*, 391–401. [CrossRef]
150. Quinard, H.; Redondo-Iglesias, E.; Pelissier, S.; Venet, P. Fast Electrical Characterizations of High-Energy Second Life Lithium-Ion Batteries for Embedded and Stationary Applications. *Batteries* **2019**, *5*, 33. [CrossRef]
151. Wang, X.; Gaustad, G.; Babbitt, C.W. Targeting High Value Metals in Lithium-Ion Battery Recycling via Shredding and Size-Based Separation. *Waste Manag.* **2016**, *51*, 204–213. [CrossRef] [PubMed]
152. Alamerew, Y.A.; Brissaud, D. Modelling Reverse Supply Chain through System Dynamics for Realizing the Transition towards the Circular Economy: A Case Study on Electric Vehicle Batteries. *J. Clean. Prod.* **2020**, *254*, 120025. [CrossRef]
153. European Parliament. *Council of the European Union Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on Batteries and Accumulators and Waste Batteries and Accumulators and Repealing Directive 91/157/EEC*; European Parliament: Brussels, Belgium, 2006.
154. European Commission. *Commission Staff Working Document on the Evaluation of the Directive 2006/66/EC on Batteries and Accumulators and Waste Batteries and Accumulators and Repealing Directive 91/157/EEC*; European Commission: Brussels, Belgium, 2019.
155. European Commission. *Inception Impact Assessment: Modernising the EU's Batteries Legislation*; European Commission: Brussels, Belgium, 2020.