sustainability

MDPI

Review

Barriers and Enablers of Circular Economy Implementation for Electric-Vehicle Batteries: From Systematic Literature Review to Conceptual Framework

Bertha Maya Sopha [1,*], Dwi Megah Purnamasari [1] and Sholeh Ma'mun [2]

[1] Industrial Engineering Program, Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia; dwipurnamasari@mail.ugm.ac.id

[2] Department of Chemical Engineering, Universitas Islam Indonesia, Yogyakarta 55584, Indonesia; sholeh.mamun@uii.ac.id

* Correspondence: bertha_sopha@ugm.ac.id

Abstract: With the burgeoning transition toward electrified automobile fleets, electric-vehicle batteries (EVBs) have become one of the critical aspects to be considered to avoid resources issues while achieving necessary climate goals. This paper compiles and syntheses reported barriers, enablers, involved stakeholders, and business models of Circular Economy (CE) implementation of the EVBs based on a systematic literature review (SLR). Findings indicate that inefficient and inadequate government policy, lack of safety standards, and high recycling costs are the three most reported barriers. The barriers have interconnections with each other, implying the necessity for simultaneous strategies. Based on the barriers-enablers analysis, the key strategies establishing the CE for the EVBs are innovative business models, economic incentives, EVB standards, legal environmental responsibilities, and certification, whereas the optimized supply-chain operations can be realized through eco-design of the EVBs, battery modularization, proper technology for checking, diagnosing, tracking, information sharing, extensive collaboration, alignment of supply-chain stakeholders, innovative business model, and certification. A conceptual framework presenting the required strategies for both establishing the CE and optimizing the circular supply chain system of the EVBs was then proposed. Potential future research directions are also discussed.

Keywords: barriers; enablers; electric-vehicle batteries; circular economy implementation; systematic literature review; system perspective; conceptual framework

check for updates

Citation: Sopha, B.M.; Purnamasari, D.M.; Ma'mun, S. Barriers and Enablers of Circular Economy Implementation for Electric-Vehicle Batteries: From Systematic Literature Review to Conceptual Framework. *Sustainability* **2022**, *14*, 6359. https://doi.org/10.3390/su14106359

Academic Editors: Benny Tjahjono, Jennifer Ferreira and David Bek

Received: 31 March 2022

Accepted: 20 May 2022

Published: 23 May 2022

1. Introduction

The transportation sector, considered the main contributor to global emissions, has accounted for about 23% of global greenhouse gas (GHG) emission, 70% of which has been attributable to road transport [1]. Because climate change has become a global challenge, many countries have committed to reducing the impact by implementing low-emission vehicles. Electric vehicles (EVs) appear to be the preferred option to replace internal combustion engine vehicles (ICEVs). Due to the commitments to reduce or phase out the ICEVs, the EVs are expected to reach 130 million by 2030 [2].

The rising EV demands, however, lead to new challenges. Although the EVs have a lower environmental impact in the operation/use phase, the production phase of the EVs has contributed to a higher environmental impact than that of the ICEVs [3]. Electric-vehicle batteries (EVBs) have become critical aspects of being considered due to their contents of residual power and rare materials such as lithium, cobalt, and nickel, which are worth recovering to meet future demand for these resources. Current linear economic practices of the take–make–consume–dispose approach undermine the goal of reducing climate change impact. To ensure sustainability and avoid burden-shifting, it is necessary to integrate a life-cycle perspective in end-of-life (EoL) management to facilitate effective material recovery. Therefore, it is necessary to adopt Circular Economy (CE), which closes the supply-chain loop through reusing, repurposing, or recycling to reduce the need for virgin materials. Despite its necessity to facilitate material recovery and waste reduction, the implementation of CE is not without challenges.

It is believed that the transition of the EVBs toward CE is unlikely to shape itself due to immaturity (early phase of development) and complexity [4]. The transition of the EVBs toward CE requires a comprehensive understanding of influential factors, involved stakeholders, and appropriate strategies/interventions to facilitate the long-term benefits of the CE. However, the existing literature on CE for the EVBs is still scattered. For instance, many studies such as Wang et al. [5] have focused on the recycling technology of the EVBs, while other studies such as Werner et al. [6] analyzed the recycling supply chain, and those such as Chirumalla et al. [7] explored actors/stakeholders in the circular business of the EVBs. Because transition toward CE requires a systemic change, a more profound and holistic understanding of socio-technical aspects of CE is required. The present study analyzes the CE implementation for the EVBs on the system level, addressing technical, financial, legal, organization, and social aspects. The paper compiles the reported influential factors and the requirements for implementing CE of the EVBs using a systematic literature review (SLR). A conceptual framework presenting strategies for establishing and functioning toward CE for the EVBs is proposed. Therefore, in supporting the framework development of the CE implementation for the EVBs, the present study addresses the following research questions:

RQ1. What are the barriers and enablers to CE implementation for the EVBs?
RQ2. What are the potential strategies to support successful CE implementation for the EVBs?

Few studies, such as Azadnia et al. [8], have analyzed the barriers to the CE implementation for the EVBs. The present study complements those studies by analyzing the connections between barriers and enablers and, subsequently, proposing the framework which systematically identifies the required strategies to support the sustainable operations of CE for the EVBs. The study adds value to the existing works in two ways. First, the present study reports on barriers and enablers concerning technical, organizational, financial, legal, and social aspects underlying the CE implementation for the EVBs from the literature, thus providing a clear and common understanding of the most important factors in CE application for the EVBs. Second, the present study proposes a conceptual framework of strategies favoring CE implementation for the EVBs, which is expected to be helpful as a starting point to design and realize CE for the EVBs.

The structure of the paper is presented as follows. The following section presents the theoretical foundation of the CE, circular supply chain (CSC), and EVBs. Section 3 describes the methods used to carry out this study, i.e., a systematic literature review (SLR) with PRISMA guidelines and bibliometric analysis. Section 4 presents the profile and content analysis addressing the barriers, enablers, involved stakeholders, and business models. Section 5 presents the synthesis of the findings, the proposed framework, limitations, and future research, which is then concluded in Section 6.

2. Theoretical Foundations

2.1. Circular Economy (CE) and Circular Supply Chain (CSC)

The paradigm of Circular Economy (CE) lies in the basic principles of resources and energy circularity, seeking to continually sustain the material and energy circulation in a closed-loop system, thus reducing the need for new raw materials. Stahel [9] stated that the CE turns products that have reached the end of their useful life into raw materials for others. Furthermore, the CE principles have provided a framework for business operations to engage with sustainability through reducing, reusing, and recycling activities [10].

Within supply-chain management, several concepts such as reverse supply chain, closed-loop supply chain, green supply chain, sustainable supply chain, and, the most recent term, circular supply chain, have emerged. Opposing the traditional supply chain, the reverse supply chain regards the product movement from customers back to retailers/manufacturers/suppliers. The reverse supply chain can be a closed loop in which products are taken back from customers and returned to the original retailers/manufacturer/vendors to recover added value by reusing all or part of them. In contrast, the open-loop reverse supply chain involves material recovery by parties other than original retailers/manufacturers/vendors [11]. Closed-loop supply chain and green supply chain have been used interchangeably. However, the definition of green supply-chain management (GSCM) and sustainable supply-chain management (SSCM) show substantial overlap. GSCM does not explicitly address social issues, whereas SSCM integrates three sustainability dimensions, i.e., economic, social, and environmental [12].

Circular supply chain management (CSCM) deals with integrating circular thinking into the supply-chain system and its surrounding industrial and natural ecosystems [13]. CSCM substantially complements GSCM and SSCM so that the CSCM systematically restores assets in the industrial and natural system through recycling, retaining, reusing, repairing, remanufacturing, refurbishing, and recovering. The CSCM moves toward zero waste by recovering value from waste flow back into the industrial system within similar or distinctive sectors. For instance, recycled textile materials are used as raw materials for insulation products [14], and waste cooking oil is converted to produce biodiesel [11]. In addition, food waste is reduced at its source, and the finished product can be composted to be used as a fertilizer in agriculture and horticulture or anaerobically digested to produce methane. The integration of industrial systems and natural ecosystems is the specific feature of CSCM compared with the above-mentioned concepts.

Consequently, the circular supply chain (CSC) helps to prevent the shortage of rare materials, cut production costs by reducing the dependency on raw materials, reduce human health and environmental damage, create job opportunities, and achieve a green image and customer trust. Figure 1 illustrates the framework of the CSC, in which the most cost-effective strategy is the reuse of products, followed by refurbishing, remanufacturing, and recycling.

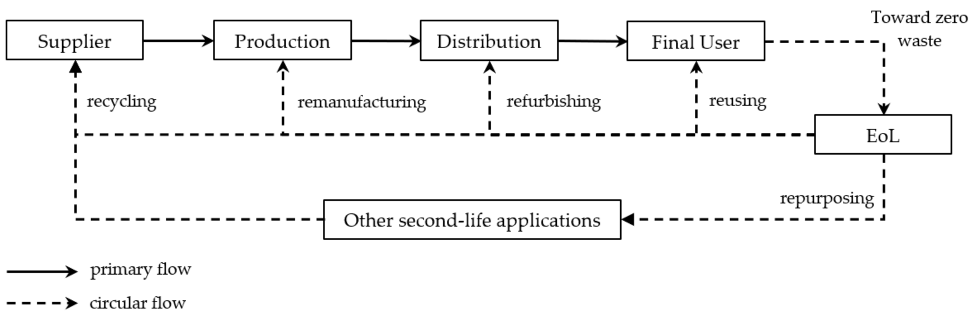

Figure 1. Schematic diagram of the circular supply chain (modified from [13]).

It is not straightforward to integrate EoL items into a closed-loop system. A comprehensive understanding of technical aspects (i.e., multiple recovery options, and collection network), financial, environmental, social, and organization is required. The involvement of all stakeholders, an innovative business model, and appropriate regulations/enforcement are also required to facilitate CE implementation [15].

2.2. Electric-Vehicle Batteries (EVBs)

The EVBs are the source of power for the EVs. Among other EV components, battery production is responsible for a significant share of environmental and economic impacts of the overall EVs [16]. Different types of EVBs, such as lead-acid, Lithium-ion (Li-ion), Lithium-Sulphur (Li-S), and Nickel Metal Hydride (Ni-MH), with different prices, capacity, safety, durability, and weight are available. Among the EVBs, Lithium-ion batteries (LiBs) appear to be dominating, particularly in the automotive industry, because the LiBs have higher energy density than other batteries. The energy density of LiB is

150 Wh/kg, compared with that of lead-acid batteries of 40–60 Wh/kg and Ni-MH batteries of 40–110 Wh/kg [17]. Moreover, LiBs have a longer service life, more compact design, lower weight, better resistance to self-discharge and high temperature, greater voltage output, and lower environmental risk [18]. LiBs are also flexible and appropriate for different EV types [19].

The EVBs consist of rare and hazardous materials, and some components are considered strategic due to high supply risks, such as lithium, cobalt, nickel, and graphite. Given that LiBs are the source of critical metals, the implementation of CE towards the EVBs is needed to deal with the concern of supply shortcomings and, at the same time, reduce the negative environmental impacts. Kotak et al. [20] have demonstrated that LiB reuse seems more promising than recycling, considering the limited existing recycling technology. Vu et al. [21] have further suggested that the used EVBs can be remanufactured to the original purpose, depending on the battery's health. Alternatively, they can be reused for the energy storage system or repurposed into 20-kWh battery packs. Similarly, Moore et al. [22] suggested other potential second-life applications for EVBs, including backup power, peak shaving, grid services, powering forklifts and electric boats, and other smaller applications, such as bicycles and scooters or robots. Figure 2 describes the waste hierarchy of the EVBs.

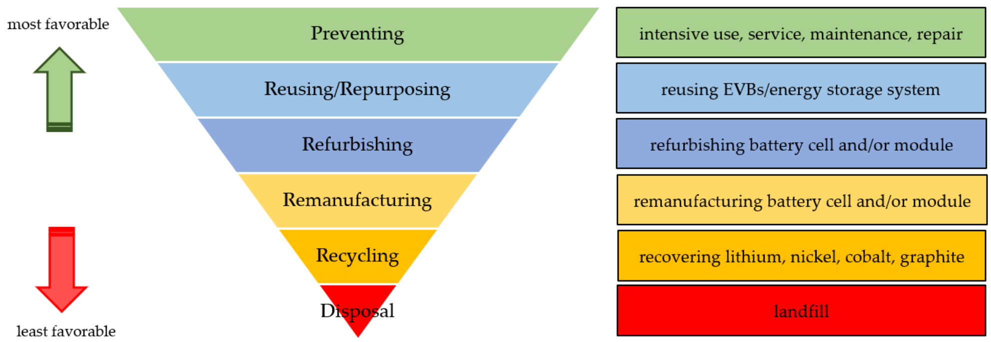

Figure 2. Waste hierarchy of the EVBs (modified from [23]).

Technologies for recycling LiBs such as mechanical-hydrometallurgical, pyrometallurgical, and pyrolysis are available [24,25]. Hydrometallurgy technology recovers 90% of the materials with 98% purity. The most commercial battery recycling technology is the pyrometallurgical process. Before recycling, pre-processes, such as preparation, including collecting, inspection, selection/separation, and sorting, are required [21]. The preparation processes are then followed by pretreatment (dismantling and de-pollution), processing (liberation and separation), and metallurgy processes (extraction and recovery) [6]. Challenges, however, exist during the recycling process, such as safety, particularly during dismantling [18,26], lack of standardization, and lack of recycling protocol [27].

3. Methodology

3.1. Systematic Literature Review (SLR)

A systematic literature review (SLR) was conducted to enable a reliable assessment to examine the barriers, enablers, involved stakeholders, business models toward CE implementation for the EVBs, including their relationships, to develop a systematic framework of the required strategies toward CE, and to identify potential future research. Following the procedure of PRISMA (Preferred Reporting Items for Systemic Reviews and Meta-Analysis (PRISMA) [28]. Figure 3 presents the processes for the SLR in the present study.

Search criteria were defined based on the research questions to determine which articles to be included or excluded from the analysis. The study used search query of ("circular economy" OR "circular supply chain" OR "circular value chain") AND ("electric-vehicle battery" OR "Lithium-ion battery"). The eligibility of literature was bound to peer-reviewed papers published in English from January 2010 to December 2021. The scholar databases used in this present study were the Scopus database and other sources, such as Google Scholars. The search resulted in 153 articles within the title, abstract, and keywords. The collected articles were checked to eliminate duplicates and articles without full text. The full text of the 48 collected articles was further examined based on the following eligibility criteria, as shown in Table 1.

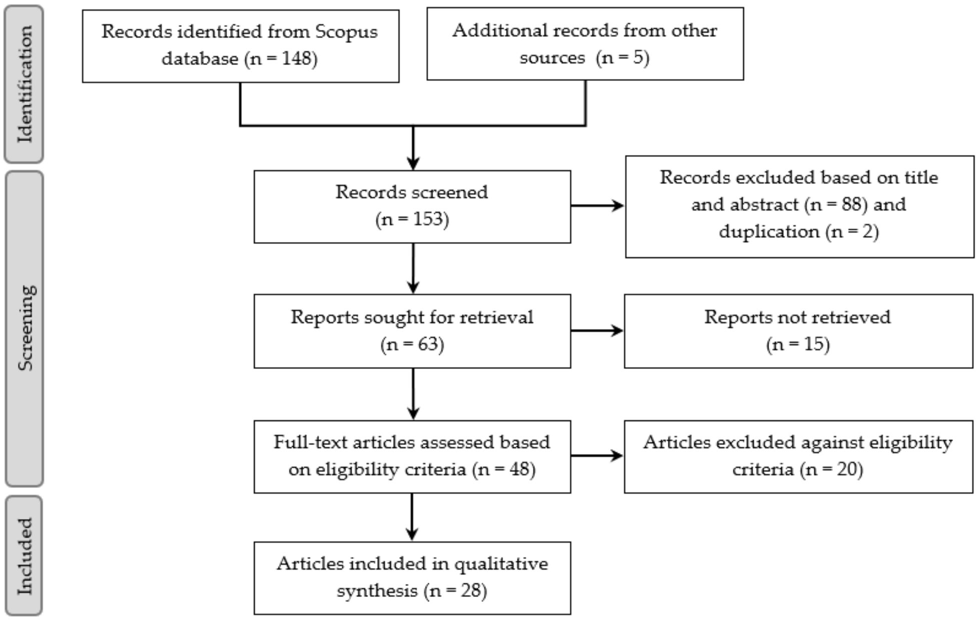

Figure 3. Flow diagram of the SLR stages in the present study.

Table 1. Inclusion/exclusion criteria.

Inclusion Criteria	Exclusion Criteria
The article was relevant to the research objective	The article was irrelevant to the research objective
The article reported the influential factors which discuss the relationship among the factors, i.e., technology, economics, organizations, social, and regulations of CE implementation for the EVBs.	The article focused only on one limited aspect, such as specific recycling technology, without addressing or connecting with other influential factors.
The article reported the implementation of CE/CSC for the EVBs	The article did not report the implementation of CE/CSC for the EVBs.
The article was interested in the broader and future development of CE implementation for EVBs	The article did not discuss the broader and future development of CE implementation for EVBs.

The literature that does not meet the eligibility criteria was excluded and resulted in 28 articles used for further analysis. The literature was read, coded, and checked for consistency. Each publication was further categorized, based on the methodology and the country of the first author's institution. The research methodology covers qualitative, quantitative, and mixed-method research. The collected articles were synthesized to address the research questions.

3.2. Bibliometric Analysis

The bibliometric analysis was to analyze the emerging topic trends. The collected articles that meet the inclusion criteria were imported to the VOSviewer (version 1.6.18) [29]. Co-occurrence analysis was carried out to assess the relations among the articles based on keywords (nodes). Using keywords of the collected articles with more than two occurrences, 14 out of the 88 keywords met the threshold. The occurrence network includes links indicating the relationship between keywords, link strength representing the correlation (frequency) strength between the two keywords appearing simultaneously, and the nodes' size indicating the frequency of occurrence.

Figure 4 presents the network visualization indicating four emerged clusters. The red cluster mainly involves the circularity of the EVBs and their supporting business models. The green cluster includes recycling technology research. The blue cluster focuses on remanufacturing and reverse logistics. The yellow cluster represents a broader research topic on recycling and sustainability.

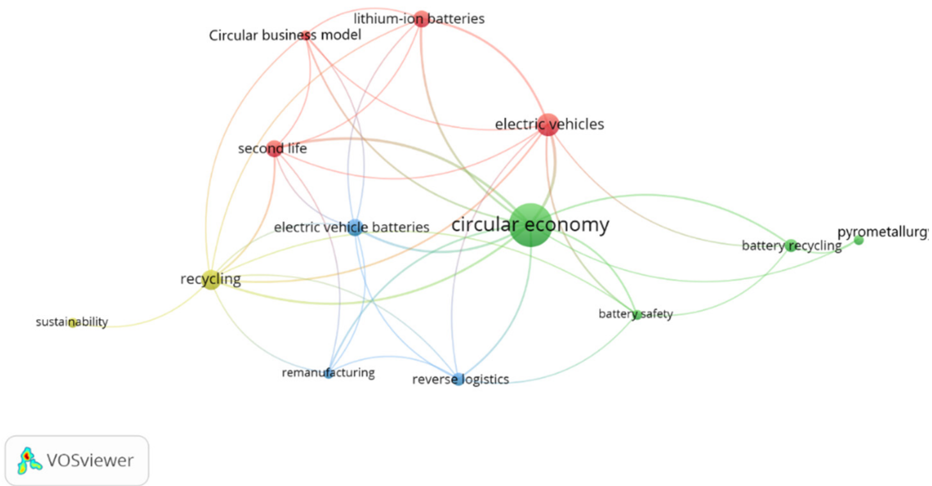

Figure 4. Network visualization from VOSviewer.

Table 2 reports the links, the link strength, the occurrences, and the resulted clusters. The circular economy has the most occurrences (14) and the highest link strength (29), implying that the concept has been established. The keyword of circular economy has a strong relationship with the keyword of, from the strongest to the weakest, electric vehicles, second life, electric-vehicle batteries, and recycling. It is also interesting to note that keywords of circular business models, battery safety, pyrometallurgy, remanufacturing, and sustainability have the lowest occurrence, implying the potential research areas worthy of further exploration.

Table 2. Co-occurrence network.

No	Keywords	Links	Total Link Strength	Occurrences	Cluster *
1	Circular business models	6	7	2	1
2	Electric vehicles	8	16	6	1
3	Lithium-ion batteries	6	10	4	1
4	Second life	7	11	4	1
5	Battery recycling	4	5	3	2
6	Battery safety	5	7	2	2
7	Circular economy	11	29	14	2
8	Pyrometallurgy	2	2	2	2
9	Electric-vehicle batteries	7	9	4	3
10	Remanufacturing	5	6	2	3
11	Reverse logistics	6	7	3	3
12	Recycling	10	14	5	4
13	Sustainability	1	1	2	4

Note: * the color indicates the color of four emerged clusters resulted from co-occurrence analysis as shown in Figure 4.

Figure 5 presents the development of the research topics from 2020 to 2021, from blue to yellow. It is observable that the research topics have shifted from the circular economy, recycling, and Lithium-ion batteries to pyrometallurgy, battery safety, and circular business models. Following the co-occurrence network analysis, the keywords of pyrometallurgy, battery safety, and circular business models are the emerging latest topics that deserve for further exploration to support CE implementation.

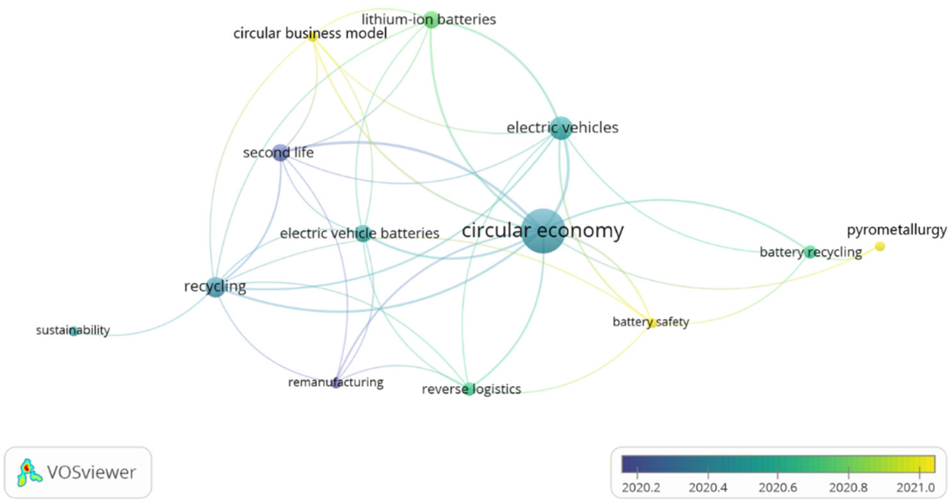

Figure 5. Overlay visualization.

4. Results and Analysis

4.1. Profile Analysis

Figure 6 shows a significant growth in the literature on the CE implementation for the EVBs. Although the literature search was set to include the literature from the last 10 years, using the above-mentioned keywords, it turned out that the earliest published literature was found in 2019. It can be explained that the circular economy for the EVBs has recently been investigated when many countries have committed to shifting to EVs, particularly after Paris Agreement in 2016. Even though the CE for the EVBs is still in the early stage of development, a significant increasing trend can be expected in the next few years along.

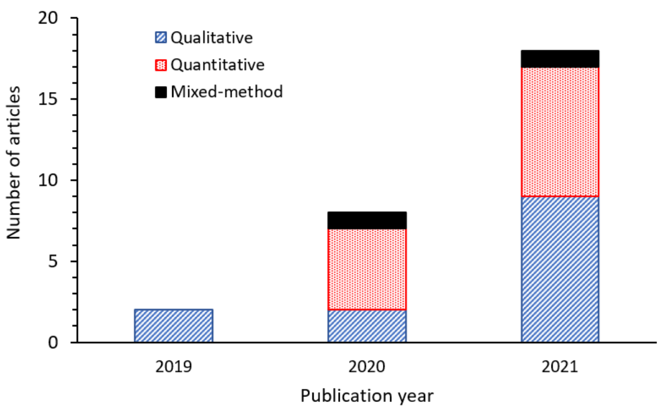

Figure 6. Temporal distribution of the collected articles based on research methodology.

As expected, in terms of the research methodology, qualitative studies were the adopted methodology in 2019. Political Economic Social Technology (PEST) analysis and case study were implemented in those studies. The following year, quantitative studies using analytical and simulation tools (i.e., system dynamics) and mixed-method research using case studies were deployed. In 2021, the methodology was more varied as the number and the investigated topics of cases were diverse. Case studies and Delphi methods appeared to be the two most frequent methods for qualitative studies, while simulation through scenario building, system dynamics, life-cycle assessment, multicriteria decision making, and experiment, are the adopted methods for quantitative studies. The business canvas model was the most applied approach for analyzing the business model. The first reported CE of the EVBs research in developing countries, published in 2021, was based on a case in India.

In terms of the country of the first author's institution, the United States (US) had the largest share of publications, followed by Germany, Sweden, and the United Kingdom as shown in Figure 7. The most cases being studied in the publications are Germany (4 articles), the EU region (3 articles), Brazil (3 articles), China (3 articles), and the UK (3 articles). It appears that Europe is at the forefront of countries leading the research on the CE implementation for the EVBs.

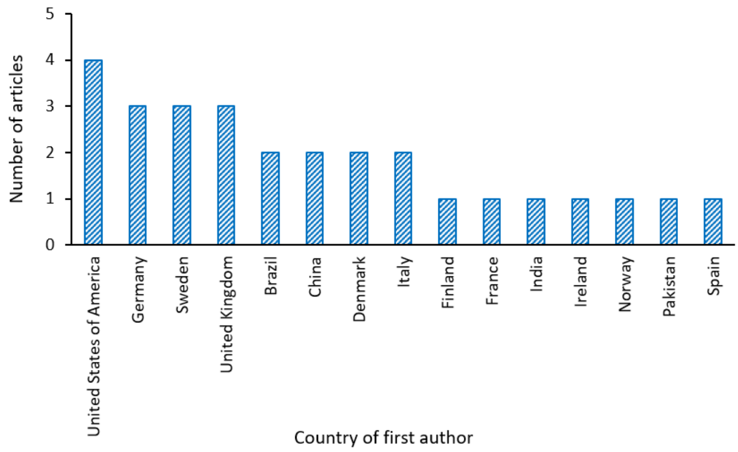

Figure 7. Distribution of the collected articles based on the country of the first author's institution.

Figure 8 shows that the contributing journals of the publications are Resource, Conservation & Recycling journal (Elsevier), followed by conference proceedings and Energies (MDPI), and Journal of Cleaner Production (Elsevier).

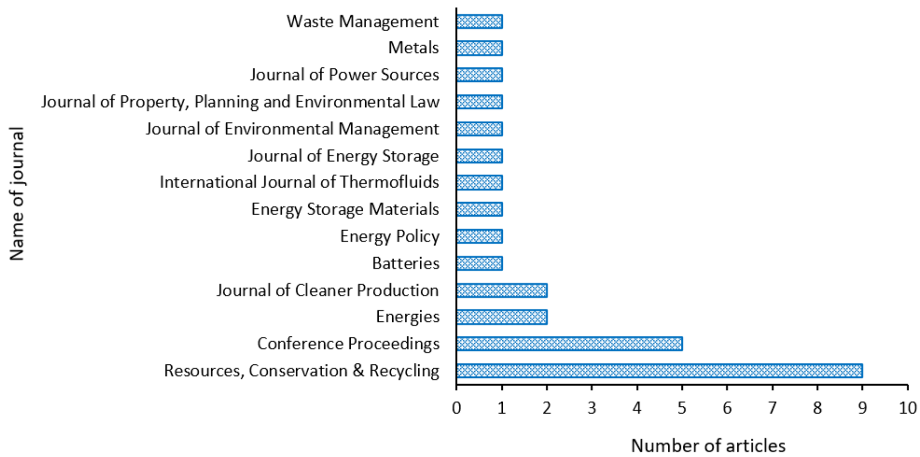

Figure 8. Distribution of the collected articles based on journal.

4.2. Barriers, Enablers, Stakeholders, and Business Models

This sub-section reports data synthesis on barriers, enablers, stakeholders, and business models from the collected articles. With respect to barriers and enablers, those identified factors were grouped into five categories. The technology and infrastructure category regards the technology supporting the recycling process, including its technical feasibility and supporting infrastructures, such as remanufacturing/recycling centers, collection points, battery technology, and information technology. The supply-chain operations and management category include the governance of upstream and downstream processes and stakeholders in EoL. The category also includes the interaction and cooperation among stakeholders in the supply chain. Economic category refers to economic factors that hinder or motivate stakeholders to implement EoL management of the EVBs. The policy and regulations category involves the government policy, regulation, and company policies on collection and recycling. The social category deals with the broader consumer markets within a society, including behavioral factors such as environmental awareness and cultural aspects.

4.2.1. Barriers

Barriers are defined as the factors that hindered the implementation of CE for the EVBs. The present study has synthesized 21 barriers from the selected articles, as shown in Table 3.

Table 3. Barriers to CE implementation of the EVBs.

Barriers	References Mentioning Barriers (*N*)
Technology and infrastructure (BT) Category	
Low efficiency of recycling (BT1)	[8,30,31] (*N* = 3)
Slower development of infrastructure—collecting, sorting, dismantling, recycling, and remanufacturing centers (BT2)	[8,32] (*N* = 2)
Unoptimized path for EoL due to inappropriate characterization, testing, and assessment, lack of standards (BT3)	[4,22,30,31,33] (*N* = 5)
Lack of EVB design considering EoL (BT4)	[4,22,30,31] [(*N* = 4)
Compositional uncertainty of EVBs (BT5)	[22,30,34] (*N* = 3)
Lack of standardization on EoL processes for EVBs (BT6)	[35] (*N* = 1)
Supply-chain operations and management (BSC) Category	
Underdeveloped recovery marketplace (BSC1)	[8] (*N* = 1)
Low rate of returned batteries (BSC2)	[8,30,31] (*N* = 3)
Lack of information sharing of EoL process (BSC3)	[31,35–37] (*N* = 4)
Uncertainty in supply (number and quality), price/value of EVBs (BSC4)	[19,30] (*N* = 2)
Lack of commitment (BSC5)	[30] (*N* = 1)
Lack of effective communication and coordination (BSC6)	[8,31] (*N* = 2)
Competitiveness (BSC7)	[22] (*N* = 1)
Economics (BE) Category	
High cost of handling, transporting, recovering process, labor, thus lack of profitability (BE1)	[21,26,27,31,32,38] (*N* = 6)
Lack of incentives (BE2)	[4,19] (*N* = 2)
Low economic value of EoL EVBs (BE3)	[24,30] (*N* = 2)
Risk on investment (BE4)	[4,38] (*N* = 2)
Policy and regulations (BP) Category	
Inefficient and inadequate government policy (BP1)	[4,8,22,27,30,34,37,38] (*N* = 8)
Lack of safety standards (BP2)	[4,18,24,26,27,31,32,34] (*N* = 8)
Social (BS) Category	
Lack of customer awareness (BS1)	[8,30,31] (*N* = 3)
Low perceived quality of the recycled products (BS2)	[21,31] (*N* = 2)

Table 3 shows that the reported barriers in the examined articles exist in all categories. It is worth noting that the barriers have also connected each other. It shows that inefficient and inadequate government policy and lack of safety standards are the most reported barriers in the literature. Inadequate policy and regulation for the second life of the EVBs lead to a limited number of participating businesses (BP1−BSC5) [30], which, subsequently, has contributed to slower development of infrastructure (BP1−BT3) [8,31]. The lack of safety standards for the collection, storage, transport, and dismantling of the EoL EVBs poses a risk to worker health and safety due to hazardous materials of the EVBs [39]. It is worsened by the compositional uncertainty of the EVBs [22,30,34]. Due to the trade-off when designing electric vehicles (i.e., safety, space optimization, and serviceability), the design of the EVBs does not allow easy disassembling. In addition, it requires specific skills of human resources, thus leading to a high cost of recycling processes (BP1−BE1) [27]. The current design of the EVBs, lack of EVB standards, and limited technology for diagnosing health states and tracking the EVBs, lead to the inappropriate characterization, testing, and assessment of the EVBs, subsequently further hindering the efficient process for reuse, remanufacturing, and recycling, and high cost of the operations (BT3−BE1) [31]. The lack of the EVB standards also leads to a low-quality perception of the recycled product by consumers (BP2−BS2) [31].

On the other hand, a lack of customer awareness leads to a low rate of returned EVBs (BS1−BSC2) [8,30,31]. The perceived low quality of the recycled products results in an underdeveloped recovery marketplace [8], as supported by Bouzon et al. [40], who have demonstrated that customers think recovered products have poorer quality, thus contributing to slower infrastructure development (BS2−BT2). Competitiveness for materials such as Lithium to be used for other purposes has contributed to the inability to achieve economies of scale of the processes, thus making CE operations for the EVBs not profitable (BSC2−BE1) [8,31]. Lack of incentives was reported as a barrier to investing in the technology (BE3−BT1), hence resulting in low recycling efficiency [30]. The low economic value of EoL EVBs has also posed a risk in investment, which in turn hinders the investment in technology development resulting in low efficiency of recycling [4]. Lack of standardization on EoL processes has made planning and managing the supply-chain operations challenging (BT6−BSC3) [35] and hindered information sharing [8,31]. Lack of customer awareness has contributed to the low rate of returned EVB and hence lack of profitability (BS1−BE1) [31]. Figure 9 visualizes some illustrations of the afore-mentioned interconnected barriers.

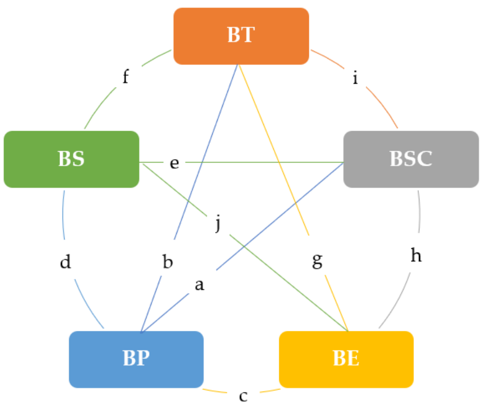

Figure 9. Illustrations for the interconnected barriers (Note: a (BP1−BSC5), b (BP1−BT3), c (BP1−BE1), d (BP2−BS2), e (BS1−BSC2), f (BS2−BT2), g (BT3−BE1), h (BSC2−BE1), i (BT6−BSC6), and j (BS1−BE1).

Finding 1: The reported barriers are observed in all categories, i.e., technology and infrastructure, supply-chain operations and management, economics, policy and regulations, and social aspects. Those barriers are interconnected, implying that these barriers should be analyzed at a system level and resolved by simultaneous and synchronized strategies to ensure that all parts work together to meet the goal of CE implementation of the EVBs.

4.2.2. Enablers

Enablers refer to the factors facilitating the effective implementation of CE for the EVBs, which are the keys to overcoming the perceived barriers. The present study has identified 18 enablers from the collected articles, as shown in Table 4.

Table 4. Enablers to CE implementation of the EVBs.

Enablers	References Mentioning Enablers (Number)
Technology and infrastructure (ET) Category	
EoL design for EVBs (design for disassembly) (ET1)	[30,38] (*N* = 2)
Battery modularization (ET2)	[31,33] (*N* = 2)
Proper status checking, diagnosing, and tracking (ET3)	[8,30,31] (*N* = 3)
Information digitalization (ET4)	[36,37] (*N* = 2)
Supply-chain operations and management (ESC) Category	
Information sharing and standards of information interfaces (ESC1)	[30,31,38] [(*N* = 3)
Extensive collaboration, cooperation, and alignment of supply-chain stakeholders (i.e., early integration in product development) (ESC2)	[22,30,41,42] (*N* = 4)
Innovative business model such as servitization, leasing platform (ESC3)	[4,21,38,41] (*N* = 4)
Economics (EE) Category	
Economic incentives for recyclers, i.e., tax breaks, subsidies, economic support, and the introduction of deposit refund (EE1)	[8,31,43,44] (*N* = 4)
Policy and regulations (EP) Category	
Eco-design directive (EP1)	[30,31] (*N* = 2)
EVB standards including compounds (EP2)	[27,35,38,43–45] (*N* = 6)
Standardization of EoL process (EP3)	[42] (*N* = 1)
Certification (EP4)	[31] (*N* = 1)
Material tax on critical elements (EP5)	[31] (*N* = 1)
Policy and legislation on information sharing (EP6)	[31] (*N* = 1)
Legal environmental responsibilities (EP7)	[24,25,27,31] (*N* = 4)
Regulation consistency in the global market (EP8)	[45] (*N* = 1)
Social (ES) Category	
Social commitment (ES1)	[41] (*N* = 1)
High customer awareness through education and training (ES2)	[31] (*N* = 1)

Table 4 indicates that most enablers have supported each other. Technology and infrastructure enablers have focused on technology support for effective and efficient CE implementation. Similarly, supply-chain operations and management enablers facilitate information sharing and collaborations among the stakeholders in the circular supply chain. Hsieh et al. [46] highlighted that integrating the entire industry chain, including automakers, battery producers, used-car dealers, and recycling companies, was necessary to achieve a circular economy. Subsequently, information technology enabling end-to-end visibility across the supply chain and facilitating coordination among the involved stakeholders is vital to reduce uncertainty and facilitate better planning and response [36]. Garrido–

Hidalgo et al. [37] further demonstrated that the required information infrastructure is needed to support the effective operation of a circular supply chain.

It is found that policy and regulation enablers have been more comprehensive, addressing product-related policy/regulation (such as eco-design directive, EVB standards, and certification), process-related policy/regulation (such as EoL process standards, information sharing, and material tax for critical materials), and stakeholder-related regulation (legal environmental responsibilities, and certification). Moreover, it is also interesting to note that the scope of policy and regulation enablers has required consistent regulation at a global level [45]. The social enablers have addressed not only increasing awareness [31] but also the commitment [41].

Finding 2: The reported enablers have existed in all categories, in which policy and regulation enablers appear to be dominant and comprehensive. It appears that the EVB standards, legal environmental responsibilities, economic incentives, extensive collaboration and alignment of the supply-chain stakeholders, and innovative business model are the most reported enablers of the successful implementation of CE for the EVBs.

4.2.3. Stakeholders

The stakeholder for this research question is defined as entities interested in EoL EVBs business and can affect or be affected by the business. Understanding the stakeholders and their independent roles is necessary to ensure transparency and credibility of the defined targets for CE in supply-chain processes, thus ensuring plan-ability for EoL operations [42].

The involved stakeholders of the circular supply chain for the EVBs can be classified as the government, manufacturers, recyclers, and users [45]. The government has played a role in formulating policy and regulations on EoL EVBs and delivering penalties for non-compliance. The term government can be local, national, regional, or global. Manufacturers are business entities that produce or manufacture the EVBs. In the circular economy, manufacturers may include mining/material companies, vehicle producers, or suppliers of the vehicle producers. Battery producers and vehicle producers usually work together to optimize the design of the battery, which meets the space, safety, and serviceability constraints of EVs. Recyclers are the entities responsible for the second life of the EVBs. In some countries, such as Norway, Columbia, and Finland, vehicle producers also act as recyclers that work together to drive EoL management for the EVBs.

Furthermore, in developing countries, the recyclers involve formal and informal sectors. Users within this context can be private individuals or companies, such as public-transport companies or energy companies. The public-transport companies have a prominent role in establishing CE for the EVBs due to their large scale [32].

The complexity of the CE creates several practical challenges which require multi-discipline work. Wrålsen et al. [32] have extended to include university and research centers that provide knowledge and information and conduct research on the technology, design of supply-chain system, and legal aspect of the CE, which is supported by Sommerville et al. [35] who emphasized the collaboration between the battery-recycling industry and academia to explore a more robust circular economy model. However, among the identified stakeholders, it was argued that the critical stakeholders for the CE are government and manufacturers [32,45].

Finding 3: The involved stakeholders in the circular economy of the EVBs depend on the scope of the circularity. Government and manufacturers are the critical stakeholders in the CE implementation of the EVBs.

4.2.4. Business Models

Business models deal with value creation, value delivery, and value capture of products or services [32]. The circular business model is particularly interesting for CE because it has not been much discussed in the existing literature, as shown in Figure 5, despite its significant role in integrating essential aspects (e.g., technology, supply-chain operations, economics, and social aspect) of the CE system. Furthermore, Vu et al. [21] argued that an appropriate business model is a crucial success factor in CE implementation. Therefore, the present study brings up the business model which links the technology with the market toward successful operations of CE for the EVBs.

To design a business model, potential paths of EoL application of the EVBs should first be identified. The literature has identified the available options for EoL paths for the EVBs, which involve repairing, reusing, refurbishing, and remanufacturing toward original purpose, repurposing, and material recovery. The potential second-life application of the EVBs includes repurposing the EVBs as power sources for small applications and energy storage systems. Technical condition of the battery (health state of the returned EVBs) [42], the number of returned EVBs, and the maturity of other second-life applications of the EVBs [21], and the existence of collaboration between manufacturers and recyclers [30] are found to be factors influencing the selected EoL path.

The current EoL path for the EVBs has been reported based on the collected articles. Vu et al. [21] confirmed that remanufacturing (original purpose) appeared to be the most applicable in Sweden because a broader scope of the second-life application of the EVBs has not yet existed, and new EVBs have not entered their first life yet. However, it was noted that remanufacturing is not always the best solution over time. Ali et al. [43] suggested that reusing is a preferable option over recycling due to optimum financial gain and environmental impact reduction, which was supported by Kotak et al. [20], who demonstrated that reusing is a good option for the current condition because the need for battery recycling would be delayed, therefore allowing recyclers to develop cost-effective and energy-efficient processes. On the other hand, Albertsen et al. [30] confirmed that, among 25 companies being interviewed, the most adopted EoL path is repurposing, followed by, from the highest to the lowest, repairing, refurbishing, and remanufacturing, which is supported by Castro et al. [47], who suggested the adoption of repurposing and remanufacturing for the EVBs.

Because the success of EoL operations of the EVBs depends on the returned EVBs, a system ensuring a high rate of returned EVBs is crucial. Two approaches are identified in the literature. The first approach regards that the Original Equipment Manufacturers (OEMs) are responsible for collecting the returned EVBs through a take-back or buy-back mechanism. The returned EVBs are delivered to recognized and approved battery operators. Before EoL, the used EVBs are returned to dealer networks. Once the EVBs reach their end-of-life, the EoL EVBs are usually collected by external recyclers or national producer responsibility organizations. Yang et el. [45] reported that China had applied battery pooling (third-party collection services) in which users can exchange the empty battery for a fully charged one. Applying the collection service minimizes informal recyclers' role, likely to achieve low recovery rates. The battery pooling also facilitates battery diagnostics to determine the EoL path of the returned EVBs. As proposed by Ahuja et al. [4], the second approach applies the concept of servitization in which the manufacturer retains ownership of assets. The proposed model focuses on access rather than ownership so that the business model can be in the form of a leasing or sharing platform. It is believed that using the approach would reduce the EVs' initial cost, which may then increase the number of returned EVBs. The approach can be combined with government incentivizing manufacturers to engage in EoL processes instead of using control regulation [4].

Finding 4: Appropriate circular business model supporting the CE implementation of the EVBs depends on market characteristics, available technology and infrastructure, involved stakeholders, and policy/regulation. Two models, i.e., the take-back and servitization models, are found in the literature to increase the returning rate of the EVBs.

5. Synthesis and Discussion

5.1. Connecting Barriers and Enablers

The current CE implementation of the EoL EVBs has many challenges in terms of lack of appropriate policy and regulation, market uncertainty, unprofitable business, and insufficient supporting infrastructure. Nevertheless, the research in this area has been progressing in the last three years, moving forward from theories to implementation.

Based on the findings, the interconnected barriers ranging from technological and technical constraints, organizational and institutional arrangement, economic appeal, regulation, and societal attitudes are closely correlated with the enablers. The enablers have a role as drivers for successful circular economy implementation of the EVBs. Based on the reported barriers and enablers from the collected literature, Table 5 presents the relationship between the barriers and the enablers to the implementation of CE for the EVBs by indicating which barriers can be resolved by which enablers. The last column indicates the literature that supports the barriers–enablers relationship, which was either explicitly or implicitly suggested.

Table 5. The relationships between barriers and enablers of CE implementation for the EVBs.

Barriers/Problems	Enablers/Solutions	References Suggesting the Connections
Technology and Infrastructure Category		
Low efficiency of recycling (BT1)	Eco-design directive (EP1)	[31]
	Economic incentives for recyclers (EE1)	[8,31,43,44]
Slower development of infrastructure (BT2)	Economic incentives for recyclers (EE1)	[8,31,43,44]
Unoptimized path for EoL (BT3)	EoL design for EVBs (design for disassembly) (ET1)	[38]
	Battery modularization (ET2)	[33]
	Proper status checking, diagnosing, and tracking (ET3)	[22,31]
	Information sharing and standards of information interfaces (ESC1)	[31]
	Extensive collaboration, cooperation, and alignment of supply-chain stakeholders (ESC2)	[22,30]
	Innovative business model (ESC3)	[4]
	Certification (EP4)	[31]
Lack of EVB design considering EoL (BT4)	EoL design for EVBs (design for disassembly) (ET1)	[38]
	Innovative business model (ESC3)	[4]
	Information digitalization (ET4)	[36]
Compositional uncertainty of EVBs (BT5)	EVB standards (EP2)	[38]
Lack of standardization on EoL process (BT6)	Standardization of EoL process (EP3)	[42]
Supply-Chain Operations and Management Category		
Underdeveloped recovery marketplace (BSC1)	Certification (EP4)	[31]
Low rate of returned batteries (BSC2)	Legal environmental responsibilities (EP7)	[31]
	Material tax on critical elements (EP5)	[31]
	Innovative business model (ESC3)	[4]
	Social commitment (ES1)	[41]
Lack of information sharing of EoL processes (BSC3)	Policy and legislation on information sharing (EP6)	[31]
	Information digitalization (ET4)	[36]
Uncertainty in supply (number and quality), price/value of EVBs (BSC4)	Proper status checking, diagnosing, and tracking (ET3)	[8]
	Innovative business model (ESC3)	[4]
Lack of commitment (BSC5)	Legal environmental responsibilities (EP7)	[31]

Table 5. *Cont.*

Barriers/Problems	Enablers/Solutions	References Suggesting the Connections
Lack of effective communication and coordination (BSC6)	Information sharing and standards of information interfaces (ESC1)	[31]
Competitiveness (BSC7)	Extensive collaboration, cooperation, and alignment of supply-chain stakeholders (ESC2)	[22]
Economics Category		
High cost of handling, transporting, and recovering process (i.e., too laborious), thus lack profitability (BE1)	Battery modularization (ET2)	[31]
	Innovative business model (ESC3)	[21,38]
	EVB standards (EP2)	[27,38]
	Economic incentives for recyclers (EE1)	[8,31,43,44]
Lack of incentives (BE2)	Economic incentives for recyclers (EE1)	[8,31,43,44]
The low economic value of EoL EVBs (BE3)	Legal environmental responsibilities (EP7)	[24]
Risk on investment (BE4)	Economic incentives for recyclers (EE1)	[8,31,43,44]
	Innovative business model (ESC3)	[4]
Policy and Regulation Category		
Inefficient and inadequate government policy (BP1)	Regulation consistency in the global market (EP8)	[45]
Lack of safety standards (BP2)	EVB standards (EP2)	[34,43]
Social Category		
Lack of customer awareness (BS1)	Social commitment (ES1)	[41]
	High customer awareness through education and training (ES2)	[31]
Low perceived quality of the recycled products (BS2)	Certification (EP4)	[31]

Table 5 indicates that the enablers are correlated with the barriers. It is also interesting to note that most barriers are resolved through the combination of various enablers. For instance, the unoptimized process for EoL EVBs can be addressed by several enablers. The EoL design of the EVBs, which considers easy and safe disassembly facilitates automated disassembling [38]. Battery modularization further supports more efficient recycling processes [33]. To ensure the appropriate EoL process, appropriate status checking, diagnosing, and tracking should also be in place [22]. Information sharing and tracking of the EVBs are also necessary to support the recycling process and the operations along the EoL supply chain [38], which is supported by the collaboration of the stakeholders in the supply chain [30]. Furthermore, an innovative business model ensures high returned EoL EVBs, so that the industrial scalability can be achieved, thus ensuring optimal balance between the collection rate and the economic feasibility [4]. Certification can also support the marketplace for recycled products [31]. All the above-mentioned enablers contribute to the optimized EoL processes, thus enabling long-term technical and economic feasibility. It was evidenced in the German case that effective EoL processes are seen as the economic enabler for the circular economy of the EVBs [36]. Another example regards with the high cost of EoL processes which can be resolved through the combination of technical solutions (battery modularization) [31], supply-chain approach (appropriate business model) [4], policy (EVB standards) [27], and economic incentives [8]. The findings imply that the CE implementation of the EVBs requires a system-level approach to avoid problem shifting and to enforce the CE practices through simultaneous strategies.

As observed in Table 5, an enabler can be served as a potential solution to some barriers. Table 6 hence presents the number of connections with the barriers for each enabler to identify the enablers which resolve the most barriers, termed as key enablers/strategies. Innovative business model is the enabler with the highest connection to the barriers. Due to its strategic role, the business model for CE implementation needs to be explored in the future, consistent with the findings of the bibliometric analysis.

Table 6. Strategies to establish the circular supply chain system for the EVBs based on the number of connections with barriers (based on Table 5).

Enablers/Strategies	Number of Connections with Barriers
Technology and Infrastructure Category	
EoL design for EVBs (design for disassembly) (ET1)	2
Battery modularization (ET2)	2
Proper status checking, diagnosing, and tracking (ET3)	2
Information digitalization (ET4)	2
Supply-Chain Operations and Management Category	
Information sharing and standards of information interfaces (ESC1)	2
Extensive collaboration, cooperation, and alignment of supply-chain stakeholders (i.e., early integration in product development) (ESC2)	2
Innovative business models such as servitization, leasing (ESC3)	6
Economics Category	
Economic incentives for recyclers, i.e., tax breaks, subsidies, economic support, the introduction of deposit refund (EE1)	5
Policy and Regulations Category	
Eco-design directive (EP1)	1
EVB standards including compounds (EP2)	3
Standardization of EoL processes (EP3)	1
Certification (EP4)	3
Material tax on critical elements (EP5)	1
Policy and legislation on information sharing (EP6)	1
Legal environmental responsibilities (EP7)	3
Regulation consistency in the global market (EP8)	1
Social Category	
Social commitment (ES1)	2
High customer awareness through education and training (ES2)	1

Drawn from the findings, it appears that the establishment of the CE for the EVBs depends on the following key strategies, i.e., innovative business models, economic incentives, EVB standards, legal environmental responsibilities, and certification, which fall in the categories of supply-chain operations and management, economics, policy and regulation, and social, respectively. However, it is argued that the successful establishment of a system can be realized once technology feasibility is achieved, which is then followed by economic profitability and social acceptability for sustaining the operations [48]. Therefore, to ensure long-term circular supply chain operations of the EVBs, the optimized path of EoL processes should be realized. Table 5 has indicated that eco-design of EVB (i.e., EVB design which considers EoL processes), battery modularization, and proper technology for checking, diagnosing, and tracking, information sharing, extensive collaboration and alignment of supply-chain stakeholders, innovative business model, and certification are the enablers for continuous operations of the circular supply chain of the EVBs.

5.2. Conceptual Framework of Strategies toward Circular Economy Implementation for the EVBs

Based on the findings, two sets of strategies can be formulated. The first one regards the strategies to establish the CE for the EVBs, whereas the second one corresponds to the strategies for optimizing the circular supply chain system for the EVBs. Innovative business model, economic incentives, EVB standards, legal environmental responsibilities, and certifications are the five strategies that can handle 15 out of 21 reported barriers, which are considered the key strategies to establish the CE for the EVBs. Meanwhile, eco-design for EVBs, battery modularization, proper technology for status checking, diagnosing, and tracking, information sharing and its supporting technology, and extensive collaboration among supply-chain stakeholders, are also in need to optimize circular supply chain operation. Currently, EVB standards, economic incentives, innovative business models, certification, eco-design, battery modularization, and social commitment have not been implemented yet in the current system. Figure 10 presents a conceptual framework presenting the required strategies both to initiate the CE for the EVBs and to optimize SCS operations. Based on the earlier findings, these strategies should be synchronized and simultaneously introduced to address the interconnected barriers as discussed in the following.

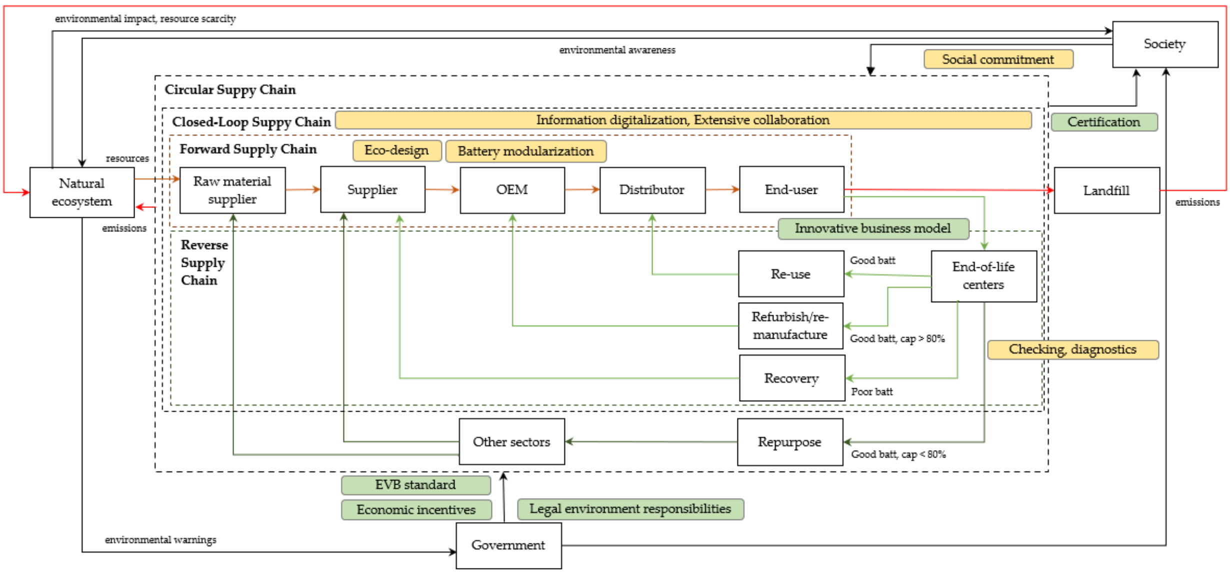

Figure 10. The conceptual framework of strategies to establish the CE for the EVBs (green boxes) and strategies to optimize circular supply chain operations (yellow boxes).

An innovative business model such as the servitization model, as suggested by Ahuja et al. [4], can increase the rate of returned EVB batteries and reduce the uncertainty in supply because the ownership of the EVBs through their life cycle is the manufacturers. Consequently, the manufacturers can facilitate proper checking, tracking, and diagnosing of battery usage [22]. In addition, it would help to build the capacity to design the EVBs considering EoL processes which then contributes to the optimized EoL processes, corresponding to lower total supply-chain cost, hence increasing profitability, and reducing risk on the investment. The findings also highlight that the constant commitment and collaboration among the involved stakeholders are crucial [8]; therefore, innovative business model should define the interactions among the stakeholders to ensure long-term profitability. The innovative business model can be combined with economic incentives for recyclers to further increase the profitability, thus attracting more business to CE for the EVBs, and, eventually, supporting faster development of infrastructure [21,31,34]. The economic incentives can be in the form of tax breaks [43], subsidies for recovery technologies [8,44], economic support for technological research and development [4], and the introduction of deposit refunds [31]. However, when the market mechanism is unable to trigger the CE, the regulation comes into play to provide a stepping-stone for initiating the CE implementation. Hence, the appropriate business model and economic incentives should be synchronized and supported by appropriate policy/regulations toward efficient, safe, and profitable supply-chain operations of the EVBs while achieving the efficiency target of recycling EVBs. For instance, the introduction of economic incentives can be coupled with the efficiency target of recycling to encourage the manufacturers/recyclers to make innovations to meet the efficient target [4]. Given various types of EVBs, it is beneficial to set the standards for the EVBs because various types and specifications of EVBs require different handling. The implementation of EVB standards standardizes the operations (particularly eliminating the compositional uncertainty of the EVBs and ensures the safety of the operations, facilitating a more efficient EoL supply chain for the EVBs [27]. Therefore, the manufacturers and recyclers may drive the cost down (by reducing high skill labor, storage, and transportation cost), subsequently increasing the economic viability. The standards for the EVBs have currently not existed yet; therefore, regulation on EVB standards should be realized to simplify the EoL processes and ensure safety compliance.

The policy and regulation interventions should also be introduced to support the supply and demand side of the circular supply chain operations. Concerning the supply side of the EVB circular supply chain, a high recovery rate is a function of both technology and legislation/governmental incentives that drive the companies to make innovations and a function of the availability of the returned EoL EVBs. Because the recycling process requires a stable feed of supply, hence, legal environmental responsibilities, such as Extended Producer Responsibilities (EPR), are necessary to further attract participating businesses and increase their commitments [24,25,27] so that a high rate of returned EVBs can be guaranteed [30,31]. As suggested by Wrålsen et al. [32], once the policy and regulation determine the actors responsible for disassembling and recovering the EoL EVBs (for example, using the principle of "polluter pays"), the responsible actors will involve in the CE implementation. Moreover, legal environmental responsibilities would also help anticipate the decrease of the EVBs' economic value due to technology enhancement [24]. The replacement of the EVB materials with cheaper materials could lower the economic value of the returned EVB, hence reducing its economic attractiveness [30,49]. On the demand side of the EVB circular supply chain, end-users play an essential role in driving the CE implementation of the EVBs [8]. A common concern for the environment, distrust of the quality and reliability of second-hand products, and lack of knowledge about the importance of CE will cause the market for second-hand batteries not to develop. Literature on socio-technical transition, such as Beltran et al. [50] and Sopha et al. [51], have highlighted that the shift in consumers' practices should foster technology innovation. In this context, the users should be encouraged to shift their practices from disposing to returning or reusing the EoL batteries to drive the circularity in the first place. Certification can be implemented to convince customers that the recycled products are safe and quality-guaranteed, thus building confidence for reusing the batteries and developing a marketplace for the second-hand product of the EVBs [41]. The behavioral change of the users should be supported by facilitating conditions such as accessible battery collection centers. Nurwidiana et al. [52] and Klöckner et al. [53] have evidenced that behavioral change can be hindered by a lack of supporting facilities. The collection centers of the EoL EVBs should be equipped with diagnostics technology to assess the condition and health state of the EoL EVBs. Based on this assessment, the appropriate path of the EoL EVBS is determined. The EVBs with a good health state can be reused. Reusing is preferable because it requires less energy and is resource-intensive compared with the effort to remanufacture/recycle. The degraded EVBs with a capacity of more than 80% are refurbished or remanufactured into new EVBs. The EoL EVBs with a capacity of less than 80% is directed to be used for other second-life applications (repurposing), such as energy storage for the

PV industry, peak shaving, and power sources for small applications. The EoL EVBs with poor health are recycled to recover critical materials.

In addition to the strategies to initiate the CE implementation for the EVBs, it is also important to highlight the strategies to support the optimized and thus long-term profitable operation of the circular supply chain system for the EVBs. Developing eco-design for EVBs is crucial [30,38]. Makuza et al. [44] confirmed that recycling facilities using pretreatment methods would not become economically profitable in the future due to high cost and long lead time, therefore re-designing the batteries considering recycling should be employed. The eco-design EVBs have already considered the EoL processes during the design phase so that eco-design EVBs allow safe and easy (or automated) disassembling/dismantling, collecting, transporting, and storage. Battery modularization and appropriate technology for checking, diagnosing, and tracking further support cost-effective EoL processes. The technological enablers should be supported by extensive collaboration among the stakeholders, which can be facilitated through information digitalization [37]. In addition, social commitment provides strong and long-term support for the market of EVBs [8].

Last but not least, the successful implementation of CE of the EoL EVBs depends on the combined leveraging of the strategies/interventions, including innovative business model, economic incentives, EVB standards, legal environmental responsibilities, certification, eco-design (design for disassembly), battery modularization, proper technology for status checking, diagnosing, tracking, extensive collaboration, information sharing, and its supporting infrastructure. However, it is worth remarking that the required strategies are not entirely existed yet. Table 7 summarizes the gap between current adopted strategies and future suggested strategies facilitating CE implementation for the EVBs.

Table 7. The gap between current adopted and future suggested strategies.

Category	Current Strategies	Future Strategies
Technology and Infrastructure	Recycling technology, battery checking, and diagnostics	Eco-design of EVBs, information digitalization, battery tracking, and battery modularization
Supply-Chain Operations and Management	Not available	Innovative business model (servitization, leasing platform)
Economics	Not available	Economic incentives
Policy and Regulations	EPR (limited to a few countries)	EVB standards, eco-design directive, certification, and global regulation
Social	Voluntary	Social commitment

Table 7 implies that the improvement of recycling technology and battery-checking and diagnostics technology should be accompanied by other technologies supporting effective and efficient CE operations, such as information digitalization enabling battery tracking and stakeholder coordination, battery modularization, and eco-design of EVBs ensuring cost-effective and safe operations. Hence, innovative business models, such as the servitization model or leasing platform, ensuring the high return of used EVBs and extensive collaboration among stakeholders, are crucial. The findings are in line with bibliometric analysis suggesting that battery safety and an innovative circular business model are the future directions of the CE implementation. Various mechanisms of economic incentives relevant to policy and regulations, which are currently unavailable, need to be explored. Current policy and regulations of the EVBs are considered insufficient [4]; therefore, the future policy and regulations should be formulated in a way to be consistent with technology (such as EVB standards, and eco-design directive) and market (such as certification, and consistent global regulation). Moreover, current voluntary participation to return the EoL EVBs is considered not sufficient [41]; hence, stronger participation in terms of social commitment is also required. The above-mentioned strategies are in line with the CE values suggested by Ripanti and Tjahjono [54] which are used as a basis for transforming from a linear to a circular supply chain.

5.3. Limitations and Future Research

Although the present study has developed a framework for strategies favoring CE establishment and functioning for the EVBs, the study has several limitations. The adopted SLR has limitations, particularly during article selection. Because the selection was based on the keywords, several publications may be relevant to the topic of the study but were not selected. Second, although the search was based on 10-year publications, the relevant literature was available for the last 3 years. Because the CE implementation of the EVBs is still a new area being explored, just right after the electric vehicle becomes a future transportation mode in many developed countries, the present study undermines the condition in the developing countries. Only two out of the collected articles were from developing countries, and only one article reported empirical evidence on the issue in a developing country, i.e., India.

Drawn from Table 7, several future research are therefore identified. In terms of technology, a more cost-effective and efficient recycling technology, information digitalization on battery diagnostics and tracking technology, and eco-design of EVBs are worth exploring. Innovative business models for different contexts, types and mechanisms of economic incentives, and consistent policy and regulations on EVB standards, eco-design directive, certification, and global regulation enforcing efficient recycling and proper dismantling are other avenues for potential future research. Moreover, studies focusing on behavioral factors underlying the behavior, such as that in Sopha [55], are required to explore various soft behavioral interventions driving social commitment.

Based on profile analysis, it is observed that existing literature has been dominated by qualitative research. Consequently, quantitative research on modeling and simulation of the CE transition to predict future paths or examine various interventions is suggested as potential research. Furthermore, scenario development on potential interventions to support CE implementation, such as increasing landfill costs to increase the high rate of the returned EoL EVBs, evaluating the effectiveness of various economic incentives facilitating long-term economic benefits, and predicting how different policies affect the future states of CE system, examining various soft intervention, and exploring other combined interventions are also suggested as future research.

Furthermore, different countries may have different challenges. Developed countries like the USA and European countries have already established technology, infrastructures, and regulation, which may not be the case in developing countries. Given the potential increase of EV deployment in developing countries such as in China [46], India [34], Indonesia [56], as the populous countries in the world, the CE implementation in developing countries needs to be initiated, encouraged, and supported. Kumar et al. [34] have observed through an empirical study that ineffective recycling, unsuccessful reuse of batteries, and the disposal of batteries are the two most challenging in India's EV battery supply chain. Similar issues may be observed in other developing countries due to technological and infrastructure constraints. In addition, informal sectors play a role in the EoL processes of the EVBs in developing countries, posing another challenge.

6. Conclusions

The implementation of the CE for the EVBs has been driven by the necessity to reduce climate change impact while avoiding burden shifting with respect to material scarcity and toxicity impact. The present paper contributes to the system perspective of the transition toward CE of the EoL EVBs by identifying barriers, enablers, involved stakeholders, and business models and eventually proposing a conceptual framework on the strategies to both establish and maintain the CE operations for the EVBs, based on SLR following the PRISMA procedure. The findings indicate that the interconnected barriers in technology and infrastructure, supply-chain operations and management, economics, policy and regulations, and social aspects are compatible with the reported enablers. Supply-chain operations and involved stakeholders depend on the circularity in which government and manufacturers are considered critical stakeholders. The proposed framework for the CE transition of the EVBs identifies the required strategies to initiate and optimize the circular supply chain system of the EVBs. The framework can be used as a basis to design and establish the CE of the EVBs and to maintain the optimized operation of CE for the EVBs. It implies that technical solutions with appropriate business models should be incorporated into the economic and regulatory framework. Furthermore, social commitment is required to support the market of EVBs in the long term. All the required strategies should be synchronized and introduced simultaneously to realize the CE implementation for the EVBs.

Author Contributions: Conceptualization, B.M.S.; methodology, B.M.S., D.M.P.; software, D.M.P.; validation, B.M.S., S.M.; formal analysis, B.M.S., D.M.P.; investigation, B.M.S.; resources, B.M.S., D.M.P.; data curation, D.M.P.; writing—original draft preparation, B.M.S., D.M.P.; writing—review and editing, B.M.S., S.M.; visualization, B.M.S., D.M.P.; supervision, B.M.S., S.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. IPCC—Intergovernmental Panel on Climate Change. 8. Transport. 2020. Available online: https://www.ipcc.ch/report/ar5/wg3/transport/ (accessed on 10 January 2022).
2. International Energy Agency. Global EV Outlook 2018. 2018. Available online: https://webstore.iea.org/global-ev-outlook-2018 (accessed on 17 February 2020).
3. Hawkins, T.R.; Singh, B.; Majeau-Bettez, G.; Stromman, A.H. Comparative environmental life cycle assessment of conventional and electric vehicles. *J. Ind. Ecol.* **2012**, *17*, 53–64. [CrossRef]
4. Ahuja, J.; Dawson, L.; Lee, R. A Circular Economy for Electric Vehicle Batteries: Driving the Change. *J. Prop. Plan. Environ. Law* **2020**, *12*, 235–250. [CrossRef]
5. Wang, Q.; Liu, W.; Yuan, X.; Tang, H.; Tang, Y.; Wang, M.; Zuo, J.; Song, Z.; Sun, J. Environmental impact analysis and process optimization of batteries based on life cycle assessment. *J. Clean. Prod.* **2018**, *174*, 1262–1273. [CrossRef]
6. Werner, D.; Peuker, U.A.; Mütze, T. Recycling chain for spent lithium-ion batteries. *Metals* **2020**, *10*, 316. [CrossRef]
7. Chirumalla, K.; Reyes, L.G.; Toorajipour, R. Mapping a circular business opportunity in electric vehicle battery value chain: A multi-stakeholder framework to create a win-win solution. *J. Bus. Res.* **2022**, *145*, 569–582. [CrossRef]
8. Azadnia, A.H.; Onofrei, G.; Ghadimi, P. Electric Vehicles Lithium-Ion Batteries Reverse Logistics Implementation Barriers Analysis: A TISM-MICMAC Approach. *Resour. Conserv. Recycl.* **2021**, *174*, 105751. [CrossRef]
9. Stahel, W.R. The circular economy. *Nature* **2016**, *531*, 435. [CrossRef]
10. Kirchherr, J.; Reike, D.; Hekkert, M. Conceptualizing the circular economy: An analysis of 114 definitions. *Resour. Conserv. Recycl.* **2017**, *127*, 221–232. [CrossRef]
11. Genovese, A.; Acquaye, A.A.; Figueroa, A.; Koh, S.C.L. Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications. *Omega* **2017**, *66*, 344–357. [CrossRef]
12. Ahi, P.; Searcy, C. A comparative literature analysis of definitions for green and sustainable supply chain management. *J. Clean Prod.* **2013**, *52*, 329–341. [CrossRef]
13. Farooque, M.; Zhang, A.; Thürer, M.; Qu, T.; Huisingh, D. Circular supply chain management: A definition and structured literature review. *J. Clean Prod.* **2019**, *228*, 882–900. [CrossRef]
14. Nasir, M.H.A.; Genovese, A.; Acquaye, A.A.; Koh, S.C.L.; Yamoah, F. Comparing linear and circular supply chains: A case study from the construction industry. *Int. J. Prod. Econ.* **2017**, *183*, 443–457. [CrossRef]
15. Ferronato, N.; Rada, E.C.; Portillo, M.A.G.; Cioca, L.I.; Ragazzi, M.; Torretta, V. Introduction of the circular economy within developing regions: A comparative analysis of advantages and opportunities for waste valorization. *J. Environ. Manag.* **2019**, *230*, 366–378. [CrossRef] [PubMed]

16. Xia, X.; Li, P. A review of the life cycle assessment of electric vehicles: Considering the influence of batteries. *Sci. Total Environ.* **2022**, *814*, 152870. [CrossRef]
17. Cano, Z.P.; Banham, D.; Ye, S.; Hintennach, A.; Lu, J.; Fowler, M.; Chen, Z. Batteries and fuel cells for emerging electric vehicle markets. *Nat. Energy* **2018**, *3*, 279–289. [CrossRef]
18. Martins, L.S.; Guimarães, L.F.; Botelho Junior, A.B.; Tenório, J.A.S.; Espinosa, D.C.R. Electric Car Battery: An Overview on Global Demand, Recycling and Future Approaches towards Sustainability. *J. Environ. Manag.* **2021**, *295*, 113091. [CrossRef]
19. Bobba, S.; Bianco, I.; Eynard, U.; Carrara, S.; Mathieux, F.; Blengini, G.A. Bridging Tools to Better Understand Environmental Performances and Raw Materials Supply of Traction Batteries in the Future EU Fleet. *Energies* **2020**, *13*, 2513. [CrossRef]
20. Kotak, Y.; Fernández, C.M.; Casals, L.C.; Kotak, B.S.; Koch, D.; Geisbauer, C.; Trilla, L.; Gómez-Núñez, A.; Schweiger, H.G. End of Electric Vehicle Batteries: Reuse vs. Recycle. *Energies* **2021**, *14*, 2217. [CrossRef]
21. Vu, F.; Rahic, M.; Chirumalla, K. Exploring Second Life Applications for Electric Vehicle Batteries. In Proceedings of the Advances in Transdisciplinary Engineering, Jönköping, Sweden, 7–8 October 2020; IOS Press BV: Amsterdam, The Netherlands, 2020; Volume 13, pp. 273–284.
22. Moore, E.A.; Russell, J.D.; Babbitt, C.W.; Tomaszewski, B.; Clark, S.S. Spatial Modeling of a Second-Use Strategy for Electric Vehicle Batteries to Improve Disaster Resilience and Circular Economy. *Resour. Conserv. Recycl.* **2020**, *160*, 104889. [CrossRef]
23. 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]
24. Doose, S.; Mayer, J.K.; Michalowski, P.; Kwade, A. Challenges in Ecofriendly Battery Recycling and Closed Material Cycles: A Perspective on Future Lithium Battery Generations. *Metals* **2021**, *11*, 291. [CrossRef]
25. dos Santos, M.P.; Garde, I.A.A.; Ronchini, C.M.B.; Filho, L.C.; de Souza, G.B.M.; Abbade, M.L.F.; Regone, N.N.; Jegatheesan, V.; de Oliveira, J.A. A Technology for Recycling Lithium-Ion Batteries Promoting the Circular Economy: The RecycLib. *Resour. Conserv. Recycl.* **2021**, *175*, 105863. [CrossRef]
26. Slattery, M.; Dunn, J.; Kendall, A. Transportation of Electric Vehicle Lithium-Ion Batteries at End-of-Life: A Literature Review. *Resour. Conserv. Recycl.* **2021**, *174*, 105755. [CrossRef]
27. Malinauskaite, J.; Anguilano, L.; Rivera, X.S. Circular Waste Management of Electric Vehicle Batteries: Legal and Technical Perspectives from the EU and the UK Post Brexit. *Int. J. Thermofluids* **2021**, *10*, 100078. [CrossRef]
28. Liberati, A.; Altman, D.G.; Tetzlaff, J.; Mulrow, C.; Gøtzsche, P.C.; Ioannidis, J.P.A.; Clarke, M.; Devereaux, P.J.; Kleijnen, J.; Moher, D. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. *J. Clin. Epidemiol.* **2009**, *62*, e1–e34. [CrossRef]
29. VOSviewer. *Center for Scienceand Technology Studies*; Leiden University: Leiden, The Netherlands, 2020. Available online: https://www.vosviewer.com/ (accessed on 11 August 2021).
30. Albertsen, L.; Richter, J.L.; Peck, P.; Dalhammar, C.; Plepys, A. Circular Business Models for Electric Vehicle Lithium-Ion Batteries: An Analysis of Current Practices of Vehicle Manufacturers and Policies in the EU. *Resour. Conserv. Recycl.* **2021**, *172*, 105658. [CrossRef]
31. Kurdve, M.; Zackrisson, M.; Johansson, M.I.; Ebin, B.; Harlin, U. Considerations When Modelling Ev Battery Circularity Systems. *Batteries* **2019**, *5*, 40. [CrossRef]
32. Wrålsen, B.; Prieto-Sandoval, V.; Mejia-Villa, A.; O'Born, R.; Hellström, M.; Faessler, B. Circular Business Models for Lithium-Ion Batteries—Stakeholders, Barriers, and Drivers. *J. Clean. Prod.* **2021**, *317*, 128393. [CrossRef]
33. Mathur, N.; Deng, S.; Singh, S.; Yih, Y.; Sutherland, J.W. Evaluating the Environmental Benefits of Implementing Industrial Symbiosis to Used Electric Vehicle Batteries. *Proc. Procedia CIRP* **2019**, *80*, 661–666. [CrossRef]
34. Kumar, P.; Singh, R.K.; Paul, J.; Sinha, O. Analyzing Challenges for Sustainable Supply Chain of Electric Vehicle Batteries Using a Hybrid Approach of Delphi and Best-Worst Method. *Resour. Conserv. Recycl.* **2021**, *175*, 105879. [CrossRef]
35. Sommerville, R.; Zhu, P.; Rajaeifar, M.A.; Heidrich, O.; Goodship, V.; Kendrick, E. A Qualitative Assessment of Lithium Ion Battery Recycling Processes. *Resour. Conserv. Recycl.* **2021**, *165*, 105219. [CrossRef]
36. Blömeke, S.; Mennenga, M.; Herrmann, C.; Kintscher, L.; Bikker, G.; Lawrenz, S.; Sharma, P.; Rausch, A.; Nippraschk, M.; Goldmann, D.; et al. Recycling 4.0: An Integrated Approach towards an Advanced Circular Economy. In Proceedings of the ACM International Conference Proceeding Series; Association for Computing Machinery, Bristol, UK, 21 June 2020; pp. 66–76.
37. Garrido-Hidalgo, C.; Ramirez, F.J.; Olivares, T.; Roda-Sanchez, L. The Adoption of Internet of Things in a Circular Supply Chain Framework for the Recovery of WEEE: The Case of Lithium-Ion Electric Vehicle Battery Packs. *Waste Manag.* **2020**, *103*, 32–44. [CrossRef] [PubMed]
38. 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]
39. Gaines, L.; Richa, K.; Spangenberger, J. Key issues for Li-ion battery recycling. *MRS Energy Sustain.* **2018**, *5*, 12. [CrossRef]
40. Bouzon, M.; Govindan, K.; Rodriguez, C.M.T. Evaluating barriers for reverse logistics implementation under a multiple stakeholders' perspective analysis using grey decision making approach. *Resour. Conserv. Recycl.* **2018**, *128*, 315–335. [CrossRef]
41. Quinteros-Condoretty, A.R.; Golroudbary, S.R.; Albareda, L.; Barbiellini, B.; Soyer, A. Impact of Circular Design of Lithium-Ion Batteries on Supply of Lithium for Electric Cars towards a Sustainable Mobility and Energy Transition. *Procedia CIRP* **2021**, *100*, 73–78. [CrossRef]

42. Schulz, M.; Niero, M.; Rehmann, L.M.; Georg, S. Exploration of Decision-Contexts for Circular Economy in Automotive Industry. *Procedia CIRP* **2021**, *98*, 19–24. [CrossRef]
43. Ali, H.; Khan, H.A.; Pecht, M.G. Circular Economy of Li Batteries: Technologies and Trends. *J. Energy Storage* **2021**, *40*, 102690. [CrossRef]
44. Makuza, B.; Tian, Q.; Guo, X.; Chattopadhyay, K.; Yu, D. Pyrometallurgical Options for Recycling Spent Lithium-Ion Batteries: A Comprehensive Review. *J. Power Sources* **2021**, *491*, 229622. [CrossRef]
45. Yang, Y.; Okonkwo, E.G.; Huang, G.; Xu, S.; Sun, W.; He, Y. On the Sustainability of Lithium Ion Battery Industry—A Review and Perspective. *Energy Storage Mater.* **2021**, *36*, 186–212. [CrossRef]
46. Hsieh, I.Y.L.; Pan, M.S.; Green, W.H. Transition to Electric Vehicles in China: Implications for Private Motorization Rate and Battery Market. *Energy Policy* **2020**, *144*, 111654. [CrossRef]
47. Castro, F.D.; Cutaia, L.; Vaccari, M. End-of-Life Automotive Lithium-Ion Batteries (LIBs) in Brazil: Prediction of Flows and Revenues by 2030. *Resour. Conserv. Recycl.* **2021**, *169*, 105522. [CrossRef]
48. Sopha, B.M.; Fet, A.M.; Keitsch, M.M.; Haskins, C. Using systems engineering to create a framework for evaluating industrial symbiosis options. *Syst. Eng.* **2010**, *13*, 149–160. [CrossRef]
49. Schulz-Mönninghoff, M.; Bey, N.; Nørregaard, P.U.; Niero, M. Integration of Energy Flow Modelling in Life Cycle Assessment of Electric Vehicle Battery Repurposing: Evaluation of Multi-Use Cases and Comparison of Circular Business Models. *Resour. Conserv. Recycl.* **2021**, *174*, 105773. [CrossRef]
50. Beltran, M.; Tjahjono, B.; Bogush, A.; Julião, J.; Reixeira, E.L.S. Food Plastic Packaging Transitions towards Circular Bioeconomy: A Systematic Review of Literature. *Sustainability* **2021**, *13*, 3896. [CrossRef]
51. Sopha, B.M.; Klöckner, C.A.; Febrianti, D. Using agent-based modeling to explore policy options supporting adoption of natural gas vehicles in Indonesia. *J. Environ. Psychol.* **2017**, *52*, 149–165. [CrossRef]
52. Nurwidiana, N.; Sopha, B.M.; Widyaparaga, A. Modelling photovoltaic system adoption for households: A systematic literature review. *Evergreen* **2021**, *8*, 69–81. [CrossRef]
53. Klöckner, C.A.; Sopha, B.M.; Matthies, E.; Bjørnstad, E. Energy efficiency in Norwegian households—Identifying motivators and barriers with a focus group approach. *Int. J. Environ. Sustain. Dev.* **2013**, *12*, 396–415. [CrossRef]
54. Ripanti, E.F.; Tjahjono, B. Unveiling the potentials of circular economy values in logistics and supply chain management. *Int. J. Logist. Manag.* **2019**, *30*, 723–742. [CrossRef]
55. Sopha, B.M. Sustainable Paper Consumption: Exploring Behavioral Factors. *Soc. Sci.* **2013**, *2*, 270–283. [CrossRef]
56. Irawan, M.Z.; Belgiawan, P.F.; Widyaparaga, A.; Deendarlianto; Budiman, A.; Muthohar, I.; Sopha, B.M. A market share analysis for hybrid cars in Indonesia. *Case Stud. Transp. Policy* **2018**, *6*, 336–341. [CrossRef]